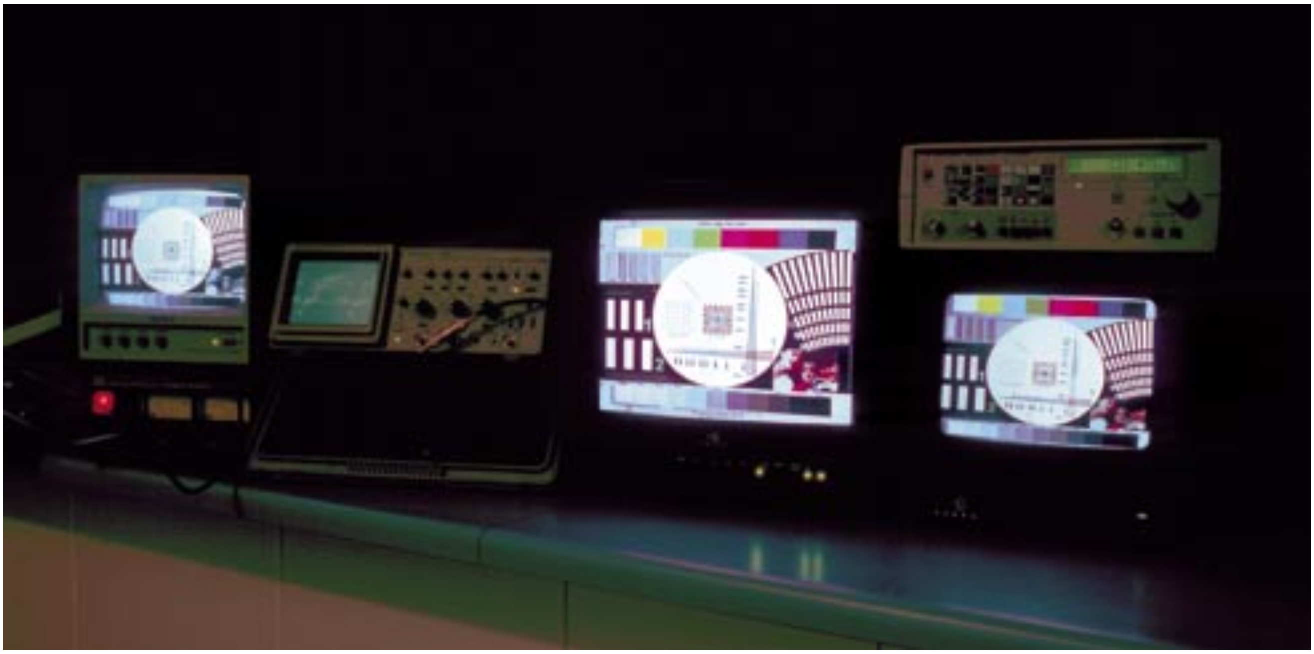
The very basics of Television

- Part two -

Before you walk into the newly opened doors of the digital CCTV it is advisable that you refresh your understanding of the analogue television principles. Understanding these principles will make understanding the digital principles easier. In this, second article, we explain the true meaning of (analogue) bandwidth and resolution.

In this second part of the very basic of television we will look at the theoretical fundamentals of the video signal's limitations, bandwidth and resolution. This is a complex subject with its fundamentals involving higher mathematics and electronics, but I will try to explain it in plain and simple language.

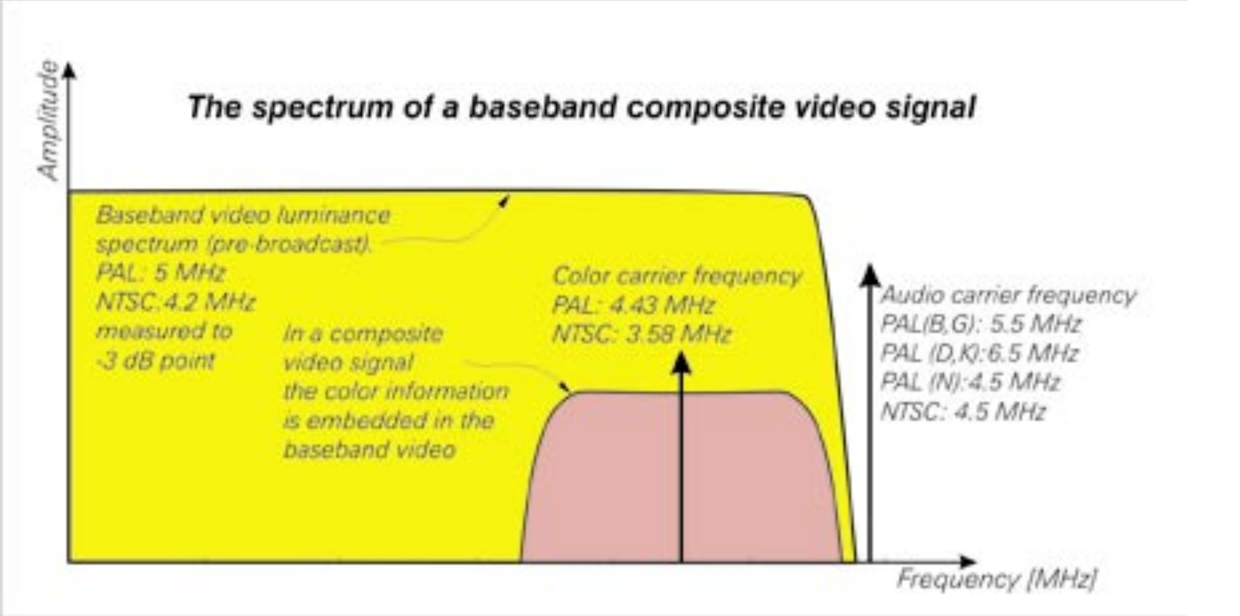
Most of the artificial electrical signals can be described mathematically. Mathematical description is very simple for signals that are periodical, like the main power, for example. A periodical function can always be represented with a sum of sinewaves, each of which may have different amplitude and phase. Similar to a spectrum of white light, this is called spectrum of an electrical signal. The more periodical the electrical signal is, the easier it can be represented and with fewer sinewave components. Each sinewave component can be represented with discrete value in the frequency spectrum of the signal. The less periodical the function is, the more components will be required to reproduce the signal. Theoretically, even a non-periodical function can be represented with a sum of various sinewaves, only that in such a case there will be a lot more sinewaves to summarize in order to get the non-periodical result. In other words, the spectral image of a non-periodical signal will have a bandwidth more densely populated with various components. The finer the details the signal has, the higher the frequencies will be in the spectrum of the signal. Very fine details in the video signal will be represented with high-frequency sine waves. This is equivalent to high resolution information. A signal rich with high frequencies will have wider bandwidth. Even

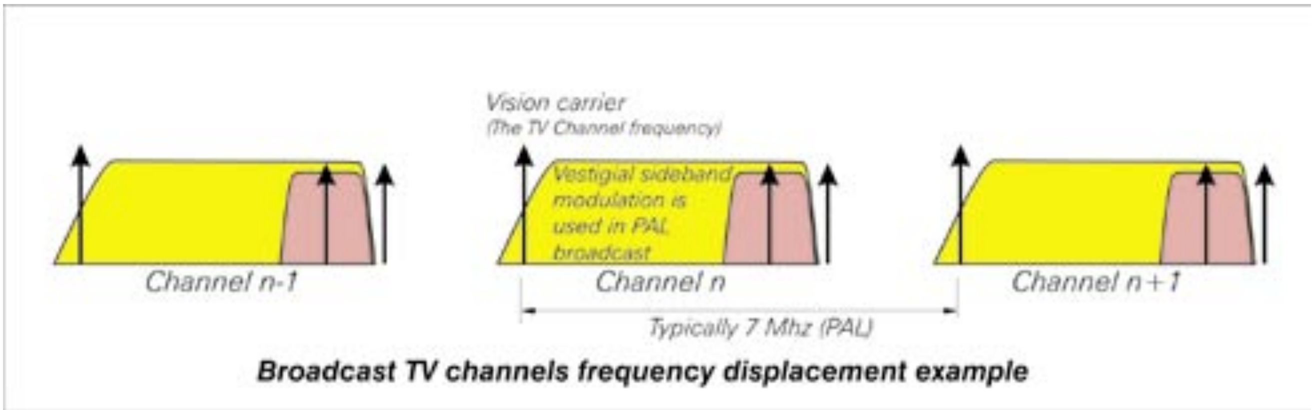


a single, but very sharp pulse, will have a very wide bandwidth.

The above describes, in a very simplified way, the very important Fourier spectral theory, which states that every signal in the time domain has its image in the frequency domain. The Fourier spectral theory can be used in practice – wide bandwidth periodical electrical signals can be more efficiently explored by analyzing their frequency spectrum. Without going deeper into the theory itself, CCTV users need to accept the concept of the spectrum analysis as very important for examining complex signals, such as the video itself. The video signal is perhaps one of the most complex electrical signals ever produced, and its precise mathematical description is almost impossible because of the constant change of the signal in the time domain. The video information (i.e., luminance and chrominance components) changes all the time. Because, however, we are composing video images by periodical beam scanning, we can approximate the video signal with some form of a periodical signal. One of the major components in this periodicity will be the line frequency – for CCIR and SECAM, 25 × 625 = 15,625 Hz; for EIA, 30 × 525 = 15,750 Hz.

It can be shown that the spectrum of a simplified video signal is composed of harmonics (multiples) of the line frequency around which there are companion components, both on the left- and right-hand sides (sidebands). The inter-component distances depend on the contents of the video picture and the dynamics of the motion activity. Also, it is very important to note that such a spectrum, composed of harmonics and its components, is convergent, which means the harmonics become smaller in amplitude as the frequency increases. One even more important conclusion from the Fourier spectral theory is that positions of the harmonics and components in the video signal spectrum depend only on the picture analysis (4:3 ratio, 625 interlaced scanning for PAl, or 525 for NTSC). The video signal energy distribution around the harmonics depends on the contents of the picture. The harmonics, though, are at exact positions because they only depend on the line frequency. In other words, the video signal dynamics and amplitude of certain components in the sidebands will vary, but the harmonics locations (as





sub-carrier frequencies) will remain constant.

This is a very important conclusion.

It helped find a way, in broadcast TV, to reduce the spectrum of a video signal to the minimum required bandwidth without losing too many details. There is always a compromise, of course, but since the majority of the video signal energy is around the zero frequency and the first few harmonics, there is no need and no way to transmit the whole video spectrum. Scientists and engineers have used all of these facts to find a compromise, to find how little of the video bandwidth need be used in a transmission, without losing too many details. As we already mentioned when discussing different TV standards, the more scanning lines that are used in a system the wider the bandwidth will be, and the higher the resolution of the signal is the wider the bandwidth will be.

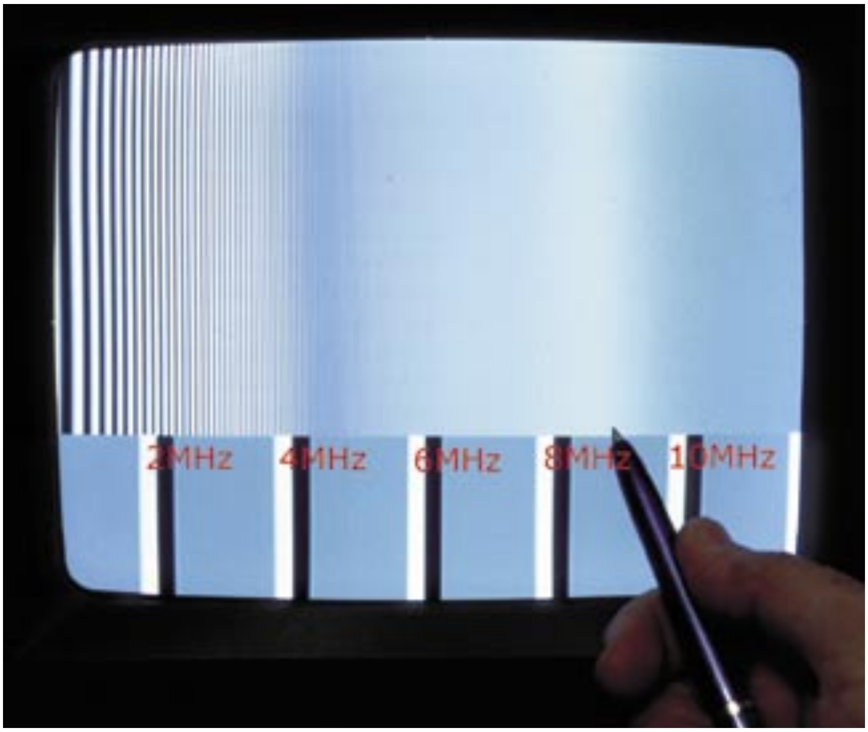
Taking into account the electron beam's limited size (which also dictates the smallest reproducible picture elements), the colour dot-pitch when a colour TV signal is discussed, the physical size of the TV screens, viewing distances and the complexity and production costs of domestic TV sets, it has been concluded that for a good reproduction of a broadcast signal, 5 MHz of video bandwidth is sufficient. Using a wider bandwidth is possible, but the quality gain factor versus the expense is very low. As a matter of fact, in the broadcast studios, cameras and recording and monitoring equipment are of much higher standards, with spectrums of up to 10 MHz. This is for internal use only, however, for quality recording and dubbing. Before such a signal is RF modulated and sent to the transmitting stage, it is cut down to 5 MHz video, to which about 0.5 MHz is added for the left and right audio channels. When such a signal comes to the TV transmitter stage it is modulated so as to have only its vestigial side band transmitted, with a total bandwidth, including the separation buffer zone, of 7 MHz (for PAL). But please note that the actual usable video bandwidth in broadcast reception is only 5 MHz. For the more curious readers we should mention that in most PAL countries, the video signal is modulated with amplitude modulation (AM) techniques, while the sound is frequency modulated (FM).

Similar considerations apply when considering NTSC signals, where the broadcasted bandwidth is around 4.2 MHz.

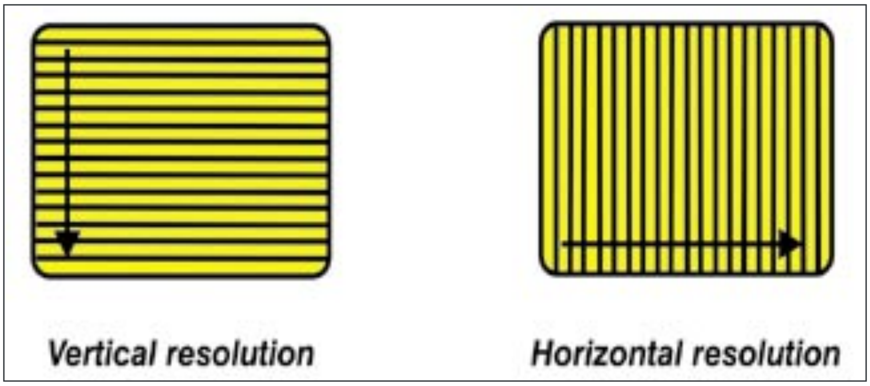
All of the above said refers to the TV broadcast signal as we (still) receive it today on our TVs.

In CCTV however, we do not have such bandwidth limitations because we do not transmit an RF-modulated video signal. We do not have to worry about interference between neighboring video channels. In CCTV, we use a raw video signal as it comes out of the camera, which is a basic bandwidth video, or usually called baseband video. This usually bears the abbreviation CVBS, which stands for composite video bar signal. The spectrum of such a signal, as already mentioned, ranges from 0 to 10 MHz, depending on the source quality.

The spectral capacity of the coaxial cable, as a transmission medium, is much wider than this. The most commonly used 75Ω coaxial cable RG-59B/U, for example, can easily transmit signals of up to 100 MHz bandwidth. This is applicable to a limited distance of a couple of hundred meters of course, but that is sufficient for the majority of CCTV systems. Different transmission media imply different bandwidth limitations, some of which are wider and some narrower than the coaxial one, but most of them are considerably wider than 10 MHz.



High resolution means wide bandwidth



Bandiwdth is directly associated with the resolution of a video signal.

Resolution

Resolution is the property of a system to display fine details. The higher the resolution, the more details we can see.

The resolution of a TV picture depends on the number of active scanning lines, the quality of the camera, the quality of the monitor and the quality of the transmitting media.

Since we use two-dimensional display units (CCD chips and CRTs), we distinguish two kinds of resolutions: vertical and horizontal.

The vertical resolution is defined by the number of vertical elements that can be captured on a camera and reproduced on a monitor screen. When many identical vertical elements are put together in the scanning direction, we get very dense horizontal lines. This is why we say the vertical resolution tells us how many horizontal lines we can distinguish. Both black and white lines are counted and the counting is done vertically. Clearly, this is limited by the number of scanning lines used in the system – we cannot count more than 625 lines in a CCIR system or 525 in an EIA system. If we take into account the duration of the vertical sync and the equalization pulses, the invisible lines and so on, the number of active lines in CCIR comes down to 575 lines and about 475 in EIA.

This is still not the actual vertical resolution. Usually, the resolution is measured with a certain patterned image in front of the camera, so there are a lot of other factors to take into account. One is that the absolute position of the supposedly high-resolution horizontal pattern can never exactly match the interlaced lines pattern. Also, the monitor screen overscanning cuts a little portion of the video picture, the thickness of the electronic beam is limited and for colour reproduction the "grill mask" is limited.

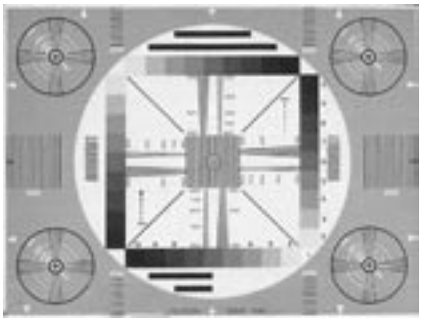
As early as 1933, Kell and his colleagues found by experimenting that a correction factor of 0.7 should be applied when calculating the "real" vertical resolution. This is known as the Kell Factor and it is accepted as a pretty good approximation of the real resolution. This means that 575 has to be corrected (multiplied) by 0.7 to get the practical limits of the vertical resolution for PAL, which is approximately 400 TV lines. The same calculation applies for the NTSC signal, which will give us approximately 330 TV lines of vertical resolution. This is all true in an ideal case, i.e., with excellent video signal transmission.

Horizontal resolution is a little bit of a different story. The horizontal resolution is defined by the number of horizontal elements that can be captured by a camera and reproduced on a monitor screen. And, similar to what we said about the vertical resolution, the horizontal tells us how many vertical lines can be counted.

One thing is different though. Because of the TV aspect ratio of 4:3, the width is greater than the height. So, to preserve the natural proportions of the images, we count only the vertical lines of the width equivalent to the height, i.e., 3/4 of the width. This is why we don't refer to the horizontal resolution as just lines but rather TV lines.

The horizontal resolution of a monochrome (B/W) TV system is theoretically only lmited to the cross section of the electron beam, the monitor electronics and, naturally, the camera specifications. In reality, there are a lot of other limitations. One is the video bandwidth applicable to the type of transmission. Even though we may have high-resolution cameras in the TV studio, we transmit only 5 MHz of the video spectrum (as discussed earlier); therefore there is no need for television manufacturers to produce TV receivers with a wider bandwidth. In CCTV, though, the video signal bandwidth is mostly dictated by the camera itself, since B/W monitors have a very high resolution (up to 1000 TV lines), which is limited only by the monitor quality, of which the most important are the electron beam precision and cross section.

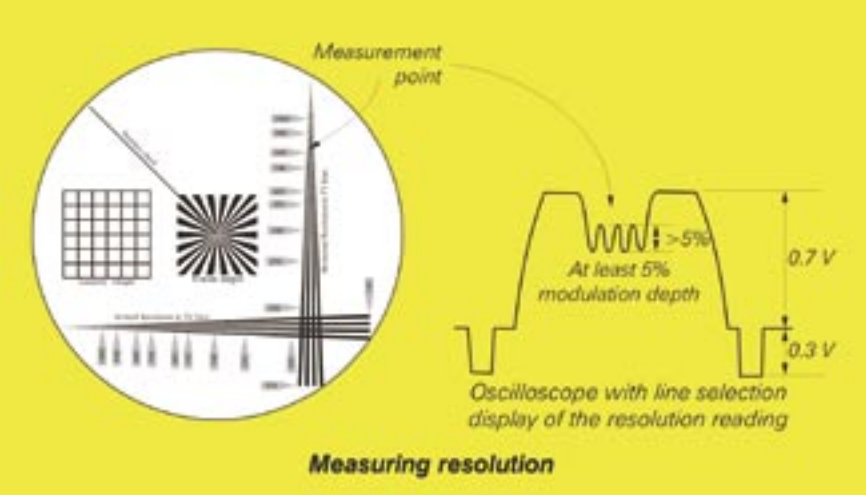
A colour system has an additional barrier, and that is the physical size of the colour mask and its pitch. The colour mask is in the form of a very fine grille. This grille is used for the colour scanning with the three primary colours, red, green and blue. The number of colour picture elements (RGB dots) the grille has

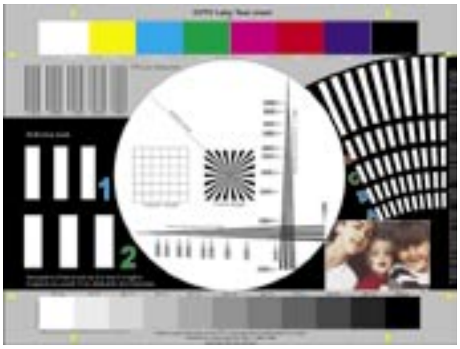


Standard RETMA chart

is determined by the size of the monitor screen and the quality of the CRT. In CCTV, anything from 330 TV lines (horizontal resolution) up to 600 TV lines is available. The most common are the standard 14 monitors with around 400 TV lines of resolution. Don't forget, we are talking about TV lines, which in the horizontal direction gives us an absolute maximum number of 400 × 4/3 = 533 vertical lines, countable.

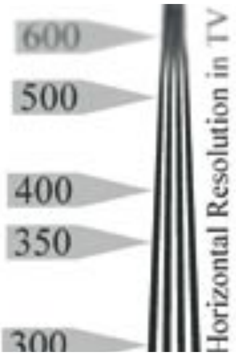
In CCTV, like in broadcast TV, we cannot change the vertical resolution since we are limited to the number defined by the scanning system. That's why we rarely argue about vertical resolution. The commonly accepted number for realistic vertical resolution is around 400 TV lines for CCIR and 330 TV lines for EIA. The horizontal resolution we can change and this will depend on the camera's horizontal resolution, the quality of the transmission





CCTV Labs Test Chart

media and the monitor. It is not rare in CCTV to come across a camera with 570 TV lines of horizontal resolution, which corresponds to a maximum of approximately 570 × 4/3 = 760 lines across the screen. This type of camera is considered a high-resolution camera. A standard resolution B/W camera would



have 400 TV lines of horizontal resolution.

There is a simple relation between the bandwidth of a video signal and the corresponding number of lines. If we take one line of a video signal, of which the active duration is 57 µs, and spread 80 TV lines across it, we will get a total of 80 × 4/3 = 107 lines. These lines, when represented as an electrical signal, will look like sinewaves. So, a pair of black and white lines actually corresponds to one period of a sine wave. Therefore, 107 lines are approximately 54 sine waves. A sinewave period would be 57 µs /54 = 1.04 µs. If we apply the known relation for time and frequency, i.e., T = 1/f, we get f = 1 MHz. The following is a very simple rule of thumb, giving us the relation between the bandwidth of a signal and its resolution: approximately 80 TV lines correspond to 1 MHz in bandwidth. [][][]