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Recommended Levels of Digital Signals Relative to Analog Video Levels

Introduction

This document provides recommendations for the operating levels of digital (64QAM and 256QAM) channels relative to the levels of analog video channels in hybrid fiber/coax (HFC) networks.

The term 'level' must be clearly defined in order to avoid ambiguity. In the case of a QAM channel, the 'level' is the true power of the signal, measured over any interval of time. In the case of an analog video signal, on the other hand, the 'level' is the true power of the modulated RF carrier measured during the interval of the horizontal synchronising pulse. It is sometimes referred to as the 'peak video envelope power'. If the same modulated carrier is measured over an extended period of time, using a so-called 'video' filter, then the result will be the 'average' power.

Audience

This technical bulletin applies to design and application HFC engineers that need to calculate levels of digital (QAM) signals relative to analog video levels.

Assumptions

Assumption 1: Amplitude Distributions of Analog and Digital Signals

The recommended QAM level is determined by first assuming that it is desirable to set it equal to the average power of an analog video signal. However, even when this is done, the two signals will have significantly different amplitude distributions; that is to say, the probability of measuring any specified amplitude at any given instant of time will be markedly different for the two signals. (Viewing an analog video signal and a digital QAM signal alternately on an oscilloscope will highlight these differences. The analog signal has a predictable, repetitive element due to the line and field blanking pulses, whereas the digital signal is essentially random). In statistical terms, it is said that the Probability Density Functions (pdf) of the two signals are dissimilar, with the digital signal having an almost Gaussian shape.

However, when a sufficiently large number of independent signals are combined, the amplitude distribution of the overall signal tends toward a Gaussian distribution. This can be proved by the Central Limit Theorem, although an exhaustive discussion of the mathematics is beyond the scope of this bulletin. (For further information, the attention of the reader is drawn to the References at the conclusion of this document). The practical consequence of this is that the 'peakiness' of the two signal types tends to become more and more similar, as the number of the signals is increased, and therefore the effect on optical transmitters, which might respond to signal peaks by 'clipping', will be the same. In this context, a 'sufficiently large' number of analog video signals are taken to be approximately 20.

Assumption 2: Difference Between Peak Envelope Power and Average Power of an Analog Video Signal

The peak envelope power of an analog video signal is equal to the power of the unmodulated RF carrier, because, in the interval of the horizontal synchronising pulse, the modulation depth is zero. The reduction in power when the carrier is modulated will be determined by the maximum modulation depth, corresponding to peak white level, and the average picture level (APL).

For a single signal, the APL will vary with scene changes and may have a significantly different value during different types of programming, but when a number of signals are combined, the APL will not be subject to such a large variation. A suitable value for the APL must therefore be selected, and the figure of 50% has been chosen for this analysis. This corresponds to an average picture luminosity mid-way between black and white, and seems to be a reasonable assumption when, again, a 'sufficiently large' number of signals is considered.

The calculations that follow are therefore largely concerned with the determination of the average power of an analog video signal having an APL of 50%.

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Assumption 3: Effect of the Vertical Blanking Interval

During the vertical blanking interval, which has a duration equivalent to 25 horizontal lines in the PAL B/G standard, no video is transmitted, although some of the 'lines' may contain teletext data and test signals. The effect of this interval on the APL is therefore hard to assess. In the calculations, a small adjustment is made to account for the vertical blanking interval, but the detailed derivation of this adjustment is not given. In the worst case, it will increase the average power of the modulated signal by about 0.2 dB.

Assumption 4: Effect of the Chrominance and Audio Signals

The amplitudes of the chrominance and audio signals are so much less than the synchronising signals and the 50% APL luminance signal, that their effect can be ignored.

Assumption 5: Choice of Television Standard

The characteristics of the PAL B/G television standard are used in the following calculations. With the simplifying assumptions that have been made, it will be seen that calculations based on the NTSC (M) standard will produce almost identical results. The PAL I standard, however, is sufficiently different (in regard to depth of modulation, in particular), to warrant a separate calculation.

Calculation

Calculations

Figure 1 shows a time-domain representation of an analog video signal during the horizontal blanking interval. It will be noted that, in documents that define in detail the characteristics of various TV signals, the duration of the horizontal synchronizing pulse and the blanking interval are specified at a certain signal level, because an instantaneous transition from one level to another is, of course, impossible.

However, the calculations are greatly simplified if such an instantaneous transition is assumed, and the durations of the horizontal synchronizing pulse and the blanking interval are average values.

Therefore, the duration of the synchronizing pulse (B) is taken to be 4.7 µs, and the duration of the blanking interval, consisting of front porch (A) and the synchronizing pulse (B), and the combined interval of the breezeway, color burst and back porch (C), is taken to be 12 µs.

If the overall amplitude of the video signal, from synchronizing tip to peak white level, is taken to be 1 volt, then blanking occurs at 0.3 volt, and a 50% white APL occurs at 0.65 volt.
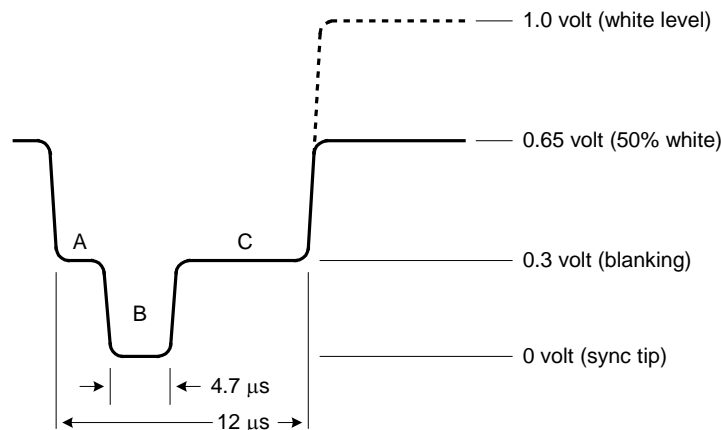

Figure 1: Analog signal during the H blanking interval

The baseband analog video signal is impressed upon an RF carrier using negative modulation (in the majority of TV systems), which means that the RF carrier is at maximum amplitude during the duration of the horizontal synchronizing pulse. In the PAL B/G standard, the 'residual' carrier amplitude when the picture is at peak white level is 0.1 times the maximum.

Calculation, Continued

(Note the distinction between 'amplitude' and 'power'). Figure 2 shows the modulated signal during the horizontal blanking interval.

The amplitude of the RF carrier corresponding to the blanking level is derived as follows:

In the baseband signal, which has a maximum amplitude from sync-tip to peak white of 1 volt, blanking occurs at 0.3 volt (see fig. 1). If the maximum amplitude of the RF carrier is taken to be 1.0, then the amplitude can vary from 1.0 to 0.1; that is, a range of 0.9. Multiplying 0.3 and 0.9 we obtain 0.27, so that blanking represents an RF carrier level of (1.0 − 0.27) = 0.73 of maximum.

Similarly, the amplitude of the RF carrier corresponding to 50% white is derived as follows:

In the baseband signal, 50% white occurs at 0.65 volt (see fig. 1). Multiplying 0.65 and 0.9 we obtain 0.585, so that 50% white represents an RF carrier level of (1.0 − 0.585) = 0.415 of maximum.

Carrier amplitude

1.00 (sync tip)

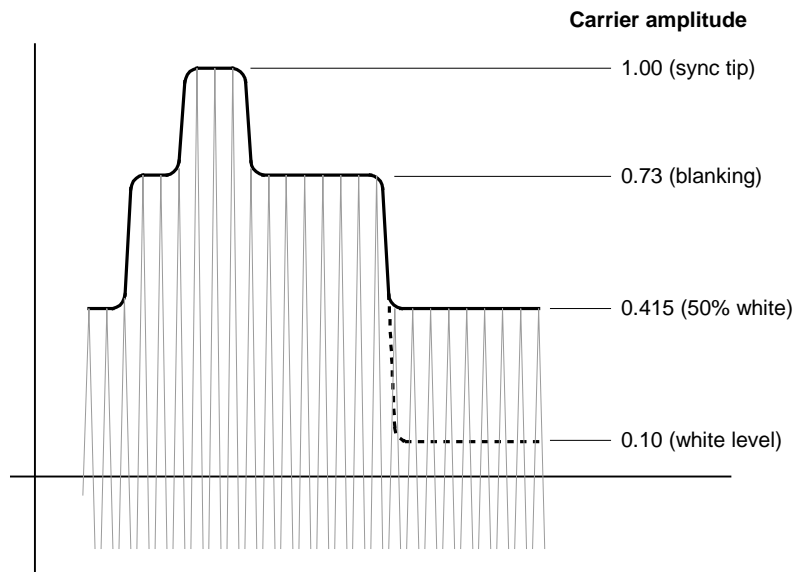0.73 (blanking)

0.415 (50% white)

0.10 (white level)

Figure 2: Modulated RF carrier during the H blanking interval

During the horizontal synchronizing pulse, the RF carrier is at maximum amplitude, or 1.0. Now the average power of the modulated carrier is determined by examining the length of time the signal remains at each of the three levels (0.415, 0.73 and 1.0) during the total interval of one horizontal line (64 μs).

Calculation, Continued

These time periods are as follows:

RF carrier level (fraction of maximum)	Duration (microseconds)
1.0 (sync. tip):	4.7
0.73 (blanking):	7.3
0.415 (50% white):	52.0
TOTAL:	64.0

The determination of the arithmetic mean must be done on a power basis, rather than a voltage basis, so because power is proportional to the square of the voltage, we can use the following equation:

$$\text{'mean} - \text{square' voltage} = \frac{4.7 \times (1.0)^2 + 7.3 \times (0.73)^2 + 52.0 \times (0.415)^2}{64.0} = 0.274$$

To find the reduction in power from the maximum, in terms of decibels, we take 10.log (0.274), which gives 5.62 dB. In other words, the average power of an RF carrier modulated by a video signal with 50% APL is 5.62 dB below the peak envelope power, or the power of the unmodulated carrier. This gives us the recommended level of a digital QAM signal, and we usually round-off the figure to 6 dB below peak envelope power.

The same type of analysis can be used to take account of the increase in RF signal power during the vertical blanking interval. However, as stated earlier, some TV channels may have a significant amount of video and text information in the VBI, while others have very little. Taking the worst-case scenario, in which no information is conveyed during the VBII, we find that the average power of the RF signal is increased by about 0.2 dB. It seems reasonable to ignore this minor adjustment, given that, in any real situation, there will certainly be some test-signal and/or other information present.

Modulation

Modification for PAL I Standard

As far as the calculation of average signal power is concerned, the fundamental difference between the PAL B/G and PAL I standards is the depth of modulation of the carrier: in PAL I, peak white level corresponds to a residual carrier of 0.2, rather than 0.1. The effect of this change is illustrated in Figure 3.
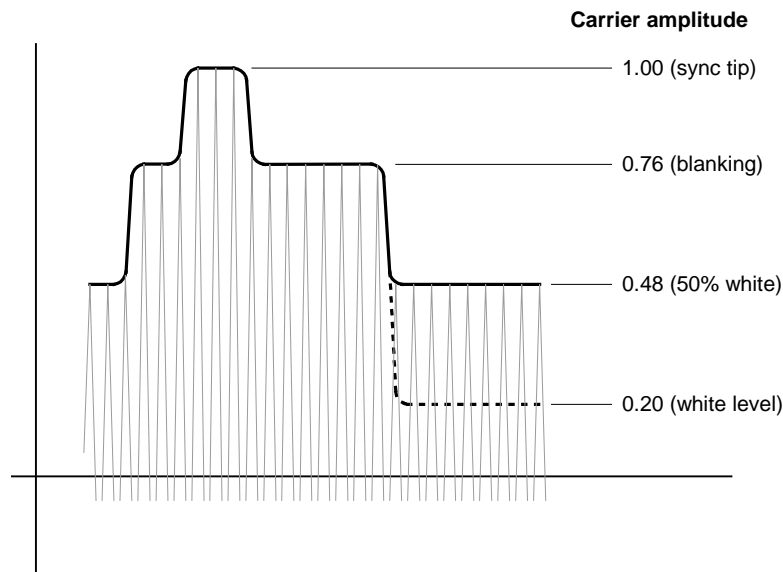

Figure 3: Modulated RF carrier during the H blanking interval; PAL I standard

The average power of the modulated carrier can be determined as before by examining the length of time the signal remains at each of the three levels (0.48, 0.76 and 1.0) during the total interval of one horizontal line (64 µs).

These time periods are as shown in the following table:

RF carrier level (fraction of maximum)	Duration (microseconds)
1.0 (sync. tip):	4.7
0.76 (blanking):	7.3
0.48 (50% white):	52.0
TOTAL:	64.0

and the determination of power reduction is as follows:

$$\text{'mean-square' voltage} = \frac{4.7 \times (1.0)^2 + 7.3 \times (0.76)^2 + 52.0 \times (0.48)^2}{64.0} = 0.3265$$

To find the reduction in power from the maximum, in terms of decibels, we take 10.log (0.3265), which gives 4.86 dB. The fact that the maximum modulation depth in the PAL I standard is less than that in the PAL B/G standard results in a higher average power of the modulated signal. We can conclude that, in PAL I systems, the level of the digital QAM channels can be set at 5 dB below peak video envelope power in order for them to have the same power as the analog video channels.

In practice, however, the broadband industry has generally opted for a universal figure of 6 dB, rather than promote different recommendations for different TV standards.

References

1. A. Papoulis, *Probability, Random Variables and Stochastic Processes*.

New York: McGraw Hill, 1965