Systematic Survey on Digital Still Cameras

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Motokazu Ohkawa

■ Abstract

Imaging is a culture that only humans can freely make use of as a means of communicating information, and from ancient times – even prior to the birth of civilization – we have exchanged, communicated, and recorded information by means of images.

The camera was invented and has evolved as a tool for recording images easily and accurately.

Although the origin of the camera goes back to the camera obscura, which was used to draw a picture by tracing an image focused on a screen in a dark box through a pinhole or a lens, since the advent of the Daguerreotype, the first real camera, which was announced in 1839, until the early 2000s, cameras have developed as tools for recording images using a photochemical reaction technique.

It was during 1981 that an electronic camera was announced that converted captured images to electronic signals by means of an image sensor and recorded them to a dedicated floppy disk. Known as the “Floppy Camera,” this was the first camera to record images using a method other than the photochemical reaction technology employed with conventional silver halide cameras.

However, the still images grabbed from the analog video signal by the Floppy Camera, which appropriated the technologies employed in existing video cameras to view images on a TV screen, was unable to produce images of sufficient quality to replace conventional cameras.

At almost the same time, Toshiba announced a prototype that recorded images digitally, and unlike the traditional analog technology used in electronic cameras, which suffered from dropout in the recording and reproduction stages, the digital signal processing techniques employed actually improved image quality. However, as image playback was slow due to the recording media (audio cassette tape) and poor image compression technology employed, and the fact that images were displayed on a TV screen, it was of no real practical use.

In the late 1980s, flash memory, a type of large-capacity non-volatile semiconductor storage, was developed and a digital still camera (DSC) that electronically recorded digital image signals on such media was announced. However, this too was unable to replace silver halide cameras due to poor image compression efficiency, the extremely high cost (1 million+ JPY), and image quality that was still just enough for viewing on a TV screen and not high enough for printing purposes.

JPEG, a high-efficiency/high-performance image compression technology, was established as an international standard in 1992, the same year that Japan proposed its use as a standard for consumer DSCs. At the same time, the price of memory dropped and Casio's launch of the QV-10 at a price of 65,000 JPY in 1995, followed by the QV-10A at 49,800 JPY in 1996, triggered the expansion of the consumer DSC market.

During the mid-1990s, with the rapid popularization of the personal computer and the advent of the internet, exchanging images electronically became more common, and the development of digital electronic appliances, such as DTVs and DVDs, brought on the Digital Information Age.

The DSC is not simply a device that records images electronically rather than using the photochemical method employed with conventional silver halide cameras, but has established itself as an image-capturing peripheral in a digital environment that is capable of interacting with computers, the internet and printers. Furthermore, as DSCs are designed to work with PCs rather than being confined to working with TVs, restrictions in terms of image size have been removed, and image quality has remarkably improved to the extent that DSCs have quickly come to replace silver halide cameras, with total annual sales and production exceeding those of silver halide cameras in 2000 and 2002 respectively. Today, DSCs boast annual sales in excess of 1 trillion JPY and the technologies and formats developed for DSCs have already been transferred into mobile phones, opening up yet another new market: image communication devices.

It should be noted that the DSC, which was born in Japan and has gone on to conquer world markets, was made a reality by the various technologies developed by Japanese industries. Furthermore, as Japanese electronics manufacturers pioneered this field, they have made it possible for Japan to maintain leadership in this market, and with the standardization of DSC specifications, consumers will no longer put off buying products for reasons of future incompatibility, and DSC manufacturers are free to concentrate on improving their technology within an established framework.

■ Profile

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1962 Graduated from the Physics Department of Tohoku University's Faculty of Science and the same year joined Tokyo Shibaura Electric Co., Ltd. (now known as Toshiba Corporation), where he was engaged in the research of acoustics at the company's Central Research Laboratory. After that he was engaged in the development of CATV, etc., at the Consumer Electronics Research Center.

1988 Engaged in digital camera development.

1991 Digital Camera Technology Committee Chairman of JEITA (Japan Electronics and Information Technology Industries Association) (originally JEIDA: Japan Electronic Industries Development Association). ISO TC42 expert.

1995 Relocated to the High-tech Visual Promotion Center.

2000 Camera & Imaging Products Association (CIPA) technical adviser.

2007 Resigned from CIPA. Chief Survey Officer, Center of the History of Japanese Industrial Technology, National Museum of Nature and Science until stepping down at the end of March 2008.
Chairman of the Japan Color Standardization Committee (JSA) during that time.

■ Contents

1 Introduction

Only humans use images as a means of communicating information, and communicating information by means of images is something that is unique to human culture. Thirty thousand or more years ago, our ancestors created an image culture to convey information through images and to leave a record of their feelings. Over the centuries, humans have devised and developed ways of more easily and accurately creating and saving images.

As a result of such efforts, while on one hand this led to the birth of the “pictorial art culture,” which sought to be more artistic, on the other hand it led to the advent of the “camera culture,” which sought a greater degree of accuracy.

The history of cameras is said to have begun approximately 170 years ago with the announcement of the Daguerreotype in 1839. Since then, over the course of more than 150 years, using the silver halide photochemical reaction, cameras have been the means by which images of subjects have been recorded; in other words, they have gone through various technological revolutions as the silver halide film camera. During the early 1980s, however, electronic cameras appeared that electronically recorded images, and by the end of the 1980s, digital still cameras (DSCs) had been announced that recorded images as digital signals in semiconductor memory.

Characteristics of early DSCs included the fact that they were instant, that there was no deterioration in quality when transferring or copying images, and that they had few moving parts. They were designed for displaying images on TV screens and image quality was by no means comparable with that of existing silver halide film cameras.

However, one of the features of DSCs is that they handle images as digital information, which means that images are easy to use on computers and peripheral devices. As society quickly embraced the personal computer and technological infrastructure was developed making things such as digitization and the internet a reality, the market for IT-related electronic devices rapidly expanded and consumer-level digital appliances, such as DSCs, flourished. Moreover, DSCs fused with mobile phones to create new communication tools, resulting in the dramatic advancements in image-based communications.

In addition to the abovementioned development of the digital information environment, the background to the rapid development of DSCs included technological innovations such as memory and image sensor-related semiconductor technology and image processing technology, such as the JPEG format. However, special mention needs to be made of the fact that DSC development originated in Japan, that the standardization of international standards was carried out at the initiative of Japan, and that Japan basically held a monopoly on the market. There are very few such examples in the consumer equipment market.

Furthermore, the camera market, which had been monopolized by the traditional camera manufacturers as the conventional precision machinery industry, became the launching pad for electronic equipment manufacturers, who were experts in electronics and software development, to launch out into the DSC market in quick succession. On account of this, the camera market, where up until that time product cycles had been long, with flagship models being used in some cases for decades, saw a shortening of product cycles, which forced camera manufacturers to shorten development time, resulting in a price war. Therefore, radical reform was required on the part of camera manufacturers producing conventional silver halide film cameras. In light of this, it could be said that DSCs caused an industrial revolution in the camera industry.

In this document, we will focus on DSCs as a modern hit product developed with Japanese initiative. In Chapter 2 we will examine history leading up to the development of the camera, while in Chapter 3 we will look at digital technologies.

Continuing on in Chapter 4, we will examine the historical flow leading up to the development of the DSC, followed by a simple explanation of DSCs in Chapter 5, and in Chapter 6 we will look at the characteristics of DSCs.

In Chapter 7, I will mention DSC-related technology from the perspective of the systematization of technology. Chapter 8 will deal with the compression standards and formats that are characteristic of DSCs.

I will explain the present state of DSC standardization in Chapter 9 and look at possible future directions for DSCs in Chapter 10 and systematically explain the history of the changes in technological development and product development led mainly by Japan, with the intention of leaving it as a record for future generations.

In this document I have used the word “image” to refer to a recorded visualization of a subject. Although some publications use the terms “image” to refer to pictures and “video” to refer to movies, where it is necessary to differentiate in this document, I refer to pictures as “still images” and movies as “video.”

Furthermore, while conventional cameras utilizing roll film are referred to in many different ways, such as “still cameras,” “ silver halide film cameras,” “film cameras” and “SH (Silver Halide) cameras,” etc., in this document they will be referred to as “silver halide cameras.”

2 The History of Image Culture

2.1 Image Culture as a Basic Human Desire

From the time that humans first appeared on the earth, they have created various tangible and intangible cultures. Among these, imaging cultures that use images to exchange, communicate and record information are noteworthy cultures and nothing similar is observed with any of the animals. The history of the development and evolution of the camera is the history of the technological progress that has supported the history of imaging cultures.

Unlike words and sentences, images, which directly appeal to the visual senses, are the most accurate way to communicate information. As mentioned in 62–60 B.C. by General Zhao Chongguo in *The Book of Han*, “Seeing once is better than hearing a hundred times,” and mankind has known from ancient times that images can communicate much more information than any other means [1]. The fact that, for example, the stereo data on a music CD is only 176.4 kB (each channel is 44.1kHz 16-bit), while the data on a digital VTR (D2) is approximately 16 MB, means that image data is approximately 100 times as large as sound data, a fact that can be proven scientifically.

Only humans can use this image data as a means of communicating information and even if animals could communicate visually by expressing actions and expressions, they are not capable of communicating using image data by means such as drawing pictures. In this way we can see that culture using images in data communications is an advanced culture unique to mankind.

2.2 What the Cave Paintings Represent

In 1994, polychrome cave paintings, such as the one shown in **Fig. 2.1**, were discovered in a cave in the département of Ardéche in southern France by a group of speleologists including Jean-Marie Chauvet. Referred to now as the cave paintings of the Chauvet-Pont-d'Arc Cave, these cave paintings, which number in excess of 300 and are thought to have been painted during the Upper Paleolithic period, are estimated to be approximately 32,000 years old, making them older than the famous cave paintings of the Cave of Altamira in Spain (**Fig. 2.2**), which were previously thought to be the oldest in the world.

In an age in which it is thought that there were no letters and language was not as yet adequately developed as a means of communication, our ancestors are thought to have used images to describe their experiences and other things they wanted to express and communicate. Deep inside the caves, far away from sunlight, these paintings, which are thought to have been drawn relying on light from lamps burning animal fat, even now, tens of thousands of years later, the feelings of the people who drew them are adequately communicated to us.

Fig. 2.1. Chauvet Cave wall painting.

Fig. 2.2. Altamira Cave wall painting.

Unlike words and sentences, images, which directly appeal to the visual senses, are the most accurate form of communicating information.

When you have seen something or thought something, although communicating that through gestures, sounds or words is something that can be seen among the higher animals other than humans, expressing it using images is an advanced means of data communication that only humans are capable of doing.

Communicating in this way using images is a basic human desire and in order to develop this advanced culture, mankind has developed many technological innovations in order to more accurately, more realistically and more easily create, communicate and preserve the images that are their means of communicating information. It could be said that the pursuit of that desire, together with technological development, has supported the wisdom of mankind as an imaging culture, resulting in the evolution of human society.

2.3 Art and Technology

From ancient times, mankind has created landscape paintings and portraits as a means of passing on image information of existing people and things to future generations and to communicate it to other people. However, not only does it take time to create pictures to leave such images, but it also requires skill and proficiency on the part of the people creating them. Therefore, this gave rise to specialist artists and repeated technological reforms and training to enable more realistic and more passionate expression. This resulted in pictures being not simply a means of leaving images, but developing into expressions of unique culture.

On the other hand, starting from the camera obscura, which used the principle of the pinhole camera that had been known before Christ, photography was invented and evolved as a means of leaving images as pictures even for people who had no skill.

The English word meaning "photography" is derived from the Greek words "photos," meaning "light," and "graphein," meaning "to draw," being used for the first time by Sir John F.W. Herschel in 1839 as a word meaning "to record images using light." Photography is a technology for leaving images as photographs of subjects, and the camera has developed as a device for photographing a subject (**Fig. 2.3**).

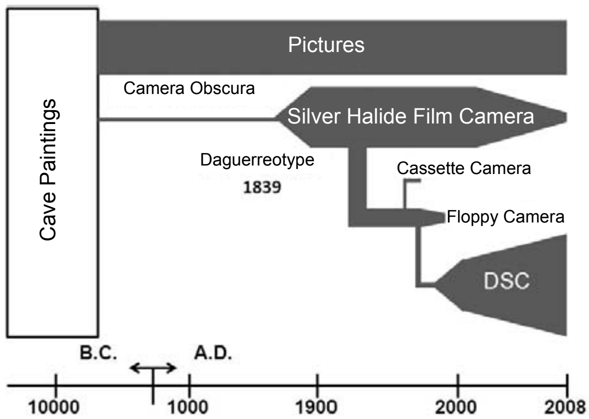


Fig. 2.3. Pictures and photographs.

Photographs make it possible to easily and accurately copy a subject within a short period of time and, compared with the skill that must be acquired in order to paint a picture, it is a technique that is easy to learn.

Therefore, it developed as a means of responding to the demand for the creation of accurate images within a short period of time, such as portrait photographs in place of portrait paintings and landscape photographs in place of landscape paintings.

As a device for taking photographs, cameras have experienced many technological changes in order to more simply and accurately produce images within a shorter period of time at a cheaper price.

Advances in photograph were not simply aimed at taking photographs of subjects more accurately, but at developing cameras for special applications, such as in harsh environments (high temperature/high pressure, etc.) and underwater.

Furthermore, combining machinery and optics according to application and purpose made it possible to produce cameras for applications such as endoscopes for photographing the inside of the body where it is impossible to carry out examinations with the human eye, and for cameras that can take panoramic photographs at a wide viewing angle.

Moreover, advances in technology for use when taking photographs and in image processing, such as for recomposing photographs after taking them and for post-processing, made it possible to display in photographic images a degree of self-expression that it was not possible to obtain simply by photographing a subject, leading to the development of the new field of photographic art.

Originally, methods of creating images with the aim of communicating information through them were divided into paintings, which required skill and practice, and photographs, which were easy for ordinary people to make, and although the former were artistically inclined, the latter proceeded in a technical direction. There were also those who were technically inclined in terms of paintings and computer art, etc., and those who were artistically inclined in the creation of photographs.

It could be said that mankind has made repeated advances, from the perspective of both skill and technology, with the universal aim of furthering mankind's imaging culture. The camera is a device that has been adopted as a means by which to take part in this imaging culture.

Note:

[1] *The Book of Han*, General Zhao Chongguo, “Since seeing once is better than hearing a hundred times, I would like to go to the battlefield in person to draw a map, then bring back some good advice.”

3 Digital and Fourier Transform

Before writing more about digital cameras, let us consider the word "digital" itself.

Although we often hear the word "digital" used in conjunction with things such as digital cameras, the first common use of this word was probably with regard to the digital watch. Since then, with the popularization of computers, the internet and mobile phones, etc., the word has come to be part of our lives.

Generally, it is thought that "digital" is a binary means of expression using "0 or 1," or "Yes or No," while by contrast "analog" expresses phenomena/events continuously. Furthermore, phrases such as "a digital person" have also appeared and there is a tendency for old-fashioned conservative things to be referred to as "analog," while things that are fresh and innovative are referred to as "digital."

The word "digital" is derived from the Latin *digitalis*, from *digitus*, meaning "finger, toe." It is said to have originally meant "pertaining to the fingers (and/or toes)" in the sense that we count on the fingers and bend them saying, "one, two, three …" and we refer to the number of "digits." By contrast, "analog" is derived from the Greek ανάλογος (analogos) meaning "proportional," and means "something that is similar to something else in some way."

For example, "the Caspian Sea has an area of 371,000 km^2" is a digital expression, while "the area of the Caspian Sea is almost the same as the area of the Japanese Archipelago" is an analogous expression. While it is difficult to get a sense of how big it is by saying that the area is 371,000 km^2, saying that it is "about the same size as Japan" means that one can imagine how big it is.

So, while analog is expressed in terms of a physical quantity, digital is a numerical expression.

The numerical system that we use in our daily lives is the decimal system, which is expressed using the ten digits 0 to 9. However, the numerical system used by computers is binary, which consists of the two digits 0 and 1.

Although it is easy for mistakes to occur due to errors in cases where vague phenomena are classified in ten categories, classifying them into only two categories is easy and there are few errors. On account of this, in the realm of telecommunications, the binary system is widely used in spite of the drawbacks of using a large number of digits.

However, as I have already mentioned, digital originally meant "expression as discrete values," and the binary system is nothing more than one type of digital expression.

Whether to handle something proportionally or symbolically is not simply a matter of a difference in the means of expressing a simple phenomenon, and leads to a major disparity in human thought processes and the processes involved in processing subject matter.

On one hand, an analog is a physical quantity, working directly on the human senses. This is the equivalent of a painted picture (which is handled as a physical phenomenon) as opposed to a written expression. This can also be seen in Buddhism, where the exterior of things is referred to as "entity."

On the other hand, a digital expression is an enumeration of numbers, through which we cannot sense any physical meaning. Only when we understand the way in which the numbers are arranged can we for the first time understand the meaning of a digital signal.

With DSCs, as all images and metadata are recorded as numbers, a system for determining what those numbers represent – a format, in other words – is necessary.

In the same way as sentences written using letters are incomprehensible unless the letters can be read, sentences are digital expressions as opposed to painted pictures. Furthermore, in that it is impossible to judge digital signals instinctively (they are metaphysical phenomena), they can be explained as what is called "emptiness" in Buddhism (**Table 3.1**).

Table 3.1. Analog and digital

Analog	Digital
Physical Quantity	Numeral
Vector quantity	Scalar quantity
Sense	Logic
Picture	Sentence
Physical	Metaphysical
Entity	Emptiness

Furthermore, although one gets the impression that in many cases analog and digital are used as continuous and discrete, the concepts of continuous and discrete do not reflect the true nature of analog and digital.

While it is possible to treat analog volume as a continuous physical quantity, it is a fact that digital information must be described as finite numerical values.

Let us consider a graphical representation of continuous quantity. When converting continuous quantity displayed in an analogous form, such as in column 3 of **Fig. 3.1**, into a graphical form, representative points, such as in column 1, are selected and the value of each representative point is described digitally as a numerical value in column 2.

There is the fixed notion that digital is discrete, however, whereas, for example, image sensor cell size is large as compared with the size of film molecules and discreteness can be ignored with analog, this becomes a problem with digital as discreteness cannot be ignored.

Digital

X	Y
1	0.955
2	0.980
3	0.995
4	1.000
5	0.995
6	0.980
7	0.955
8	0.921
9	0.878
10	0.825
11	0.765
12	0.697
13	0.622
14	0.540
15	0.454
...	...

Analog

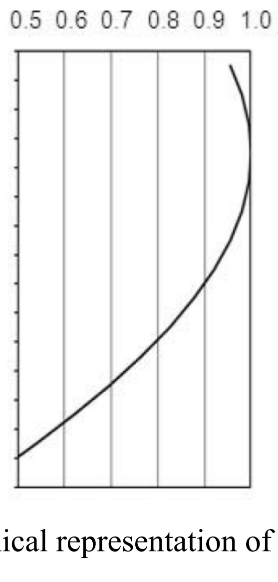


Fig. 3.1. Graphical representation of continuous quantity.

For example, supposing that a fine probe is placed on part of a tape on which an analog signal of shade is recorded, as in **Fig. 3.2**, and the shade data for that point is expressed numerically as a digital signal, it is possible to constantly change the position of the probe. From this we can understand that there is no requirement that being sampled, in other words discrete, is not an intrinsic prerequisite for digital, but in a sufficient condition that is in reality required for operation.

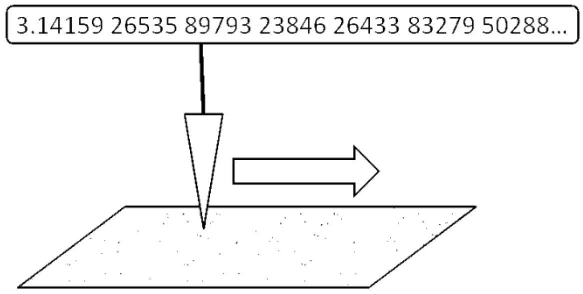


Fig. 3.2. Continuous digital conversion.

With digital, as numerical values that are less than the minimum number described are not displayed, sampling points that are next to each other seem to be in no particular sequence. This is due to the fact that the numbers used to describe them are finite, and if it is possible to have non-terminating descriptions with continuously moving sampling points, then continuous digital expressions become a possibility.

The horizontal axis in **Fig. 3.2** is not digital and has a discrete nature, and digital information is obtained from the vertical axis. In this way digital must be considered separately from discrete.

The meanings of digital and analog should be understood as explained above and superficial interpretations that consider them to be simply “different methods of expression” should be avoided.

For example, the definition of one meter was determined by the General Conference on Weights and Measures and although the analog representation of a meter was the distance between two points marked on the international prototype of the meter managed by the International Bureau of Weights and Measures in Paris, it was difficult to maintain its immutability due to factors such as temperature, impact and general wear and tear. Therefore, in 1983 it was amended to the digital expression "the distance traveled by light in a vacuum in 1/299,792,458th of a second."

In light of that, the appearance of DSCs, which, unlike conventional silver halide cameras that physically record images, record images and related information logically as numerically expressed multimedia data, was an epoch-making event that brought about a change in human thought processes. That is to say, it caused a paradigm shift in the camera industry as it negated the view that in the same way as electronic cameras up until that time, DSCs were merely using electronic technology as a means of recording images and that they were an alternative means of recording images to the photochemical process.

In reality, by incorporating digital technology into DSCs it was possible to realize new possibilities that were unthinkable with the electronic cameras that had been developed up until that time.

In analog electronic cameras that used floppy disks as recording media, image processing consisted of handling still images that had been taken as a physical quantity and the physical changes that could be made were limited to things such as transforming, projecting, trimming and changing the color, gamma and brightness of images as a whole.

However, with DSCs, images consist of pixels and by handling data from each pixel numerically it is possible to process data from each individual pixel individually. For example, in single-plate type image sensors there is what is referred to as de-mosaicing, which is signal interpolation and compensation for defective cells.

3.1 Characteristics of Digital Information

Although physical phenomena exist as analog values, in order to express them as digital information, which is logical value, it is necessary to convert analog values to digital values using an A/D converter.

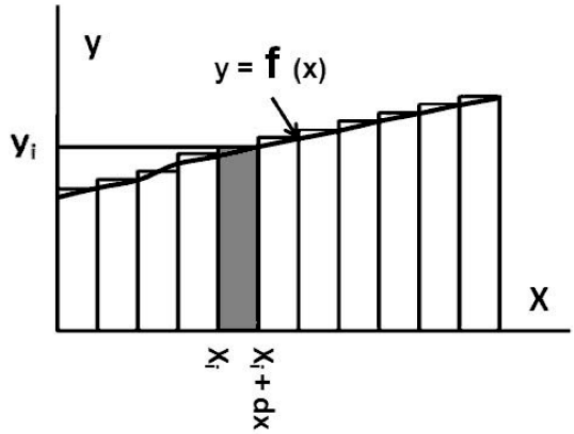


Fig. 3.3 Sampling during A/D conversion.

The A/D conversion process is identical to that shown in **Fig. 3.1**.

When digitizing continuous physical quantities expressed as y = f(x) as shown in **Fig. 3.3**, firstly a representative point (known as the "sampling point") is sought and the value of each sampling point is expressed as a numerical value, a process that is known as "sampling."

With sampling, the next sampling point after the sampling point x_i will be $x_i + 1$, which is a point separated from x_i by a distance dx.

When handling analog information, although in reality dx = 0, when handling digital information, it is necessary to take dx as a finite value. In other words, the horizontal axis in **Fig. 3.3** becomes discrete.

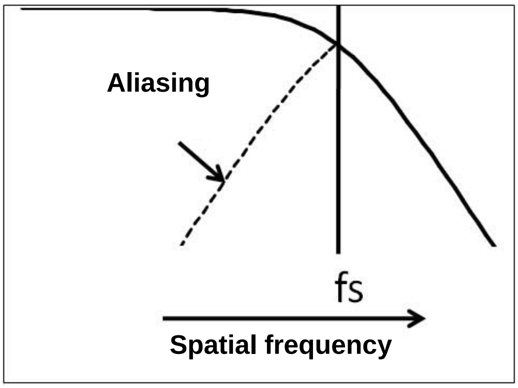


Fig. 3.4. Aliasing.

In **Fig. 3.3**, the value between the sampling point x_i and the neighboring sampling point $x_i + 1$, which is shown in gray, is shown as y_i at x_i. In other words, the value y_i is maintained between x_i and $x_i + 1$. This is referred to as a "hold."

However, with film, for example, which is an analog image record, the photosensitive materials must become discrete on the molecular level and in reality, even with analog, it is impossible to make dx = 0.

The fact that sampling of signals with properties f(x) (in this instance the image input signal) is carried out at a sampling frequency f_s, is equivalent to modulating the carrier wave frequency f_s of an electrical signal, and as is shown in **Fig. 3.4**, frequencies higher than f_s become aliasing distortion as image noise.

With regard to image compression, which will be mentioned in more detail below, the JPEG used in Exif [1] in most consumer DSCs uses discrete cosine transform (DCT), which is a type of Fourier transform, however, as DCT is a value obtained through discrete sampling, it is a method of frequency analysis and can be adopted even without the use of digital.

3.2 Fourier Transform

Using the integrable function *f* (*x*) defined as $0 \le x \le 2\pi$, with a_n and b_n as coefficients obtained with the following formulae,

$$\left.\begin{aligned} a_n &= \frac{1}{\pi}\int_0^{2\pi} f(x)\cos nx\,dx \\ b_n &= \frac{1}{\pi}\int_0^{2\pi} f(x)\sin nx\,dx \end{aligned}\right\} \quad (1)$$

the coefficient *f* (*x*) can be transformed as a Fourier series as follows:

$$f(x) \sim \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n \cos nx + b_n \sin nx) \quad (2)$$

More specifically, the real function *f* (*x*) will be converted to a function in the frequency domain as the sum of a harmonic component, which has a basic frequency of $0 \le x \le 2\pi$.

The output from the cell of an image sensor can be handled as a solitary wave with a width equivalent to either the vertical or horizontal dimensions of the cell.

If the cell dimensions are $2X_0$ and cell output is E, then the Fourier transform of the cell output can be derived using the following formula.

$$F(j\omega) = 2EX_0\frac{\sin \omega x_0}{\omega x_0} \quad (3)$$

This is shown in **Fig. 3.5**.

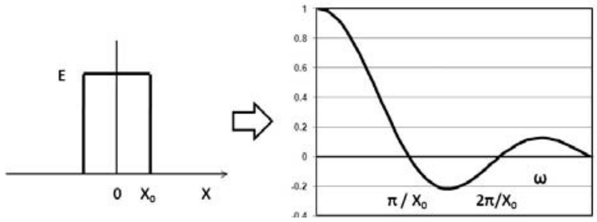


Fig. 3.5. Solitary wave Fourier transform.

From this the output signal provided by the aggregation of the solidary waves distributed over the surface of the image sensor can be converted to the aggregation of the continuous spectrum inside the image sensor, making it possible to calculate the signal value at any designated location even if a cell is not located in such a location.

Furthermore, applying the discrete Fourier transform gives N real numbers y_i (i = 0,1,…N-1), to which by applying the discrete cosine transform

$$x_k = \sum_{i=1}^{N-1} y_i \cos\left[\frac{\pi}{N}\left(i+\frac{1}{2}\right)k\right] \quad (4)$$

(k=0,1,⋯N-1)

and with the resulting coefficient

$$y_i = \sum_{k=1}^{N-1} x_k \cos\left[\frac{\pi}{N}\left(k+\frac{1}{2}\right)\left(i+\frac{1}{2}\right)\right] \quad (5)$$

(i=0,1,⋯N-1)

can be used to calculate the transform.

Although this example is a one-dimensional transform, an M × N two-dimensional transform can be calculated in the same way. With a two-dimensional transform, the M × N frequency coefficient can be sought for from the DCT using M × N sampling points.

While DCT can be applied to even functions, the coefficient is a real number and characteristically energy is concentrated in low-order coefficients. This characteristic whereby energy is concentrated in low-orders produces non-uniform entropy and by using this property it is possible to compress data volumes.

With the JPEGs used in DSCs, after a bilaterally symmetrical image has been added to the image to make an even function, it is converted to the frequency domain using DCT calculation. Furthermore, using the previously mentioned non-uniform entropy it is possible to achieve highly efficient data compression.

Note:

[1] "Exchangeable Image File Format," Standard of Japan Electronics and Information Technology Industries Association CP-3451, 3451-1.

4 The History of the Camera

4.1 Overview

It is said that the Greek philosopher Aristotle, who lived during the 4th century BC, knew that an outside scene could be projected inverted onto the wall of a dark room through a small hole. Applying this principle of the pinhole camera to image creation, it was the camera obscura, which was conceived around the 15th century as a device for copying the image of a subject onto paper, that was the launching pad for the creation of a unique camera culture separate from image culture that was reliant on the skill of the individual to draw pictures.

The camera obscura was a tool for recording images by tracing by hand an image projected on paper and which still depended on the artistic ability of the individual. As a result of wanting a means of retaining images without needing to rely on individual artistic ability or the help of others, a way of chemically fixing images was invented and subsequently led to the age of the silver halide camera, which continued for many years.

It was toward the end of the 20th century in 1981 when the camera became computerized and it was immediately prior to the last ten years of the 20th century that digital technology was introduced and the digital camera in its present form was born.

Let us now take a look at the history of the camera up until the advent of the DSC (**Fig. 4.1**).

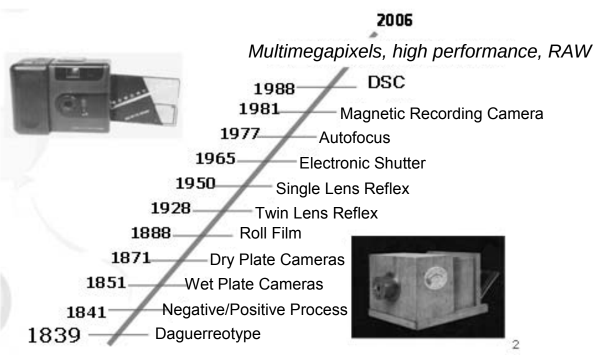


Fig. 4.1. Camera development.

4.2 Capturing Images

It is said that around 1250, using the principle of the pinhole camera, that the Italian author and architect Leone Battista Alberti invented the camera obscura. This enabled even people with no artistic ability to record images more accurately in a shorter period of time.

This device was also used by Leonardo da Vinci and is the forerunner of the modern camera.

In the 16th century, as lenses came to be used in camera obscuras and they were made more compact, not only were they used by many French painters when painting portraits, which were in great demand at the time, but also by ordinary people as a tool for painting landscapes.

Fig. 4.2. A camera obscura [1].

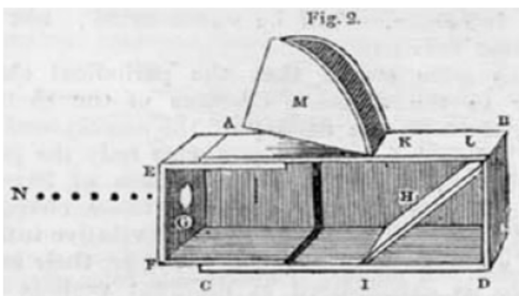


Fig. 4.3. Camera obscura structure [2].

An external view of a Camera obscura is shown in **Fig. 4.2** while its structure is shown in **Fig. 4.3**. Incidentally, camera means “room” and “obscura” means “dark” in Latin.

In 1725, the German Johan Heinrich Schultze discovered the light sensitivity of silver nitrate, and the English pottery manufacturer Wedgewood is said to have been the first to use the photographic method to record images using a chemical reaction to print pictures on pottery.

In 1824, the Frenchman Joseph Niepce Nicephore announced the development of heliography. While this used the phenomenon whereby dried bitumen derived from asphalt hardens when photosensitized, it required a long exposure time of over six hours. “A Man Leading a Horse [3],” which was taken by Niepce in 1825 and is said to be the world's oldest photograph, is shown in **Fig. 4.4**.

Fig. 4.4. Niepce's “A Man Leading a Horse.”

The first in the world to be sold as a camera was the Daguerreotype camera, which was jointly developed by Niepce and compatriot Louis Jacques Mande Daguerre, and announced by Daguerre on March 19, 1839 after the death of Niepce. The Daguerreotype is shown in **Fig. 4.5**.

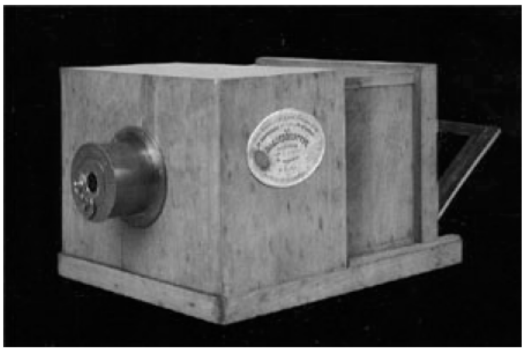


Fig. 4.5. Daguerreotype.

This camera required an exposure time of 30 minutes. Incidentally, the anniversary of the Daguerreotype is celebrated on March 19 each year as the Anniversary of the Invention of the Camera.

Although the Daguerreotype was not able to duplicate photographs, in 1841, the Englishman William Henry Fox Talbot invented the negative/positive process which not only enabled copies to be made, but greatly reduced exposure time to two to three minutes. Furthermore, in 1851, Frederick Scott Archer invented the wet plate photographic process, which used a liquid called collodion (a solution of nitrocellulose dissolved in a mixture of ethanol and diethylether) mixed with soluble iodide that was applied to a glass plate before being immersed in silver nitrate to create a photosensitive film, which was then used while wet to take a photograph. This process further shortened exposure time to less than ten seconds.

4.3 Cameras as Optical Instruments

In 1871, in place of the wet plate process, the dry plate process was invented whereby glass plates were coated with silver halide, and in 1888 the US company Eastman Kodak released a set consisting of a camera and film made by coating a celluloid film with silver halide. From that time the film camera became the predominant type of camera and as it used silver halide it came to be referred to as the silver halide camera (SH Camera).

In 1928, the German company Franke und Heidecke GmbH released the twin-lens reflex camera the Rolleiflex with an image size of 6×6 cm, and in 1950, the world's first pentaprism-type single-lens reflex camera, the CONTAX-S, was released by the German company Zeiss Ikon.

4.4 The Electronization of Cameras

In terms of the incorporation of electronics into silver halide cameras, in addition to flashes, electronic exposure devices, motorized zooms and motor drives, although in 1965 the electronic shutter was announced, followed by autofocus in 1977, despite the fact that many other devices other than the camera had been made electronic, the incorporation of electronics into cameras was comparatively slow as they require an internal battery.

Up until that time, as silver halide cameras were optical devices that used the silver halide chemical reaction, many film and camera manufacturer technical personnel had backgrounds in the fields of chemistry or precision machinery and it could be said that the computerization of the camera involving electrical/electronic technicians was aimed at the development of technology to supplement the picture-taking function of cameras.

It was from 1981 that the photographic method itself made the transition to electronic, and the DSC in its present form, using digital technology, was developed in Japan in 1988.

4.5 Electronic Cameras

In 1981, Sony's Mavica electronic camera (**Fig. 4.6**), which was also known as a floppy camera, was the world's first electronic device made in Japan to use a semiconductor image pickup device referred to as a CCD (Charge Coupled Device) in place of the film used in silver halide cameras, which in that respect made it an epoch-making event.

Fig. 4.6. Floppy Mavica.

This electronic camera magnetically recorded a single frame from a video movie camera (camcorder), which were already popular at the time, as an analog signal to a 2-inch dedicated floppy disk, and although image quality was on par with that of video cameras, it was a far cry from that of silver halide cameras. However, compared with conventional silver halide cameras it had characteristics such as the following:

1. Instant image replay.
2. Reusable recording media.
3. The ability to transfer images through telecommunications.

Furthermore, it did not require a chemical process and was enthusiastically welcomed by the news media, etc., as a groundbreaking camera that could record images electronically.

This electronic camera was the device that lifted the curtain on the electronic revolution that transformed the camera from a chemical-based device to an electronic device, and it could be said that it boasted a number of advantages ahead of the DSC that was to subsequently appear.

4.6 Digital Recording of Still Images

In 1980, a research report from Toshiba regarding the digitization and recording of still images onto cassette tape was submitted to the Magnetic Recording Committee of the Institute of Electrical and Electronics Engineers, Inc. (IEEE) of Japan [4], and in 1985 the prototype shown in **Fig. 4.7** was announced by the Institute of Electrical and Electronics Engineers (IEEE) [5].

This device, which recorded a digitized still image taken with a video camera and recorded in onto a C-90 cassette tape installed in a cassette deck, was able to record approximately 300 still images. The reason that a C-90 tape was used as the recording media was because data dropout was minor when carrying out digital recording due to the thin nature of the base layer. Although this is thought to have probably been the archetypal digital still camera, it did not lead to any product sales.

Fig. 4.7. Cassette camera.

4.7 The Age of the DSC

4-7-1 Background to the Birth of the DSC

In 1992, the Exif standard incorporating the JPEG data compression format came to be used in almost all consumer DSCs as a uniform international standard and became the driving force behind the growth of the market.

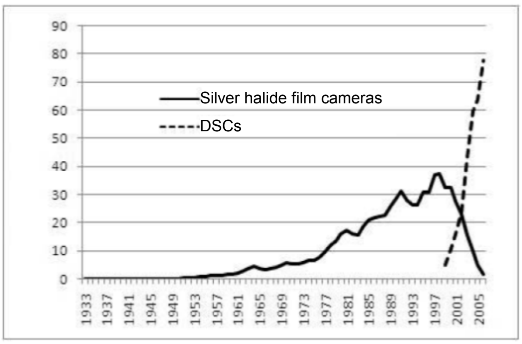


Fig. 4.8. Silver halide film camera and DSC production volume trends [6].

Furthermore, in addition to the dramatic improvements in image quality and functionality that were realized through many technological reforms, riding on the wave of infrastructure development (personal computers/the internet), and the success of Casio's QV-10 (65,000 JPY) that was released in 1995 and QV-10A (49,500 JPY) that was released the following year, the market for consumer communication devices rapidly expanded, with DSCs exceeding silver halide cameras in terms of production value in 2000 and production units in 2002 to develop into an industry with an annual production value in excess of 1 trillion JPY.

Figure 4.8 shows production trends in Japan for silver halide cameras and DSCs since 1935 in terms of the number of units produced. Since the development of DSCs, although there was a rapid drop in the number of silver halide camera produced, overall camera production has steadily increased since 1935. **Figures 4.9** and **4.10** show monthly production in terms of units and value for silver halide cameras and DSCs since 1999 when DSC statistics became available for the first time. According to these figures, recently, while DSC monthly production has been in excess of 5 million units with a shipment value in excess of approximately 100 billion JPY, silver halide camera monthly production has dropped to 100,000 units with a shipment value of about 500 million JPY [7].

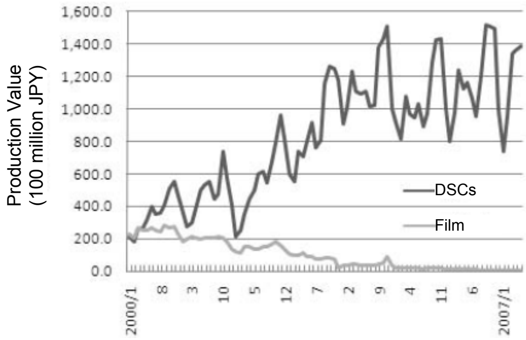


Fig. 4.9. DSC/silver halide film camera production value trends.

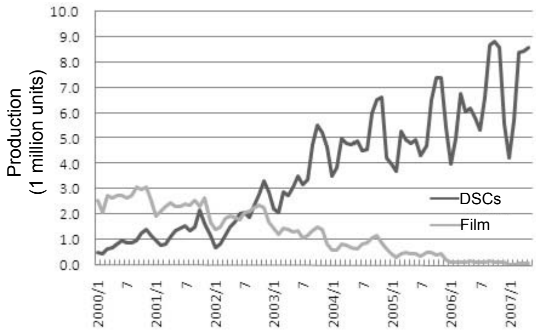


Fig. 4.10. DSC/silver halide film camera production trends.

4-7-2 The Path to Electronization

Although some are of the opinion that the advent of DSCs can be attributed to measures to deal with the depletion of the silver resources that are essential for silver halide cameras and environmental problems, was that really the case?

Certainly during the period between the latter half of the 1970s to the first half of the 1980s measures to deal with resource depletion and control pollution were a major issue in society. Due to these concerns regarding the depletion of resources, the price of silver continued to soar and the US National Association of Photographic Manufacturers (NAPM) [8] lobbied the government to abolish one USD coins using silver, while in Japan, although the silver in 100 JPY coins had already been replaced with nickel silver, the price of old 100 JPY coins made of silver had already exceeded 100 JPY on account of the value of the silver.

The film and photographic paper used with silver halide cameras used silver and chemicals were used during the developing process.

However, at the time when DSCs were developed at the end of the 1980s, these problems had already been solved.

That is to say, the price of silver had stabilized due to forecasts of long-term stable supply and the adoption of silver recovery processes. With monochrome (black and white photographs), as silver remains in film and on prints, minute volumes of silver are, in fact, consumed. Nevertheless, with color photography, only dye called a coupler bonded with silver particles and remained on film and prints and silver was completely recovered during the developing process.

Furthermore, strict antipollution laws were enacted with regard to the use of chemicals by shops developing, printing and enlarging photographs, thus completely solving such environmental pollution problems. In this way, in the silver halide camera industry, which is in reality a chemical industry, measures regarding resource depletion and environmental conservation had already been introduced and the problems faced by silver halide photography had already been solved.

However, the sense of uncertainty regarding resources and demands for environmental conservation were general social phenomena and the industry-wide trend to move from chemical-based technology to electronics-based technology – which could be referred to as the second industrial revolution – had already reared its head and was gaining traction. In the midst of this technological revolution, there were moves to introduce technological reform into the photographic industry. As the technological environment was ripe for change, these moves resulted in a time of catastrophic change within the photographic industry from which a new industrial model emerged.

Fuji Photo Film (now Fujifilm), the top film manufacturer in Japan, was not only a film manufacturer, but also sold cameras and single-use cameras (QuickSnap) as part of its imaging business and in 1966 the 8 mm film movie camera Fujica Single 8 sold in huge numbers after the airing of the “I can shoot movies, too” commercial.

However, as using the Fuji Single 8 was expensive due to film and processing costs, it quickly lost its place to the 8 mm video camera when it was announced in 1985.

This “replacement drama” was due to factors such as the instant nature, ease of playback, and the low cost of the reusable recording media used in the 8 mm video camera, which used electronic technology.

Fujifilm currently has a nationwide service system for printing images taken with DSCs and the photographs obtained through this service use the same chemical reaction as used in silver halide photographic prints.

In this way we can see that although the chemical industry still emphasizes quality and mass processing capacity in its commercial business, consumers have welcomed the advantages of electronics in consumer products.

Furthermore, in terms of the camera's relationship with the news media, as they were in need of a means to send photographs instantly rather than having to develop and print them before wiring them, by the time of the Los Angeles Olympics the media had already enthusiastically embraced the use of electronic cameras. In this way, even in the world of photographs, the transition from chemicals to electronics continued as the industry was swept along by the inevitable flow of technology.

Electronics is the field in which electrical manufacturers perform the best and they have many specialist technicians. However, in the latter half of the 1980s, there were companies among the camera manufacturers and film manufacturers, which had been built on the foundation of precision machinery and chemistry, that strengthened their electronics capabilities with the aim of further expanding their technological capabilities and product range by following the trend of using electronics in cameras and they started work on DSCs.

During the same period, nonvolatile memory that was rewritable electronically was developed at Toshiba and they had been searching for applications that used memory cards using that technology. Furthermore, they had been making progress on technology for digitally recording still images and the performance of semiconductor devices that supported that technology, such as seen in the previously mentioned Toshiba audio cassette tape still image recording device.

Up until that time, the A/D (Analog to Digital) converter that digitized the images did not have adequate performance to be able to digitize images in real time, high-efficiency compression technology with only low levels of degradation had yet to be developed, and there was no way to store digitized images other than SRAM (Static Random Access Memory), which required backup power to store them in semiconductor memory. Therefore, even though it was theoretically possible to propose a DSC, the realization of the concept was considered to still be some time away.

Nevertheless, memory was developed using a new principle that overcame the limitations of the recording media that existed at the time.

4-7-3 Early DSCs

In addition to functioning as a camera that records images, as we will see, a DSC is an image information device that simultaneously records various information associated with images that are taken.

In 1988, Fujifilm announced the world's first fully digital camera, the DS-1P (**Fig. 4.11**), which recorded an image acquired using a CCD as a digital signal on a memory card jointly developed with Toshiba, and in December of the following year, they released the world's first digital camera (Fujifilm: DS-X; Toshiba: IMC-100) (**Fig. 4.12**) with the aim of carrying out the world's first DSC market survey.

In November 1990, the MC-200, which was the world's first commercially produced DSC, was released by Toshiba.

Fig. 4.11. DS-1P.

Fig. 4.12. DS-X (IMC-100)

These early DSCs, which captured a single frame (or a single field) in the same way as an electronic camera or a video movie camera (camcorder), compressed it as a digitized image signal and recorded it to semiconductor memory, and as the aim was to replay these images on a TV in the same way as an electronic camera or camcorder, they had about the same number of pixels (350,000) as displays using the Video Graphics Array (VGA) standard.

As it is necessary for cameras taking still images to be able to handle taking them on a vertical or horizontal angle, although it is desirable for the image sensor to have a square pixel aspect, as production lots are small and special development of image sensors costs a huge amount of money, in these early DSCs a single 2/3-inch 400,000 pixel FIT (Frame Interline transfer) CCD with a non-square pixel aspect ratio for use in a movie camera was used and image processing was used to create square pixel data.

Moreover, as at the time there was no appropriate form of data compression technology, sub-sampling was used for 2D compression and ADPCM (Adaptive Differential Pulse Code Modulation) was used for signal compression and 6 or 12 images were recorded to 9 Mbit (1.125MB) or 18 Mbit (2.25MB) SRAM memory cards respectively that were backed up by battery.

In terms of image processing circuits, as the number required was too small to develop a dedicated Large Scale Integration (LSI) for mass production and custom-order parts were used, the beta unit for market survey purposes was not only not up to standard in terms of performance, but the price was expensive at 1.6 million JPY as it included peripherals, such as a playback device, a DAT recorder and modem.

Therefore, as image quality was nowhere near as good as that of silver halide cameras and the high price of early DSCs meant that it was utterly impossible to even consider putting on the shelves in stores for sale to the general public as a consumer camera, there was no option other than to try and find customers who valued the features not found in silver halide cameras; namely their instant nature and the ability to transfer images.

One of the major customers at that time was an airline who used DSCs at their maintenance facility in Hokkaido. Whereas previously they had wired photos from their maintenance facility in Haneda in order to verify areas for repair, using DSCs they were able to transfer the information over a telephone line and so that repairs could be checked by both parties. In addition, customers who had previously used conventional wire photos, including nationwide auction networks, etc., were limited to certain applications and other R&D divisions within the same industry who were carrying out their own DSC development, meaning that DSCs were never made available to the general public.

As the technological level of early DSCs at that time could not rank with that of silver halide cameras in terms of quality or price, they lacked the ability to develop a consumer market.

However, in addition to the fact that electronic cameras had revolutionized the industry by taking the camera out of the chemical industry and into the electronics industry by rendering images electronically, DSCs had advantages such as the following over electronic cameras:

1. By changing the recording format from analog to digital, they eliminated the degradation of images transferred or copied.
2. By recording images electronically to semiconductor memory rather than magnetically to floppy disks, the drive section of recording media was eliminated and recording and reading times were shortened.

However, with early DSCs, even though images were able to be imported into personal computers (PCs), as image processing software functions were inadequate, compatibility with PCs due to the use of digital signals was a feature that was not that remarkable.

Furthermore, as the internet had yet to be developed throughout the country, even though images taken on a DSC could be imported into a PC, it was not possible to send and receive them over the internet, which is almost second-nature to us now, but rather images were sent and received at that time on the VGA level via TV telephone or shared through direct PC to PC communication.

4-7-4 From Viewing on TVs to Viewing on PCs

With image quality designed for replaying images on a TV screen, even if images are printed out they are coarse and scanning lines are visible, and in terms of image quality, it is not even as good as disposable silver halide cameras.

Moreover, as the price of DSCs was in excess of several hundred thousand yen, at that time, it was impossible to predict that they would ever replace silver halide cameras as consumer cameras as they have, in fact, done now.

Although Apple released a consumer DSC, the Quick Take 100, in 1994, it failed to catch on.

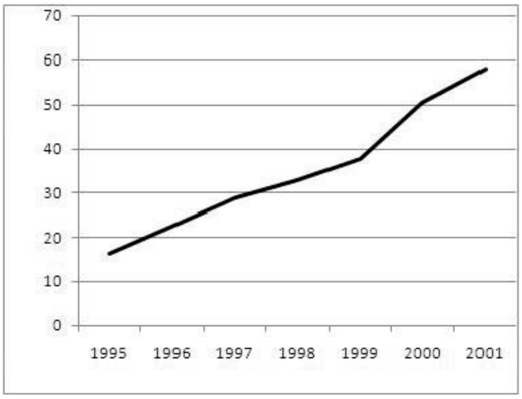


Fig. 4.13. PC ownership [9].

At the time, the segment of the market that was buying DSCs was mainly the media, who prized the instantaneous nature of the technology and ease of transmitting images, and in light of this, in 1995 Fujifilm released the DS-505 (1.4MP), Nikon released the E2S (1.4MP), Canon released the EOS-DCS3 (1.3MP), Minolta (now Konica-Minolta) released the RD-175 (1.75MP), all of which were professional DSCs.

Nevertheless, although the household PC ownership rate (excluding single parent households) around 1993 was around 10%, from around that time it started to increase (**Fig. 4.13**).

If the main purpose is to import images into a PC, then as long as they are compatible with the image sensor, image limitations are eliminated and DSC specifications, such as the number of pixels, image size and aspect ratio, can be freely selected and it is possible to easily create photographs at home using a printer connected to a PC.

In this way, by changing the aim of the DSC from replaying images on a TV to inputting them into a computer, it could be said that the road into the future was opened up for DSCs as a consumer device, and the fact that it was Casio that led the way probably means that it needed a company that was not tied to TV or video technology to come up with that idea.

The household PC ownership rate rose to around 15% in 1994, exceeded 20% in 1997 and from around 1999 rapidly increased to the extent that today it is in excess of 70%.

Moreover, internet access was made available in Japan from 1994 and with DSCs being recommended as tools for creating images for use on websites and images taken on DSCs being shared over the internet, this had a major impact on the growth of the DSC market (**Fig. 4.14**).

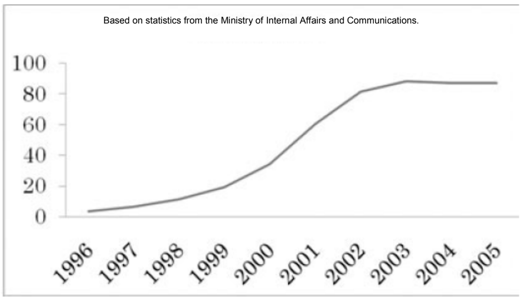


Fig. 4.14. Internet utilization trends [10].

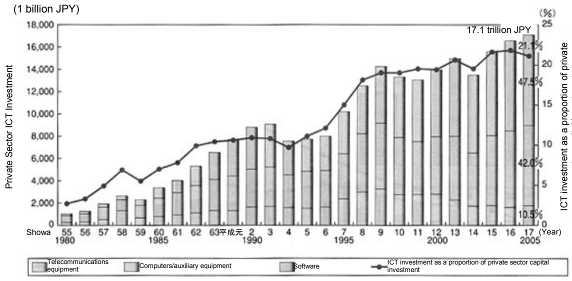


Fig. 4.15. Real ICT investment trends [11].

Capital investment in ICT, including the internet, has rapidly increased since 1995 (**Fig. 4.15**).

It could be said that by skillfully riding the ICT wave that sales of DSCs rapidly increased.

4-7-5 The Advent of Consumer DSCs

The fact that the aim of DSCs was changed from playing images back on a TV to importing them into a PC was a major turning point for DSCs. However, at a time when the household PC ownership was less than 20%, it was impossible to create a market for consumer DSCs purely from households with PCs and first it was necessary to reduce the price and arouse the curiosity of that section of the consumer market that liked “new things.” At Casio, an unofficial project by a small group of researchers was working to develop a low-cost DSC.

Although the first units developed were given the nicknames “*Omoko*” (“heavy child”) and “*Atsuko*” (“hot child”) (**Fig. 4.16**) as the former was an extremely heavy prototype and the latter was a prototype that got very hot due to high power consumption, ultimately the specifications for a consumer unit were finalized and in 1995 the QV-10 (**Fig. 4.17**) was released at a price of 65,000 JPY.

Moreover, the following year, the QV-10A, which had basically the same functions, was released at a price of 49,800 JPY. As up until that time there had never been a DSC priced under 100,000 JPY, the release of these models at this price point had a major impact on the camera manufacturers.

Fig. 4.16. Casio's DSC prototype "*Atsuko*."

Fig. 4.17. Casio's QV-10.

However, the QV-10 and QV-10A only had 250,000 pixels and as the image quality of the dedicated printer was poor, it could be said that almost none of the camera manufacturers expected that the DSC would displace the camera and that it would become an image data device that would go even beyond the silver halide camera. Therefore, the DSC R&D departments of the camera manufacturers were mostly full of electronics technicians, in many cases what they were doing was away from the mainstream, and few camera specialists developing optics, etc., were involved.

The QV-10 and QV-10A used the Exif standard, which we will examine in more detail below, that had already been adopted as the standard for DSCs in Japan and which had been proposed as an international standard.

Exif, which incorporated the JPEG image compression format that was cutting-edge technology at the time and which was an international standard developed in Japan, was adopted by all DSC manufacturers. As all products therefore shared the same specifications, consumer desire to buy was not dampened, which made it possible to achieve higher household penetration, leading to rapid market growth.

In addition to the above, as consumer appliance manufacturers, who were experts in computer technology, entered the market that was previously the domain of the optical instrument manufacturers, the shape of the camera industry, including manufacturing and marketing structure, was radically changed with the appearance of DSCs.

The performance of DSCs being sold at present surpasses that of silver halide cameras and they are being sold at a somewhat cheaper price than equivalent silver halide cameras.

4-7-6 Digital Single Lens Reflex Cameras (DSLRs)

Cameras can be classified into four different categories according the type of finder they use for verifying the subject prior to taking the photograph:

(1) Viewfinder Cameras

In addition to the lens used for taking the photograph, these cameras have an inspection window through which the subject can be verified. As they are cheap, many compact cameras are of this type.

(2) Single Lens Reflex Cameras (SLRs)

The image of the subject as seen through the lens used for taking the photograph is reflected by a mirror onto a focusing screen so that the subject can be verified. Only at the moment when the shutter is released does the mirror move out of the way to expose the photosensitive surface (film or an image sensor). Many high-end cameras use this type and many feature interchangeable lenses.

(3) Twin-Lens Reflex Cameras

In addition to the lens used for taking the photograph, this type of camera has another lens coupled with that lens through which the subject can be viewed. Although the subject can be viewed when the shutter is pressed, there is the disadvantage of parallax.

(4) View Cameras

A focusing screen is placed on the imaging surface and after verifying the subject sheet film or a dry plate, etc., is inserted in its place and the photograph taken. This type of camera is often used in places such as studios.

Although the structure of an SLR is complicated, as we can see from **Fig. 4.18**, as it is possible to verify exactly the same image as that projected onto the photosensitive surface, this type of viewfinder is used in high-end cameras.

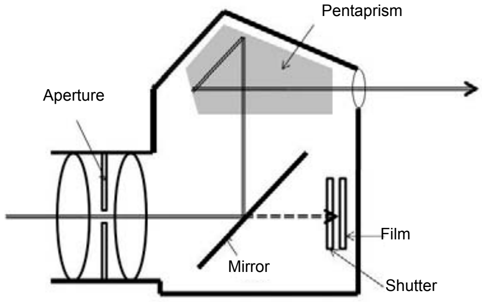


Fig. 4.18. SLR structure.

The first SLR is said to have been the Ihagee Kine-Exakta, which was released in 1884.

However, the first SLR welcomed by the market was the CONTAX S, which was released in May 1949. In Japan, Asahi Optical (now Pentax) released the Asahiflex in 1952.

With DSCs, from the time that the first DSCs appeared, although SLR-type DSCs started to appear in media-related fields, they did not really catch on.

It was Nikon's D1, which was released in 1999 at a price of 650,000 JPY, and Canon's EOS-D30, which used an APS-size image sensor and was released the following year at a price of 358,000 JPY, that really launched the digital SLR (D-SLR). Since the D30, the focal length of interchangeable lens-type D-SLRs has gained popularity as being "35 mm equivalent."

With DSCs, as the sensor signal is displayed on a monitor screen, such as a Liquid Crystal Display (LCD), this makes it possible to verify the picture being taken in the finder just as it really is.

With regard to the aim of making it possible to change lenses and verify the picture using a more detailed image, this too has been achieved and sales of D-SLRs are growing, with models for the commercial, professional and high-end amateur markets.

D-SLRs have now become mainstream and offer not only higher quality images, but also the traditional advantages of an SLR, such as interchangeable lenses and the ability to verify the picture using a more detailed image.

While general consumer DSC image data is 8-bit and this is output with JPEG compression using the sRGB color space, which is the same color reproduction range as that used in TV monitors, as most SLRs striving for high image quality can extract raw data which is almost identical to the output signal from the sensor, this allows the use of a greater bit-depth and a color space that is much wider than sRGB.

However, as raw data is output in a format specific to the image sensor, there is the disadvantage that proprietary software unique to each camera is required in order to obtain (develop) an image.

Consumer DSC image files are recorded in accordance with the unified Exif standard and as it is possible to process files in a standard manner in accordance with DCF (design rule for camera file system) [12], in light of the fact that it is possible to process images in a common way regardless of the type of camera, although there were moves to standardize raw data under an ISO standard, as there is the possibility that it may lead to the disclosure of the know-how of each company, DSC manufacturers were loathe to do so.

4-7-7 Camera Phones (CP)

The first mobile phone to be equipped with a camera function was manufactured in 1999 by Kyosera and sold by DDI Pocket (now WILCOM) as the VP-210. Although this was a PHS phone with a 110,000-pixel

Complementary Metal Oxide Silicon (CMOS) sensor, both the camera and the LCD screen were on the same side as it was designed for use as a videophone. In addition to this, although TUKA and NTT DOCOMO released a trial model to which a camera function could be added by means of an adaptor, it did not catch on.

The first real commercial CP was the J-SH04 that was jointly developed by J-Phone (now SoftBank Mobile) and Sharp and brought to market in November 2000. The ability to send images by mail was welcomed by the market and J-Phone quickly gained market share.

After that, the various carriers followed, with Tuka and Sanyo releasing the TS11 in 2001, joined the following year by au and Casio with the A3012CA and NTT and Sharp with the SH251i.

Early CPs had few pixels and although the image taken could be replayed on the screen of the phone, from 2003 the various companies introduced models with more than 1MP (megapixel), followed in December of the same year by models from NTT DOCOMO, Vodafone and au with 2MP. Models with 4MP arrived in 2005 and now there are even models with 5MP, which is about the same as that of general DSCs.

Mobile phone production trends are shown in **Fig. 4.19**.

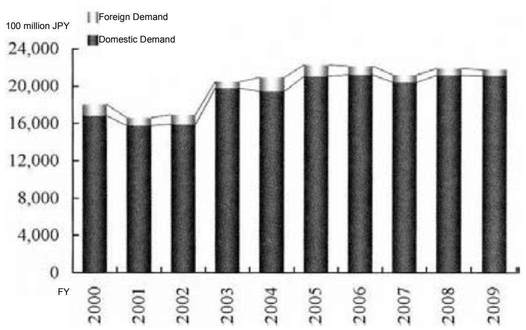


Fig. 4.19. Mobile phone production trends [13].

In terms of the technological concept behind CPs, they were developed under the direction of the terminal manufacturers and as these manufacturers were also DSC manufacturers, DSC technology was transferred to CPs. Therefore, Exif, which was used in DSCs, was adopted as the image file format for CPs, meaning that image files could be exchanged between CPs and that images taken on a CP were compatible when saved to a PC.

Considered only in terms of the number of pixels, CPs compare favorably with DSCs and although they have other camera features, such as zoom functions, they are by nature small, mobile handsets for communication purposes that as an auxiliary feature have a camera and in terms of lens and image quality, at present they do not measure up to the capabilities of dedicated DSCs – and even if CP camera performance increases, DSC performance is most likely to already be one step ahead. However, they are mobile and convenient, the images taken can be transferred and saved, and CPs with basic picture-taking capabilities mean that it is not necessary to carry a camera in addition to a mobile phone, they are ideal for snapshots and in 2003 they outstripped sales of mobile phones with no camera function to become mainstream.

While there are legal restrictions regarding providing DSCs with communication functions, CPs are positioned as a new consumer data communications device, the main function of which is telecommunications. By providing mobile phones with a camera function, if the purpose is just snapshots and there is no real emphasis on image quality, then it could be said that there is no real necessity to carry a DSC in addition to a mobile phone.

Therefore, it is thought that a major new market for CPs as snapshot cameras will be created in addition to the high-end camera and compact camera markets.

Notes:

[1] Image provided by the Japan Camera and optical instruments Inspection and testing Institute (JCII) Camera Museum.

[2] *Saturday Magazine*, 1838 (Issue No. unknown).

[3] Although it was previously thought that "View from the Window at Le Gras" taken by Niepce in 1826 was the oldest photograph, "A Man Leading a Horse" was discovered early this century and is now said to be the oldest.

[4] Kageyama et al., “Digital Still Image Recording Device using a Cassette Deck,” *Magnetic Recording Committee of the IEEE Japan*, MR80-25, October, 1980.

[5] S. Kageyama, K. Kudo, M. Tanaka, M. Ohyama and M. Ohkawa, “Digital Still Picture Recorder utilizing an Ordinary Audio Cassette Deck,” *IEEE Transactions on Consumer Electronics*, Vol. CE-31, No. 2, pp.96–107, May 1995.

[6] Created based on statistics from the Camera and Imaging Products Association (CIPA) and statistics from the JCII Camera Museum.

[7] Created based on statistics from the Camera and Imaging Products Association (CIPA).

[8] The National Association of Photographic Manufacturers (NAPM) was created in 1946, changed its name in 1997 to the Photographic and Imaging Manufacturers Association (PIMA), and merged with the DIG (Digital Imaging Group) to become the International Imaging Industry Association (I3A) in 2001.

[9] Ministry of Public Management, Home Affairs, Posts and Telecommunications, *Telecommunication Usage Trend Survey Results (Consumer Edition)*, 2001 Edition, p.1.

[10] Ministry of Internal Affairs and Communications, *Information and Communications in Japan*, 2007 Edition p.151.

[11] Ministry of Internal Affairs and Communications, *Information and Communications in Japan*, 2007 Edition, p.12.

[12] “Design Rules for Camera File Systems, DCF 2.0” in *Japan Electronics and Information Technology Industries Association (JEITA) Standard*, September 2003.

[13] “Forecast of Industrial Electronic Equipment Demand,” Japan Electronics and Information Technology Industries Association (JEITA), p. 16, FY2006−2009.

5 DSC Structure

According to ISO12231 (Vocabulary), a DSC is defined as a "portable, hand-held device which incorporates an image sensor and which produces a digital signal representing a still picture," with a note stating, "The digital signal is typically recorded on removable memory, such as a solid-state memory card or magnetic disk."

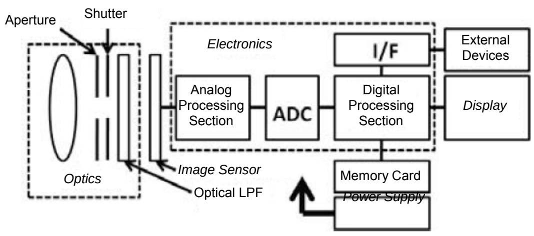


Fig. 5.1 DSC structure.

In other words, an image sensor is essential for a DSC, which is a mobile image data device where the light from the subject forms an image on the flat surface of the image sensor with its rows of photoelectric transducer cells, and the electrical output from each cell is extracted and converted to digital and generally recorded on semiconductor memory or magnetic disk as image data.

The basic structure of a DSC is shown in **Fig. 5.1**. Overall, it is divided into an image sensor (which converts light into electrical signals), and optics, electronics, storage (memory card), display (LCD, etc.) and power supply (battery, etc.) systems.

The optics system consists of a lens, shutter, iris, optical low-pass filter (LPF) and an IR-cut filter, etc. In compact DSCs, exposure time is adjusted electronically and some units do not have a mechanical shutter.

The electronics system consists of an analog signal processor, digital signal processor, controller, and output and recording sections. The main constituent elements of DSCs are described in more detail below.

5.1 Image Sensors

The image pickup devices (image sensors) used in DSCs can basically be categorized into two types – CCD and CMOS sensors – depending on how the signal is read from each cell and how that signal is amplified. With both types, extremely small photoelectric transducers (photodiodes) only a few microns in size that use the internal photoelectric effect of semiconductors (silicon) are arranged in a regular two-dimensional pattern.

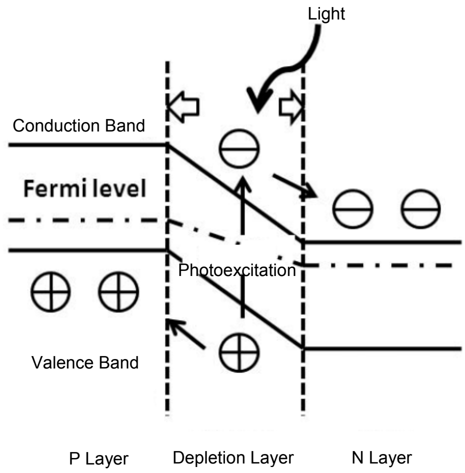


Fig. 5.2. P-N junction photodiode band structure.

The state when reverse bias is applied to the P-N junction of a semiconductor made of silicon, etc., is shown as an energy band structure in **Fig. 5.2**. When light from outside illuminates this junction, excitation of the electrons in the valence band occurs on the conduction band in the depletion layer, leaving a positive hole in the valence band. These electrons and positive holes are attracted to the impressed electrodes to produce current in proportion to the strength (intensity) of the light over a wide illumination range. This is the principle of the photodiode and each cell of the image sensor extracts output from a photodiode.

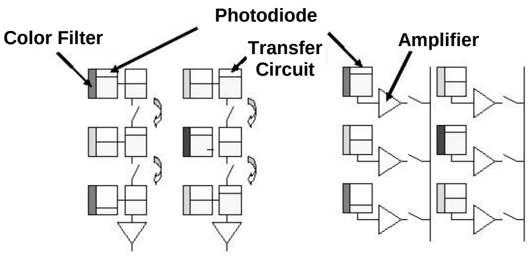


Fig. 5.3. CCD and CMOS sensors.

The typical structure of commonly used Interline Transfer CCD (IT-CCD) and CMOS image sensors is shown in **Fig. 5.3**.

In IT-CCD sensors, cells are formed in a grid pattern on the circuit board and the charge produced in each cell according to the intensity of the light is transferred simultaneously to the charge transfer register (bucket) of each cell. The contents of each bucket are then transferred out in a vertical direction in turn from the cell above to the cell below, and at the bottom the contents are then transferred out in a horizontal direction to the right. This differs from a CMOS sensor in the sense that the contents of each cell are read out using an address line.

Moreover, with a CCD, in the final stage of the bucket relay, a single amplifier amplifies the signal, while with a CMOS sensor there is an amplifier for each cell.

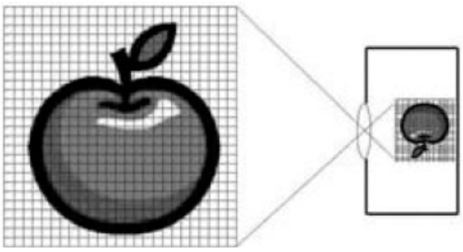


Fig. 5.4. Subject and image sensor.

A model of the relationship between the subject and the image sensor is shown in **Fig. 5.4**. As cells are the smallest units of the image sensor, the data of incoming light within a solid angle entering each cell is dealt with as an average value for the data within the solid angle and it is impossible to further divide up the data of the subject seen through the lens within the solid angle into smaller parts. Therefore, when light emitted from two points that are extremely close together on the subject enter into the same cell, it is impossible to distinguish those two points apart on the subject.

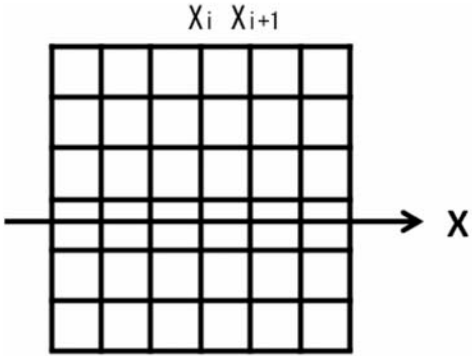


Fig. 5.5. Schematic depiction of a cell.

That is to say, the subject is recorded as a mosaic-like image corresponding with the cell pattern for the subject. Generally, the higher the number of pixels, the smaller the solid angle of each cell is expected to be, and the more detailed the mosaic pattern becomes. Therefore, each cell must correspond to an adequately small part of the subject.

When considering image sensors with a square cell structure arranged in a grid pattern on a substrate such as shown in **Fig. 5.5**, a single direction on the image sensor corresponds to the horizontal axis x in **Fig. 3.3**.

In other words, images captured by the image sensor are spatially discrete, and the output signal from each cell is derived as a digital value through later processing.

The total number of cells on an image sensor is referred to as the gross sensor resolution. However, not all cells are used to form an image, and the cells on the image sensor that are used to form an image are known as effective pixels. The number of effective pixels on the image sensor is referred to as the effective sensor resolution.

In **Fig. 5.6,** an image on an image sensor is shown. The central grid area is the output image, while the cells in the surrounding gray area are cells called ring pixels that are used for image processing purposes, such as sharpening and pixel interpolation.

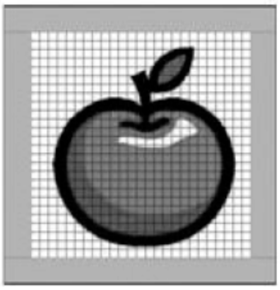


Fig. 5.6. The concept of ring pixels.

Although cell data from this area will not be displayed as an actual image, such data plays an effective role in improving image quality, and ring pixels are permitted to be included when describing the effective sensor resolution.

The definition of resolution is a physical quantity that expresses the spatial frequency response characteristics of a subject, and in order to measure this, a chart with continuous changes in spatial frequency, such as that shown in **Fig. 5.7**, is photographed to show to what degree spatial frequencies can be reproduced, or patterns with changes in black and white graduations, such as shown in **Fig. 5.8**, are photographed and the spatial frequency response (SFR) is sought by carrying out Fourier analysis of the output signals.

Fig. 5.7. An example of a resolution measurement chart.

Fig. 5.8. An example of an SFR measurement pattern.

In addition to these, various methods of measuring resolution and charts and software for calculating resolution are proposed and discussed in ISO TC42. The chart shown in **Fig. 5.9** is a resolution measurement chart proposed by Japan (ISO 12233 chart).

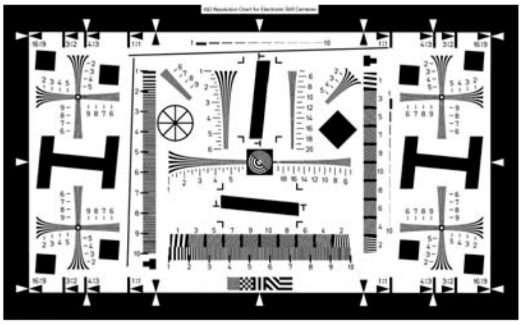


Fig. 5.9. An ISO12232 resolution chart.

In many cases it is mistakenly thought that DSC resolution is primarily determined on the basis of the number of pixels. Although it is true that the number of pixels is a factor in determining resolution, resolution is also governed by factors other than the number of pixels, such as image processing methods, filter structure and optical performance, and depending on whether image quality is set to fine or normal when shooting, etc.

It is difficult to seek a numerical value to effectively compare the number of pixels on a DSC with film as the grains of photosensitive substances are not arranged in a regular manner and depending on sensitivity the size of such grains varies. It is possible, however, to estimate such a value by measuring spatial frequency characteristics using ISO charts, etc. It is therefore said that ISO100 film is the equivalent of 6MP to 10MP, while ISO400 film is the equivalent of 4.5MP to 10MP.

Therefore, strictly in terms of the number of pixels, it could be said that recent DSCs are on par with or superior to film cameras.

As they are, the cells on CCD and CMOS sensors react to the intensity of light and are similar in that respect to monochrome film. Therefore, in order for them to respond to color, it is necessary for each cell to have a color filter. On single-plate image sensors, the color filter on each cell is arranged in a mosaic pattern, while three-plate image sensors use prisms, etc., to direct incoming light from the subject through color filters and onto the three image sensors.

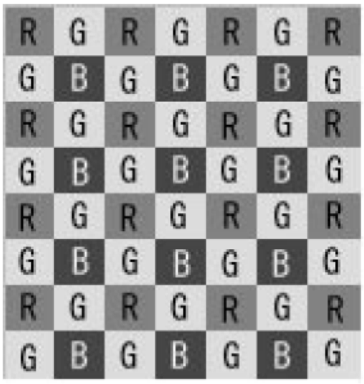


Fig. 5.10. Bayer primary color filter.

In terms of color filters, there are primary color types, which pass light through the three primary colors (red, green and blue), and complementary color types, which pass light through cyan, magenta and yellow filters.

An example of the primary color filter type (Bayer type) is shown in **Fig. 5.10**. There reason that there are twice as many green filters as there are red or blue is that the human eye is more sensitive to green than it is to red or blue, and increasing the number of green filters has the effect of increasing visual resolution.

Each cell on an image sensor is called a pixel (pixel = picture element) and the number of effective pixels on a DSC image sensor is described in terms of megapixels, for example 3MP.

On the other hand, pixel is also used to refer to the smallest constituent element of an image after carrying out image processing, such as the compression of image sensor output and image correction.

Although the former is a concept for expressing the smallest physical constituent element on the image sensor that captures images and is specific to each image sensor, the latter is a concept describing the smallest constituent element of an output image, something that changes due to processing, such as image compression.

In this document we will refer to the smallest constituent element of an image sensor on the input side as a cell, while referring to the smallest constituent element on the output image as a pixel.

The number of cells per millimeter is described as the spatial frequency of the image sensor.

5.2 Optics

Optical technologies, such as lens design and flare countermeasures, have been developed over many years by silver halide camera manufacturers, and for camera manufacturers who have established their own know-how in silver halide cameras, this is one of the areas where they can demonstrate their expertise the most.

However, in order to design an optimum lens system it is necessary to consider image sensor dimensions and physical characteristics.

As we can see in **Fig. 5.11**, the size of the photosensitive surface of 35 mm film is 36×24 mm and it has a diagonal measurement of approximately 43.3 mm. By contrast, while in some DSCs the size of the image sensor is the same as that of the photosensitive surface of 35 mm film, it is usually smaller and for D-SLRs is about 24×16 mm (diagonal measurement of 28.8 mm), while the 2/3 type image sensors used in many fixed-lens DSCs is 8.8×6.6 mm (diagonal measurement of 11 mm) and the 1/3 type is 4.8×3.6 mm (6 mm diagonally).

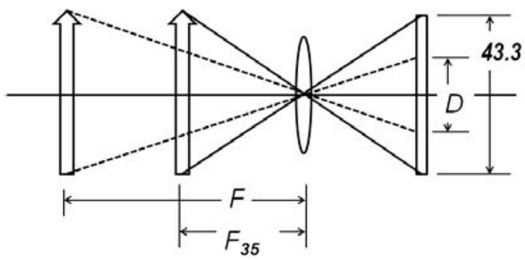


Fig. 5.11. Image sensor size and focal length.

If the size of the image sensor is small, then the photographable range of the subject (angle of view) is also small, and when the images taken are played black at the same size as they were taken, then images with a small angle of view look like they were taken with a telephoto lens. In other words, if a 35 mm lens for use with 35 mm film is used on a DSC with an image sensor where the diagonal length of the image sensor is D (mm), then the apparent focal length of the lens can be obtained using the following formula:

$$F = F_{35} \times \frac{43.3}{D}$$

Therefore, when using a 35 mm film lens on an interchangeable lens-type DSLR, the focal length will be shifted to the telephoto range. So, for users who are used to the 35 mm film focal length, the focal length in the above equation is displayed as 35 mm.

On the photosensitive surface of the image sensor, for images with a higher frequency than the previously mentioned spatial frequency, or in other words, for images that are finer than the size of the cells, image data for more than one image will be input into a single cell. As a result, images with a spatial frequency that is higher than that of the cell spatial frequency will not only playback badly, but artifacts will be produced. In order to prevent this, an optical low pass filter (OLPF) is required to block image signals with a spatial frequency that is higher than the spatial frequency of the cells by using crystal birefringence, etc.

Although it is easy to emphasize electronic technology when talking about devices using novel digital technologies, in terms of the main focus of development, the optical design capabilities inherited from the silver halide era are essential for enhancing the optical performance of DSCs.

5.3 Electronics

The output from the image sensor itself is an analog signal. After passing through a Correlated Double Sampling (CDS) circuit to reduce image sensor noise, this output signal is converted by the A/D converter into a digital signal. The digital signal in consumer DSCs is 8-bit (256 colors).

Output data from this A/D converter that has only been processed for data linearity, dark current reduction, shading and sensitivity correction, flare removal and white balance is referred to as raw data.

In digital image processing, after cell defect and variation correction, de-mosaicing (mentioned later) and sharpness correction have been carried out, in consumer DSCs the image file and metadata are then created in accordance with the Exif image file format.

5.4 Recording

In most consumer DSCs, memory cards containing semiconductor memory are used as recording media.

Although PC cards containing SRAM were used in early DSCs, a backup battery was required inside the card and memory size was small.

Since the release of flash memory in 1984, various companies have released new memory cards, such as CompactFlash, which was released by SanDisk in 1994, SmartMedia [4], which was released by Toshiba in 1995, MMC [5], which was released by Siemens and SanDisk in 1997, and Memory Sticks, which were released by Sony and SanDisk in 1998.

Not only do these cards come in various shapes and sizes according to their intended applications, they use various memory control and data transfer methods and can have various other features, such as security. However, the image files recorded in these cards all comply with the Exif standard, regardless of what kind of memory card they may be contained in, and the directory structures within the cards are all based on DCF.

Therefore, when using PC-compatible memory cards, it is possible for image files to be read from and written to memory cards, regardless of the type of card.

The creation of an image format independent of recording media type was one of the major features of DSCs and preempted the kind of format wars seen with video between the VHS and Betamax formats that only served to confuse the market. This also resulted in fair competition for all DSCs and without a doubt contributed to the rapid growth of the market.

5.5 Displays

Another feature of DSCs is that the image taken can be verified on the spot and the photograph taken again if necessary. The first consumer DSC model equipped with an LCD was the Casio QV-10.

When using a film camera, the fixed shooting style is to hold the camera up to the face and look through the viewfinder with one eye. However, with DSCs, despite the fact that most DSCs have an optical viewfinder, in many cases the shooting style used is to hold the camera away from the face by extending the arms to a certain degree in order to see the LCD screen. In terms of preventing camera-shake, although it may be preferable to hold the camera up to the face, being able to verify images while shooting seems to be the preferred option in terms of shooting style.

Under the DCF file handling specification used by DSCs, devices for replaying images are called Readers, with devices equipped with image playback as a secondary function being referred to as Reader 1 and devices whose primary function is image playback being referred to as Reader 2.

As the main function of DSCs is to take photographs, the display inside the DSC is treated as Reader 1. As will be seen later in **Table 8.6**, with Reader 1, it is not an essential requirement to display the main image and a reduced size image (a thumbnail) can be displayed instead.

6 DSC Characteristics

The image sensors in DSCs are the equivalent film in film cameras. While in film cameras the amount of light received determines the degree of chemical change that occurs to form an image, in DSCs, the amount of light received determines the degree of charge produced that results in the formation of an image. DSCs are characterized by the ability to immediately view the resulting image and the fact that the recording media can be repeatedly reused. A general comparison of DSCs and silver halide cameras is shown in **Table 6.1**.

Table 6.1. A general comparison of DSCs and silver halide film cameras

	DSCs	Silver Halide Film Cameras
Structure	Integrated optics and image processing	Optics – Camera Photography – Film
Advantages	Instant Low running cost. No chemical processing required. Can be written directly to a PC. People can do their own image processing. Storage does not require a lot of space. No change over time.	Camera body is cheap. No equipment is required to view images. Good color reproduction. Wide latitude for exposure. Minor deterioration in quality when enlarged.
Disadvantages	Camera body is expensive. Battery consumption.	Results are unknown until the film is developed. A separate device is required for digitization.

However, the differences between DSCs and film cameras are not simply limited to differences in image viewing time.

6.1 Sensitivity Properties

DSCs differ from silver halide cameras in the sense that with silver halide cameras the device for creating images (the camera) and the recording media (the film) are separate and that it is possible to select various different kinds of film to use in a single camera, while with the vast majority of DSCs it is the camera itself that is the device for taking photographs and recording images.

With silver halide cameras, optimum image exposure is achieved by selecting the F-number, which shows the brightness in the optics system, and the ISO number, which indicates the sensitivity of the film. When setting the exposure manually, bearing film sensitivity in mind, the optimum exposure is given as a recommended exposure index.

By comparison, with DSCs, as the image sensor used cannot be changed, the optimum exposure at the time of taking a photograph is determined by the DSC used.

In shooting situations such as studio shoots where strong lighting is used, when incoming light is acquired immediately prior to the DSC image sensor becoming saturated, the recommended exposure index is derived from the amount of light saturating the DSC image sensor.

On the other hand, when shooting subjects in a comparatively small amount of light, noise in dark areas becomes a problem and the recommended exposure index is calculated from the amount of noise.

Furthermore, in normal shooting situations, the recommended exposure index is determined so that the image sensor output is approximately half of the saturation level on the basis of the luminous intensity of the midway point in the illuminance distribution of the subject.

Moreover, depending on differences in sensor characteristics, there are fundamental differences between film cameras and DSCs in terms of design, camera characteristics and structure.

Film is coated with a silver halide emulsion containing a pigment called a coupler and when it is exposed to light the silver molecules are deposited together with the coupler. When the silver particles are removed during the developing process, only the coupler remains, which brings out the color.

If the exposure value (input) is deemed to be H and coupler density (output) is deemed to be D, then over a certain range the following coefficient is produced.

$$D = \gamma \times \log(H)$$

The exposure value maintained by this correlation – in other words the optimum exposure value – is said to be the latitude. The sensitivity characteristics of negative film, reversal film and DSC image sensors are shown in **Fig. 6.1**.

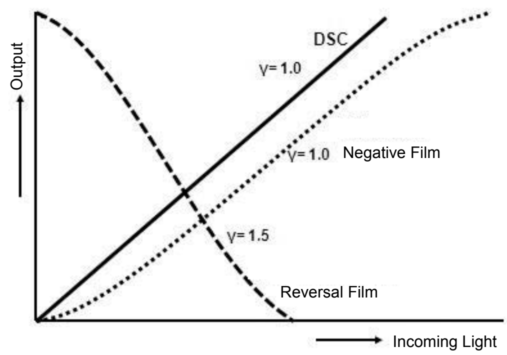


Fig. 6.1. Schematic depiction of sensitivity.

When γ is large, the difference in sensitivity with regard to the difference in exposure value is large, producing what is said to be a "hard" image, while conversely if γ is small, then the broad exposure range is expressed as a narrow output range, producing what is referred to as a "soft" image. In terms of the sensitivity characteristics of negative film, generally, γ is small. Moreover, as overall it has an S-shaped sensitivity curve, it can handle a broader exposure range. On the other hand, with reversal film, as the near γ = 1 range is used, this range in exposure – in other words the optimum exposure range – is also narrower than that of negative film.

Therefore, for standard snapshots, etc., negative film is frequently used as it is possible, to a certain extent, to correct exposure during processing without having to emphasize optimum exposure, while for printing and graphical materials where accurate output is required corresponding to the exposure value, reversal film is used.

That is to say, while with negative film the emphasis is on obtaining as much information as possible regarding the subject, with reversal film, as exposure characteristics are as close as possible to what is seen by the human eye, although it is possible to obtain light characteristics close to those of natural light by using projectors, etc., as the optimum exposure range is narrow, it is not suited to shooting subjects with a wide dynamic range and in some cases lighting is required in order to keep the subject within the optimum exposure range. In this respect, negative film is scene-oriented, while reversal film is output-oriented.

With standard consumer DSCs, as the image sensor output at γ = 1 is 8-bit, the output range is 1:256, or approximately 24 dB. This means that with compact DSCs gamma properties are added electrically in order to provide image characteristics close to those of negative film.

Furthermore, as with the Fujifilm Super Honeycomb SR sensor shown in **Fig. 7.8**, there are image sensors that aim to effectively increase latitude by combining two types of unit sensors (cells) of different sizes.

As previously mentioned, film is coated with an emulsion containing silver halide and the silver particles are arranged irregularly. By contrast, as the image sensors used in DSCs are arranged in a regular manner, modulation occurs between the spatial frequencies of the input signals (image signals). This is why an optical low pass filter is essential in DSCs.

6.2 Shooting Time Lag

With DSCs, generally, focusing is carried out by half-pressing the shutter release button after which the shutter itself is activated by fully pressing the shutter button. However, when pressing the shutter button from the half-pressed position, in some cases the shutter is not immediately activated, resulting in a delay in taking the photograph. In many cases this delay is obvious, especially when there is a lack of light in the surrounding area.

When the shutter release button is half-pressed in a DSC, image sensor output is sent to a circuit separate from that used for image processing and used to measure focusing distance, meaning that as a result, the optimum focusing distance obtained is combined mechanically with the optics system. The image sensor signal used for measuring distance must be completely eliminated prior to fully pressing the shutter release button. Thanks to technical improvements, the delay produced through this action has gradually been reduced.

6.3 Smear

CCD image sensors use a bucket relay system to initially transfer the electrical charge generated in each cell in response to the intensity of incoming light to a vertical register, after which it is transferred to a horizontal register. At that time, if a single cell is exposed to excessive incoming light, in cases where the electrical charge produced is not able to be fully absorbed by the cell, the excess electrical charge is superimposed successively onto other cells in a vertical direction, resulting in a white linear pattern appearing on the image. This is known as a smear and is one of the characteristics of charge relay-type CCDs. In order to prevent this, a mechanical shutter is used to block excess incoming light.

6.4 Color Filters

There are two types of color filter used in DSCs, primary color filters (red, green, blue: RGB) and complementary color filters (cyan, magenta, yellow and green: CMYG). Primary color filters are used where the emphasis is on compatibility with devices using primary color signals, such as PCs, etc., and most consumer DSCs use primary color filters. On the other hand, complementary color filters use a green signal, which is highly visible to humans, to improve apparent resolution. Either way, it is possible to change the displayed color gamut depending on output signal calculations, and it is also possible to convert different color display systems. Therefore, on many DSCs, it is possible to adjust the white balance by adjusting the output signal. This is a function that film cameras were not capable of.

6.5 Image Stabilization

Most DSCs have an LCD display on the back and in many cases the camera is held at arm's length in order to be able to see the display when shooting, which means it is easy for camera-shake to occur. Although there are even film cameras with image stabilization, many models of DSC are equipped with this function.

There are two types of image stabilization, the electronic type and the optical type. Electronic image stabilization is unique to DSCs and camera-shake is removed from the output of each cell on the image sensor through interpolation processing. On the other hand, optical image stabilization uses signals from devices such as gyros for reference to optically control and maintain a specific light path, driving the optical system itself or controlling the light path using things such as polarizing plates.

6.6 Making Cameras Thinner

With film cameras, it is not possible to make camera bodies thinner than the thickness of the film magazine (the container holding the film). On the other hand, with DSCs, as there is nothing to limit thickness, it is possible to make cameras thinner by carefully locating the image sensor and bending the light pathway using means such as a reflective mirror.

With the Minolta Dimage X, which was released in 2002, it was possible to reduce the thickness of the camera to 20 mm by bending the light path 90-degrees using a prism. This made it possible to make a DSC thin enough that it could be kept in a shirt pocket, something that was unthinkable with a film camera.

6.7 Fixed Lens SLRs

With DSLRs, the image sensor input signal is formed in the finder as a real image using a mirror. With this method, there is the disadvantage of the image in the finder disappearing at the instant the shutter is pressed because the light path of incoming light is changed to the sensor. With methods such as that developed by Fujifilm, the image from a small CCD is displayed in an SLR-type viewfinder. Although optically it is not the real image that is viewed, and resolution is not as good as with a focusing screen, it is characterized by the fact that the image does not disappear at the instant the shutter is pressed.

6.8 Power Consumption

Even with recent film cameras, functions such as autofocus, zoom, exposure adjustment and flash have been computerized, and cameras with a continuous shooting function use electronics to wind on the film, meaning that in all cases batteries are required. However, DSCs require more power because in addition to the various functions of film cameras, they need to power the image sensor, image-processing LSI and read and write images to and from memory. In order to solve this problem, efforts have been made to make low-power electronic circuits and long-life batteries.

6.9 Autofocus

With autofocus in film cameras, there is the active type, whereby an ultrasound or infrared signal is sent from the camera to the subject and the distance determined on the basis of the time taken to receive the reflected signal from the subject, and the passive type, which adjusts focus optically. The world's first passive type autofocusing was developed by Konica Minolta (for compact cameras by the former Konica and for SLRs by the former Minolta), and this solved the problem that active-type autofocus had of not being able to focus through glass.

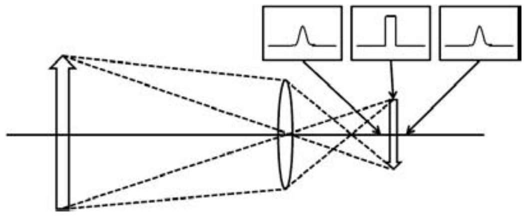


Fig. 6.2. The principle of autofocus.

As we can see in **Fig. 6.2**, the response to the spatial frequency of the subject is at its highest when the subject is in focus and drops when it is out of focus. Using this principle, the position where the spatial frequency response is highest is sought by moving the lens to obtain optimum focus. However, for subjects where it is not possible to determine a spatial frequency, such as a monochromatic wall, it is difficult to obtain an accurate focus point.

Although a sensor is necessary for focusing with film cameras, with DSCs, as the output from the image sensor can be used for focusing, a dedicated focusing sensor is not required.

6.10 Digital Zoom

With DSCs, in addition to zooming by changing the focal length of the lens mechanically, it is possible to use an electronic zoom function to obtain a telephoto effect by electronically enlarging the central part of the image formed on the image sensor.

For example, by enlarging the 1MP area in the middle of a 4MP image sensor it is possible to obtain an image twice the size to give an image with a field of view the same as if it were taken using a lens with a focal length twice as long. With this electronic zoom function it became possible to realize a far wider zoom range with a DSC than would be possible using a silver halide camera.

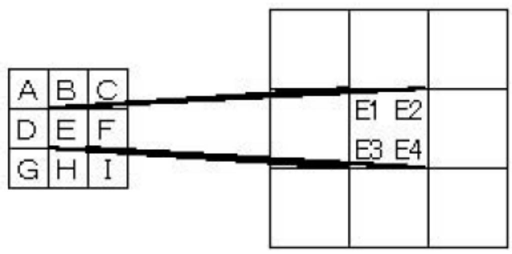


Fig. 6.3. Digital zoom.

However, the greater the magnification of this telescopic effect, the fewer the number of pixels that are used on the image sensor, meaning that mosaic patterns in the image become more significant if left as they are.

In the case of **Fig. 6.3**, by enlarging and displaying the signal for cell E on the image sensor as four separate image signals (E1, E2, E3, E4) the image becomes jagged and coarse. In order to improve this, image interpolation technology is used to seek signals for positions equivalent to E1 through to E4 by calculating using signals from cell E and cells A, B, C, D, F, G, H and I which border it. However, if the enlargement ratio is too higher, then as the number of original source pixels will decrease, there will be a major deterioration in image quality with telephoto images produced electronically as compared with telephoto images produced using an optical zoom.

When using the digital zoom function or changing image size in DSCs it is necessary to continually change the number of pixels that form the image. This also uses digital filter technology whereby new pixel location data is interpolated on top of a new image from the original image. This makes it possible to reduce the jagged nature of images when they are enlarged.

So, with DSCs, we can see that in addition to zooming by changing the focal length of the lens, it is possible to use an electronic zoom function by electronically enlarging the central part of the image formed in the image sensor to obtain a telescopic effect.

7 DSC-Related Technology and Systematization

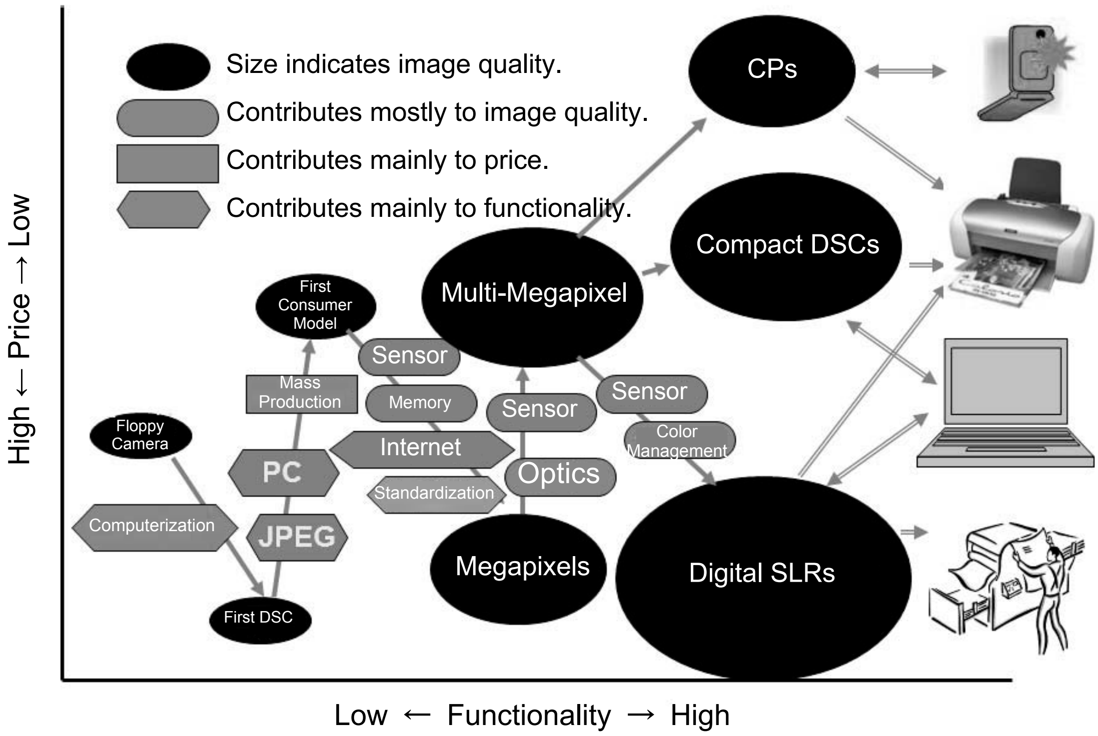


Fig. 7.1. DSC development.

Technologies that contributed to the development of DSCs include:

1. Semiconductor Technology
   (1) Memory
   (2) Image pickup devices
   (3) Dedicated LSIs
2. Digital Signal Processing Technology
   (1) Image processing
   (2) Image compression
   (3) Computer OS/image processing software
3. Color Reproduction Management Technology
4. PCs and peripherals, such as printers

Optical technologies, such as lens design, and precision machinery technology, that have been developed over many years by conventional silver halide camera manufacturers, have come to be used in DSCs. We will now look at some of the main technologies involved (**Fig. 7.1**).

7.1 Image Sensors

Among the various technologies that have contributed to the development of DSCs, the most noteworthy has been the development of semiconductors. Image pickup devices and memory in particular have made a major contribution to the development of consumer DSCs. Firstly we shall look at the technological progress made in terms of image pickup devices.

7-1-1 Multipixels

The DS-1P, the first DSC trialed in 1988, and the first commercially sold DSC, the DS-X (IMC-100), both used a 400,000 pixel CCD.

As the purpose of these DSCs was to playback images on TVs, the design concept behind them was that the 307,200 pixels (640 × 480) of VGA would be adequate.

Although the Casio QV-10, which was released in 1995 and pioneered the consumer market, and the QV-10A that was released the following year were both designed to replay images on a PC display, they only had 250,000 pixels.

However, when replaying on a PC monitor, it is possible to replay images using standards that have a higher resolution, such as SVGA (Super VGA = 800×600 pixels), XGA (eXtended Graphic Array = 1,024×768 pixels), SXGA (Super XGA = 1,280×1,024 pixels) or UXGA (Ultra XGA = 1,600×1,200 pixels) and to display multiple or enlarged images through the use of image processing without being limited by the number of pixels.

However, when printing out images, TV-quality images are inadequate and an image the size of a business card requires approximately 1 million pixels.

In line with such demands, DSCs featuring CCDs with more than 1 million pixels were released in 1997, such as the Fujix DS-300 (Fujifilm), Camedia C-1400 (Olympus) and the Konica Q-M100 (Konica), followed in 1998 by DSCs with more than 2 million pixels, such as the EOS D2000 (Canon), Dimage RD3000 (Minolta), FinePix700 (Fujifilm) and Nikon D2 (Nikon).

After that, the number of pixels continued to increase and as of 2007 there are models with more than 10 megapixels (10MP).

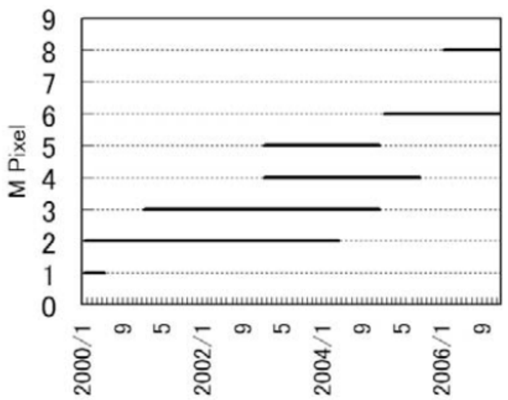


Fig. 7.2. The trend toward higher pixels numbers [1].

There are two conceivable ways to increase the number of pixels:

1. Decrease the dimensions of individual cells, or
2. Increase the overall size of the image sensor.

However, if the size of the individual cells is reduced, as the charge produced per cell in response to the same amount of light is reduced, unless noise produced by dark currents when there is no incoming light is reduced, the signal to noise ratio (S/N ratio) drops, producing images with a lot of noise.

Furthermore, if the size of the image sensor itself is increased, then the yield rate at which absolutely defect-free sensors can be produced drops. In 1992, the Society for Imaging Science & Technology (IS&T) announced that sensor yield rate was inversely proportional to size cubed, and as yield rate drops to 1/8 if sensor size is doubled, this led some to believe that the commercialization of large image sensors would not succeed.

What made large image sensors possible was the fact that the signal from a defective cell could be corrected by image interpolation technology using the signals of surrounding cells, meaning that an image sensor could still be used even if it had a certain number of defective cells. This made the production of low-cost image sensors a reality.

According to statistics regarding DSC image sensor pixel numbers released by CIPA, although in 2000 it ranged from under 1MP, to 1MP–2MP, to 2MP or more, from 2006 this changed dramatically, ranging from under 6MP, to 6MP–8MP, to 8MP or more. Those trends are shown in **Fig. 7.2**.

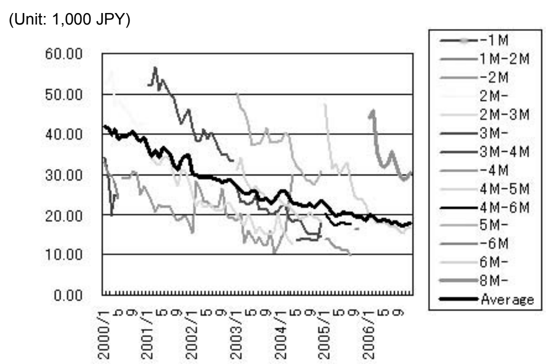


Fig. 7.3. Trends in the number of pixels (Megapixels) [2].

Figure 7.3 shows average price trends for DSCs according to the effective number of pixels on the image sensor. While the price of DSCs with the same number of pixels is dropping each year, by making new products with more pixels the main focus, such models are supporting the DSC market overall.

7-1-2 Proprietary DSC Image Sensor Development

A single image is divided into minute pixels and the signal from each pixel is output consecutively. The process of outputting this data is called scanning and as we can see from **Fig. 7.4**, there is interlaced scanning (left hand side) and progressive scanning (right hand side).

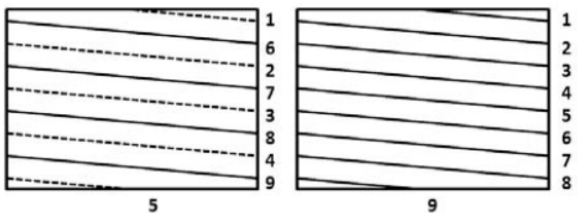


Fig. 7.4. Interlaced (left) and progressive (right) scanning.

Movies and videos are recognized as moving images by the human eye by consecutively presenting still images. One of the characteristics of the human eye is that the shorter the interval between the still images presented, the more the movement is perceived as being fluid with little flicker. The point at which that occurs is 1/50th of a second. Therefore, with an emphasis on improving flicker on consumer video movie cameras, interlaced scanning was adopted. As can be seen on the left in **Fig. 7.4**, with interlaced scanning, scanning is first carried out at approximately 1/60th of a second, as shown by the solid lines, followed by scanning at approximately 1/60th of a second as shown by the dotted lines. This is referred to as odd scanning and even scanning, and the images obtained are referred to as odd fields and even fields.

When interlaced scanning is carried out, the images are perceived to be more fluid, with less flicker, than progressively scanned images, where entire frames are scanned consecutively and presented approximately every 1/30th of a second, as shown on the right in **Fig. 7.4**,.

Fig.7.5 Movement shot with interlaced scanning.

Incidentally, with interlaced scanning, as a time difference arises when scanning odd and even fields, if a moving subject is shot as exaggerated and shown in **Fig. 7.5**, then a discrepancy (smear) in the image will be produced.

With the first DSCs, as the performance of CMOS sensors was poor, as we will see later, interlaced scan-type CCDs (IT-CCD) for video movie cameras were used. However, if IT-CCDs are used as they are for recording still images, then the above-mentioned problem will occur.

In terms of CCDs for DSCs, in order to exclude this kind of defect, although the Frame Interline Transfer CCD (FIT-CCD) was developed that placed a frame-like storage area around the charge transfer register, this resulted in a more complex structure with the disadvantage of reduced sensitivity as compared with an IT-CCD of the same size.

Therefore, with compact DSCs using a CCD, either a FIT-CCD or an IT-CCD with a mechanical shutter is used, and after all cells have been exposed to light, they are read and interlaced.

With video cameras, although the camera is never used on its side to shoot footage, with DSCs, sometimes the camera is turned on its side to take photographs, such as when taking portraits. The aspect ratio of video camera image sensors (the width-height ratio of a single cell) uses non-square pixels for ease of signal processing.

As mentioned in **Chapter 3**, image sensor output, which is the aggregation of solitary waves, can be converted by Fourier transform to the aggregation of the continuous frequency spectrum inside the image sensor.

Therefore, after converting the output from each cell on the image sensor arranged at interval T_1 (as shown in **Fig. 7.6**) to a continuous signal, it is possible to treat it in the same was as when using an image sensor with square pixels by resampling it at the same interval T_2 in a vertical direction and horizontal direction.

This works by passing the signal, which has been read at a set time interval t_1 from each cell on the image sensor, through a low-pass filter and then capturing it at a common time interval t_2 vertically and horizontally.

However, while it is possible in this way to use an image sensor with non-square pixels to create a signal equivalent to one obtained from an image sensor with square pixels, in such a case the maximum vertical and horizontal spatial frequencies are different and the resolution is different vertically from what it is horizontally.

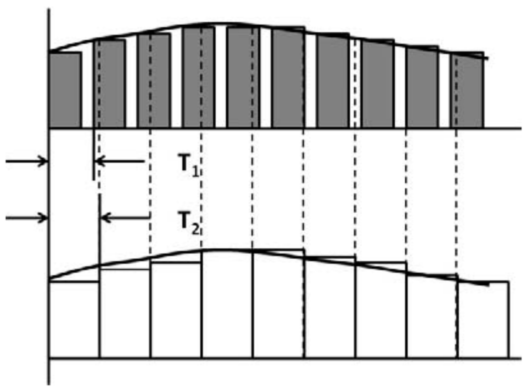


Fig. 7.6. Cell output resampling.

Therefore, with DSCs, it is preferable that the image sensor cells are square and that all cells are configured in such a way that they are exposed to light simultaneously. Given this need, it was necessary to independently develop image sensors for use with DSCs, despite the fact that in the early 1990s when the DSC market had yet to take off it was difficult to develop new image sensors intended only for use with DSCs.

7-1-3 Commercialization of CMOS Image Sensors

With CMOS sensors, as it was possible to form the CMOS logic section on the same board, the power supply was more simple than for a CCD, and the smear produced with CCDs (when bright light produces a charge that overloads the charge storing section it bleeds to adjacent cells, resulting in a straight line of light being formed on the image) did not occur, it was hoped that they could be used as elements in multipixel image sensors.

However, with CMOS, as each element is read individually, when shooting a moving subject the time at which each cell is read differs, meaning that distortion will be produced. In order to prevent this, it is essential to use a mechanical shutter.

Furthermore, as mentioned in the previous chapter, with CCDs, during the final stage of the bucket relay the signal is amplified by a single amplifier, while with CMOS sensors each cell has its own amplifier, meaning that it was difficult to suppress variation on a cell-by-cell basis. This is why CCDs have been used for so long despite disadvantages such as high power consumption, the need for multiple power supplies and difficulties with increasing speed.

On the other hand, Canon developed their own proprietary CMOS sensors and by improving the manufacturing process and reducing noise by storing dark currents from each cell in an image processor they succeeding in commercializing CMOS sensors, using an APS-size CMOS sensor in the EOS D30 released in 2000.

Since then, on the basis of the merits outlined above, CMOS sensors have come to be widely used in multipixel DSCs such as DSLRs.

7-1-4 Special Configuration Image Sensor Development

Fujifilm developed the Super Honeycomb CCD in 2000 and released the FinePix 4700Z, with the equivalent of 4.32MP, into the 2.4MP CCD market. As can be seen in **Fig. 7.7**, this Super Honeycomb CCD is characterized by photodiodes with octagonal-shaped openings arranged in a checkered pattern.

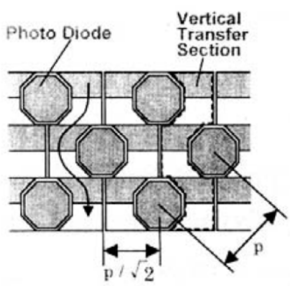


Fig. 7.7. Honeycomb CCD [3].

Although the accumulated signal charge is sequentially transferred through the vertical transfer register in the same way as with an IT-CCD, these vertical transfer registers are arranged in a zigzag pattern between the photodiodes.

As a result, compared with conventional IT-CCDs, the Super Honeycomb CCD, highly sensitive due to the large area of its photodiodes, has 1.4 times the horizontal/vertical resolution of IT-CCDs due to the fact that horizontal/vertical pixel pitch is 0.71 times that of IT-CCDs. Furthermore, as in the natural world there are many horizontal and vertical edges, and in terms of human optical characteristics we are more sensitive to horizontal and vertical directions than we are to diagonals, this type of CCD also provides more of a sense of high resolution visually.

In 2003, Fujifilm developed fourth generation Super CCD Honeycomb sensors, which were called the Super CCD Honeycomb HR and the Super Honeycomb SR, with the former being used in the FinePix F410 and the latter being used in the FinePix F700.

Figure 7.8 shows the Super Honeycomb SR II. This featured a honeycomb arrangement with two different types of cells of different area: highly-sensitive S cells and R cells to increase the dynamic range.

This was similar to the structure of the film used in silver halide cameras, where highly-sensitive large silver halide particles and low-sensitivity fine silver halide particles that became light-sensitive when exposed to high-intensity light were combined into the coating.

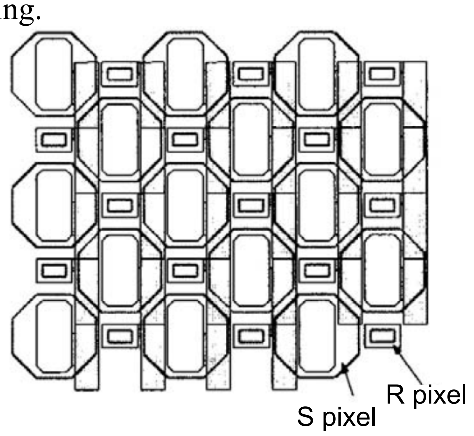


Fig. 7.8. Super CCD SR II structure [4].

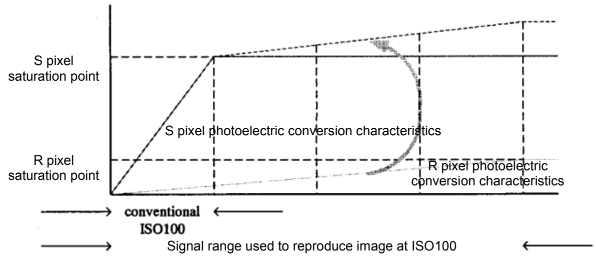


Fig. 7.9. Super CCD SRII characteristics [5].

In other words, as can be seen in **Fig. 7.9**, while improving sensitivity using S cells, R cells dealt with high-intensity light that over-saturated S cells, meaning that overall the sensor was designed to work with a broad range of incoming light and had a dynamic range that was four times greater than Fujifilm's previous models.

On the other hand, Foveon, Inc. developed the Foveon X3 image sensor (**Fig. 7.10**) that improved resolution by using a multilayer structure consisting of three sensor layers, each corresponding to one of the three primary colors, releasing the first model with this sensor, the Sigma SD9, in 2002.

This sensor was similar in structure to the color film used in silver halide cameras in the sense that the cells comprising each layer corresponded with a single color.

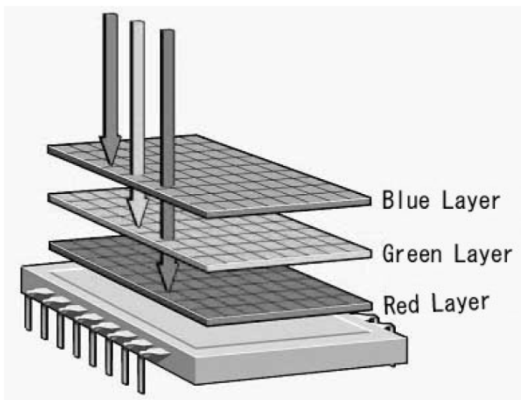


Fig. 7.10. Foveon X3 structure [6].

7.2 The Invention of Flash Memory

Early DSCs, such as the DS-1P and the DS-X, used memory cards with SRAM chips as recording media that required a small battery. Not only did this mean that a backup battery was required, but that storage capacity was limited to approximately 2MB, which is extremely small and capacity was limited to about ten images. Toshiba then invented flash memory, which is compact, long-lasting, easily rewritable and does not require a power source. As large-capacity memory became available at a cheap price, the position of DSCs was further strengthened in terms of their economy and instant nature.

It would be certainly no exaggeration to say that the single greatest driving force behind DSCs that has allowed them to develop into what they are today has been flash memory.

Flash memory is a type of Electronically Erasable Programmable Read-Only Memory (EEPROM) and as each chip is comprised of a single element, the area of each unit is small, which makes it possible to manufacture large-capacity memory chips.

This flash memory was invented by Dr. Fujio Masuoka (presently Professor Emeritus at Tohoku University) while researching semiconductors at Toshiba during the 1980s. Featuring a novel structure whereby charge accumulated in a floating gate using quantum tunneling, this invention was widely acclaimed both within Japan and throughout the world.

A model of the structure of flash memory is shown in **Fig. 7.11**.

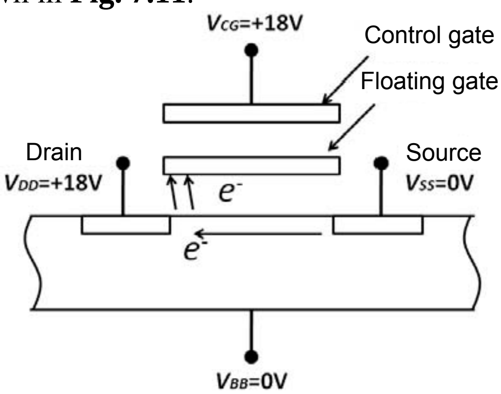


Fig. 7.11. Flash Memory structure [7].

When writing (W) to flash memory, there is 0V on the source, 18V in the drain and an 18V electric potential is applied to the control gate, exciting electrons in the vicinity of the channel causing hot electrons, which are acquired by the floating gate through the metal oxide film by means of quantum tunneling. As these electrons are insulated from their surroundings, they are trapped semipermanently.

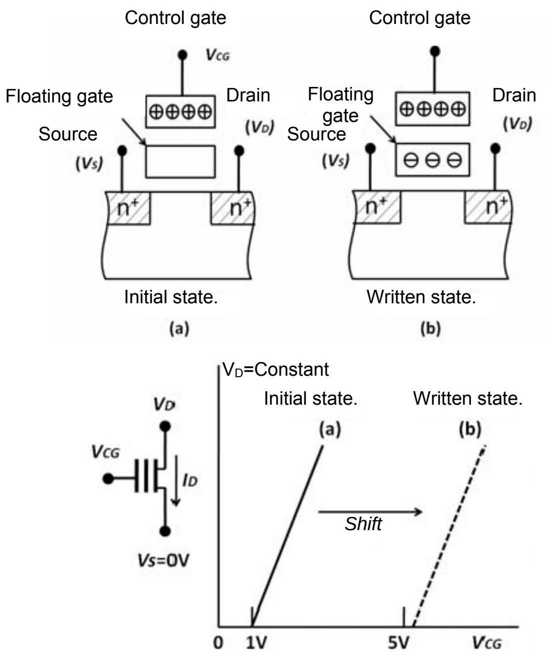


Fig. 7.12. The principle of writing to and reading from flash memory [8].

The principle behind reading from flash memory (R) is shown in **Fig. 7.12**. The horizontal axis of the graph represents the voltage applied to the control gate, while the vertical axis represents the current that flows between the source and the drain at that time. When there is no charge on the floating gate, such as shown on the left, and a voltage of 1V or more is applied to the control gate, then current flows. This is referred to as having a threshold voltage of 1V.

On the other hand, when electrons are trapped in the floating gate, such as shown in the top right graphic of **Fig. 7.12**, as the voltage applied to the control gate is initially captured by the charge of the floating gate and does not affect the channel, the only current to flow between the source and the drain is when a voltage of 6V or more is applied to the control gate. Therefore, by applying a voltage of between 1V and 6V to the control gate and checking whether or not there is any current, it is possible to read whether the signal written in the control gate is a 0 or a 1.

When erasing data (E), as shown in **Fig. 7.13**, a high-voltage positive charge is applied to the erasing gate, pulling the electron off the floating gate.

As writing and erasing is carried out using tunnel currents, less power is consumed than with the SRAM used previously, meaning that flash memory uses only about 1/10 of the power used by Hard Disk Drives (HDDs) of the same capacity.

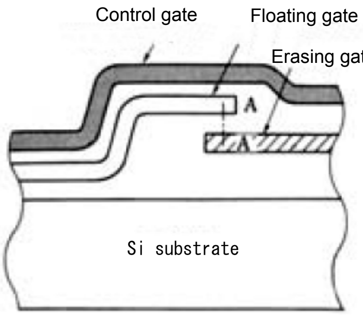


Fig. 7.13. Erasing flash memory [9].

Dr. Masuoka came up with the concept for the structure of flash memory around 1980 and in June 1984 presented papers regarding it at the IEEE's International Electron Devices Meeting (IEDM) and International Solid-State Circuits Conference (ISSCC).

Although Dr. Masuoka saw flash memory as a recording media to replace HDDs, he was assisted in his research by the division that was developing DSCs within the company and together they were able to create prototype 4MB NAND flash memory in February 1983, release it in December 1984 and present it at the International Solid State Circuits Conference (ISCC) in San Francisco in February 1985.

There are two main types of flash memory that use memory with 1-byte (8-bit) units: NOR and NAND.

Dr. Masuoka described it thus: NOR is like houses with individual entrances, while NAND is like an apartment building with a common entrance.

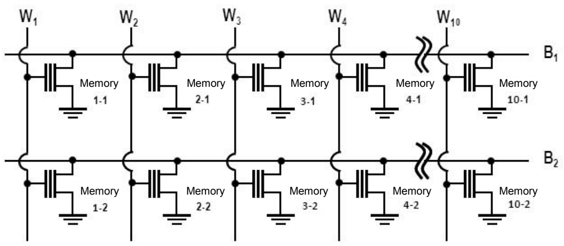


Fig. 7.14. NOR structure [10].

As shown in **Fig. 7.14**, NOR memory consists of a single memory cell connected between a bit line B and an earth.

If there is a charge between any one of the memory cells that are connected to a single bit line, then the electrical potential drops, meaning that all of the connected memory cells do not operate. In order to operate the selected memory cell, all that is required is to make all of the bit lines other than the bit line connected to that memory cell charged and to control the write line (W) of the memory cell.

On the other hand, as we can see from **Fig. 7.15**, NAND has series-connected memory cells.

When reading from (R) or writing to (W) a selected memory cell, an electrical potential of 0V is applied to the gate of that memory cell while an electrical potential of 5V is applied to the gates of other memory cells. This causes all of the memory cells other than the one selected to be in a state of conduction.

When reading from a memory cell, if the selected memory cell is 0, then the bit line is non-conductive, while if it is 1 then it is conductive. When erasing, the electrons are displaced from all of the floating gates and all bits are in the 1 state.

Although random access is not possible with this NAND EEPROM like it is with NOR, it can be compact with a large capacity and low power consumption, and it is ideally suited to writing large blocks of data at a time, such as image data.

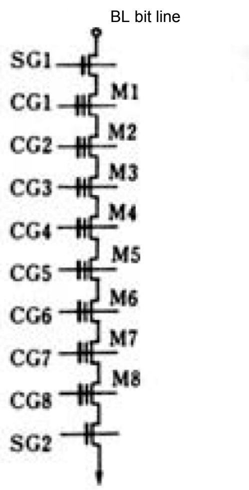


Fig. 7.15. NAND structure [11].

7.3 Memory Cards

7-3-1 PC Cards

In 1985, an IC memory card technology expert committee was established in JEIDA [12] and discussions began regarding the creation of a memory card standard. In 1989, the Personal Computer Memory Card International Association (PCMCIA) [13] was established in the US and although the same kind of matters were considered, the Japanese extended an invitation and in 1990 the decision was made to work on the issue together, resulting in the establishment of unified PC card standards in 1993.

With early DSCs, PC cards with SRAM memory elements were used as recording media for images. As SRAM requires an external voltage to be applied in order to maintain recorded data, a small battery was built into these PC cards for backup. As the storage capacity of SRAM was small, the storage capacity of PC cards was approximately 2MB, which is extremely small.

7-3-2 The Birth of Various Memory Cards

Flash memory came to be used in memory cards in place of conventional SRAM. At the same time, in addition to the PC cards that had mainly come to be the standard type of card used in laptop PCs, various other memory cards were introduced, such as the CF card in 1994, the SM card in 1995, the MMC card in 1997 and the MS card in 1998.

Of these memory cards, CF cards had a large capacity and were ATA compatible, SM cards were thin and contained only memory, and MS cards had a serial I/O interface, meaning that each had their merits and the various DSC manufacturers selected them for use in DSCs in light of those merits.

I will now provide an overview of the main types of memory card used in DSCs since the latter half of the 1990s, which include CF, SM and MS cards.

1. CF: CompactFlash cards were proposed by SanDisk Corporation in 1994 and the specifications were determined by the CompactFlash Association (CFA). The block diagram of a CF card is shown in **Fig. 7.16**.

   As external input/output is based on the ATA standard, a CF card can be treated in the same was as an HDD by the host. The properties of the internal memory are absorbed in the controller, meaning they do not influence the host. Furthermore, as it is possible to internalize large-capacity memory, they can be connected to a PC card slot by means of a simple passive adapter.

   The external dimensions are 42.8 (W) × 36.4 (L) mm and Type I cards have a thickness of 3.3 mm, while Type II cards have a thickness of 5 mm.

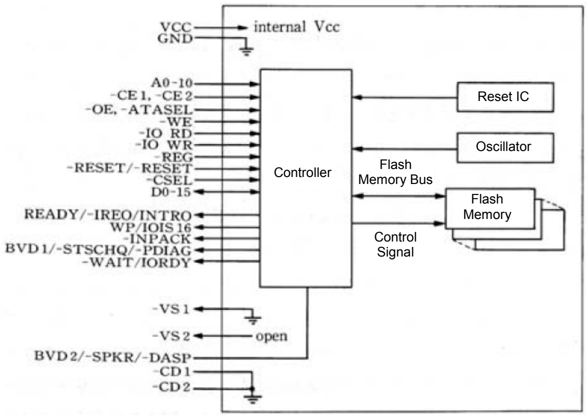


Fig. 7.16. CF card block diagram [14].

2. SM (SSFDC＝Solid State Floppy Disc): Smart Media is a postage stamp-sized compact, thin NAND type of flash memory card announced by Toshiba in 1995 and has dimensions of 37 (W) × 45 (L) × 0.76 (T) mm, a capacity of between 2MB and 128MB and uses a common 22-pin interface regardless of capacity. As is shown in **Fig. 7.17**, this interface is an I/O interface comprised of an 8-bit parallel bus and is able to be controlled by assigning two I/O addresses [4].

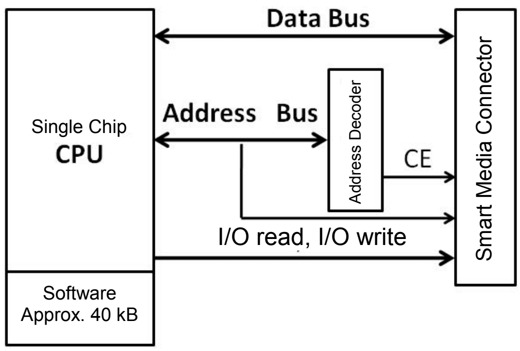


Fig. 7.17. Smart media interface [15].

One of the characteristics of SmartMedia was that the cards were extremely thin, but prompted by calls for expanded capacity and improved security, Toshiba announced the successor to SM card, the xD card, and also announced the Secure Digital (SD) card, which they developed in cooperation with Panasonic.

3. MS: The Memory Stick was announced by Sony in 1998. One of the characteristics was that it had a bus state controller-type serial interface to interface with the host. The MS block diagram is shown in **Fig. 7.18**.

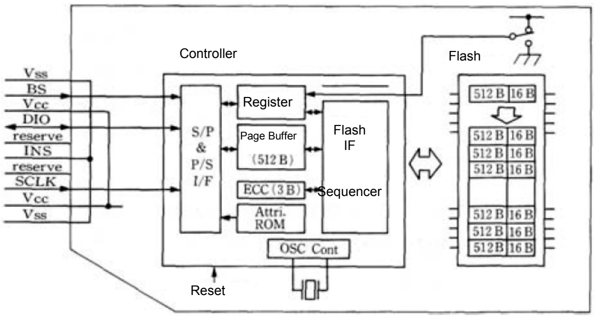


Fig. 7.18. Memory stick block diagram [16].

The Memory Stick family included the Memory Stick PRO, which made large capacity high-speed data transfer possible, the small Memory Stick Duo and the even smaller Memory Stick Micro (M2).

A situation where image format differs according to the type of recording media would inconvenience DSC users. Furthermore, should unnecessary disputes arise regarding which type of recording media and format is better, consumers would refrain from making purchases.

In order to avoid such a situation, Japan proposed the Exif and DCF formats, which are not reliant on recording media, and has succeeded in having most of the consumer DSCs in the world at present use these formats.

Not only are all of these memory cards different in terms of external dimensions and function, but the formats in which DSC images are formed and stored are also different, depending on the memory card used.

On the other hand, in addition to differences among the memory chips used, there are at present a number of different types of recording media on the market, such as the various types of memory cards, with each being used on account of its own individual merits, such as whether or not it has internal memory controllers or security features, etc. At present, there are models on the market with a capacity on par with that of HDDs, and when used for DSCs, even though the various cards may be different, the data stored on them is the same, regardless of what kind of memory card is used.

The main memory cards being used as of 2008 are shown in **Table 7.1**.

Table 7.1. The main types of memory card

Major Types	Product
CompactFlash	I
	II
SmartMedia	SmartMedia
MMC	MMC
	RS-MMC
	MMCmobile
	MMCplus
	MMCmicro
Memory Stick	Standard
	PRO
	PRO Duo
	PRO-HG Duo
	Micro (M2)
Secure Digital	SD
	miniSD
	microSD
	SDHC
	miniSDHC
	microSDHC
xD	xD
	Type M
	Type H
USB flash drive	USB flash drive

7.4 Digital Signal Processing Technology

It is possible to perform various kinds of signal processing on DSC image sensor outputs that have been converted into digital signals by the internal A/D converter using the digital properties of the signal.

Because DSCs could digitize and then utilize such data, it was possible to carry out image processing within the camera that would have been difficult with silver halide photographs. This made it possible to improve image quality, reduce the price of DSCs and provide new features.

While early DSCs had a single multipurpose central processing unit (CPU) referred to as a single-chip microcomputer that carried out such processing, with the mass production of DSCs, such processing has come to be handled by a special LSI called an image processing engine, or is performed within the DSC by the CPU. The target of such processing and the algorithms, etc., involved are the know-how of the various companies and are one of the things that differentiate their various DSCs from one another, and each of the companies is also involved in developing their own proprietary LSIs.

We will now look at a number of the technologies that have been employed in digital signal processing. Only after digital signal processing became a reality were these technologies able to be commercialized and they are what have clearly distinguished DSCs from earlier electronic cameras.

7-4-1 Image Effect Processing

As shown in **Fig. 7.19**, the Spatial Frequency Response (SFR) of DSCs drops as the spatial frequency of the subject increases and is 0 at the cutoff frequency (fc).

Although response characteristics once again appear with spatial frequencies of fc and above, this is due to intermodulation and as this becomes a source of noise called artifacts it must be removed. Therefore, DSCs are equipped with an optical low pass filter that uses crystal birefringence, etc., to shut out the spatial frequency components of fc and above.

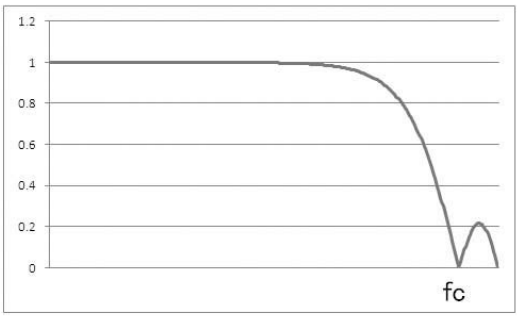


Fig. 7.19. Frequency response characteristics.

On the other hand, if the high frequency component in spatial frequency response characteristics is sharply cut off at fc, the outline of the subject will not be clear and visually the image will seem “soft.” In order to correct this, in many cases edge enhancement is employed to raise spatial frequency response characteristics in the vicinity of fc using a digital filter. However, as excessive edge enhancement will appear unnatural, just how such edge enhancement is carried out comes down the know-how of each individual company.

This kind of image processing is carried out using the unique algorithms in the proprietary processors of each company. These processors are also used for pixel interpolation (as mentioned in greater detail below), meaning that even if there are a number of defective pixels on an image sensor, defective pixels can be compensated for before output images are displayed, something that has greatly contributed to the improvement of yield rates in the manufacture of image sensors.

7-4-2 Image Sensor Defect Correction

While it is necessary for each cell on an image sensor to have uniform characteristics, the yield rate for large image sensors that are free from defects in all cells and with even characteristics is extremely low and it was not thought to be commercial viable from a manufacturing perspective.

If when shooting still images using an analog signal there were any defects in the cells of the image sensor, then corresponding areas in the output image would be missing, and the sensor would therefore have been considered to be defective.

However, if the signals from the cell are stored as digital data, by interpolating data from the cells surrounding the defective cell it is possible to use image sensors with defective cells that would have previously been considered to be defective, something that has greatly contributed towards reducing the costs of DSCs.

Generally, a filter with the following properties is used for this pixel interpolation:

$$\sin(x)/x$$

In this way, based on pixel data from neighboring cells, data for the location of the defective cell can be interpolated. This is a technology that was impossible with conventional VTRs and because this technology was first commercialized only after digital technology had been introduced, it is no exaggeration to say that it made a major contribution to reducing the price of DSCs.

7-4-3 De-mosaicing

Normal DSCs use a single-plate image sensor and have a color filter on the surface of each cell on the image sensor, allowing only a certain color to pass through primary colors (RGB) or complementary colors (CMY). For example, cells with an R filter only reproduce an R signal.

Therefore, in a DSC with, for example, a 4MP single-plate primary color image sensor, there will generally be 1MP of R pixels, 1MP of B pixels and 2MP of G pixels.

However, when carrying out image compression, in situations such as outputting to an external device, data for all three primary colors in each cell location is sought. Therefore, in a DSC, the G and B signal for an R cell is interpolated and reproduced using digital filter technology from neighboring G and B signals.

Furthermore, by using pixel interpolation, while, for example, data from a 3MP CCD can be output as 4MP recording pixel data, it is important to remember that pixel interpolation does not create new data, but is a technology that converts the original image data into the necessary format without data loss.

7.5 Optical Technology for DSCs

Lens design and flare countermeasures are optical technologies that have been developed over many years by silver halide camera manufacturers. Philipp Ludwig von Seidel grouped spherical lens aberrations into five different categories: spherical aberration, coma, astigmatism, curvature of field, and distortion, in addition to chromatic aberration. How to suppress these is one of the important themes of lens design.

Furthermore, with an ideal lens, when the subject is a light source, the image is formed on the image pickup device in the position where it is completely in focus, and if the light source is move backwards or forwards, then the image goes out of focus. However, in reality, even if the light source is moved backwards or forwards, there is a certain degree of tolerance with regard to where the image can be formed and still be in focus.

The permissible range of the light source at that time is called the depth of field. Depth of field is reliant on the size of the image pickup device and the smaller the image pickup device, the greater the depth of field.

In DSCs with an image pickup device smaller than 35 mm film size, as the depth of field will be greater than that of a 35 mm silver halide camera, there is the disadvantage of it being difficult to create nice *bokeh* effect (out-of-focus background blur) in situations such as shooting close-ups. This problem has been solved in recent DSLR cameras, where the image pickup device used is equivalent to the 35 mm size.

In many cases, the development of early DSCs was carried out by the video camera development departments of consumer electronic manufacturers, or by non-mainstream electronic technicians in the various camera manufacturers. Therefore, as it was difficult to design dedicated optics for early DSCs, in some cases existing lens systems were cannibalized with relay lenses to convert the light path.

The optics of the IMC-100 developed by Toshiba were reliant on Fuji Photo Film Co., Ltd., while for the optics of the IMC-200 Toshiba was unable to gain the cooperation of specialized optics companies within the Toshiba group, and instead had to contract them out to a specialized lens manufacturer.

When it was clear that the DSC market was rapidly growing while the market for silver halide cameras was dramatically shrinking, the various companies hired outstanding optical technicians to work on the design of optics for DSCs and the performance of DSCs notably improved.

7-5-1 Oblique Incident Light

Film comprises stacked photosensitive layers for the various colors, so that even if there is a problem with color shift due to oblique incident light, it has little influence on photosensitive efficiency.

On the other hand, the photoelectric transducers of semiconductor image sensors have a layered structure, as seen in **Fig. 7.20** and each individual photodiode (cell), which is the photosensitive element, is located in the bottom of a well formed in the semiconductor substrate.

On account of this, if incident light is anything other than perpendicular, then the amount of light will decrease. Furthermore, as the color filter mounted on each cell is efficient at receiving incident perpendicular light, and is designed to operate as an accurate color filter, not only will photoelectric conversion efficiency drop with oblique incident light, but it is feared that it will impede accurate color reproduction.

Moreover, with small-aperture lenses, as incident light diverges from the perpendicular in the area around the image sensor to become oblique incident light, the error increases.

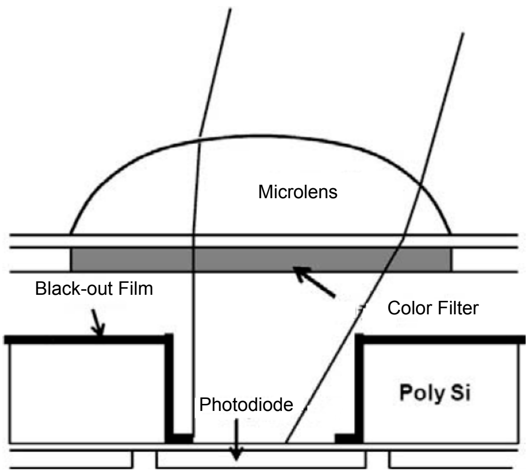


Fig. 7.20. Oblique incidence.

Therefore, lenses for DSCs are designed to have a larger aperture the closer they are to the image sensor in the interest of making the light coming into the sensor as perpendicular to the sensor as possible.

7-5-2 Flare

While it is desirable that the inside of the camera itself be completely dark, some of the light passing through the lens is reflected when it hits the film or image sensor positioned on the focal plane, leaking into the inside of the camera. This is a phenomenon known as flare and as the surface of semiconductor image sensors has a higher degree of reflectance than the surface of film, countermeasures, such as surface treatments, are required to suppress the flare.

7.6 Color Reproduction Management

Electromagnetic waves fill the environment in which we exist and the wavelengths that are visible to the human eye are extremely limited, ranging from 360–400 nm (1 nm = $1/10^6$ mm) on the shortwave end to 760–830 nm on the long-wave end (**Fig. 7.21**).

As shown in **Fig. 7.22**, the human retina consists of two types of visual cells, rod-shaped cells that detect only the intensity of comparatively weak incident light, and cone-shaped cells that detect the chrominance of comparatively stronger incident light.

There are three different types of cones that react to red (R), green (G) and blue (B) and which exist on a ratio of approximately 32:16:1. While there are approximately 100 million rods, there are only about 7 million cones, which are concentrated around the central area of the visual axis called the *fovea centralis*, as shown in **Fig. 7.23**.

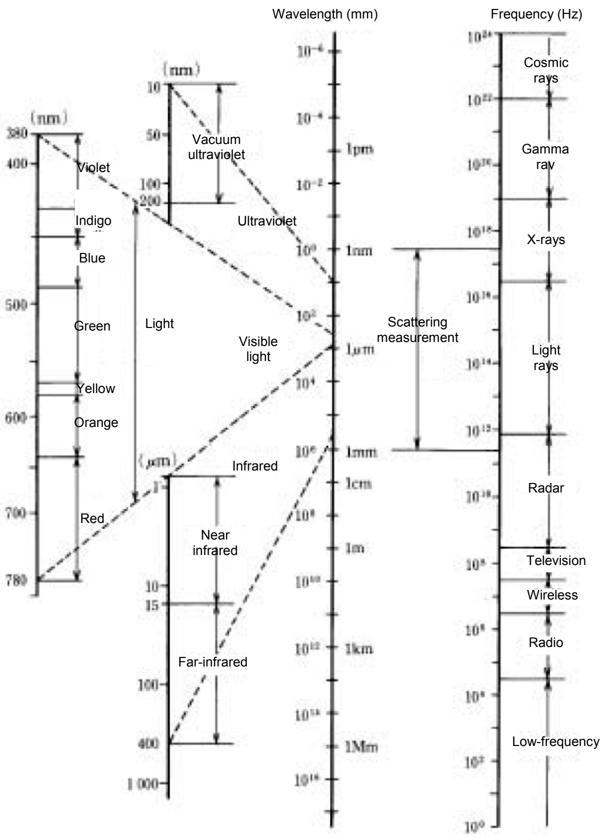


Fig. 7.21. Electromagnetic radiation wavelengths [17].

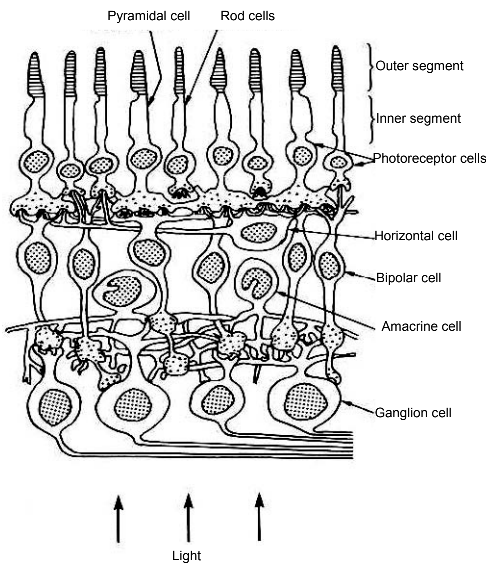


Fig. 7.22. Structure of the retina [18].

In other words, while the large number of rods is used for overall sight, color differentiation is mainly carried out by cones in the central area of the visual axis.

The diameter of the rods and cones in the outer segment shown in **Fig. 7.22** is 1–2 µm and 1–5 µm respectively. Incidentally, the diameter of the silver halide used in silver halide photographs is 0.05–3 µm. The density of the visual cells in the vicinity of the fovea is approximately 60,000/1 mm^2, meaning that there are more of them than the approximately 15,000 (12MP, 35 mm size) pixels used in DSCs and the approximately 30,000 grains used in color film photographs.

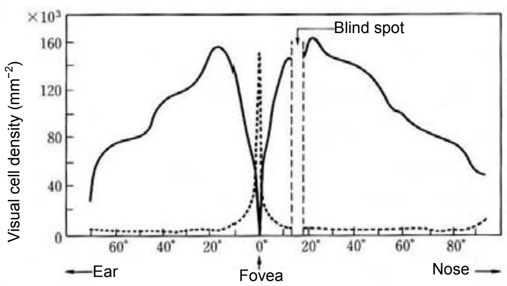


Fig. 7.23. Rod and cone distribution [19].

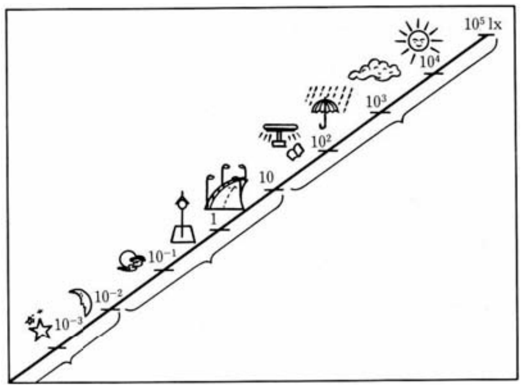


Fig. 7.24. Brightness estimation [20].

As shown in **Fig. 7.24**, illuminance in the natural world ranges from direct light on the coast during mid-summer to starlight at night, ranging from 10^5 lx to 10^{-3} lx or less, which is actually eight decimal places or 160 dB or more.

The human eye is capable of adapting to this wide range of brightness by adjusting the amount of light via the pupillary light reflex and using cone cells that are sensitive in bright light and rod cells that are sensitive in dim light.

By contrast, consumer DSCs are 8-bit; in other words, when used as they are they have 256 colors and a dynamic range of only approximately 48 dB. With DSCs, the aperture is adjusted to optimize exposure and cope with changes in lighting conditions.

In order to accommodate the brightness range of the subject, there is the choice of either capturing an encoded image with the dynamic range compressed in a non-linear fashion for a wide brightness range, or capturing an image with the range limited to the appropriate level.

In the case of the former, even if optimum exposure is not set, it can to a certain degree be compensated for, but there will be a discrepancy in the value used non-linearly and noise will be produced. On the other hand, with the latter, although the linearity of color reproduction is outstanding, it results in images that are impossible to repair when the optimum exposure is not set.

On the other hand, because perception of color by the human eye is carried out by the three types of cone cells as already mentioned above, this three primary color theory is widely used in DSCs and other imaging fields.

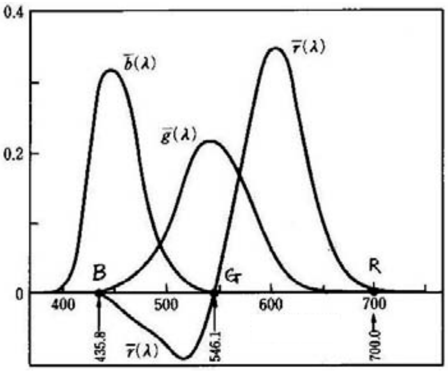


Fig. 7.25. Color matching in the RGB color space [21].

In 1931, the International Commission on Illumination (CIE: Commission Internationale d'Eclairage) [21] introduced the CIE 1931 RGB color space, which was demonstrated to be able to approximate any color by color matching the three primary colors – R (700.0 nm), G (546.1 nm) and B (435.8 nm) – which are called the reference stimuli.

However, as shown in **Fig. 7.25**, between 435.8 nm and 546.1 nm, R must be negative. This represents adding R to the subject color to make a mixture of G and B to match it. As negative color does not actually exist, it is not possible to make colors in this fashion. For this reason, the theoretical reference stimuli X, Y and Z, were introduced as the XYZ color space to avoid negative RGB values. Although color-matching functions in this xyz color space are represented by x, y and z, generally

$$x + y + z = 1$$

and the two-dimensional x and y coordinates are used to express chromacity.

PCs and other IT devices commonly use the RGB color model, but television signals reproduce color using the YCbCr color space with luminance (Y) and chrominance (Cb and Cr) signals.

Color information in DSCs is reproduced with the three primary colors in the same way as with the human eye.

Although DSC image sensors use filters with the three primary colors (RGB), or their complementary colors cyan, magenta and yellow (CMY), as JPEG is compatible with composite signals, RGB signals are converted to and stored as YCbCr values.

When recording in recording media as compressed images, these color values are recorded as they are and converted into RGB when rendered on a PC display.

Moreover, when images are printed on a printer, color must be converted to CMYK values (the subtractive CMY values with black (K) added). This process is depicted in **Fig. 7.26**.

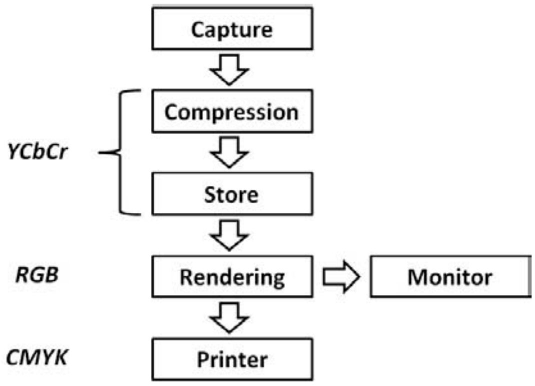


Fig. 7.26. DSC system color display overview.

Exif adopted the sRGB color space that was initially determined by the International Electrotechnical Commission (IEC)'s TC100 as IEC 61966-2-1. This sRGB color space was for color management on CRT displays, and is optimized for that purpose. On the other hand, printers and other peripherals can reproduce a wider range of colors than CRT displays, and it was suggested that color management was inadequate with sRGB. Consequently, DCF 2.0 added support for Adobe RGB, a color space often used in desktop publishing (DTP), etc., that has a wider gamut than sRGB.

DSCs capture images of physical phenomena (subjects) in the form of digital data, accumulate them in the logical realm, and output them as digital signals to displays, printers and PCs, etc. after image processing, etc.

During that process, such physical information only becomes visible when viewed on a display, such as a DSC LCD.

In other words, as depicted in **Fig. 7.27**, image data in DSCs is handled in the logical realm, and can be perceived as physical information via interfaces such as printers and displays.

For us, only when this physical information is made visible via these interfaces can we perceive digital images.

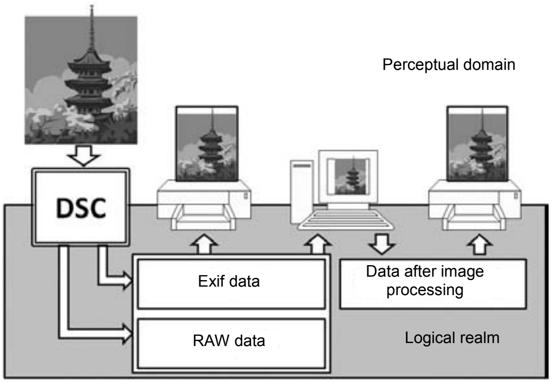


Fig. 7.27. Perceptual realm/logical realm image flow.

In terms of the concept of color management, which involves the handling of chromacity, saturation and luminance, color encodings based on faithfully taking the color of the subject and reproducing it on the basis of the subject are thought of as being input-referred, while color encodings designed for color reproducibility on the device that reproduces the exposed image are thought of as being output-referred. This concept as it applies to images is known as image state (**Table 7.2**).

Table 7.2. Image state

Input Referred
Scene Referred • • • DSC
Original Referred • • • Copy, CG
Subject-oriented color rendering
Output Referred
Output device-based color rendering

Although this concept of image state was born from within the International Standardization Committee ISO/TC 42 (Photography), it is also extremely valid when connecting with other devices and transferring image data.

Furthermore, when attempting to achieve optimum color reproduction of images received through various interfaces, the options in terms of foundational standards are:

1. Subject color
2. Remembered color
3. Pleasant color.

Like with a photocopy, etc., when it is possible to evaluate equivalence if an output image is in the same form as the subject, it is possible to carry out color management based on the “subject color.” Requirements change, however, depending on illuminating light and other environmental factors that influence viewing conditions when images on two-dimensional media such as paper or PC are used to display subjects that are natural objects (existing in three-dimensional space like the DSC itself). When this happens, color reproduction management is standardized to “remembered color” or “pleasant color.”

If a color is within the realm of reproducibility, it is possible for that color to be changed via mathematical operations. There are many software programs on the market for changing the color of and applying effects to DSC images.

Although the range of color that can be captured by DSCs is determined by the characteristics of the filters used in them, even DSCs using sRGB for a color space are capable of taking a wider gamut of color than is possible to reproduce within the confines of the sRGB color space. However, when the color signal output of DSCs is written using the sRGB color space, colors outside of the sRGB gamut are “clipped” (thrown away).

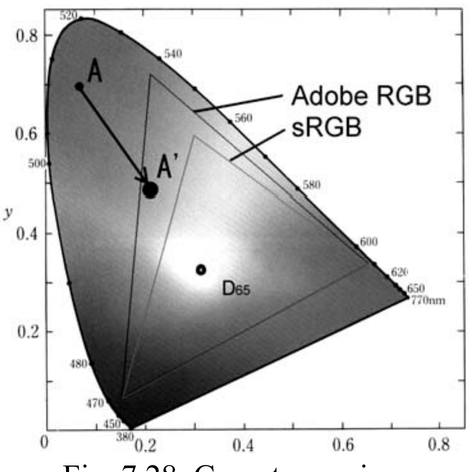


Fig. 7.28. Gamut mapping.

As a consequence, a color such as Point A in **Fig. 7.28** would be saturated at Point A2C in sRGB, and even in Adobe RGB it would be saturated at Point A1C, while in the case of Adobe RGB, for example, the color difference between Point A and Point A1C would not be able to be expressed. In order to avoid this, gamut mapping is carried via mathematical color conversion (for example Point A would be moved to Point A1 in Adobe RGB, and point A2 in sRGB).

Figure 7.29 shows the image processing flow that happens in DSCs in accordance with ISO 17321.

Image sensor output passes through the A/D converter and becomes raw data possessing the characteristics of the image sensor. After this raw data is corrected in terms of exposure, white balance and image sensor characterization compensation, scene-referred editing is carried out.

As it is unknown what device the data will be output with, data is processed up to this point on the input side with no regard for what the output will be, which is known as scene-referred editing.

In the case of paper scanners and computer graphics, this is called original-referred editing, and together they are known as input-referred editing.

Data that has been through this process is passed through color rendering, where things such as tonality correction are carried out by PCs, etc.

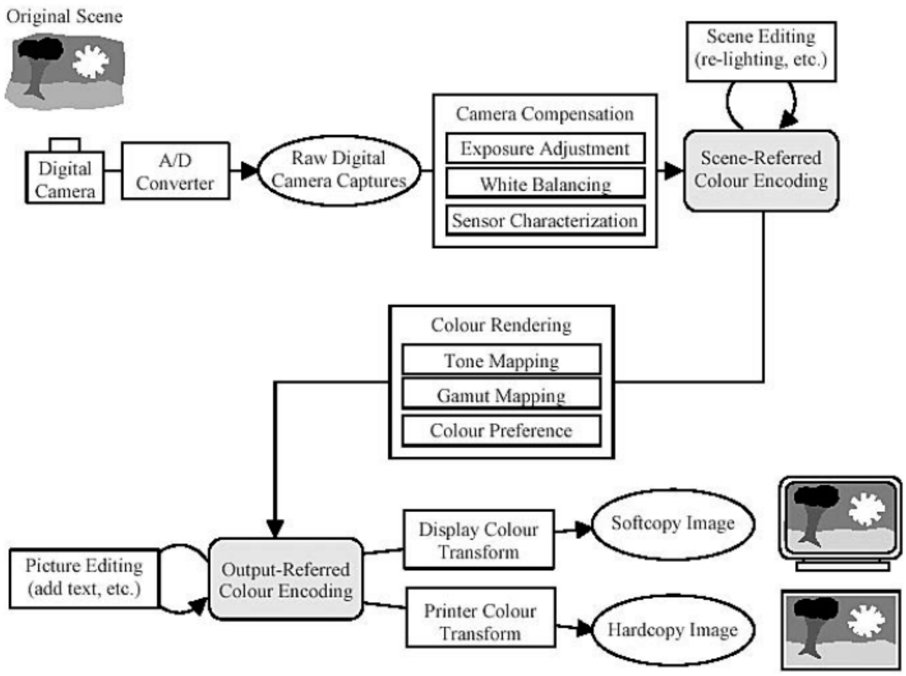


Fig. 7.29. Image processing flowchart.

Notes.

[1], [2] From CIPA statistics.

[3] Provided by Masafumi Inuiya of Fujifilm.

[4], [5] "Development of a Wide Dynamic Range Image Sensor for SLR, Super CCD SR II," *Fujifilm Research and Development*, No. 50, 2005. (provided by Masafumi Inuiya) and "Design Rule for Camera File System," Standard of Japan Electronics and Information Technology Industries Association CP-3461.

[6] From a Sigma press releases.

[7], [8], [9], [10], [11]
F. Masuoka, "Rapidly-Advancing Flash Memory," Kogyo Chosakai Publishing Co., Ltd.

[12] The Japan Electronic Industries Development Association (JEIDA) merged with the Electronic Industries Association of Japan (EIAJ) to form the Japan Electronics and Information Technology Industries Association (JEITA).

[13] Personal Computer Memory Card International Association

[14] "Fine Imaging and Digital Photography," Corona Publishing Co., Ltd., p. 174.

[15] "Fine Imaging and Digital Photography," Corona Publishing Co., Ltd., p. 190
"Guidelines for Physics, Electricity, Physical Formats, Logical Formats, Interface Design" and "Guidelines for Voltage Capacity Notation," in *SmartMedia specifications* (SSFDC Forum Publishing, 1999 Edition).

[16] "Fine Imaging and Digital Photography," Corona Publishing Co., Ltd., p. 180.

[17], [18], [19], [20], [21]
"Color Engineering," Tokyo Denki University Press.

8 Image Compression and Formats

8.1 Image Compression and JPEG

A simple calculation of the output data volume from a DSC with a 1MP image sensor where the output from each cell is 1 byte shows that it is 1MB. This means that only about 64 images can be recorded on a 64MB card. As there was a great demand to be able to record more images on memory cards with limited storage capacity, in response, methods of efficiently reducing image data volume with minimum deterioration in image quality were developed.

Image compression methods include spatial compression, temporal compression and entropy compression. Of these, spatial compression and entropy compression are used in DSCs for handling still images. In early DSCs, ADPCM, which is a form of entropy compression, was employed. Using the fact that there is little difference between signals from adjacent pixels, after digitizing each pixel, the signal for a third pixel is predicted on the basis of the signals from the first and second pixels and the difference between the actual and predicted signals is used.

Other compression methods that have been considered for still images include cosign transform (DCT for digital), which is a type of Fourier transform that breaks up data into spatial frequency components, wavelet transform (localized Fourier transform) and fractal transform, which breaks up data into cyclic patterns. Furthermore, entropy compression, which minimizes the redundancy of data after encoding, is an efficient means of improving communication and recording efficiency.

In 1986, with the aim of internationally standardizing image compression methods, ISO TC7 SC2 WG8 and the International Telegram and Telephone Consultative Committee (CCITT) SC VIII were combined to form the Joint Photographic Experts Group (JPEG) under ISO/IEC JTC1 SC2 WG8.

Initially, although there was fierce debate regarding the DCT method proposed by Europe, the Vector Quantization (VQ) method proposed by Japan and the arithmetic coding proposed by the US, it was Hiroshi Yasuda of the NTT Musashino Central Research Center, who was the chairman of WG8 at the time, who resolved the issue.

Under the direction of Mr. Yasuda, the still image compression format (Digital Compression and Coding of Continuous-Tone Still Images) was created in 1992 and introduced in 1994 as ISO 10918-1, taking on the name of the group that created it: JPEG. This group is currently engaged in working on JPEG 2000 and JPEG XR as ISO/IEC JTC1 SC29 WG1.

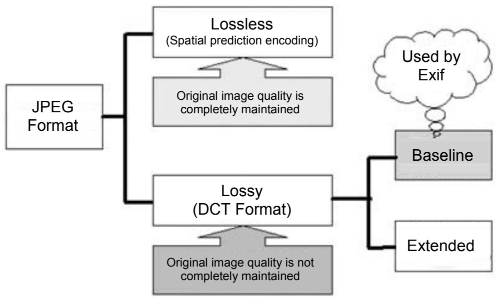


Fig. 8.1. JPEG structure.

As shown in **Fig. 8.1**, JPEG uses spatial prediction, which is lossless and makes lossless compression possible by means of spatial prediction encoding, and DCT encoding, which is lossy and uses Adaptive Discrete Cosine Transform (ADCT) to analyze spatial frequencies and encode image data, in combination with entropy compression.

With the lossless method, although if data is restored after compression then it is possible to recreate the original image quality, it is not possible to increase the compression ratio. On the other hand, with the lossy method, although part of the data from the original image will be lost due to compression, it is possible to carry out image compression of 10:1 or more without any real deterioration in image quality.

Table 8.1. JPEG baseline and extended methods

		Baseline	Extended
Bit/ (Pixel,Colour)	8	Y	Y
	12		Y
Mode	Sequencial	Y	Y
	Progressive		Y
Coding	Huffman	Y	Y
	Arithmetic		Y

Depending on the number of bits, the mode and the encoding method used, as shown in **Table 8.1**, this lossy compression method can be divided into baseline and extended types. The baseline type was used in consumer DSCs. A block diagram of the coder in the DCT coding used in JPEG is shown in **Fig. 8.2**.

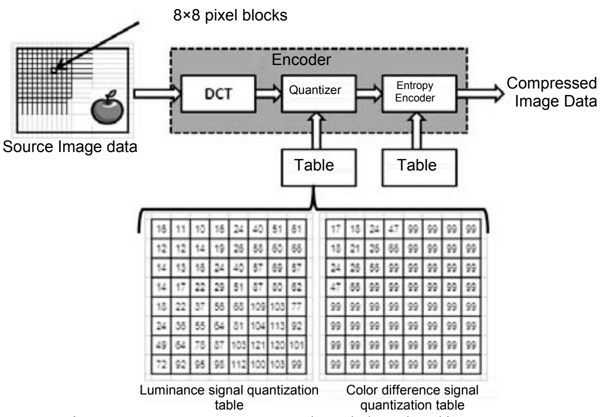


Fig. 8.2. DCT encoder block diagram.

In the encoder, input image data is broken up into 8×8 pixel blocks and each block is transformed by a DCT operation.

DCT is a type of cosine transform carried out with regard to symmetrical samples in the Fourier transform that handles discrete sampling points. This transforms the image, which was a 2D spatial function, into a 2D frequency function with an 8×8 coefficient. At that point, there is no reduction in the amount of data and if it were to be decoded as it is, then it could be recreated with no deterioration in the quality of the source image.

This DCT coefficient is shown in **Fig. 8.3**. The coefficient in the top left (0, 0) is the DC component, while the coefficient in the bottom right is the high-frequency component. DCT characteristics include the concentration of components in the low-frequency domain, and as human visual characteristics include a reduction in sensitivity in the high-frequency domain, the importance of the DCT coefficient therefore drops as it goes from the top left to the bottom right.

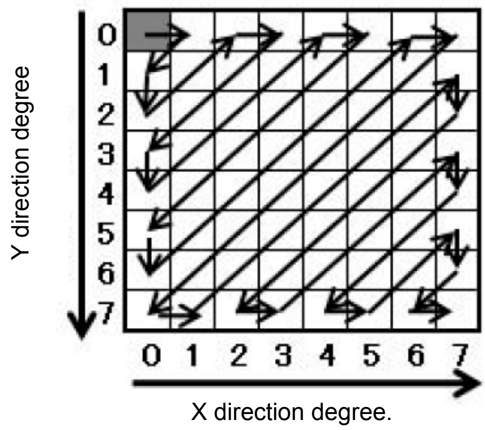


Fig. 8.3. DCT coefficients and zigzag scan.

That is to say, when reading the coefficients in a zigzag pattern from the upper left to the bottom right, as shown in **Fig. 8.3**, data volume can be reduced as precision is reduced towards the bottom right, and even with compression of 10:1 or more there is little deterioration in image quality.

With DCT encoding for JPEGs there are quantization tables for both luminance and color difference and division is carried out using the numerical values in the tables according to each coefficient.

The quantized coefficients are then passed to an entropy encoding procedure called a Huffman coding, which compresses the data by assigning a short code to numerals that occur with a high frequency. Although it is possible to use default values as quantization table values, generally, they are included in the image file together with the entropy-encoding table.

With JPEG, as input image data is broken up into 8×8 pixel blocks and each block is transformed by the forward DCT, if the compression ratio is set too high (i.e. the number of bits per pixel is reduced) then the boundary line between neighboring blocks can stand out, which is a phenomenon known as block noise. Incidentally, the block noise reduction effect is emphasized in JPEG2000, which uses wavelet transform, and JPEG XR, which uses 2D DCT.

8.2 The Necessity of Formatting

With silver halide cameras, although it is possible to directly view an image after it has been taken by developing the film, an image taken using a DSCs is an arrangement of encoded logical values and unless the structure of the encoding is understood, it is impossible to decode the logical value and read the data as a physical quantity, meaning that it is impossible to playback the image.

Therefore, there must be agreement regarding the metadata contained in the image file, for example the color space, which is the coordinates for describing color information, and common rules regarding the structure of such metadata must be determined.

In addition to this kind of image data, shooting conditions, such as creation date/time, shutter speed and comments, etc., are appended as metadata, which together comprise what is called the "image file." In a broad sense, what dictates the structural conditions of the image file is the format.

In other words, the types of data recorded in the file, the structure of each type of data recorded, methods of identifying each kind of data, the file format and the file recording method – everything – is required as structural elements of the format.

Data is recorded as a digital signal and in order to recreate it as data, an optimal and common format for such data processing is essential.

When discussing formats, it is convenient to cite the Open Systems Interconnection (OSI) 7-stage model shown in **Table 8.2**.

Table 8.2. The 7 layers of the OSI model

Upper Layers	Application layer	Controls data semantic content
	Presentation layer	Controls data expression format
	Session layer	Controls dialog units
Lower Layers	Transport layer	Controls data transfer between systems
	Network layer	Controls networking
	Data link layer	Controls transfer errors
	Physical layer	Controls electrical/physical properties of the line

By defining the protocols used when transferring data during interconnection and the content of transferred data in layers in accordance with this model, it is possible to specify the transfer methods used when delivering data. This concept was introduced by Japan during deliberations at the ISO and as it was useful in defining the object of such deliberations it was incorporated into ISO 12234. This 7-level OSI model is shown in **Table 8.2**. These levels consist of the upper three layers that are not recording media-reliant and the lower four layers that are recording media-reliant. Control of each layer is defined by the content of the layer beneath it.

These layers in the DSC format can be defined from the layers beneath as follows:

1. The physical layer: recording media.
2. Controls reading from/writing to the recording media.
3. Determines how image files, including images and other data, are handled.
4. Determines image file structure.
5. Determines the description format for recording various types of data.
6. Determines how various data is created in the image file.

By determining the definition of each of these layers it is possible to transfer data with no errors.

8.3 Recording Media-Reliant Formats

- Discussions regarding recording media and formats were carried out in the DSC Ad-Hoc Working Group (WG) that was established in JEIDA's PC Technology Committee in 1990 and in addition to almost all of the Japanese domestic camera manufacturers and electronic device manufacturers, there was also much interest from the US.

With the initial DSC format, the main objective was to determine a method for recording images as digital signals on designated recording media, there was no notion of a format that was not reliant on recording media and there was no concept of any detailed developmental direction for handling IT devices that used digital characteristics.

In the JEIDA DSC Ad-Hoc WG, work proceeded on the standardization of a format for both 20-pin and 68-pin cards, which were the remaining options in terms of PC cards, in specially established 20-pin and 68-pin subworking groups (SWGs).

Due to the small number of pins in 20-pin cards especially, there were plans to make them the main type of memory cards for use with DSCs, taking advantage of the fact that it took much less effort to install and remove them than with 68-pin cards.

The format for a 20-pin card is shown in **Table 8.3**.

Table 8.3. 20-pin card format

#	Symbol	I/O	Meaning
1	GND	–	Ground
2	D0	I/O	Bidirectional data bus
3	D1	I/O	”Ditto
4	D2	I/O	Ditto
5	D3	I/O	Ditto
6	D4	I/O	Ditto
7	D5	I/O	Ditto
8	D6	I/O	Ditto
9	D7	I/O	Ditto
10	Vcc	–	Supply voltage
11	(Vpp)	–	Programing supply voltage
12	RDY/BSY	O	Ready signal
13	CE	I	Card enable
14	A/D	I	Address/Data
15	R/W	I	Read/Write
16	BCK	I	Bus Clock
17	RFU	NC	Reserved for Future Use*
18	RFU	NC	Reserved for Future Use*
19	RFU	NC	Reserved for Future Use*
20	GND	–	Ground

This 20-pin card format had the following characteristics:

a. The card had an I/O bus interface and was compliant with the I/O bus IC card standard determined under the JEIDA guidelines.
b. There were 20 pins. According to the JEIDA standard the thickness of the edge of 20-pin cards was to be 2.2mm (a maximum of 5 mm was permitted in the central part), but with these memory cards the thickness was 2.2 mm over the entire length of the card.
c. Images, sound and other data were all handled as separate packets.
d. The cluster method was employed as the packet recording method.
e. The size of one cluster was 8 KB.

As can be seen from the above, this format was used to control the read and write operations and was designed with the expectation of handling data such as images, sound and other data, with no detailed image format being specified.

In early DSCs, image data was digitized with 8-bits per NTSC scanning line [3] and used the ADPCM format, which recorded the difference between predicted and actual values.

Although the format was determined with the expectation that 20-pin cards would be used in the first DSCs, in the end, after discussions, JEIDA and PCMCIA settled on 68-pin cards and PCMCIA strongly demanded the removal of 20-pin cards from the market in order to avoid confusion among consumers. Therefore, discussions regarding formats at JEIDA then came to center around 68-pin cards and no consumer DSCs using 20-pin cards were ever released.

The format for a 68-pin card is shown in **Table 8.4**. This format used a logical memory allocation table (MAT) formed on the physical format of the PC card.

Table 8.4. 68-pin card format

00h	Tuple ID[90h]
01 h	Pointer to next tuple
02h	Scanning method
03h-05h	Image mode
06h	Bits per pixel
07h	Gamma characteristics
08h-17h	Signal level
18h-1Fh	Number of pixels
20h	Reserved [00h]
21h-25h	Screen/pixel aspect ratio
26h	Encoding method
27h	Compression ratio
28h	Uncompressed data recording mode
29h-2Fh	Reserved [00000000000000h]
n-1	Empty
n	Next tuple

On the other hand, the various DSC manufacturers developed proprietary memory cards other than PC card and DSCs that used proprietary memory card formats and began to release them into the market. In other words, other than the Still Image, Sound and Related Information Format (SISRIF), which was used by PC cards, various proprietary formats were used: SM cards used Exif, CF cards used the Camera Image File Format (CIFF) and MemorySticks used the Universal Disk Format (UDF). Furthermore, the Auto-Indexing Mass Storage (AIMS) card, which was a memory card for computers, was proposed by the US, which gave the impression that the situation could develop into the kind of format wars that occurred between VHS and Betamax in the video tape recorder market.

In order to overcome this situation, the JEIDA committee called for a “format not reliant on recording media” and decided to separate themselves from discussions regarding recording media and sought to unify the individual formats that already existed.

8.4 Formats Not Reliant on Recording Media

While details regarding coding and data compression methods are determined within JPEG, which was established as a standard by JTC1 (the international standardization subcommittee for programming languages, their environments and system software interfaces, which is an ISO/IEC joint technical committee), protocols for transferring and recording image data are not determined. Generally, the JPEG File Interchange Format (JFIF) is used when recording images as JPEGs.

JFIF was proposed by C-Cube Microsystems in 1991 and uses a file-exchange protocol that is specific to the JPEG compression format, which was released as v1.02 in 1992 and can be identified by the fact that JFIF is noted in application segment 0 (App0) in the JPEG file. JFIF contains formatting rules for image data files containing compressed image data and metadata. For example, although there are no stipulations regarding colors to be used in JPEG, they can be stipulated in JFIF.

On the other hand, the Tagged Image File Format (TIFF), which was created in 1986 by Aldus (now Adobe Systems) and Microsoft initially for handling images from scanners, is a format for consolidating and storing different types of image data created using different specifications into a single file (**Fig. 8.4**).

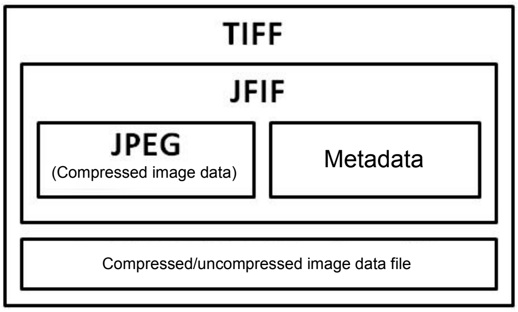


Fig. 8.4. JPEG, JFIF, TIFF relationship.

With TIFF, the metadata within image files is treated as packages, with tags being assigned to show the content of each package.

While JFIF only deals with JPEG files, TIFF can handle image files that were created in formats other than JPEG. However, it was not able to handle compressed images until TIFF 6.0 was released in 1992.

JFIF and TIFF are both logical concepts that are not reliant on recording media or system and are, I believe, suitable formats for use with digital content.

8.5 Exif

In order to create the kind of multipurpose DSC format that is not reliant on recording media and which is essential for the popularization of DSCs, it is necessary to decide on the following control formats that are defined in the lower layers of the OSI model.

1. The types of image data that will be handled as image files and their file structure.
2. The description format for each type of data recorded, such as tag format and Extensible Markup Language (XML) format.
3. Methods of creating each type of data within the file, such as compression methods for images and audio, coding methods and the color space employed.

Although in the new format the aim was to handle both compressed and uncompressed image files, when handling compressed image files, with consumer models especially, in order to ensure the popularization of any new format it is necessary to employ image file compression methods with little degradation in image quality.

In light of these things, the JEIDA committee obtained information regarding the JPEG standard before it was officially released and began to consider the matter.

As shown in **Fig. 8.1**, JPEG includes lossless compression, which completely preserves the original image quality, and lossy compression, which, while it does not preserve the original quality, makes it possible to reduce file size.

As a result of their investigations, in 1992, JEIDA adopted Baseline JPEG format, which is categorized under lossy compression, ahead of the official announcement of JPEG as an international standard.

Furthermore, JEIDA negotiated with Adobe and Microsoft in order to use TIFF as a base for the image file description format.

However, as compressed images were not able to be handled by TIFF 5.0 at the beginning of 1992, which was the year in which the JEIDA committee created their draft proposal, JPEG – JFIF to be more specific – was used for compressed images, while uncompressed images and the overall structure and metadata followed the example of TIFF.

The image file thus created for DSCs was newly named Exif and at the same time the items needing to be defined in the lower layers of the OSI model were formulated as Exif R98.

After the basic proposal for Exif had been formulated, in June 1992, TIFF was revised to include support for JPEG (TIFF Revision 6.0), based on which the US made a counterproposal to Exif to the ISO in the form of TIFF/EP.

As the structure of both of these specifications was basically the same, after internal discussions at the ISO it was decided that interoperability should be maintained between both specifications by using the same tags and that Exif would be used for consumer use while TIFF/EP would be used for professional use.

Presently, TIFF/EP has been established as ISO 12234 Part 2 and Exif has been approved as a JEITA specification in ISO 12234 Part 1.

At the time that Exif was formulated as a unified standard that is not reliant on recording media, fortunately the DSC market was still small, meaning that the loss suffered by each company by conceding to change to the new format was comparatively small. On the other hand, the advantage of introducing a unified standard was recognized through the work of the technicians on the JEIDA committee and came to be understood by each of the different companies.

The US proposed the establishment of a new working group in ISO TC42 (Photography) to deliberate on standards regarding DSCs, a proposal that was approved by a majority vote. Consequently, in September 1991, WG18 (Electronic Still Picture Imaging) was formed, with initial projects focusing on ISO exposure index, resolution test targets, definitions/terminology and memory cards.

In light of this, Japanese Industrial Standards Committee (JISC) instructed that the JEIDA working group was to handle ISO discussions regarding formats and at the first meeting of WG18 in February 1992 in Las Vegas the JEIDA specification was proposed.

So, the DSC file format was born out of discussions regarding the formation of the JEIDA specification in Japan and was proposed as an international standard at the ISO to actually become the Exif global unified standard for consumer DSCs.

At the same time, a PC card format that was not reliant on recording media was separately proposed to the ISO and approved as the SISRIF international standard for PC cards.

As we can see from **Fig. 8.5**, the basic structure of Exif consists of a header, a data file containing related information, such as shooting conditions and audio, etc., a thumbnail image containing compressed image data and an image file containing image data.

In Exif, which uses the structure of TIFF, the physical values stored in the image file are each assigned a tag as individual metadata.

For each of the metadata that express the data content, metadata determined in TIFF uses the TIFF tags just as they, while necessary metadata that is unique to DSCs uses newly added tags.

Detailed tag structure and arrangement differs according to whether or not a file is compressed. Exif compressed file structure is shown in **Fig. 8.6**. In compressed files, the JPEG Application Marker Segment (App) contains an Exif marker with Exif metadata in App1 and a FlashPix-compatible marker in App2 by which they can be recognized as Exif-compatible files.

Fig. 8.5. Exif basic structure.

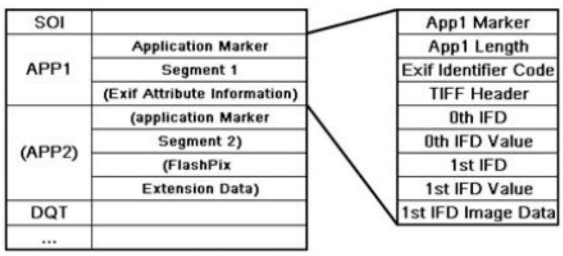


Fig. 8.6. Exif compressed file structure.

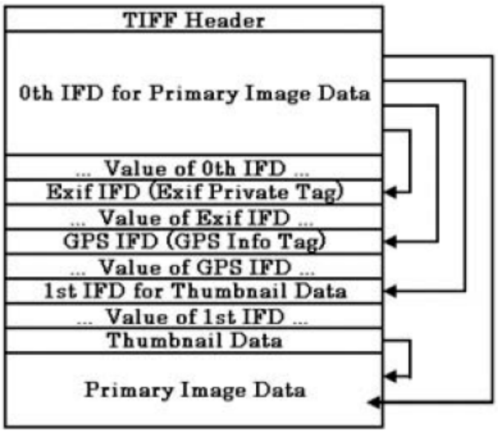


Fig. 8.7 Exif uncompressed file structure.

On the other hand, with uncompressed files, as shown in **Fig. 8.7**, the basic structure of TIFF is retained.

Some of the tags used in Exif are shown in **Table 8.5**. Each tag represents certain metadata and there are three levels of tags: M (Mandatory), R (Recommended) and O (Optional). The recording function of DSCs must support all M tags.

As an interchangeable image file format, Exif has characteristics such as the following:

1. It can handle both compressed and uncompressed image files.
2. It has a tag structure (a common numbering structure is used to show the content of each individual chunk).
3. It can be used in combination with DCF image format handling rules.
4. It is basically aimed at consumer DSCs.
5. If it is only a matter of viewing images, then they can be viewed as JPEG. If an Exif-compatible device or software is used, then it is possible to view Exif data and Exif metadata, and even after resaving after retouching Exif data is not lost.

In addition to image data, Exif contains various kinds of data regarding shooting conditions that was unable to be recorded with silver halide cameras, such as tags regarding Global Positioning System (GPS) data that show where a photograph was taken, as well as tags for recording audio and video.

This shows that DSCs are not simply devices for recording images, but have a place as information terminal devices.

Table 8.5. Exif tag example

Class	Field Name	Tag name	Tag ID
A. Tags relating to image data structure			
	ImageWidth	Image width	256
	ImageLength	Image height	257
	BitsPerSample	Number of bits per component	258
	Compression	Compression scheme	259
	PhotometricInterpretation	Pixel composition	262
	Orientation	Orientation of image	274
	SamplesPerPixel	Number of components	277
	PlanarConfiguration	Image data arrangement	284
	YCbCrSubSampling	Subsampling ratio of Y to C	530
	YCbCrPositioning	Y and C positioning	531
	XResolution	Image resolution in width direction	282
	YResolution	Image resolution in height direction	283
	ResolutionUnit	Unit of X and Y resolution	296
B. Tags relating to recording offset			
	StripOffsets	Image data location	273
	RowsPerStrip	Number of rows per strip	278
	StripByteCounts	Bytes per compressed strip	279
	JPEGInterchangeFormat	Offset to JPEG SOI	513
	JPEGInterchangeFormatLength	Bytes of JPEG data	514
C. Tags relating to image data characteristics			
	TransferFunction	Transfer function	301
	WhitePoint	White point chromaticity	318
	PrimaryChromaticities	Chromaticities of primaries	319
	YCbCrCoefficients	Color space transformation matrix coefficients	529
	ReferenceBlackWhite	Pair of black and white reference values	532
D. Other Tags			
	DateTime	File change date and time	306
	ImageDescription	Image title	270
	Make	Image input equipment manufacturer	271
	Model	Image input equipment model	272
	Software	Software used	305
	Artist	Person who created the image	315
	Copyright	Copyright holder	33432

8.6 DCF

Consumer DSC image files recorded in accordance with the Exif standard can be played back regardless of recording media if using devices and software that support Exif. However, if, for example, the recording media contains a mixture of image files and other files such as text files, unless rules for handling such files have been established, then in some cases when using the same recording media in other DSCs, errors may occur, resulting in the deletion of recorded image files. Therefore, it is preferable that image files are recorded in accordance with set rules by the recording device and that such files are played back in accordance with those same rules.

Although specifications regarding image files were standardized as Exif based on the old Exif standard, methods of controlling reading from and writing to such recording media and protocols regarding methods of handling image files including images and other data, especially in light of the fact that such files were not expected to be handled while mixed with other different files, were inadequate under Exif R98.

After considering this matter, JEIDA released DCF, which was a new specification for handling image files in recording media based on CIFF and Exif R98 (**Fig. 8.8**).

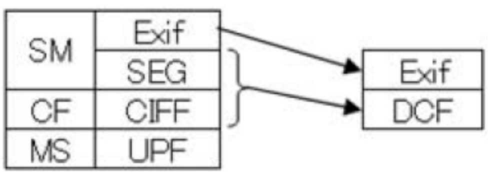


Fig. 8.8. The place of Exif and DCF.

In other words, the upper layers in the OSI 7-layer model came to be handled by Exif while the lower layers were handled by CIFF.

With DCF, the image recording side, for example a DSC, is called a Writer, while the image playback side is called a Reader. On the Reader side there are devices that do not necessarily need to playback the main image, such as a DSC monitor display, (Reader 1) and devices where the main function is to playback the main image, such as printers (Reader 2). Devices such as computers need both Reader and Writer specifications.

The place of Exif and DCF is shown in **Fig. 8.9** and related rules for Reader1 and Reader2 are shown in **Table 8.6**.

Based on the DCF specification, image files that are structured in accordance with Exif can be stored together with shooting data on removable recording media.

As of the time of writing this document, the Japanese-proposed DCF is also in the process of being approved in the ISO specification ISO 12234 Part 1.

Table 8.6. Readers and writers under DCF

	Main Image	Thumbnail	Device
Reader 1	Optional	Can be used to replace the main image when playback is impossible.	DSC
Reader 2	Required up to 1,800 × 1,200		Printer

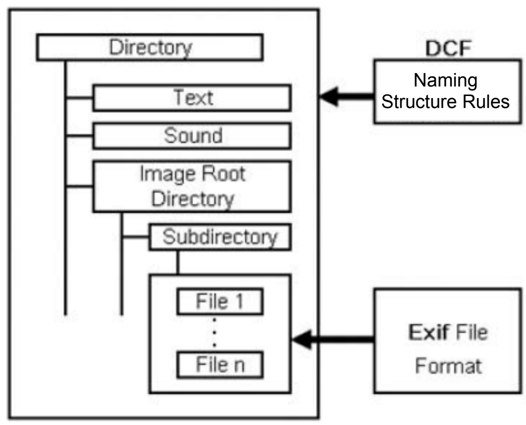


Fig. 8.9. Exif and DCF relationship.

8.7 Exif and DCF Revisions

A preliminary draft of Exif was formulated by JEIDA in 1992 and after being officially submitted to the ISO as a revised draft in April 1994, it went through the revision process shown in **Table 8.7** until reaching its present form (Version 2.21) in 2003. Care was taken to ensure that each of these revisions was backwards compatible and the major revisions were from Exif 2.1 to Exif 2.2 and from Exif 2.2 to Exif 2.21.

Table 8.7. Exif revision history

1994/4	Proposed by JEIDA	
1995	Version 1.0	
1997/5	Version 1.1	(Addition of optional metadata.)
1997/11	Version 2.0	(FlashPix compatibility, audio data processing function)
2000	Version 2.1	
2001	Version 2.2	(Exif Print)
2003	Version 2.21	(DCF 2.0 Compatible with extended color space)

Exif 2.2 was published in 2001 and was referred to as “Exif Print.” With Exif Print, when printing images shot using a compatible DSC, if the printer is also compatible and has an automatic image processing function, then the image may be printed in such a way that does not reflect the original intent of the photographer. Exif 2.2 enabled compatible DSCs to save more information about an image at the time it was recorded, data that is then used for reference when the printer automatically processes the photograph, resulting in images that more faithfully match the original scene.

For example, in terms of exposure modes, when manual exposure, exposure adjustment or auto bracketing are used, as there is a high possibility that the photographer intentionally controlled exposure, no correction is carried out, while with auto exposure, exposure optimization is carried out.

With white balance, color calibration correction is only carried out when automatic processing is being carried out. Furthermore, flash status is checked and if a flash was used, then overexposure is improved and overall contrast and background brightness improved and corrected.

In terms of scene modes (portrait, landscape or night modes), if portrait mode is selected then contrast is optimized while making adjustments to present the nicest skin tones before the photograph is printed. If landscape mode is selected, then contrast and brightness are adjusted, color corrected and saturation adjusted in order to present a contrasty scene. With night mode, dark areas are constrained while bright areas are emphasized in order to ensure that prints faithfully reproduce the intent of the photographer.

Although DSCs were to use the sRGB color space as stipulated under IEC 61966-2-1 and the sRGB color space is compatible with monitors, the color space recorded by DSCs is capable of reproducing a wider range of colors than the color space of monitors.

Furthermore, as the JPEG image compression standard used by DSCs uses the YCC color space, in reality, RGB was converted to the YCC color space within DSCs.

Therefore, from Exif 2.2, sYCC was defined as the color space (IEC 61966-2-1 Amendment 1). sYCC is mathematically calculated from sRGB, making it possible to use a wider color gamut.

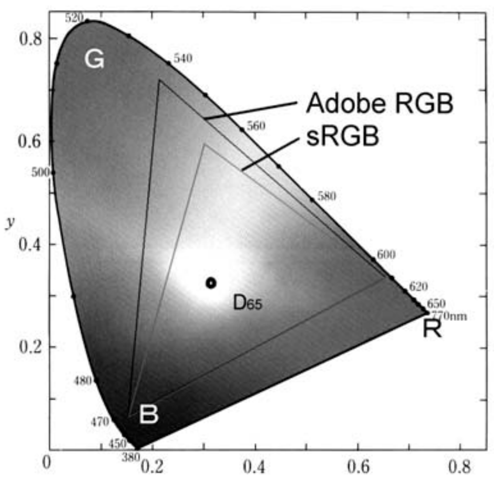


Fig. 8.10. sRGB and Adobe RGB color gamut comparison.

The revision from Exif 2.2 to Exif 2.21 was carried out when DCF 1.0 was revised to DCF 2.0.

As DSC functionality improved, although they came to be used in printing and publishing, color reproduction using the

sRGB color space was inadequate. Therefore, Adobe Photoshop® was generally used for rendering and there were moves among some camera manufacturers to incorporate the use of Adobe RGB. A comparison of the color gamut of sRGB and Adobe RGB is shown in **Fig. 8.10**.
However, as existing Readers were not able to identify Adobe RGB, photographs taken using the Adobe RGB color space were played back in the sRGB color space, meaning that they were not able to utilize the capabilities of printers that were able to reproduce the Adobe RGB color space. Furthermore, even if the colors were able to be corrected in the printer to reproduce colors in the Adobe RGB color space, there would still be a slight difference in terms of color reproduction for images taken using sRGB and Adobe RGB.

Therefore, after considering the matter in 2002, CIPA announced DCF2.0, which added DCF option files that could use Adobe RGB as an optional DCF color space. Details regarding the revision from DCF 1.0 to DCF 2.0 are shown in **Table 8.8**.

Table 8.8. Content of DCF1.0 to DCF2.0 revision

Purpose of Revision	Revision Content	Details
Ability to also use Adobe RGB	Additional definition of DCF optional files	File names starting with "_" (underscore)
		Interoperability Index = "R03"
		Color Space Tag = "Uncalibrated"
		Tag showing color space properties (*)
Writer Specification Revision	Able to record DCF optional files	
Reader 1 Revision	Playback of DCF optional file thumbnails made mandatory	
Reader 2 Revision	Playback of DCF optional files made optional	

*Color space characteristics: White point, three primary colors, YCbCr properties, γ.

In DCF 2.0, facility was made to be able to identify photographs taken using the Adobe RGB color space by assigning a file name starting with an under bar as a DCF option file.

Table 8.9. DCF Reader color reproduction

Writer	Reader	
	DCF 1.0	DCF 2.0
sRGB	sRGB	sRGB
Adobe RGB	sRGB	Adobe RGB

As shown in **Table 8.9**, images taken using the Adobe RGB color space are played back by a DCF 1.0 Reader as sRGB while they can be played back as Adobe RGB color space by Readers that support DCF 2.0.

As Exif and DCF are complementary, with the revision of DCF to 2.0 Exif was revised from Version 2.2 to Version 2.21. Details regarding that revision are shown in **Table 8.10**.

Both Exif and DCF were considered as international standards by the ISO, with Exif being approved as ISO 12234-1 while DCF is currently in the process of being approved. However, while it could be said that in general Adobe RGB is becoming more popular, as it is a Proprietary Standard determined by a single company, it is unable to be incorporated in international standards. Therefore, the IEC sought to establish a new standard called opRGB (IEC 61966-2-5) on the basis of content disclosed by Adobe. Although this was formally released after Adobe submitted Adobe RGB to the International Colour Consortium (ICC) in 2006, Adobe still retains the copyright. So, while it would be good for DSCs if support for Adobe RGB could be integrated in some way into international standards, just how that can be achieved is something that is currently being worked on by the IEC and ISO.

Table 8.10. Exif 2.21 revision details

ExifVersion Tag	"2.21"
Gamma Tag	Added
ColorSpace Tag	Definition changed
InterOperabilityIndex Tag	Permissible value added
Flash Tag	Definition changed
FileSource Tag	Permissible value added
TransferFunction	Levels recorded changed
Description Added	Pixel composition and image sampling description

In addition to revising Exif and DCF to make them compatible with Exif 2.2 (Exif Print) and Adobe RGB, various consortium standards and industry standards were also formulated, such as Digital Print Order Format (DPOF) and PictBridge, which were auxiliary rules for printing.

DPOF was a consortium standard created by Canon, Eastman Kodak, Fujifilm and Panasonic to enable digital devices compatible with DPOF to:

a. Designate the frames, number of copies and to include the date when printing;
b. Automatically print as designated merely by inserting a memory card into a home printer;
c. Order prints from a shop without the need to enter on an order form details such as the frames and number of prints to be printed.

PictBridge was proposed by Canon, Fujifilm, HP, Olympus, Seiko Epson and Sony as a direct printing compatible standard for directly printing images from a DSC without the need to use a computer, and was announced as a CIPA standard (CIPA DC-001-2003) in February 2003.

Up until that time, when directly printing DSC images, only dedicated or specific printers were compatible, but with a PictBridge-compatible DSC it became possible to connect any printer, regardless of make or type.

Notes:

[1] "New MPEG Textbook," ASCII Media Works, p. 57.
[2] Compiled from OSI, Japan Standards Association.
[3] NTSC: National Television Standard Committee.

9 Standardization of DSCs

9.1 ISO Activities

The international standardization of DSCs is carried out by the ISO/TC42 (Photography) committee. The scope of TC 42 is: Standardization primarily, but not exclusively in the field of still picture imaging – chemical and electronic – including, but not limited to:

- definitions for still imaging systems;
- methods for measuring, testing, rating, packaging, labeling, specifying and classifying the dimensions, physical properties and performance characteristics of media, materials and devices used in chemical and electronic still imaging;
- specifications and recommendations of logical and physical characteristics, practices, interfaces and formats for still imaging capture, processing and output systems; and
- methods, measurements, specifications and recommended practices for storage, permanence, integrity and security of imaging media and materials, and imaging materials disposition.

Of those items handled by TC42, although the following are handled by other ISO TCs or IEC and JTC1, there is mutual collaboration between these groups.

- Equipment and systems in the field of audio, video and audio-visual engineering (IEC/TC130)
- Cinematography (ISO/TC36)
- Graphic technology (ISO/TC130)
- Document imaging applications (ISO/TC171)
- Office equipment (ISO/IEC JTC1/SC28)
- Physical keeping of documents (ISO/TC46/SC10)

The following working groups (WGs) and joint working groups (JWGs) exist within ISO/TC42.

WG 2	Photoflash units (dormant)
WG 3	Image measurement, viewing and sensitometry
WG 4	Mechanical elements of photographic equipment
WG 5	Physical properties and image permanence of photographic materials
WG 6	Photographic chemicals and processing
WG 8	Joint TC 42-TC 6 WG: Imaging materials - Dimensions
WG 9	Still projectors and transparencies (dormant)
WG 17	TC 42/WG 3-TC 106- FDI (Fédération Dentaire Internationale) JWG
WG 18	Electronic still picture imaging
WG 19	Recycling of photographic materials (dormant)
JWG 20	ISO/TC 42-IEC JWG: Digital still cameras
WG 21	TC 42-TC 130 JWG: Density measurements
JWG 22	IEC/TC 100-ISO/TC 42-TC 130 JWG: Colour management
WG 23	TC 42-TC 130-CIE JWG: Extended color encodings for digital image storage, manipulation and interchange
JWG 24	TC 42-TC 130 WG: Revision of ISO 3664: 200

As DSCs fall under the product classification of "cameras," international standardization was first managed by the ISO. However, in 2000, a complaint was filed by the IEC with the ISO-IEC Joint Technical Advisory Board (JTAB), and as a result of discussions it was decided that:

- with regard to DSCs and color reproduction management, when the

ISO and the IEC are both concerned, work would be carried out jointly;

- as mentioned above, JWGs managed by the ISO would handle matters concerning DSCs, while joint project teams (JPTs) managed by the IEC would manage matters concerning color reproduction management.

At present, the most active groups are WG18 and the associated JWGs 20, 22 and 23, and formats for DSCs are being reviewed by WG18 as ISO 12234.

ISO 12234 is comprised of two parts: The various conditions that must be fulfilled by DSC storage media are specified in Part 1. Media and recording formats that conform to these rules are included in the same as shown below:

Annex A (Informative) Media profile − PC Card

Annex B (Informative) Image data format – SISRIF) a format proposed by Japan for the PC card)

Annex C (Informative) Image data format – Exif

Annex D (Informative) Image data format – TIFF/EP

From among these, TIFF/EP, which was proposed by the US as described in Annex D, was made an independent standard: ISO 12234 Part 2.

The reason why Exif was included as an Annex instead of being made an independent standard was that making it an independent standard with the ISO would have meant that the copyright, etc., would belong to the ISO, and it was feared that revision work would no longer be able to be carried out by Japan alone.

Furthermore, DCF, which was also proposed by Japan, is also being reviewed as ISO-12234-1 Annex E.

Standardization work being carried out in connection with ISO/TC 42 WG18 is shown in **Table 9.1**. From among these, ISO 12234-1 Annexes B, C and E, and ISO 20462-2, were proposed by Japan, while other standards, including ISO 12231, 12232 and 22028, incorporate many Japanese opinions.

Table 9.1. DSC-related topics considered by ISO TC42

ISO No.	Topics	Content
12231	Specialized terminology	Terminology
12232	Sensitivity	Measurement methods
12233	Resolution	Tools
12234(1-2)	Format	Model
14524	OECF	Measurement methods
15739	Noise	Measurement methods
15740	PTP	Protocols
16067(1-2)	Scanner	Measurement methods
17321	Color properties	Color characterization
20462(l-3)	Psychophysical evaluation	Evaluation methods
21550	Scanner D range	Measurement methods
22028	Expanded color encodings	Color management

The domestic council for the ISO in Japan is the Photo-sensitized Materials Manufacturers' Association (PMMA), which is the secretariat for the ISO TC42 Domestic Council, and within the Technical Committee is the Digital Image Working Group, which deliberates on the subject of digital imaging.

Because this Digital Image Working Group functions as a domestic deliberative body for international standardization activities, it deliberates on problems that are not part of the activities of CIPA. Because of this, CIPA is the secretariat of the Digital Image Working Group but remains independent as an organization.

9.2 CIPA Standards

CIPA is an industry association established on July 1, 2002 with the aim of contributing to the growth of its members who are engaged in the development, production, or sale of digital and silver halide cameras and related devices, equipment and software, and handles problems on behalf of the industry, such as environmental concerns, and ensures product compatibility and fair market competition, while also carrying out investigative research and information exchange for further expansion. It is possible for Japanese branches of foreign corporations to be members if they come under one of categories described above.

One of the business goals of CIPA is to "formulate and promote technical standards for the compatibility/interconnection of imaging-related devices," and within CIPA a Standardization Committee has been established that carries out activities associated with the goal stated above.

However, as CIPA aims for standardization that contributes to the expansion of its member companies, all of the problems deliberated on at the ISO do not necessarily become the subject of deliberation at CIPA, and CIPA undertakes standardization efforts of its own.

As of November 2007, standards that have become CIPA standards (apart from the Japanese Camera Industry Standard (JCIS) and Digital Camera Graphical Symbols (DSCSG), which were transferred from the Japan Camera Industries Association (JCIA) that functioned as an industry association for the camera industry prior to the establishment of CIPA) include:

- CIPA DC-001
  Digital Photo Solutions for Imaging Devices (February 3, 2003)
- CIPA DC-002
  Standard Procedure for Measuring Digital Still Camera Battery Consumption (December 17, 2003)
- CIPA DC-003
  Resolution Measurement Methods for Digital Cameras (December 17, 2003)
- CIPA DC-004
  Sensitivity of digital cameras (July 27, 2004)
- CIPA DC-005
  "Picture Transfer Protocol" over TCP/IP networks (November 8, 2005)

There are also other guidelines, such as the "Specification Guideline for Digital Cameras" and the "Guideline for Noting Digital Camera Specification in Catalogs."

9.3 Collaboration with the US I3A

The International Imaging Industry Association (I3A) is an industry organization dealing with matters relating to cameras and imaging devices, etc., in the US. Within the I3A there are working groups called initiative groups, in addition to a technical committee. The technical committee is commissioned by the American National Standards Institute (ANSI), the secretariat of the ISO/TC 42 in the US, to administer its affairs. For this reason, businesses may freely participate in the technical committee while observing the reasonable and non-discriminatory terms (RAND) policy of the ISO with regard to intellectual property (IP) rights, but initiatives are contracted research to be carried out by restricted members and as such their content is private.

The technical committee of the I3A is the equivalent of the ISO/TC 42 Domestic Council Technical Committee in Japan, and its position as the secretariat of the technical committee in the USA is the equivalent of that of the PMMA (secretariat of the ISO/TC 42 Domestic Council) in Japan. Furthermore, it could be said, from the similarities in the IP policy of the initiative groups of the I3A, that they are the equivalent of the Standardization Committee in CIPA.

I3A and CIPA are both international organizations, and as they are industry associations for manufactures of imaging devices, a cooperative framework for both parties has been discussed a number of times in the past. However, on account of differences in attitude toward IP, although there is mutual exchange, a cooperative framework has yet to be established.

10 The Future of DSCs

According to a survey of consumer trends published by Japan's Economic and Social Research Institute (ESRI), the spread of DSCs has been rapid (as shown in **Fig. 10.1**), and it was reported that they had achieved an adoption rate in excess of a 60% by 2007 [1].

Moreover, according to the Ministry of Internal Affairs and Communications, people own 2.5 color televisions, 1.9 mobile phones, 1.0 personal computers, 0.9 DVD players/recorders, and 0.7 digital cameras per household [2].

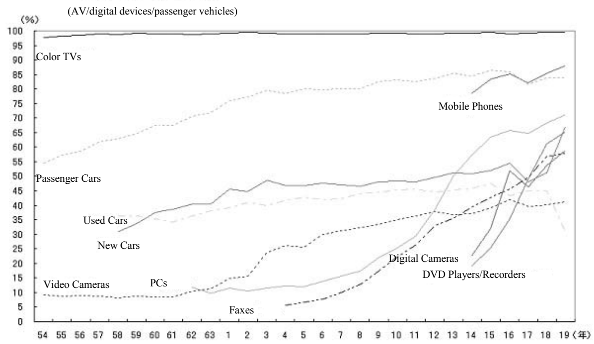


Fig. 10.1. Ownership of durable consumer goods.

Although consumer DSCs have achieved a surprising degree of market penetration in the 10 or so years since they were released into the market, future challenges are already arising.

Legally speaking, DSCs are optical instruments and like machine tools and clocks fall under the jurisdiction of the Industrial Machinery Division of the Ministry of Economy, Trade and Industry's (METI) Manufacturing Industries Bureau. However, rather than DSCs being classified simply as a substitute for their predecessors, silver halide cameras, they are classified as a kind of information appliance for creating images as electronic information.

We will now explore some of the problems (including the abovementioned stance of the METI) that will need to be considered with regard to DSCs in the future.

10.1 The Future of Formats for DSCs

Ten or more years have already passed since the establishment of Exif/DCF as a unified format for consumer DSCs. Although they underwent several revisions during that time, the greatest challenge with those revisions was to maintain compatibility with previous versions. Within the camera market, at a time when DSCs already have an overwhelming share of the market, the introduction of new format that break compatibility with old versions would predictably confuse the market and stir discontent among users, meaning that it would not be a good policy for manufacturers. Consequently, in terms of consumer DSCs, it follows that it is necessary to further evolve the existing Exif/DCF technology while preserving backwards compatibility.

On the other hand, it is true that some (including the US) say that developing new technology and introducing new formats rather than maintaining compatibility with Exif/DCF would be good for both the industry and consumers.

One of the main challenges that frequency comes up is the issue of formats.

10-1-1 Color Space Considerations

The revision of DCF 1.0 to DCF 2.0 and Exif 2.2 to 2.21 was due to requests for expansion of the color gamut.

Color spaces are classified into input- and output-referred color spaces. Input-referred color spaces are color spaces for input-referred image data, such as from actual scenes, computer-simulated scenes and scanners, and include RAW data and silver halide negative film, both of which have a wide dynamic range.

On the other hand, output-referred color spaces are for recording data processed for specific purposes (monitors, printers, etc.), and include DSCs in general and reversal film.

Table 10.1. Various color spaces

	sRGB	sYCC	ROMM RGB	RIMM RGB	Adobe RGB
Referred	Output CRT	Extended Output	Output Print	Scene	Output Print
R:x.y	0.6400 0.3300		0.7347 0.2653		0.6400 0.3300
G:x,y	0.3000 0.6000		0.1596 0.8404		0.2100 0.7100
B:x,y	0.1500 0.0600		0.0366 0.0001		0.1500 0.0600
	IEC6196 6-2-1	IEC6196 6-2-1 Amend1	ANSI/I3 A-IT10 7666	ANSI/13 A-IT10 7466	Adobe RGB (ICC)

The various color spaces used in DSCs are shown in **Fig. 10.1**. Among these is a format proposed by the US to the ISO and which (as a result of deliberation) became RIMM-RGB (ANSI/I3A-IT10.7466), which describes a scene-referred (a form of input-referred) color space. Research is currently being carried out in the US with a view to introducing RIMM RGB and Camera RAW file format compatibility (described below) into the format.

Furthermore, the handling of not only the three primary colors (RGB), but also many colors, and ultimately colors as a spectrum is also being considered, but specific proposals have yet to be presented. It is hoped that interacting with the printing industry, which takes multicolor as a given, will stimulate research in this field.

10-1-2 Camera RAW Image Data

Figure 7.3 shows the average unit price of DSCs by pixel resolution, but while the unit price of DSCs with equal pixel resolution decreases, increases in pixel resolution enable models to be marketed as higher-grade products, and it can be seen that as this process repeats, the expansion of the market as a whole is maintained (from CIPA statistics).

According to recent CIPA statistics, as can be seem in **Fig. 10.2**, the proportion of the DSC market occupied by SLR cameras is increasing, reaching about 10% in terms of the number of units sold and exceeding 20% in terms of value. Nearly all of these SLRs have their own RAW image data output format.

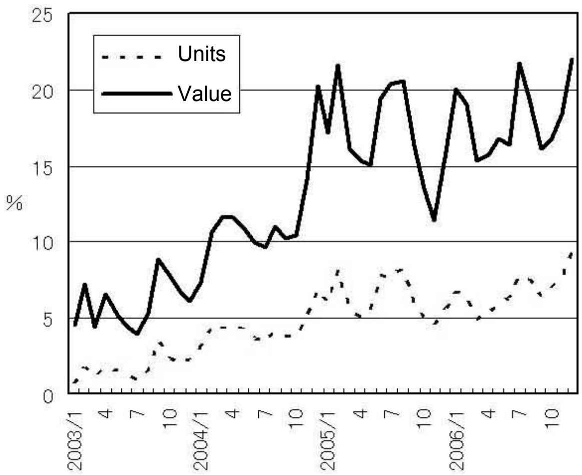


Fig. 10.2. D-SLR trends.

DSC RAW image data is “raw” data generated by the DSC's sensor that has not undergone image processing.

Not included in this definition of image processing are A/D conversion, linearization, dark current and frame removal, shading and sensitivity (linear domain) compensation, flare removal, white balance, and restoration of missing pixels. Because RAW Image Data preserves high image quality, processing images afterwards is easy, meaning that this format is preferred by photographers and publishers, etc.

However, file formats differ according to make and model without any unified standard, and the specifications are the know-how of the various manufacturers.

For example, RAW image data differs according to image pickup device, configuration, number of pixels and chromaticity, etc. Examples of image pickup devices used for SLRs are shown in **Table 10.2**.

On account of this, companies must prepare an extension that uniquely identifies their RAW images and software that is compatible with them. Examples of extensions that identify RAW image files are shown in **Table 10.3**.

Table 10.2. Examples of image sensors for SLRs

DSC	Sensor	Size (mm^2)	Pixels
Canon EOS 20D	CMOS	22.5×15.0	8.2M
Canon EOS 5D	CMOS	35.8×23.9	12.8M
Nikon D70S	CCD	23.7×15.6	6.1M
Nikon D2X	CMOS	23.7×15.7	12.4M
Nikon D200	CCD	23.6×15.8	10.2M

Table 10.3. Examples of extension names

Type	Extension	File Format
Nikon	NEF	TIFF/EP
PENTAX	PEF	
Minolta	MRW	TIFF
Olympus	ORF	
Fujifilm	RAF	
SONY	SRF	
EPSON	ERF	
Adobe Digital Negative	DNG	
Canon	CR2	
	CRW	CIFF
SIGMA	X3F	Proprietary Format
ProBack	DRF	

Provisions to handle these RAW image files are not included in the current Exif/DCF standards. Consequently, either formats that cover beyond the stipulated range of Exif/DCF, such as TIFF or TIFF/EP, or proprietary formats are used.

As it is difficult to handle these in a unified manner, at present even Adobe Digital Negative (DNG) and Windows Vista, which claim to be able to handle RAW image data, use plug-ins with the format in which RAW image data is recorded to handle such images.

Although there are moves to support RAW under TIFF/EP, investigation is still underway with regard to what conditions would be required.

10-1-3 Compression Methods

The JPEG image compression algorithm adopted with Exif performs DCT within 8×8 blocks of pixels that have 8-bits per pixel before carrying out spatial compression, and then performs further compression of code length using Huffman coding (a form of entropy coding). The mathematics of this compression algorithm is simple and the deterioration in picture quality with a compression ratio of up to 10:1 is almost imperceptible.

However, there are concerns that increasing the compression ratio will cause blocking artifacts (where the boundaries of the 8×8 blocks becomes obvious), and that corporations with patent claims pertaining to Huffman coding may appear.

JPEG was adopted as a standard by ISO/IEC JTC 1/SC 29, followed by JPEG 2000 in January 2001. The discrete wavelet transform (DWT) used by JPEG 2000 in its image compression algorithm is shown in **Fig. 8.3**.

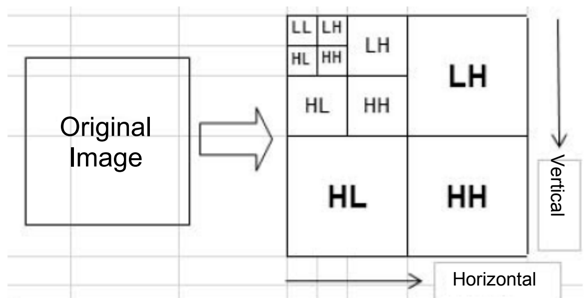


Fig. 10.3. The principle of DWT.

While DCT uses a common orthogonal function to transform the whole image into spatial frequencies, DWT uses a wavelet, which is a local orthogonal function that performs orthogonal transformation as a digital operation.

The spatial frequency values resulting from the orthogonal transformation vary according to their position on the image. In **Fig. 10.3**, H represents high spatial frequency components and L represents low spatial frequency components. In this example, LL represents images composed of low spatial frequency components vertically and horizontally, and HH represents images composed of high spatial frequency components vertically and horizontally.

An image comprised only of LL would be entirely blurred, and would become clearer as the component on the lower right is added to it. JPEG 2000 supports lossless compression, and also has the feature of being able to store images with differing compression rates inside the same image file at the same time.

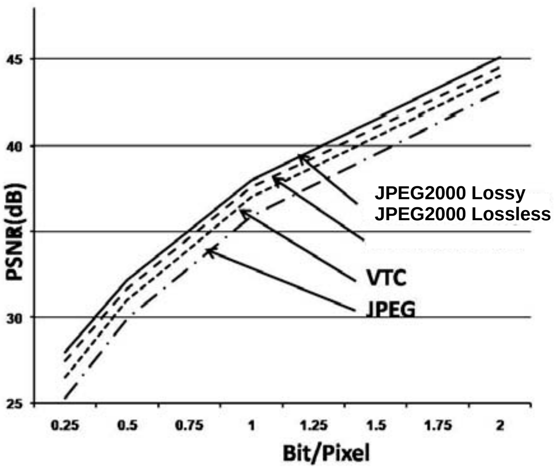


Fig. 10.4. Compression technology and noise.

According to *IEEE Signal Processing Magazine***,** although JPEG 2000 is reported to produce less noise (**Fig. 10.4**) even under high compression, the difference was 2–3 dB.

Complex mathematical operations are not the only drawback with JPEG 2000; attempting to include it in Exif/DCF, which has undergone revision with an emphasis on compatibility, would present great difficulties as it is not at all compatible with JPEG. Although there has been a proposal to create a new tag to recognize the existence of JPEG 2000 files in order to enable coexistence of JPEG 2000 and JPEG image files in Exif, from the perspective of focusing on the functions that are sought after in a consumer DSC, it was thought that realizing this would be difficult. At this point in time, it is agreed that the focus should be on providing standardization of metadata for DSCs.

A comparison of Exif/DCF and JPEG2000 is shown in **Table 10.4**.

Table 10.4. A comparison of Exif/DCF and JPEG 2000

Image Compression	Exif/DCF DCT	JPEG 2000 DWT
Bits/Pixels	8	Up to 32
Color Space	sRGB/Option	Not specified
Encoding	Huffman	EBCDT (Embedded Block Coding with Optimized Truncation)
Image compression	Lossy	Lossy to Lossless
Disadvantages	Maximum block noise at high compression	Complex operation
Notes	Most popular	Layered images

10-1-4 Description Formats

Files are described using the TIFF format in Exif/DCF. The US has proposed describing them using XML. Although XML and TIFF are both languages that use tags in a similar way for description, their formats are different. At this point in time it would be difficult to change DSC tags to XML, and attempts are being made to standardize metadata so that it can be adopted as tags.

Furthermore, a proposal to describe ICC profiles instead of designating a color space has been presented by the US. ICC profiles are specifications specified by the ICC. The proposal is to make color spaces not reliant on input/output devices by embedding the specifications of the input device in the form of a profile, describing input images with color spaces not reliant on devices (XYZ or LAB color spaces for example) and compensating on the output side for the profile of the output device. A scheme has been prepared to embed these ICC profiles in TIFF/EP.

This appears to be more than what is

required for consumer DSCs and although it is a fact that current ICC profiles have yet to attain perfect color reproduction, in response to demands from the printing and publishing industries for higher image quality, consideration of such a specification may be necessary.

The strongest attractions of DSCs are their ability to review images immediately and to simply and without delay print and save a hard copy of necessary images using a dedicated or generic printer at home. DSCs have become the center of the still imaging industry as an exceedingly convenient and appropriate means for creating image data that is essential for our modern life, and are responsible for leading the development of the entire industry while maintaining compatibility with the surrounding technological environment.

In the past, printers were treated as office machines, and it is primarily because of the popularization of DSCs that they have come to be used so extensively in the home for printing photographs. It cannot therefore be said that compatibility between DSCs and printers is altogether satisfactory. Revisions of Exif, DPOF and PictBridge, etc., have thus far been designed to provide compatibility between DSCs and printers, but there is no shortage of problems, such as whether or not the color gamut of DSCs can be reflected in the range of colors reproducible by printers, and whether or not RGB and CMYK color spaces can be matched, as well as the matter of investigating how to increase color range.

DSCs initially adopted sRGB, a color space for CRT displays. DSCs, however, have a wider color gamut than displays, although conversely it could be said that the color gamuts of displays have not yet caught up with those of cameras. For this reason, when using the industry standard raster graphics editor Adobe Photoshop®, as the true colors are unable to be verified by viewing the actual colors on a computer display, they are verified by checking the displayed RGB values.

However, in recent times, with improvements in computer display technology, displays have been released (by Mitsubishi Electric, for example) that can reproduce the Adobe RGB color gamut. DSCs in the future will no doubt maintain a reciprocal relationship with peripheral devices as a pivotal device in the image industry and keep advancing technologically, while influencing the industries of surrounding equipment and expanding the market.

10.2 Coordination with Other Industries

With silver halide cameras, all that was necessary was to think about how to take and produce a photograph, which is somewhat of a narrow perspective. By contrast, however, with DSCs it became necessary to think of compatibility with other related fields. Although such requirements are especially important with professional DSCs, as there are not necessarily any precise classifications separating consumer models from professional products, this could be interpreted as posing a problem for all DSCs.

10-2-1 Compatibility with IT Equipment

In the beginning, DSCs were developed with playback of images on TVs in mind, and the emphasis came to be placed on compatibility with computers as a consequence of the spread of computers and the expansion of the internet. Operating system developers were contacted for this reason, and were successfully persuaded to support Exif/DCF. With today's popularization of DSCs, operating system support for DSCs is a great advantage for computers, and has resulted in a synergistic effect that has helped the expansion of both. The connection between DSCs and computers is expected to grow more intimate as time progresses.

10-2-2 Printing-related Compatibility

Digitization of printing and the graphics editing process which precedes printing is rapidly advancing, and although DSCs are widely used as image input devices for printing, it cannot be said that the dynamic range and reproducible color gamut of consumer DSCs that conform to Exif/DCF is adequate.

Although the color space first adopted for DSCs was sRGB (an output-referred color space based on CRT displays), because DSCs were capable of capturing a wider color space than sRGB, the interpretation of the color space was changed to sYCC. Furthermore, support for Adobe RGB was added in Exif 2.21/DCF 2.0 for popular image editing software such as Adobe Photoshop®.

Although SLR-type DSCs for professional use can produce RAW data, this is in order to provide support for photographic subjects with a wide dynamic range. For this reason, the US has proposed the concept of using input-referred color spaces for RAW data.

The improvement of DSCs based on the exchange of information with the printing industry is very important when formulating standards. For this reason, ISO/TC 42, which deliberates on international standards for DSCs, has a very close relationship with ISO/TC 130, which is in charge of graphic technology, forming a joint working group to deliberate on color management and related subjects.

10-2-3 Compatibility with Communication Devices

In recent years, phones equipped with a camera function (camera phones) have become mainstream, but the mobile phone industry in Japan is working in a different field from consumer devices as phones involve the use of radio waves. However, because the companies that manufacture telephones and offer them to carriers overlap with those manufacturing DSCs, and because camera phones utilize a considerable amount of DSC technology, making camera technology the main subject of technical investigation for camera phones is not thought to be impossible.

Camera Phone Image Quality (CPIQ) is already included in an investigation regarding image quality as one of the initiatives of the I3A.

Notes:

[1] Consumer behavior study published by the Department of Business Statistics, Economic and Social Research Institute in April 2007.

[2] White paper published in 2007 by the Ministry of Internal Affairs and Communications: Appendix.

11 Discussion and Acknowledgements

Mankind has used images as a means of communication since ancient times. Communication by means of images is an excellent method that enables the perception of meaning without knowledge of symbolic constructs such as language and letters. This excellent means of communication is, furthermore, only used by mankind.

Mankind developed "imaging culture" and developed diverse technical innovations to further advance that imaging culture. Imaging culture led to the formation of cultures known as the pictorial arts and has left behind many technical innovations for their development.

Subsequent technical developments resulted in the development of the camera, which enabled the easy creation of satisfyingly good quality technically difficult pictures without the need to be technically proficient.

The course of camera development can be classified into technologies that support cameras as imaging devices and technologies that support them as IT equipment, as is systematically shown in the attached figures.

The origin of cameras dates back to the 3rd century B.C. when Aristotle mentioned the camera obscura.

After the beginning of the 19th century, images were first successfully made with a photochemical reaction. Subsequently, ongoing technological reforms made it possible to take accurate images in a shorter time more easily and cheaply, and as a result of the development of user-friendly features, such as automatic exposure and autofocus, photography came to the point where it was said that cameras were a must-have status symbol in postwar Japan.

However, in the latter part of 20th century, which could be called the electronic age, the camera appeared to be keeping its place as a device based on chemical reactions amidst the computerization of a wide range of daily necessities.

The computerization of imaging devices began with broadcasting devices. Video cameras and 8 mm camcorders for household use and other such video devices are consumer versions of broadcasting level devices.

These devices nevertheless recorded image information as analog signals on media such as magnetic tape or magnetic disks, and it was not possible to prevent the deterioration of picture quality when transmitting or copying.

The Mavica electronic camera, which was released in 1981, took one frame from a video camera and recorded it to a floppy disk as a still image. This should be recognized as the first commercial device that recorded still images electronically.

However, even with this electronic camera, aside from image information, although it was possible for it to record audio information at the same time, which was something used in a secondary manner as auxiliary information for the recorded images, it could not go so far as to record information regarding when the picture was taken or related metadata.

Only after the first DSCs appeared were images handled as logical information in a true multimedia-compatible environment.

Digital is outside of human perception, and is a method of logically describing physical phenomena. The silver halide cameras of the past obtained latent images with chemical reactions, but these latent images could be materialized and viewed without special rules or arrangements.

By contrast, DSC images are encoded and recorded according to specified rules, and viewing the image would be impossible without such rules being made known. While communication via images began as a means of directly physically influencing another party visually, it should be noted that DSCs rely on a logical means of transmitting and storing images.

Compared with previous means of communication that transmitted or stored perceptible physical quantities as they were, with DSCs (apart from the input/output portion that exerts an influence upon the senses) all transmission, storage and processing, etc., used rational logical quantities know as digital. It also became possible to record auxiliary information at the same time as images according to logical description along with the image information.

On account of such properties, the status of DSCs is as an image input device inside an image information system, whereas silver halide cameras were devices for the purpose of taking images.

A great contribution toward the realization of this was the creation of a format that used JPEG and TIFF as a base. The advent of flash memory and the memory cards that used it also contributed greatly.

The first DSC released into the market cost about the same as a car after including the cost of the playback device and recording apparatus, etc., but since 1995, when the QV-10A was released at a cost of just under ¥50,000, the price of DSCs has come down in price every year while performance has continued to improve. The first DSCs in 1989 used CCDs with 400,000 pixels, and fell very much short of the resolution of silver halide cameras, but by 1983, "megapixel" CCDs with over 1,000,000 pixels had been introduced, and pixel resolution has advanced year after year ever since.

During the period that the resolution of DSCs was poor as compared with that of silver halide cameras, large-format film was the mainstay in the printing industry for posters and publications, etc. Among recent DSCs, however, there are some that compare favorably with large-format silver halide cameras both in terms of resolution and color reproducibility, and the adoption of digital technology is rapidly increasing in the field of printing, with increased technological interaction with DSCs.

Among compact DSCs for consumers are models that presently sell for around 10,000 JPY, and personal computers are a significant reason for the existence of these DSCs.

Operating systems have improved to the point that PCs can now process DSC images, and printer manufacturers have worked together with DSC manufacturers to make image printing from DSCs easier and to improve functionality.

Moreover, mobile phones achieved rapid growth as personal data devices, with more than half of such phone featuring a camera.

These camera phones were also the recipients of technology transfer from DSCs, and are compatible with images photographed with DSCs due to the fact that they work with the same format. Because of this, it could be thought that these phones with cameras could be placed in the same category as DSCs. There is, no doubt, a market for camera phones especially among users who feel that having to carry around a DSC in addition to a mobile phone is inconvenient, users who are satisfied with the image quality of camera phones, and users who send photos that they take to their friends more often than they save them.

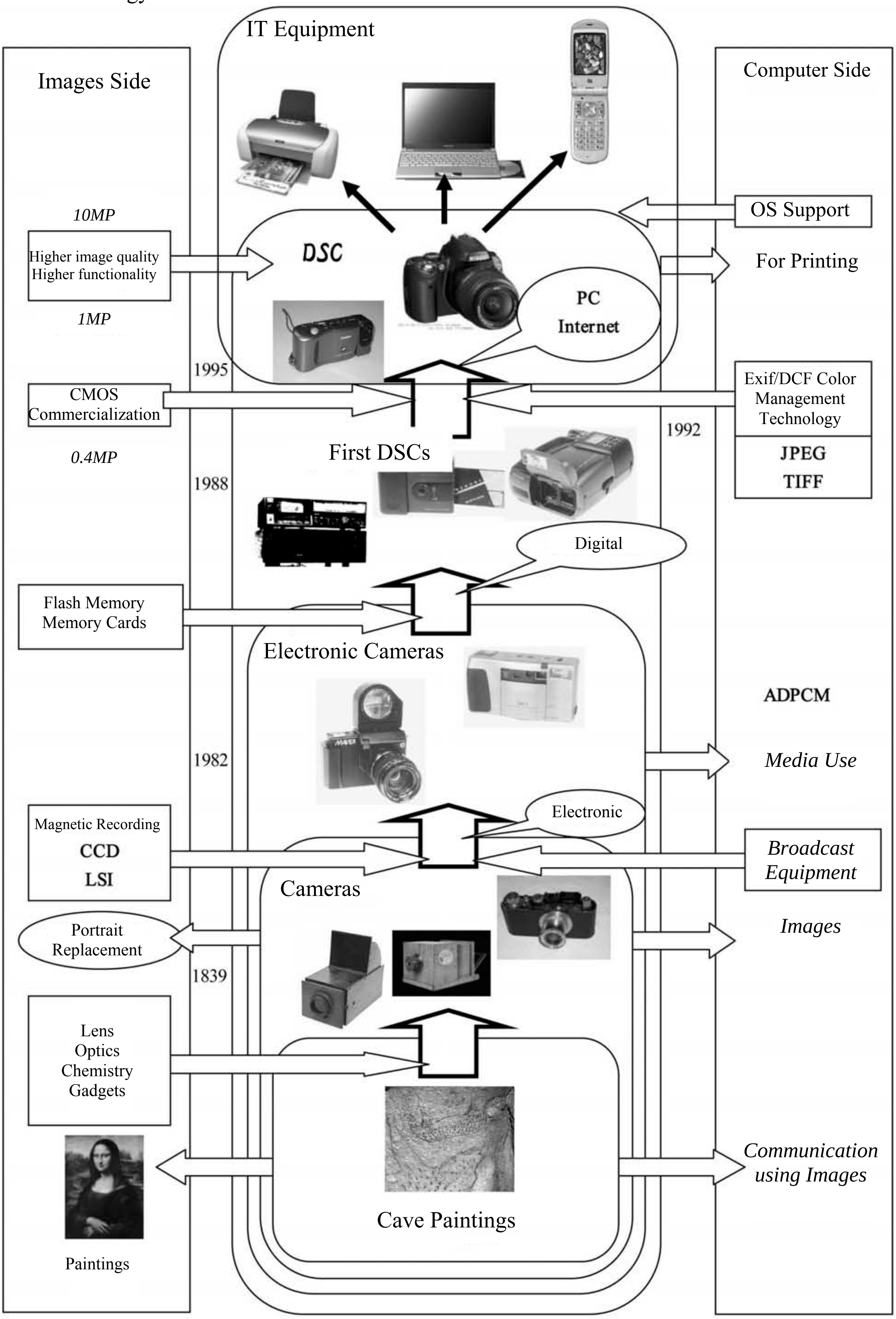
In the future, DSCs are expected to continue to develop as image information devices. One goal is to split development on the basis of performance, with models for professional and high-end amateur users with an emphasis on high resolution and performance and compact, easy-to-use DSCs for consumer use. The other goal is to further develop camera phones for users who do not want to carry around a DSC and who are satisfied with the picture quality of mobile phones. A three-model solution is thereby emerging that brings these two goals together.

In closing, I would like to express my deep gratitude to those who took time to share information, provide material, and otherwise assist in the compilation of this report.

[1] Japan Camera Industry Institute
[2] Camera and Imaging Products Association (CIPA)
[3] Canon, Inc., Image Communication Products Operations and Public Affairs Headquarters
[4] Fujifilm Co., Ltd., Corporate Communications Office and Masafumi Inuiya of the Frontier Core-Technology Laboratories
[5] Hiroyuki Suetaka, Casio Hitachi Mobile Communications Co, Ltd.
[6] Toshiba Science Museum
[7] Fujio Masuoka, Tohoku University Professor Emeritus
[8] Masayuki Uchiyama, President, Image Link, Inc.
[9] Shigeharu Ochi, Japanese representative for InvenSense, formerly of Fuji Photo Film Co., Ltd.
[10] Toru Takahashi, Vice President, Internet Association Japan; Founder & Chairman, Research Institute for Internet Strategies, Inc.
[11] Masanobu Iseri, President, Impress R&D

(In no particular order.)

DSC Genealogy



Appendix 1. List of significant models

	Name	Reference Type	Address	Manufacturer	Year	Comments
1	Digital camera prototype DC-90 Nickname: "*Atsuko*" (Hot)	Actual Unit	2-229-1 Sakuragaoka, Higashi-Yamato City, Tokyo Casio Hitachi Mobile Communications Co., Ltd.	Casio Computer Co., Ltd.	1991	A working prototype created together with "*Omoko*" (heavy) as a prototype for the QV-10 digital camera with LCD monitor released by Casio Computer Co., Ltd. in 1995. As this unit produced a lot of heat it was nicknamed "*Atsuko*" (hot). As operation would become unstable due to the heat generated, the viewfinder was removed and a cooling fan installed in its place and an LCD TV hooked up and used in place of the viewfinder, which led to the use of LCD monitors in digital cameras.
2	Digital Camera Prototype DC-90 Nickname: "*Omoko*" (Heavy)	Actual Unit			1991	A working prototype of the QV-10 created together with "*Atsuko*" (hot). As this unit was made using generic parts, making it heavy, it was nicknamed "*Omoko*" (heavy).
3	EOS Kiss DIGITAL	Actual Unit	3-30-2 Shimomaruko, Ohta-ku, Tokyo	Canon, Inc.	2003	Featuring a large 6.3MP single-plate CMOS sensor (22.7×15.1 mm (APS-C equivalent)) developed by Canon couple with Canon's proprietary high-performance DIGIC image processor, this model was the company's response to demands by many users for a camera with high resolution, high image quality and natural colors.
4	FUJIX DS-1P	Actual Unit	9-7-3, Akasaka, Minato-ku, Tokyo (Tokyo Midtown)	Fujifilm Corporation	1988	After converting light to an electrical signal using a CCD and passing it through an AD converter, the resulting digital data was saved to a memory card, making this the world's first true digital camera. It was able to record ten images in field mode and five images in frame mode in a single 2MB SRAM card. Digital data was read from the memory card to a PC where it was processed. Dimensions: 105 (W) × 75 (H) × 50 (D) mm, Body weight: 400 g
5	FUJIX DS-X	Actual Unit			1990	The world's first commercially-produced and sold digital camera. It could compress (PCM (ADPCM)) and record up to six images in frame mode on a 2MB SRAM card. Furthermore, its binocular design diverged from that of traditional film cameras.
6	FinePix 4700	Actual Unit			2000	This was the first digital camera to use Fujifilm's proprietary Super CCD honeycomb sensor (2.4MP), which improved resolution by arranging octagonal CCD photodiodes in a diamond honeycomb pattern to optimize light concentration and realize an improved SN ratio to produce 4.32 megapixel images.
7	FinePix F700	Actual Unit			2003	Featuring the Super CCD Honeycomb 4SR sensor with its unique pairs of pixels with different sensitivity (6.2 million pixels: 3.1 million high-sensitivity S pixels and 3.1 million R pixels with a wide dynamic range), this digital camera realized a 400% increase in dynamic range over previous models, and was strongly resistant to white-out and loss of black detail, resulting in images with smooth graduations from light to dark.

Appendix 2. Chronology

Year	Details	Number of Pixels (Unit: 10,000 pixels)*	PC Penetration (%)	Internet Users (%)	DSC Production (100 million JPY)
30,000 B.C.	Altamira Cave wall paintings				
16,000–8,000 B.C.	Aristotle, the original form of the camera obscura				
– 350 B.C.	Ancient Egypt wall paintings				
2,400 B.C.	Kitora and Takamatsuzuka tomb paintings, Japan's oldest portraits (Prince Shotoku)				
Late 1600s to early 1700s	Popularization of the Camera Obscura				
18th Century	Thomas Wedgewood, method of fixing an image using silver nitrate				
1802	Nicéphore Niépce, Heliography announced				
1824	Oldest existing photograph (Niépce's "Man leading a horse")				
1825	Daguerreotype announced				
1839	Talbot, the invention of the negative/positive process				
1841	Archer, the invention of the wet-plate photographic process				
1851	Invention of the dry plate photographic process				
1871	Eastman Kodak, Camera and film set released				
1888	RolleiFlex released				
1928	Autofocus				
1981	Mavica released				
1985	Still Picture Recording Processor using Audio Cassette Deck announced				
1987	World's first DSC prototype DS-1P (Fujifilm)	40	11.7		
1988	World's first commercially available DSC DS-X(Fuji Photo), IMC-100 (Toshiba)		9.7		
1989			11.6		
1990	JEIDA digital camera WG formed		10.6		
1991	ISO TC42 WG18 established, format proposed by Japan		11.5		
	Atsuko and *Omoko* prototypes (Casio)				
1992	Exif standard (JEIDA) JPEG standard (ISO/IEC JTC1)		12.2		
1993	VC-1000 (Olympus)		11.9		
1994	QV-10A (Casio) Exif proposed to the ISO (JEIDA)		13.9		
1995	QV-10 (Casio) (¥49,800) Exif Version 1		15.6		
1996	Various companies introduce 0.3–0.8MP DSCs		17.3		
1997	Exif Version 1.1 /Version2.0	100	22.1	9.2	
1998	Compact megapixel DSC FinePix700 (Fujifilm)		25.2	13.4	
1999	Rise of DSLRs	200	29.5	21.4	
2000	Super CCD honeycomb (Fujifilm) EOS D30 with CMOS sensor equivalent to C-size sensor (Canon) Compact DSC IXY DIGITAL (Canon) Mobile phone with camera (Sharp J-SH04)	300	38.6	37.1	4,257
2001	5MP COOLPIX 5000 (Nikon)	500	50.1	44.0	5,725
2002	FOVEON X3		57.2	54.5	6,742
2003	Super CCD honeycomb 4SR (Fujifilm) DSLR entry-level model EOS Kiss DIGITAL (Canon)		63.3	60.6	10,720
2004	Exif approved in IOS2234		65.7	62.3	13,628
2005	Adobe DNG		64.6	66.8	12,762
2006	10MP DSLRs	1000	68.3	68.5	14.033
2007	12MP D3 / D300 (Nikon)		71.0		

* Consumer DSCs.

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