Video Signals and Circuits Part 1

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The transmission of video signals over a carrier wave for broadcasting purposes requires that some format be chosen so as to include picture content, audio (if requires) and synchronization information. With todays wide use of video, some understanding of its nature is desirable if one is to use and interface various video devices such as cameras, monitors, DVD and VCRs, etc. We will discuss those systems that use the standard NTSC (National Television System Committee) video signal format (USA, Canadian, etc.) A typical video signal of the NTSC format is shown in Fig. 1 This is the typical NTSC signal composite video signal transmitted by your local TV station. Several things are evident. The waveform appears complex, with a combination of pulses and another component that has no specific waveshape. The pulse sequence is not obviously simple, but will be found to be repetitive. There are also other high frequency components present. If this waveform were applied to an audio amplifier it would produce a sound like a noisy, raspy buzz which varies somewhat with picture content. The video information, which carries information about the picture may have frequency components up to 4 MHz or so, and appears between periodic, regularly shaped pulses of large amplitude. These pulse signals are used by the receiver or monitor to synchronize and process the picture information and to control those circuits which will produce a display on the monitor screen (CRT or LCD, etc). The picture information is sent as a sequence of elements called lines. The picture is cut up horizontally by the camera into 525 horizontal lines, sent starting top left to top right, and progressively toward the bottom. The lines could be sent in sequence, but in practice, every other line is sent (first, third, fifth and all odd numbered lines) until line 525 is reached then the even lines 2, 4, 6, etc are sent next. Therefore a complete frame consists of two fields, an odd and even. The scan rate is nominally 30 frames a second, with each odd and even field sent 30 times per second. This is called interlaced scanning and makes for a vertical scanning rate of 60 Hz as each field has two vertical scans. The horizontal scan rate is therefore 525 times 30 frames per second or 15750 lines per second, which corresponds to a scan frequency of nominally 15,750 Hz. (In actual color TV practice 15734 Hz is used, and the vertical scan rate is 1/525 of this or 29.97 Hz). A scan line occupies actually very close to 63.5 microseconds. However this includes the sync and blanking pulses. The horizontal sync and horizontal blanking pulses make up the horizontal blanking interval. This is about 10.5 microseconds. During those periods between line scans and fields, the picture display should be cut off (made black) as otherwise the return between scan lines of the scan from right to left could show up as a "retrace line" The horizontal and vertical blanking pulses are used to cut off the display during these intervals. Computer monitors generally use non interlaced scanning and frequently much higher scan rates, up to nearly 80 to 120 Hz vertical and 70 to 80 kHz horizontal. Blanking and video signals are commonly separated as well. We will confine most of this discussion to ordinary video as used in television transmission and security work.

The actual time interval that video is present is then about 52 microseconds. However, the extreme ends of the line scan are usually cut off from viewing by the TV or monitor screen to ensure that the picture fills the entire screen area so the useful scan portion is close to 50 microseconds. In this active part of the horizontal scan interval a video signal of 4 MHz (assume a sine wave) will go through 200 complete cycles. If the positive half of the signal produces a darkening of the display screen and the negative half produces a lightening, we will see 200 pairs of dark and light bands across the screen. If the screen is 2 feet wide (Typical for a 31 inch TV) there will be 100 pairs per foot, or about 8 pairs per inch, and each line will be about 1/16 inch wide. This would be typical of a "TV quality" picture. A computer monitor must do much better. With active horizontal scan times as short as 10 microseconds, details of as small as .01 to .015 inch must be displayed. For a 21 inch monitor with a horizontal screen width of 16 inches, this means that as many as 1600 lines could be visible. In 10 microseconds, 1600 dark lines would be produced by a video frequency sinewave signal of 160 MHz. Computer monitors typically run at 72 or 96 pixels (picture elements) per inch. This is why video bandwidths of 150 to 300 MHz are commonly encountered in better computer monitors. The typical NTSC TV bandwidth of 4 MHz does not allow definition good enough for computer work, where sharp edges are a must in text work and graphics.

The horizontal blanking (narrow) and vertical blanking (wide) pulses are constant and are independent of the transmitted video (picture) signal. The horizontal blanking pulse has a narrower pulse ``piggybacked'' on top of it. This narrower pulse is called the synch pulse. These synch pulses occur during the horizontal and vertical sweep retrace of the video signal and normally do not produce a visible component on the TV image. They are used to synchronize the TV horizontal sweep circuitry to the video signal. The widest part of the pulse is called the blanking pulse, and has an amplitude such that it reduces the luminance on the CRT (cathode-ray tube) to zero. Naturally, the video level must not be so great as to exceed the synch pulse level, otherwise the level-sensitive synch circuits will be ``confused'' and the TV picture will not synchronize properly. Deliberate distortion of these pulses is commonly used as a means of "scrambling" the picture to prevent unauthorized reception, as is done on cable TV. A sync regenerator system (descrambler) is needed to restore these distorted sync pulses to a usable format so the picture can be viewed.

The vertical blanking interval (VBI) occurs between fields and at a nominal 60 Hz rate. However, there is a slight difference between the vertical blanking pulse at the beginning of the odd and even fields. The fact that interlacing is used means that there are 525/2 or 262.5 lines per field. Since there are 30 frames per second, and 60 scans, the ratio of horizontal to vertical scan frequencies is 262.5 This makes the relative timing of pulses different in successive fields by half a line scan or about 31.75 microseconds. Also, during the vertical blanking interval (VBI) horizontal synchronization must be maintained. The VBI is equal to about 0.07 of the vertical scan time (16.67 mS), or abour about 1.15 milliseconds. The vertical sync pulse is nine horizontal lines, or about 570 microseconds. It consists of a blanking pulse plus a wide sync pulse about 180 usec wide at the center. This sync pulse is serrated with twice -

horizontal frequency pulses. During this time pulses at twice the horizontal rate are added to the vertical blanking pulses, maintaining horizontal sync. The twice horizontal pulses line frequency also makes up for the half line difference in timing between the even and odd fields and are called equalizing pulses for this reason. The vertical pulses are easily filtered out from the horizontal pulses by a simple R-C low pass filter, network, called the vertical integrating network. The output of this is only the 60 Hz vertical pulses, the horizontal pulse components being greatly attenuated. Right after the vertical sync pulses are ten or so blanked lines with only horizontal pulses. These intervals can be used for system test signals or control purposes as their scan lines are normally above the top edge of the picture. By the way, the scan lines are numbered from the beginning of the VBI, so the actual picture does not start until about line 20 (first field) or line 283 (second field) of the picture. If you adjust your TV set so it just starts to lose vertical sync and rolls, (easier on older and low end B/W sets with accessible V and H sync controls) and adjust the contrast and the brightness controls as well, you can see some of this stuff on the wide horizontal bar appearing between frames. A little study of this bar will illustrate just what is happening. The equalizing pulses will appear as a black section at the center of the bar, and test signals in the VBI will appear as black and white line portions on the lowest part of the bar.

The color section needs some information to properly sync to the picture as well. Right after the horizontal synch pulse trailing edge, but before the blanking pulse trailing edge, (called ther horizontal pulse "back porch") a signal consisting of eight to eleven sine-wave cycles at 3.58 MHz (actually 3.579545 MHz or 455/2 times the horizontal scan frequency) will be found on color video signals. This signal is the color synch (burst) signal; it is used to synchronize the color circuitry in the TV receiver and turn it on for color programs. This is done by a phase locked loop in the color circuitry, or sometimes it is simply filtered out in a narrowband crystal filter circuit, where it "rings" a 3.579545 crystal, producing a continuous wave signal at 3.58 MHz. The color synch signal is not needed if the transmitted program is black and white, as is often used in security and surveillance work and other applications where color is unnecessary. Thus, in its absence (during a B/W program), the color circuitry in the TV receiver automatically shuts down. This prevents random noise in the color channels from producing colored snow and streaks in the black-and-white program. However, note that in actual practice, this burst is not always disabled by the programmer during B/W transmissions, as there may be some color information (logos, ID signals, etc) even though the transmission is mainly black and white. This is often seen on cable and satellite TV, where the channel logo in the lower right corner stays in color, even with a black and white movie.

Audio information is frequency modulated on a 4.5-MHz signal that is added into the composite video signal, but it may also be modulated on a separate carrier that is 4.5 MHz higher or lower than the picture carrier frequency. This carrier is like a standard FM (frequency modulated) radio signal except the deviation is limited to ±25 kHz (monaural) instead of the ±75 kHz used for FM broadcasting. Audio preemphasis is also used as in FM broadcast practice, as is stereo transmissiom using multiplex techniques as in FM broadcast, with a 15.734 Khz pilot and 31.5 Khz subcarrier

replacing the 19 and 38 Khz frequencies used in commercial FM stereo. In the TV receiver, this 4.5-MHz signal appears at the video detector and is picked off and processed in a 4.5-MHz limiter/detector (or quadrature demodulator) in much the same way as the 10.7-MHz system used in an FM broadcast receiver. If the signal is not 4.5 MHz, the sound will be absent and only random noise (hiss) will be heard, unless a squelch circuit is used. This will be discussed later as it plays little role in the video, which is our major focus of this article.

Note that levels must be maintained and waveform polarities are important. In the NTSC system, a standard level video signal is 1 volt into 75 ohms, with the sync polarity negative. The vertical blanking level is referenced at zero volts. Sometimes the IRE unit is used, in which pure white is + 1 volt, pure black is zero volts, and sync tips are –40 units (-0.4 volts). In actual practice, white is taken as 92 IRE, black at about 7 IRE units. Much video equipment is made to interface with this kind of signal, where the video level varies from zero to 1 volt, and the sync is – 0.4 volts. Standard impedance is generally 75 ohms in video work. Due to stringent requirements of waveform, any long leads (over about a foot or so) should be 75 ohm cable with proper terminations and impedance matching. Loss of higher frequencies will result in loss of picture detail. Reflections will show up as "ghost" lines or image artifacts around the actual subject. Phase delays must be considered when using multiple video sources as phaseshift can distort colors. Remember that the condition for distortionless transmission of information through any medium or network is the presence of flat frequency response and constant time delay with respect to frequency, (linear phase response versus frequency).

As aforementioned, there are 15,734 pulses transmitted per second; this corresponds to 525 lines of 59.94 fields transmitted per second. Each field consists of 262 .5 lines (interlaced scanning), and two fields make a frame. Alternate lines are scanned on each field. (For example; lines 1, 3, 5, 7, etc., of the first field are scanned, and then, lines 2, 4, 6, 8, etc., of the second field are scanned.) For simplicity, we will round off these numbers to 15,750 horizontal and 30 vertical frames per second. Note, that the vertical pulses occur at a 60-Hz rate, but that alternate pulses are slightly different, due to the interlacing. The main point to remember is that these horizontal and vertical pulses—and the color burst signal—are used for the timing and synchronization necessary to reproduce the TV picture. If any of these pulses are absent, distorted, or altered, it becomes difficult or impossible to synchronize the TV picture. The screen will roll, tear, and the colors will be incorrect, rendering the picture unwatchable. The successful use of the NTSC video signal requires careful attention to levels and polarities of the signal components. The picture components are luminance (brightness) component, and chrominance (color) component which contains the color information, or more correctly, the "color difference" information. This method of transmitting the chrominance information (color) was employed when the NTSC system was developed half a century ago, for reasons of compatibility with existing B/W TV receivers. This still is a good method for ensuring that a B/W receiver can receive color transmissions, producing a corresponding B/W image and

rejecting the color information with no resulting interference or degradation of quality.

The color signal is a bit more complex to understand but, basically, it is a 3.58-MHz (actually 3.579545 MHz) signal that is both amplitude modulated and phase modulated. The amplitude of this signal determines the saturation of a color (whether it is, for example, white, light pink, rose, or red), and the phase determines the hue (whether it is red, orange, yellow, etc.). If the burst-signal phase is used as a reference, a signal in phase with it would produce a greenish-yellow hue. It is important to understand that the *amplitude* of the composite color signal is used to determine the *difference* from white; *not the intensity* of a particular color. In this way, a color signal with a zero level would produce a neutral colored raster, allowing compatibility between color and black-and-white reception on the same TV receiver. Whether the color is, say a dark red or bright red is determined by the luminance component of the signal. For example, a brown object would have the chrominance phase component of an orange color, but a lower luminance component (dark grey), since browns are a dark shades of oranges. A sky blue would have a blue chrominance component with a large luminance component (very light grey). Neutral colors (whites, grays, and blacks) would have zero chrominance component. Near neutrals (beiges, ivories, off whites, etc) would have a very low level of chrominance component. Saturated colors would have a high value of chrominance component. Very bright saturated colors having a high chrominance and luminance component (yellows, greens, cyans, etc) could conceivably produce signal levels exceeding the dynamic range of the system. This amplitude has to be limited, and is one of several reasons why a color TV system cannot reproduce certain colors perfectly.

The TV camera that is used for producing a video signal basically divides the televised scene into three image components, these components carrying the red, green, and blue information respectively that is present in the scene. This was done optically using prisms, mirrors, and filters in early cameras, along with three vidicon tubes. It is done today in the solid state cameras with CCD chips having integral color filters or arrays. The camera must generate the sync signals for the horizontal, vertical, and color components, and produce a complete composite video signal. Broadcast and studio camera installations have separate master sync generators, which is necessary in multicamera installations. A sync generator used to occupy a large rack and have many tubes. Today, LSI circuitry does all this in a much smaller package. Sync generator chips are widely available for a few dollars, and complete color CCD camera for under $100 in some instances. The self contained camera must process these components into a complete NTSC format signal that can be directly received on a monitor or fed to various video devices.

The three video signals produced in each of the three primary colors (red, green, and blue) have amplitudes that vary with the level of that primary present in the color at a particular point in the scene. We will assume for simplicity that each signal can be between zero and +1 volt, where zero represents none of a particular primary, and +1 is the full amount of that primary. This is commonly called an RGB

system. This is because these colors are added together in various proportions to reproduce the original scene colors. All reproducible colors are mixtures of these three primaries. White is a mixture of all three at maximum level. Black is a total lack of all three (zero level). A fully saturated pure red object will produce 1 volt of red signal, and zero of green and blue. Similarly, a pure blue will produce 1 volt of blue signal, with zero red and green, etc. Intermediate colors (yellow, orange, etc.) will produce primary levels in two or all three colors, depending on the exact shade of the color. Most colors found in nature will a mixture of all three colors, as pure colors seldom occur outside of test and laboratory situations.

The luminance part of the video signal will be discussed first. This is the part that contains brightness and contrast information for the scene. It is the black and white portion and if viewed separately, would produce a black and white (B/W) image as seen on the TV or monitor. However, you cannot simply get a true appearing B-W image by simply combining the three primary colors, of red, green, and blue (RGB). Tonal relationships in the B/W image would suffer, with blues and reds appearing too light and "unnatural" while greens would appear a little too dark and "flat", the image appearing overall muddy and dull. The human eye is more sensitive to green, and less sensitive to red and blue. Therefore this factor has to be taken into account. Also, TV and monitor phosphors have limitations as to exact color and brightness levels obtainable, and CCD cameras tend to favor reds. What is done is to mix the red, green, and blue components in unequal proportions, determined from these considerations. The luminance signal is made up as follows:

Luminance (Vy) or Y component = 0.30 Vr + 0.59 Vg + 0.11 Vb

The three color video signal components are called Vr, Vg, and Vb, for red, green, and blue, respectively

This gives a good, "natural" appearing black and white image with the various colors appearing as shades of gray that correspond to their percieved brightness in nature, by the human eye. Photography buffs that specialize in B/W work will know what we mean. We want yellows, oranges, and some greens to appear bright, while reds should be a little darker, and blues, purples and browns darker still.

Notice that the three components add up to 1.0 or 100 percent, which would represent white. Neutral colors, blacks, greys, and whites, would appear as proportionate combinations of these three colors at lower levels. Grayed or off white colors appear as intermediate combinations of these three primary colors with relative red, green, and blue ratios close to those of neutrals, i.e. .30-.59-.11. The video luminance level as seen by the luminance video amplifier and monochrome monitor screen would appear as in the following table. The RGB relative composition is the approximate mixture to get the perceived color, and the Relative Luminance level is the sums of the amplitudes of the RGB components, given in terms of a black to white tonal (grey) scale of zero to one, as seen in a B/W photo or TV image.

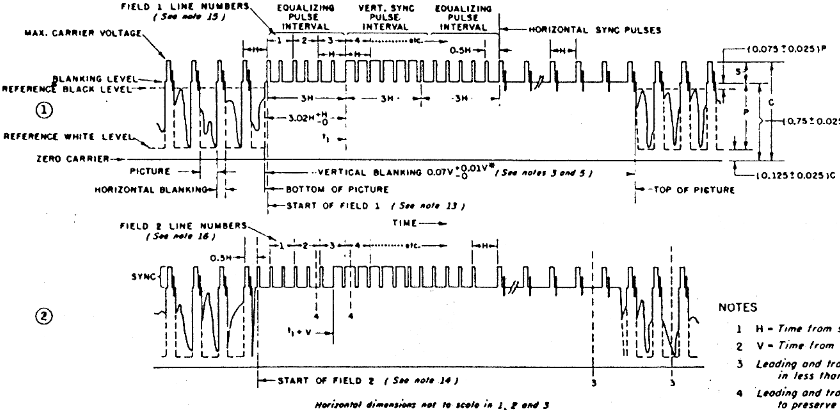
Perceived Color	RGB Relative Composition	Relative Luminance level
White	.30R + .59G + .11B	1.00 White
Ivory	.30R + .59G +.05 B	0.95 Almost white
Yellow	.30R + .59G	0.89 Very Light grey
Cyan	.59G + .11B	0.70 Light grey
Orange	.30R + .30G	0.60
Green	.59G	0.59
Grey	.15R + .295G + .055B	0.50 Middle Grey
Magenta	.30R + .11 B	0.41
Red	.30 R	0.30 Dark grey
Blue	.11B	0.11 Very dark grey
Black	- 0 -	0.00 Black

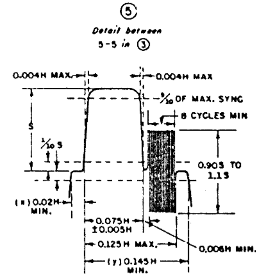
It can be seen that the relative levels of these colors will appear "natural". B/W is an abstract concept, as there is no exact relationship between colors and their corresponding grey tones, only what we think would "look right". There are some esthetic considerations as well as technical here. However, with this system, the various colors would appear about as bright as the average human eye would see them, but in corresponding shades of grey as given by the value of luminance in the right hand column.

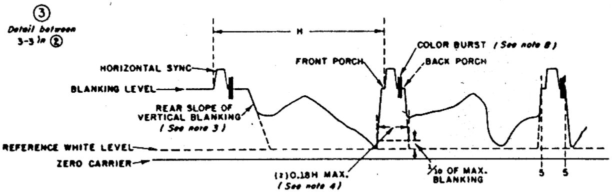
So far, we have a color video signal generated with three color video components in the three primaries, with a "correct" luminance or Y channel. This Y signal will appear as a plain B/W signal, so the color information must be added on in such a way as to be able to recover it and generate the original R,G,and B components at the monitor or receiver so as to get a color image. This will be covered in the next part of this article

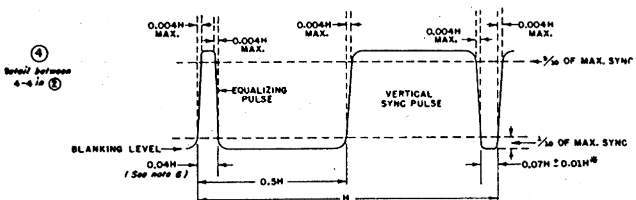
TELEVISION SYNCHRONIZING WAVEFORM

FOR COLOR TRANSMISSION



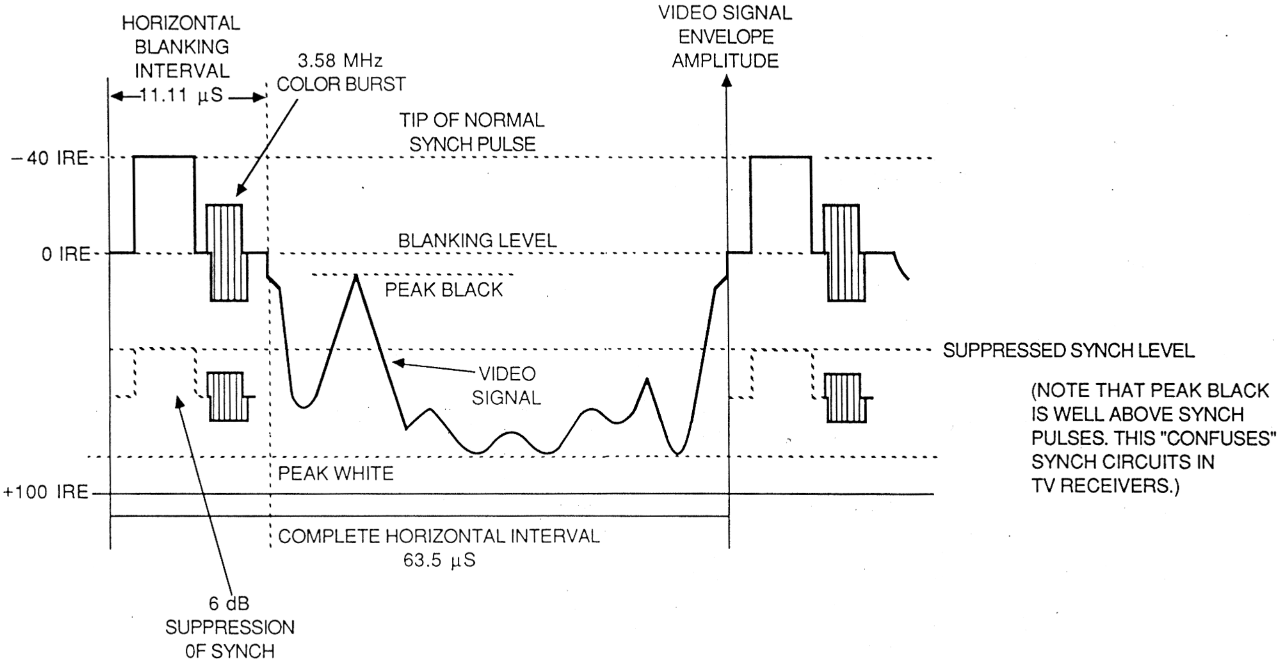






NOTES

1. H = *Time from start of one line to start of next line.*
2. V = *Time from start of one field to start of next field.*
3. *Leading and trailing edges of vertical blanking should be complete in less than 0.1H.*
4. *Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x+y) and (z) under all conditions of picture content.*
5. * *Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles.*
6. *Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync pulse.*
7. *Color burst follows each horizontal pulse, but is omitted following the equalizing pulses and during the broad vertical pulses.*
8. *Color bursts to be omitted during monochrome transmission.*
9. *The burst frequency shall be 3.579545 mc. The tolerance on the frequency shall be ±10 cycles with a maximum rate of change of frequency not to exceed 1/10 cycle per second per second.*
10. *The horizontal scanning frequency shall be $\frac{2}{455}$ times the burst frequency.*
11. *The dimensions specified for the burst determine the times of starting and stopping the burst, but not its phase. The color burst consists of amplitude modulation of a continuous sine wave.*
12. *Dimension "P" represents the peak excursion of the luminance signal from blanking level, but does not include the chrominance signal. Dimension "S" is the sync amplitude above blanking level. Dimension "C" is the peak carrier amplitude.*
13. *Start of Field 1 is defined by a whole line between first equalizing pulse and preceding H sync pulses.*
14. *Start of Field 2 is defined by a half line between first equalizing pulse and preceding H sync pulses.*
15. *Field 1 line numbers start with first equalizing pulse in Field 1.*
16. *Field 2 line numbers start with second equalizing pulse in Field 2.*
17. *Refer to text for further explanations and tolerances*


HORIZONTAL BLANKING INTERVAL
11.11 µS
3.58 MHz COLOR BURST
VIDEO SIGNAL ENVELOPE AMPLITUDE
TIP OF NORMAL SYNCH PULSE
−40 IRE
BLANKING LEVEL
0 IRE
PEAK BLACK
SUPPRESSED SYNCH LEVEL
VIDEO SIGNAL
(NOTE THAT PEAK BLACK IS WELL ABOVE SYNCH PULSES. THIS "CONFUSES" SYNCH CIRCUITS IN TV RECEIVERS.)
PEAK WHITE
+100 IRE
COMPLETE HORIZONTAL INTERVAL
63.5 µS
6 dB SUPPRESSION 0F SYNCH