Modulation Index and FM Improvement for Analog TV

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ABSTRACT

The concepts of modulation index and FM improvement are simple and straightforward when the modulating signals are sinesoidal. For a complex baseband waveform such as analog TV, the FM improvement may be seriously underestimated.

A method for computer simulation of video waveforms and the resulting spectra are presented.

Key Words: FM improvement, modulation index, analog TV.

INTRODUCTION

Acceptable TV transmission requires a very high (35 to 40 dB) peak signal to RMS noise ratio. If the available modulation index is underestimated, then the S/N must be made up by increasing the C/N. Increasing C/N is usually costly. This analysis shows that proper understanding of modulation index allows operation of TV links down to FM threshold.

WHAT IS MODULATION INDEX?

The basic definition for the modulation index is the peak phase shift, in radians, due to the modulation. Defining modulation index as the maximum frequency deviation divided by the modulating frequency is correct <u>only for single sine waves.</u> The proof for this is seldom developed, but is straightforward. The basic block diagram of the frequency modulator is shown in Figure 1.

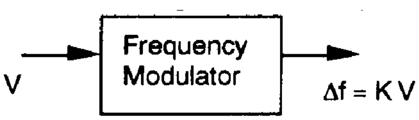

Figure 1 - Basic Frequency Modulator

$$\beta = \phi_{max} = 2\pi \int \Delta f \; dt = 2\pi K \int V \, dt \qquad (1)$$

If V is sinusoidal, then,

$$\beta = 2\pi KA \int Sin(\omega t) \, dt = \frac{2\pi KA}{\omega} Cos(\omega t) \qquad (2)$$

where A is the amplitude of the sine wave, but,

$$KA = \Delta f_{max} \qquad (3)$$

and $$\omega = 2\pi f_{mod} \qquad (4)$$

thus $$\beta = \frac{\Delta f}{f_{mod}} \qquad (5)$$

which is the widely used definition for modulation index. It is obvious, looking at this derivation, that Equation (5) cannot be correct if V is not a sine wave.

The only reason that modulation index is important is in the prediction of data link performance. A good TV picture requires a peak-to-rms signal-to-noise ratio of 35 to 40 dB in order to be useful for most surveillance tasks. We are not transmitting "Felix the Cat" here. If Equation (5) is used to calculate mod index for a TV signal, the maximum deviation is easy to determine. The big question is what value to use for f_{mod}?

Freeman [1] uses 4.2 MHZ., the -3 dB bandwidth of NTSC video low-pass filters for his f_{mod}. This results in low values of mod index, and unaccepably high values of C/N for TV operation. However, Freeman's experience in TV transmission was that the actual S/N was higher than predicted. He came up with "Correction Factors" totaling more than 18 dB which are added to the FM improvement factor. There should be a more straightforward, better way.

If we use Equation (1) as the basic definition of modulation index, and look at one video line as the minimum portion of the TV frame to consider, then the modulating signal is not anything like a sine wave. The modulating signal can be represented as a complicated sum of square waves, as shown in Figure 2.

Figure 2 looks a bit different from the usual representation of a video line, in that I have started and stopped the line in the middle of the active video rather than at part of the synch structure. This is only for convenience in calculating the phase change produced by the modulating signal.

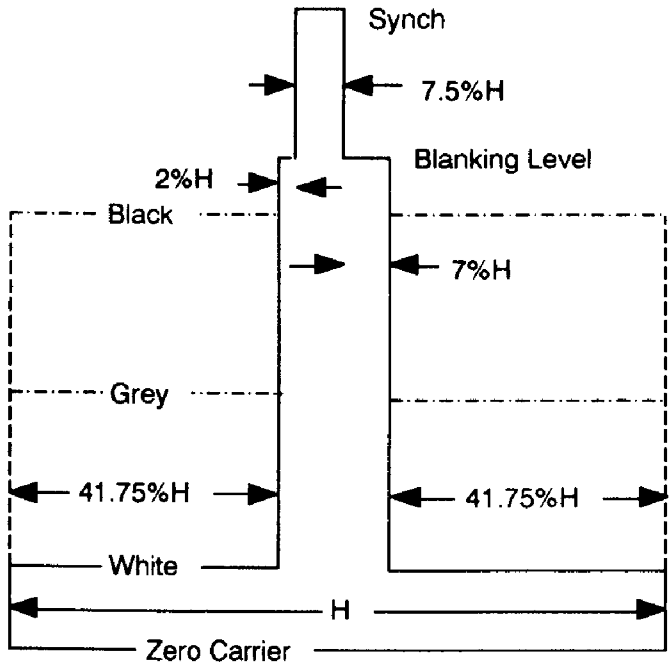

Figure 2 - Simplified TV Video Line

Prior to the AC coupling of the transmitter, the zero carrier level is 0 volts, the white level is at 0. 125 volts, the blanking level is at 0.75 volts, and the synch peak is at 1.0 volts. After AC coupling, the picture portion of the video line will be at a negative voltage while the blanking and synch will still be positive. The phase vs. Time can be calculated by

$$\phi = 2\pi \int_0^H \Delta f \, dt = 2\pi K \int_0^H V \, dt \qquad (6)$$

where K is the modulation sensitivity of 5 MHZ/V and H is the line time of 63.556μSec. If we can approximate the line as a blank frame of some grey level, the calculated phase will be within the limits shown in Table 1.

Table 1 - Calculated Beta and FM Improvement for various scene contents

Scene	Black	Grey	White
Video	0.625	0.375	0.125
Line Avg.	0.664	0.456	0.247
Beta	32.82	67.21	101.60
Imp., dB	35.09	41.32	44.91

No matter what the scene content may be, the integral of equation (6) smooths the high frequency components out. This results in beta values which lie between the values given here. The minimum FM improvement of 35 dB is so high that any C/N which is over about 15 dB is sufficient to provide an “excellent” video scene. This means that data link calculations may be done on the basis of a 15 dB C/N, without any worry about the effects of modulation index.

DIGITAL SIMULATION

A digital simulation has been performed for a waveform similar to that of Figure 2 using the Fast Fourier Transform (FFT). Most people, even experts in the FFT such as Bracewell[2], assume that the input to an FFT program must be real values. For angle modulation, real values carry no information at all. The amplitude of the RF is constant, and only the phase or frequency carries information. The way around the problem is to load the FFT array with Sine and Cosine components of a rotating, unit magnitude vector. The vector rotation is described in Equation (1).

An approximation to the phase integral of Equation (1) is given by Equation (7).

$$\Phi_{n+1} = \Phi_n + V_n K/512 \qquad (7)$$

where Φ is the phase in radians, V is the voltage corresponding to the time of sample n, and K is the modulation sensitivity of the transmitter. Input to the FFT is the complex value;

$$E_n = \mathrm{Cos}(\Phi_n) + j\mathrm{Sin}(\Phi_n) \qquad (8)$$

A sketch of the phase rotation produced by equation (7) is shown as Figure 3. It can be seen that the slow rotation of the unit vector during the picture portion of the line is reversed and speeded up as the front porch is entered.

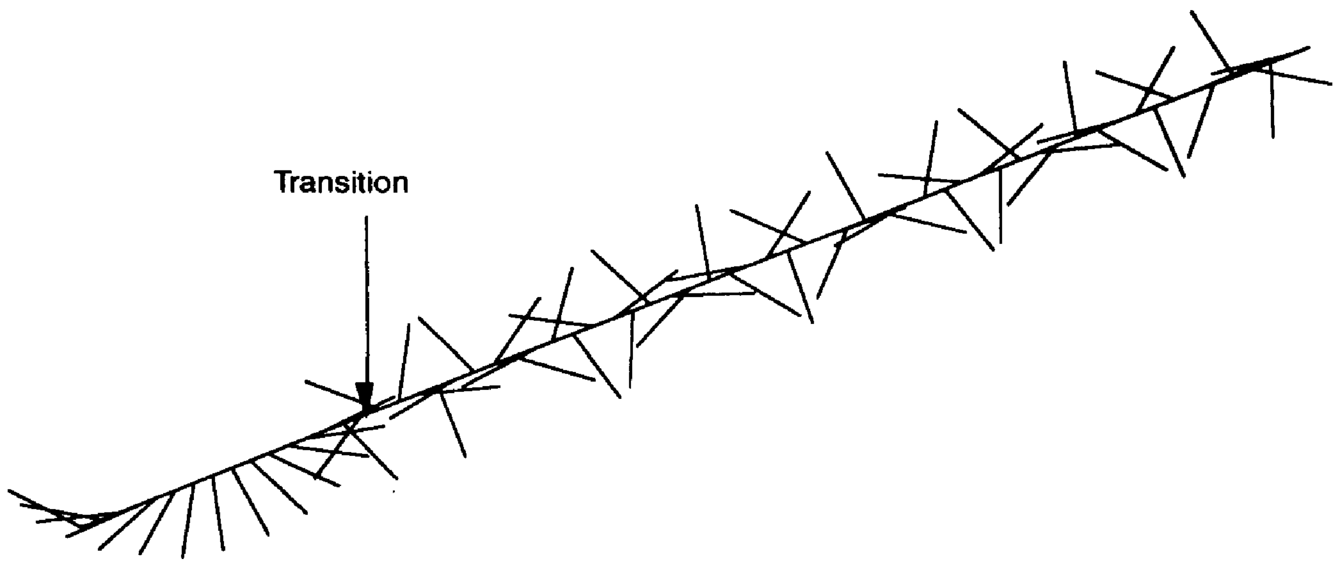

Figure 3 - Phase Transition from Grey Picture
to Blanking Level

Figure 4 is a sketch of a simulated TV frame consisting of two white and two black bars. This is about as complex a picture line as is needed to show the complexity of the RF spectrum.

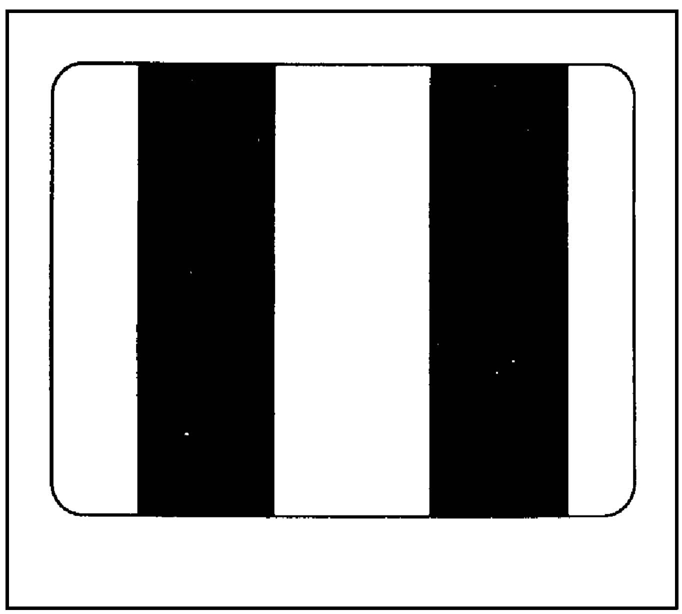

Figure 4 - TV Monitor Display for Fig. 5 Spectra

The RF spectrum of this picture, after frequency modulation, is shown as Figure 5. The spectrum must be broken into two frames for presentation in order for the details of the spectral lines to be seen. Figure 5a is the spectrum from about 800 kHz below the carrier to about 2.2 MHZ above the carrier. Figure 5b shows the spectral lines from 2.2 to 5.2 MHZ above the carrier. The spectrum produced by frequency modulation of a TV line is asymetric, since the voltage waveform which produced it is asymetric.

Some features of the spectrum are easily identifiable. The lines due to the synch pulse are very high, about (-22dBc), and show the typical (Sin(x)/x) pattern. The width of this peak is due to the short duration of the synch pulse.

A similar pattern at about +1.3 MHZ is due to the front and back porch blanking. Since there is the possibility of combining out of phase for the sidebands produced by equal voltages at different times, the pattern due to the blanking pulses may be larger or smaller than those shown here.

Most of the picture information is in the marked group of sidebands. The remaining sidebands are thos due to rise and fall times of the picture and pulse transitions. Sidebands not shown fall quickly down below -60 dBc in both directions. Any signal lower than about -48 dBc is going to make only an insignificant change to the picture quality.

CONCLUSION

Low modulation index produces a low number of sidebands. Figure 5 shows that the spectrum of the FM signal has a very large number of sidebands, corresponding to a high modulation index. This means that the FM improvement for analog TV transmission is high, and any C/N > 15 dB will produce a nearly perfect TV display.

1. Freeman, Roger L., Radio System Design for Telecommunications, 1 st Ed., John Wiley & Sons, New York.

2. Bracewell, R. N., “Numerical Transforms”, Science, Vol 248, 11 May 1990, pp. 697-704.

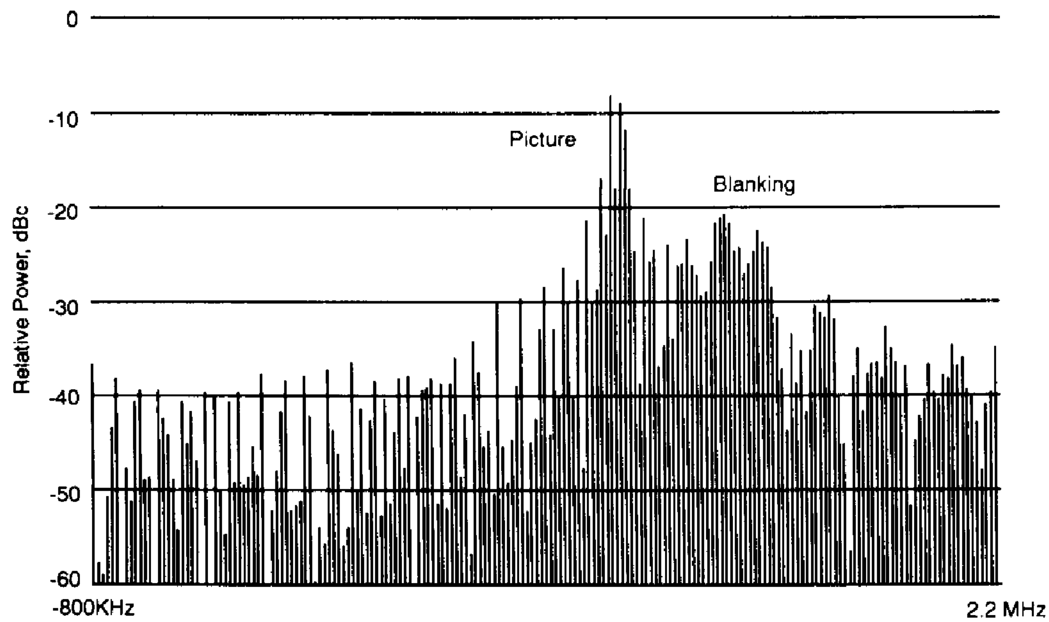

Figure 5a - Low End Spectrum of Two White, two Black Bars

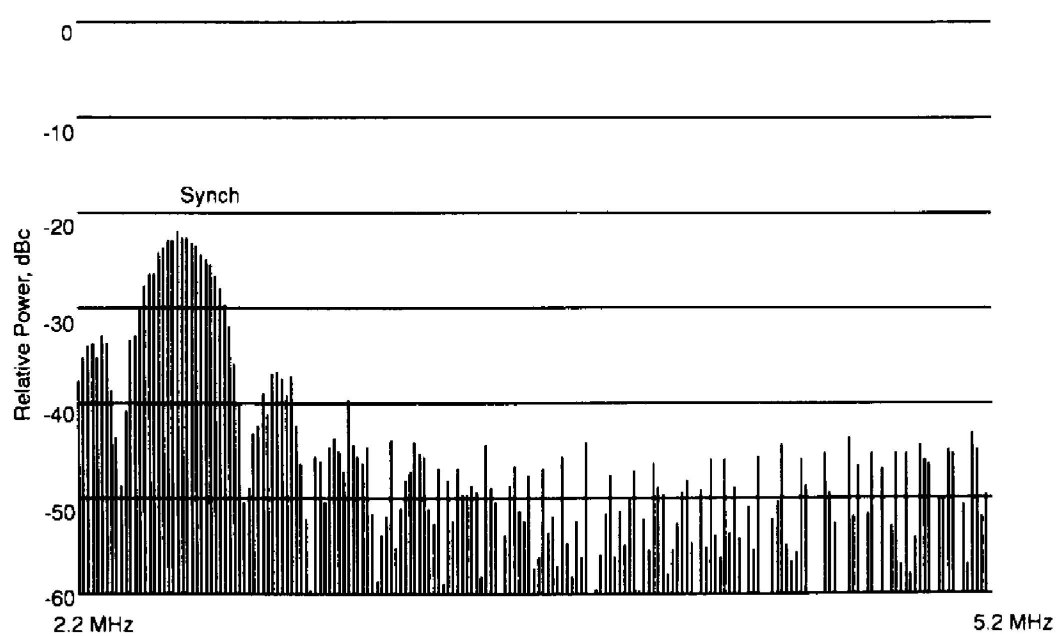

Figure 5b - High End Spectrum of Two White, two Black Bars