J. Webster (ed.), *Wiley Encyclopedia of Electrical and Electronics Engineering*

TELEVISION BROADCAST RECEPTION

The electric transmission and subsequent reception of a television image can be traced back to 1927, when Baird's mechanical scanning television used the medium-wave band (300 kHz to 3 MHz) to convey 30 lines of image information at 12.5 frames/s from the transmitter to the receiver. The use of the medium-wave band was possible because Baird's original system had a small bandwidth (22.5 kHz) that would fit into its small range of frequencies.

With the introduction of an all-electric 405-line scanning transmitter in 1936 by Marconi-EMI offering 25 frames/s at a bandwidth of 3.4 MHz, and of Baird's improved 240-line scanning also at 25 frames/s, the medium-wave band could no longer offer the required transmission bandwidths, forcing transmission to use higher-frequency carriers with each channel occupying a larger bandwidth. The all-electric 405-line television system won the technology battle and was subsequently termed system A. However, at that time, the current state of technology could only offer reliable high power commercial transmission below 50 MHz, where only a few television channels could be conveyed due to the required video bandwidth for each channel.

After World War II, the technology was soon available to transmit in the lower frequencies of the very high frequency (*VHF*) band (30 MHz to 300 MHz), allowing approximately 10 usable channels for a given area such as a large city. Amplitude modulation (*AM*) was exclusively used to modulate the video information onto a radio frequency (*RF*) carrier for terrestrial transmission. Single sideband AM (*SSB-AM*) could not be used, as this does not allow the transmission of the very low frequency components of the video signal. If double sideband AM (*DSB-AM*) was used, then the bandwidth required for each channel was 2×3.4 MHz, allowing for the transmission of the upper and lower sidebands. This large bandwidth was seen as a problem, so the Radio Manufacturers Association (RMA) agreed to adopt upper vestigial sideband (*VSB*) modulation (see below) in 1938, and VSB modulation was adopted by the Federal Communications Commission (*FCC*) in 1941 to be first implemented in the US. VSB modulation is now exclusively used throughout the world.

In the early 1960s, technology allowed high-power transmission of television signals in the lower frequencies of the ultra high frequency (*UHF*) band (300 MHz to 3 GHz), offering approximately 50 usable channels for each television transmission area. Today, system A is now obsolete and has been upgraded by other analog television standards: NTSC (termed system M), PAL, and SECAM, offering color, teletext, etc. However, to complicate the broadcast television issue, countries transmitting PAL or SECAM also have subtle differences (line frequencies, sound carrier, modulation polarity, etc.), resulting in 11 analog television systems with up to six different video bandwidths that are not all interoperable. When modulated, each video signal results in its own modulated bandwidth, and various countries also modify the width of the VSB bandwidth. Therefore, television broadcast reception varies throughout the world in standards, frequencies, and bandwidth. However, there are issues that affect the quality of reception of all of these systems, including distortions that occur during transmission, propagation characteristics, injected noise, and receiver misalignment.

Table 1: Example of Terrestrial TV Spectrum Allocation Bands for the US and UK

	US		UK	
Band	Frequency range[a] (MHz)	Channel Numbers	Frequency Range (MHz)	Channel Numbers
I	54–72, 76–88	2–4 5–6	45, 51.75-71.75[b]	1, 2–5
III	174–216	7–13	179.75–219.75[b]	6–13
IV	470–590	14–33	471.25–583.25[c]	21–34
V	590–890	36–83	615.25–855.25[c]	39–68

[a]6-MHz channels. [b]5-MHz channels. [c]8-MHz channels.

Vestigial Sideband Modulation

In 1928, Nyquist, working in Bell Labs, published a modulation scheme that required less bandwidth than DSB and only slightly more than SSB. This proposal was called VSB, taking its name from the fact that a vestige (meaning a slight amount) of one of the sidebands (upper or lower) was transmitted along with the carrier and most of the other sideband (lower or upper). The other sideband (lower or upper) has a portion removed from its lower spectrum, and the vestige is mirrored around the carrier. VSB modulation therefore allows the transmission of the low-frequency components of the video signal, and since a full-strength carrier is present, a simple envelope detector can be used to recover the modulated video signal.

For terrestrial television broadcasting, upper VSB is used, with each country implementing different vestige bandwidths to suit its own television channel allocations. In addition, to allow for commercial or more professional equipment, the VSB spectral shaping is left to the receiver, and to allow for this, all of the upper sideband and an unattenuated part of the vestige are transmitted. Thus in practice each PAL terrestrial transmission channel generally occupies 8 MHz, while NTSC occupies 6 MHz. (The obsolete system A occupied 5 MHz.)

Spectrum Allocation

Each country governs its own allocation of TV channels in the VHF and UHF spectrum. For example, the FCC is the governing body for the US. The VHF and UHF spectrum has been split into five bands for broadcast, with bands I, II, and III covering the VHF spectrum and bands IV and V covering the UHF spectrum. Each band contains a fixed number of channels at specific frequencies. Band II is generally reserved for FM broadcast audio and thus does not carry video. To highlight the differences in allocations, Table 1 presents the ranges of frequencies and television channel numbers for the US and the UK (some of which are reserved and currently not used for television). Also, note that in the UK, PAL can only be transmitted at UHF, and thus bands I and III are only for system A. Today, as can be seen, the majority of terrestrial transmission around the world use the UHF band, as it offers the majority of available channels.

VHF Versus UHF Propagation

UHF propagation is generally considered to offer reliable communication only over a line of sight. Therefore, TV transmitter antennas and repeaters are situated as high as possible. To supply coverage in hilly areas, small repeaters rebroadcast the video signals on different channels to avoid cochannel interference (particularly from strong transmissions).

On the other hand, VHF transmission does have some ability to follow the earth's surface by ionospheric reflection, so that it offers farther communication than UHF. The lack of bandwidth that VHF offers is the prime motive for use of the UHF band. Also, as UHF has a smaller wavelength than VHF, compact high-gain directive antennas are easier to construct at UHF than at VHF.

Receivers

The conventional terrestrial television receiver has an antenna to pick up the VHF or (more commonly) UHF radio transmission. The antenna is electrically connected to the receiver via an unbalanced coaxial cable (a single cable insulated inside an outer braid) or a balanced feeder (two identical wires in parallel spaced from one another by a fixed distance). The television receiver is very similar to a normal commercial radio in that the signal from the antenna is amplified and subsequently mixed with a local oscillator whose frequency is dependent on what channel you wish to watch, downconverting (heterodyning) the antenna signal to a much lower *intermediate frequency* (*IF*). In this way, the RF signal spectrum has been shifted down to a manageable frequency centered on the IF carrier frequency. IF carriers are on the order of 40 MHz to 50 MHz, depending on the adopted standard. The circuit between the antenna input and the IF stage is often called the *tuner*. The IF is then amplified and applied to a surface acoustic wave (*SAW*) filter, which shapes the IF signal spectrum as closely as practical to the ideal VSB response while attenuating signals from outside of the selected channel. The IF signal is then mixed again with another local oscillator at the IF carrier frequency, and after low-pass filtering the demodulated composite video signal is extracted. Modern receivers use an integrated synchronous detector in preference to the simple envelope detector.

One of the main points to note is that all the receiver processes from the antenna to demodulation are linear, and so any distortions arriving at the antenna along with the intended modulated video signal are also demodulated, corrupting the composite video signal. The receiver also generates its own electrical noise, along with unwanted nonlinear distortions, corrupting the composite video signal even further.

The composite video signal has its synchronization pulses extracted for reconstructing the two-dimensional image from the one-dimensional transmitted video signal, while audio, luminance, and chrominance information is decoded according to the video standard (NTSC, PAL, or SECAM), resulting in audio for the loudspeaker and the red, green, and blue electric signals for the color screen.

Interference

Interference in terrestrial television can originate from various sources and can manifest itself in many ways in the picture. As the analog television signal is transmitted, propagated, and received, linear and nonlinear interference is added to the signal, causing, in most cases, irreparable damage to it.

Shot and thermal noise is introduced into the video signal by the electronics of the receiver itself (amplifiers, filters, and mixers), causing the inclusion of a random noise signal in the wanted video signal, which appears as “snow.” Atmospheric noise and external electrical noise are very broadband and may contain frequency components within the VHF or UHF channel being used by the modulated video signal. Thus, the receiver can detect this noise along with the wanted video. All these types of noise add a random element into the composite video signal and add to the overall deterioration, causing blurring, color mismatching, and luminance errors. When the interference is severe, short electric impulses are induced into the video signal that cause the video signal to be damaged over the period of the pulse, creating a speckle or streak effect in the picture.

Cochannel interference occurs when a secondary video source is mixed into the wanted video signal. A similar effect can happen when nonlinear distortion occurs in repeaters and when video signals are transmitted by cable. Such interference has also been known to happen when atmospheric conditions allow the receiver to pick up video signals on the same channel transmitted from a long distance away that it would not normally be able to pick up. This type of interference manifests itself as a secondary image crawling across the wanted image (the sync pulses of the secondary image may also cause crawling herringbone patterns to be present).

By far the most objectionable type of interference is caused by echoes. Echoes occur when the transmitted RF signal is reflected from buildings, mountains, trees and even aircraft, causing the reception of the wanted signal along with time-displaced and attenuated versions of itself (1). The echoes are all at the same carrier frequency and are all detected by the receiver, causing a *ghost* to be seen on the screen for each echo. As the television scans from left to right (as we see it), ghosts that arrive after the wanted signal appear to the right of the intended image, and so are termed postghosts. Preghosts can exist where the first signal to arrive is smaller in amplitude than the second, causing the television to synchronize with the second image. In view of the speed of the RF signal and the maximum practical distance it can travel for reception, ghosts tend to arrive between 3 μs before the main signal and 40 μs after it. When an echo is large, its horizontal synchronization pulse may be seen as a vertical bar in the picture. Echoes of less than 1 μs duration are so close to the main signal that a smeared or "peaked" picture rather than a discrete ghost can be seen (often the case in cable television).

Multipath Equalization

When echoes are present, there is more than one transmission path between the transmitter and receiver, and so a *multipath* condition is said to exist. The removal of multipath distortion is termed *multipath equalization*. Multipath equalization is required in many forms of communication. In television, each path creates a ghost image on the screen, and the subsequent removal of these images is termed *deghosting*.

Ghosting is caused by linear processes, and it can be combatted by applying a linear filter to the received composite ghosted video signal. Deghosting of composite video signals has been discussed for many years, the first deghosting systems having been reported as long ago as 1978. As signal-processing technology advanced and integrated circuits became cost-effective, many video deghosters were presented.

Consider the modulated intended video signal being transmitted through a multipath channel. After heterodyning to the IF, the ghosted IF signal may be described as

$$s_{\mathrm{IF}}(t) = v(t)\cos\,\omega_{\mathrm{c}}t + \sum_{i=1}^{N}\alpha_i v(t - t_{\mathrm{d}i})\cos(\omega_{\mathrm{c}}t + \theta_i) \qquad (1)$$

where $v(t)$ is the original transmitted baseband video signal, ω_{c} is the IF carrier radian frequency, N is the number of paths present, α_i is the attenuation of the *ghost* ith relative to the intended video, $t_{\mathrm{d}i}$ is the additive path delay of the ith ghost, and θ_i is its carrier phase relative to the received video carrier due to the additive path delay. After amplification, the IF signal is applied to the VSB filter. Due to the asymmetric response of the sidebands around the carrier produced by VSB modulation, a quadrature carrier is generated from each of the IF carriers present. The modulated information on each quadrature carrier $\tilde{v}(t)$ is given by a modified

Hilbert transform (2) convolved with $v(t)$. Therefore, the output of the VSB filter, S_{VSB}, may be described as

$$s_{\mathrm{VSB}}(t) = v(t)\cos\omega_{\mathrm{c}}t + \sum_{i=1}^{N}\alpha_i v(t - t_{\mathrm{d}i})\cos(\omega_{\mathrm{c}}t + \theta_i) \\ -\tilde{v}(t)\sin\omega_{\mathrm{c}}t - \sum_{i=1}^{N}\alpha_i \tilde{v}(t - t_{\mathrm{d}i})\,\sin(\omega_{\mathrm{c}}t + \theta_i) \qquad (2)$$

With ideal detection (multiplication of Eq. (2) by cos $\omega_{\mathrm{c}}t$, and subsequent low-pass filtering, the detected ghosted composite video signal, $v_{\mathrm{g}}(t)$, is described as

$$v_{\mathrm{g}}(t) = v(t) + \sum_{i=1}^{N}\alpha_i\cos\theta_i\, v(t - t_{\mathrm{d}i}) - \sum_{i=1}^{N}\alpha_i\sin\theta_i\,\tilde{v}(t - t_{\mathrm{d}i}) \qquad (3)$$

Unfortunately, as can be seen from Eq. (3), due to the presence of the VSB filter, deghosting is not simply a case of removing scaled and delayed versions of the intended video signal.

A video deghoster consists of a channel identification algorithm that probes the distorted channel to calculate the distortions that exist. The calculated channel distortion information is subsequently passed to a large digital filter with the purpose of canceling the ghosts within the detected composite video. All commercial video deghosting systems find the distortion present by comparing (in the frequency or time domain) the received ghosted video signal with an unghosted version. The comparison is performed on a *ghost cancellation reference* (*GCR*) training signal that has been inserted into a portion of the video signal just before the teletext information.

Many GCR signals have been presented (3), and after field trials for television system M (4), a chirp signal, developed by Philips Labs, was chosen by the Advanced Television Systems Committee (*ATSC*) in 1992 and transmitted on line 19. The chirp has excellent autocorrelation properties (5) and a flat spectrum over the entire video bandwidth, and insertion into existing transmitters was easy. Other countries followed by developing chirp-type CGR signals specifically for their own video standards, and bandwidths, and available video lines, with no excursion below 0 IRE for European standards (6). Figure 1 presents the NTSC GCR signal that is transmitted and stored in the receiver for comparison.

The most popular video deghoster is constructed using a generic channel equalizer, whose filter has a frequency response inversely related to that of the channel. Thus all linear distortions can be canceled. Many integrated circuits have been developed to perform the long finite impulse response (*FIR*) filtering (often up to 540 taps) required to cover the ghost arrival range (– 3 μs to 40 μs) at the high video sampling rates (7). Figure 2 presents a block diagram of the generic channel equalization for video deghosting.

Television receivers can now be purchased with ghost cancellation hardware included, or a separate set-top box can be purchased for existing receivers.

Digital Receivers

When discussing digital receivers, it must be clarified exactly what is intended. The inclusion of digital electronics and signal processing in analog television receivers has been increasing since approximately 1985. To

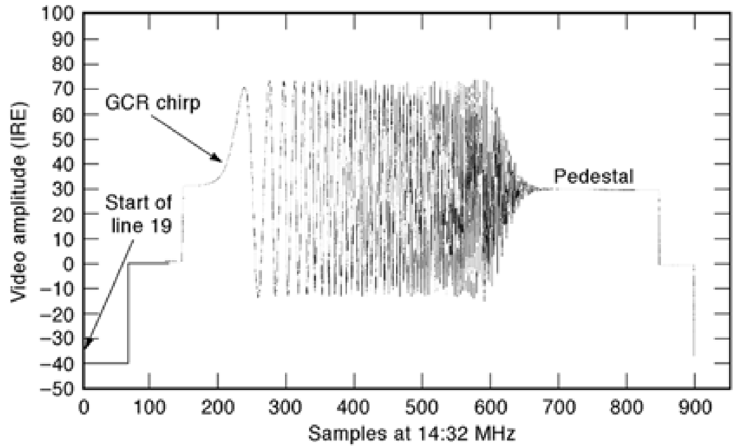

Fig. 1. The NTSC GCR signal (with color burst ignored for clarity) that is used to find the ghost parameters by comparing the received ghosted signal with the unghosted one.

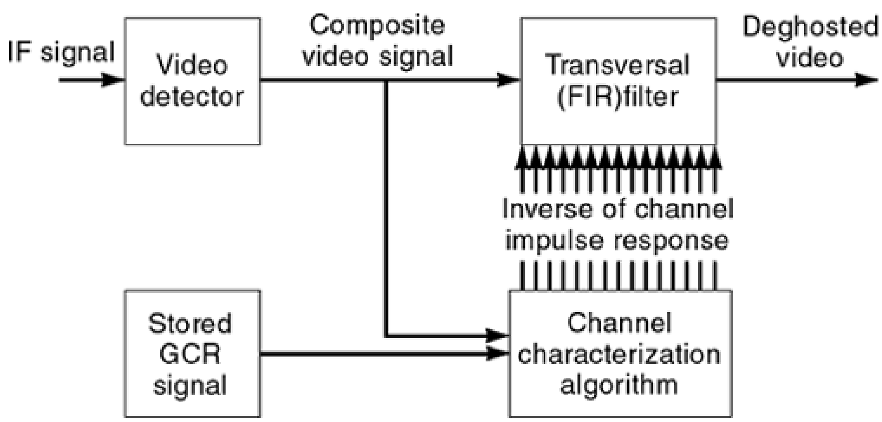

Fig. 2. A block diagram of the generic channel equalizer that is used for removing ghosts and other linear distortions.

date the basic functions of the television receiver are usually performed by analog electronic circuits: tuning, filtering, amplification, and some necessary impedance matching. Including digital systems in television receivers has produced more reliable and stable receivers, because digital synchronization can decode multiple standards and handle more channels. Teletext, digital audio, and program identification are only some of the facilities available to the consumer that have only been made available by the addition of digital electronic circuitry to the analog television receiver.

The world is seeing many benefits of the digital age in computing, communications, and entertainment, and not surprisingly, television is undergoing this revolution too. The conversion to fully digital television has been somewhat slower than for other media, due to the amount of video information (bandwidth and high sampling rates) that needs to be conveyed in small broadcast channels, requiring high levels of compression. However, by using digital modulation rather than analog, the majority of problems that have prevailed with the analog television standards will eventually be solved, producing clean and crisp images.

A full discussion of the new digital television standards is beyond the scope of this article and the reader is directed to the Reading List. To aid communication over different media (satellite, cable, and terrestrial) while not altering the underlying standards, digital standards have emerged with the addition of various levels of error protection (Reed–Solomon encoding, interleaving, and convolutional coding). Two main broadcast standards have emerged:

(1) The ATSC system, used in the US and elsewhere, which currently uses eight level VSB modulation
(2) The European Digital Video Broadcasting (*DVB*) system, used in Europe and elsewhere, which uses modulation in various formats from basic quadrature phase-shift keying (*QPSK*) to 64-level quadrature amplitude modulation (*64-QAM*) over COFDM

The implications for receivers are now immense. With the digital technology available, video, computing, and audio are merging and the traditional television sitting in the corner of the room may indeed die out. Powerful digital home entertainment systems offering television, video, phone, and audio may become commonplace. For this to happen we must consider the communication methods and bandwidth available with respect to commercial cost viability.

BIBLIOGRAPHY

1. W. Ciciora G. Sgrignoli W. Thomas A tutorial on ghost cancelling in television systems, *IEEE Trans. Consum. Electron.*, **25**(1): 9–44, 1979.
2. L. I. Bluestein Envelope detection of vestigial sideband signals with application to television reception, *IEEE Trans. Consum. Electron.*, **21**(4): 369–379, 1975.
3. S. Herman *An overview of ghost cancellation reference signals, National Association of Broadcasters Engineering Conf.*, 1992, pp. 78–81.
4. B. Caron Video ghost cancelling: evaluation by computer simulation and laboratory testing, *IEEE Trans. Consum. Electron.*, **38**(3): xxvi–xxxiii, 1992.
5. R. S. Sherratt Identification and minimization of IIR tap coefficients for the cancellation of complex multipath in terrestrial television, *IEEE Trans. Circuits Syst. Video Technol.*, **6** (6): 703–706, 1996.
6. P. N. Gardiner D. M. Brockhurst J. S. Curtis Ghost cancellation for 625 line systems, *International Broadcasting Convention*, 1994, pp. 673–678.
7. S. Suzuki et al. An advanced single chip digital filter for ghost canceller, *IEEE Trans. Consum. Electron.*, **39**(3): 381–385, 1993.

READING LIST

K. G. Jackson G. B. Townsend *TV and Video Engineers Reference Book*, London: Butterworth-Heinemann, 1991.

G. H. Hutson P. J. Shepherd W. S. J. Brice *Colour Television System Principles, Engineering Practice and Applied Technology*, 2nd ed., London: McGraw-Hill, 1990.

J. Van Tassel *Advanced Television Systems: Brave New TV*, Newton MA: Butterworth-Heinemann, 1996.

P. Dambacher *Digital Broadcasting*, London: IEE Press, 1996.

H. Benoit *Satellite Television Techniques of Analogue and Digital Television*, New York: Arnold, 1999.

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