MULTI-CHANNEL CARS BAND DISTRIBUTION
USING STANDARD FM MICROWAVE EQUIPMENT

Presented By

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Introduction

I would like to open this talk with a brief explanation of its title, "Multi-
Channel CARS Band Distribution using Standard FM Microwave Equipment".
"Multi-Channel" means up to nineteen video channels distributed either on
an intercity or intracity basis. "Standard FM Microwave Equipment" refers
to broadband single channel FM radio equipment of the type that has been
in use for many years, and with which many of you are familiar.

Nineteen Channel CARS Band Distribution

At Microwave Associates, we have developed a technique of carrying nine-
teen full quality video signals in the CARS Band spectrum from 12.7 to
12.95 GHz, while maintaining the inherent transmission advantages of
broadband FM transmission. This has been accomplished by careful control
of both the transmitter output power spectrum and the receiver input
filtering to produce a transmission characteristic equal to that of the tele-
vision intercity relays and headend to hub distribution systems that
Microwave Associates has been manufacturing for over six years. This
equipment is not new in concept and is well proven by the existence of over
600 Microwave Associates systems in use in the United States by television
broadcasters, telephone companies, and CATV operators.

What is new about this nineteen channel system is that we are able to produce
transmitter output powers of 1/2 watt per channel, which allows multiple
power splits for local distribution and adequate power for intercity relay
distances. Also, highly stable solid state sources and improved receiver
sensitivity allow the very close channel spacing required for the carriage
of nineteen channels in the CARS Band.

Standard FM Microwave

My definition of standard FM microwave in this talk is frequency modulated
radio equipment in which the fully modulated carrier deviation is 4 MHz

peak, or 8 MHz peak-to-peak, and which employs C.C.I.R. 525 line television pre and de-emphasis for improved color video performance.

The purpose of this talk is to compare the video signal-to-noise performance of this system with an amplitude modulated microwave system, and with an FM system employing a carrier frequency deviation significantly less than 4 MHz peak. Of course, there are many other elements that can be compared, but time prohibits full investigation of all aspects of the systems.

Receiver AM Threshold

A basic starting point for signal-to-noise calculations on any radio system is the determination of the receiver AM threshold. By definition, the receiver threshold is the level of the thermal noise generated across the input resistance of the receiver mixer plus the noise generated by the mixer and first preamplifier stage of the receiver.

This chart (Appendix Exhibit 1) illustrated calculation of the AM threshold for a typical microwave receiver.

The formula for AM threshold in dBw (referenced to one watt) is:

$$10 \log_{10} KTBN$$

Where:

B is the receiver RF bandwidth, taken in this example as 15 MHz. It will be shown later that the choice of bandwidth at this point has no effect on the final calculated video signal-to-noise ratio.

K is the Boltzmann's Constant.

T is the thermal noise temperature at the antenna input in degrees Kelvin.

N is the receiver noise figure, which is typically 11 dB at 13 GHz when the insertion loss of the RF filter is included. This noise figure indicates that the receiver input noise is effectively multiplied by 12.9 times due to the imperfection of the receiver mixer and first I.F. pre-amplifier. A perfect receiver, yet to be realized in practice, would have a noise figure of 0 dB.

The solution of this formula indicates that this receiver AM threshold is -121.4 dBw or -91.4 dBm when referenced to one milliwatt. Therefore, any received signal must exceed this level before the receiver can detect its presence in the thermal noise produced by the antenna and the receiver.

The term AM threshold, rather than FM threshold, has been used because the capture effect of an FM receiver tends to reject the received signal until it is above the AM threshold by 9 to 10 dB. This is caused by the peak thermal noise pulses being 9 to 10 dB greater in amplitude than the RMS noise level. Therefore, the detectable received carrier level of an FM receiver is 10 dB less than the same AM receiver. This point is called the FM threshold and is -81.4 dBm in this case. However, this threshold differential is unimportant in video systems because the video signal-to-noise ratio at the FM threshold is so low that the signal is unusable.

AM Carrier to Noise Ratio

The next step in obtaining the video signal-to-noise ratio of the system is the determination of the AM Carrier-to-Noise (C/N) ratio. This ratio is the level of the system received signal level above the AM threshold of the receiver.

To obtain the C/N ratio, the level of the received carrier must first be calculated. This chart (Appendix Exhibit 2) illustrates a typical microwave path calculation under unfaded conditions. The path length has been arbitrarily set at 15 miles. Two six-foot parabolic antennas were selected, and the 1/2 watt transmitter power output produced a received carrier level of -35.3 dBm on the path. This signal level produces a fade margin to FM threshold of 46 dB, which produces very high reliability on a 15 mile path in most areas of the United States.

In this case, our resulting AM carrier-to-noise ratio is equal to +56.1 dB.

Calculation of the Video Signal-to-Noise Ratio from the AM Carrier-to-Noise Ratio

The formula on this chart (Appendix Exhibit 3) is one of the most useful tools available to the system engineer for the evaluation of the signal-to-noise performance of a microwave system. It is from this formula that the video signal-to-noise ratio can be determined when the level of the received carrier above the receiver AM threshold is known.

The formula states that:

$$\text{Video S/N PP/RMS (dB)} = \text{C/N dB} + 10 \log_{10} \frac{\text{BWrf}}{2\text{BW}_m} + 9 \text{ dB}$$

$$+ 10 \log_{10} 3\left(\frac{D}{\text{BW}_m}\right)^2 + \text{Emphasis Improvement (dB)}$$

The constant 9 dB represents the conversion to peak-to-peak/RMS from RMS/RMS.

Emphasis improvement, usually employed only in FM systems, is approximately +2 dB for the standard 525 line C.C.I.R. emphasis. Of course, other systems may employ different emphasis, but I am limiting this comparison to standard FM systems.

The factor $10 \log_{10} \dfrac{BWrf}{2BW_m}$ (where BWrf is the RF bandwidth used in the calculation of the receiver threshold and BW_m is the video bandwidth of interest) is the bandwidth correction factor which is applicable to both the FM and AM systems. The constant 2 accounts for noise in both side-bands of the detected signal. This bandwidth correction factor eliminates the effect on video signal-to-noise produced by the choice of receiver RF bandwidth as was mentioned earlier. You will note that the selection of a narrower receiver bandwidth will result in a lower AM threshold and corresponding higher AM C/N ratio, but the bandwidth correction factor will decrease proportionately with no resulting difference in the final system video signal-to-noise.

This second factor $10 \log_{10} 3 \left(\dfrac{D}{BWm} \right)^2$ is the so called FM improvement factor and is one of the most important items in the noise performance comparison of FM and AM systems. The constant 3 is due to the fact that the broadband noise detected by an FM demodulator has a triangular spectrum. D is the peak deviation of the FM carrier and BW_m is the video bandwidth.

Sample Video Signal-to-Noise Calculations

This chart (Appendix Exhibit 4) illustrates the results obtained when the preceding formula is applied to three typical systems. The first is an AM system, the second is a standard FM system with 4 MHz peak deviation, and the third is an FM system where the peak deviation has been reduced to 1 MHz to conserve RF spectrum space.

In the case of the AM system, the solution indicates tha the video signal-to-noise peak-to-peak/RMS equals the C/N ratio plus 11.5 dB.

When the same factors are applied to the standard FM system, the video signal-to-noise will be 17.8 dB greater than the C/N ratio, illustrating that the video signal-to-noise ratio of the standard FM system is over 6 dB better than the equivalent AM system.

However, in the case of the narrow deviation FM system, the signal-to-noise ratio will be approximately 12 dB below the standard FM system and nearly 6 dB below the AM system. As you will note, when the ratio of D to BWm is 0.46, the total FM improvement, including the emphasis improvement, is zero and the system is equivalent in noise performance to an AM system. If this ratio is further, the FM improvement becomes negative at a ratio of $20 \log_{10} \dfrac{D}{BWm}$, which amounts to -6 dB each time the ratio is reduced by a factor of 2. Obviously, this effect is positive when the ratio is increased, but the sacrifice in RF spectrum does not justify the use of modulation indexes greater than 1 when transmitting broadband video on the system.

Video Signal-to-Noise Ratio versus Receiver Carrier Level
In an Operating System

Thus far this talk has been on a somewhat theoretical situation, so this last chart (Appendix Exhibit 5) has been prepared to illustrate the performance of the systems under actual operational conditions.

As we all know, microwave systems are subject to constant and sometimes extreme variations in received carrier level due to atmospheric variables such as rainfall, ducting, etc. Therefore, we are most interested in the performance of the system during these received carrier level variations.

The chart is prepared by determining the C/N ratio for two different received carrier levels, adding the "Improvement" factors to determine the video S/N, and plotting these points on the chart. This is not too difficult since there is a one for one relationship between received carrier level and video signal-to-noise over the useful portion of the curves.

A point of interest on the curves is the non-linearity that occurs at high received carrier levels. This is due to the fact that all active electronic systems have an inherent noise output caused by power supply ripples, component noise, etc. That limits the video signal-to-noise performance of the system. In this case, I have selected a video signal-to-noise ratio of 67 dB as the maximum system limit and all three curves will become tangent to this maximum point regardless of how strong the received carrier becomes.

Another discontinuity illustrated on the chart is the FM Threshold mentioned earlier. Below -81.4 dBm the noise begins to capture the FM system and the video signal-to-noise deteriorates very rapidly.

However, this is not a serious problem because the video signal-to-noise ratio is below the useable level before this received carrier level is reached. This video signal-to-noise ratio is defined as 29 dB PP/RMS flat weighted, and below this point the viewer is expected to give up his TV and listen to the radio.

The curve does indicate that the useable received signal range of the standard FM system exceeds the range of the AM system and the narrow band FM system by the same number of dB that was shown in the earlier calculations. The standard FM system provides then, a higher video signal-to-noise ratio and a greater dynamic signal range than either the AM system or narrow deviation FM system.

Conclusion

I have attempted to describe some of the basic advantages of wideband standard FM microwave radio in a relatively brief period of time. It has not been possible to go to any greater depth of coverage of this subject at this time; however, if further enlargement is desired on any of the formulas or graphs presented this afternoon, please feel free to contact me at Microwave Associates.

APPENDIX

EXHIBIT 1

CALCULATION OF RECEIVER AM THRESHOLD

AM THRESHOLD

$$\text{AM Threshold} = 10 \log_{10} KTBN$$

Where:

B is the Receiver RF Bandwidth = 15 MHz

K is the Boltzmann's Constant = 1.37×10^{-23} joule/degree Kelvin

T is the noise temperature at the antenna input = 293° Kelvin

N is the Receiver Noise Figure of 12.6 = 11 dB

With the above figure:

$$\text{AM Threshold} = 10 \log_{10} (1.37 \times 10^{-23} \times 293 \times 15 \times 10^{6} \times 12.6)$$
$$= 10 \log_{10} (7.24 \times 10^{-13})$$
$$= -121.4 \text{ dBw}$$

Where:

-121.4 dBw is the receiver thermal noise power relative to one watt. To convert to milliwatts, a more common reference in path calculations, add +30 dB.

Therefore:

The Receiver AM Threshold = -91.4 dBm for an 11 dB receiver Noise Figure and 15 MHz RF Bandwidth.

EXHIBIT 2

SAMPLE MICROWAVE PATH CALCULATION

Operating Frequency 12.825 GHz

Path Length 15 Miles

Losses

Free Space Path Loss   -142.3 dB

Fixed Losses

      Elliptical Waveguide 40 ft.   -1.8 dB

      Branching (Typical Multichannel)   -4.0 dB

      Antenna Radomes   -2.2 dB

      Misc. (Alignment, etc.)   -2.0 dB

      Total Fixed Losses from above   - 10.0 dB

      Total System Losses   -152.3 dB

Gains

      Transmitter Power (0.5 watt)   +27 dBm

      Antennas (2-6' Parabolas   +90 dBm

          at 47 dBi each)

      Total System Gains   117.0 dB

      Received Carrier Level (Sum of Loss plus Gains)   -35.3 dBm

AM Carrier-to-Noise (C/N) Ratio = Received Carrier Level (above)
- AM Threshold (From Exhibit 1).

AM C/N Ratio = -35.3 dBm - (-91.4 dBm) = +56.1 dB

EXHIBIT 3

CALCULATION OF VIDEO SIGNAL-TO-NOISE RATIO
FROM THE CALCULATED CARRIER-TO-NOISE RATIO

The following formula is employed to derive the video S/N ratio when the AM C/N ratio has been determined.

$$\text{Video S/N (dB)} = \text{C/N dB} + 10 \log_{10} \frac{\text{BWrf}}{2\text{BW}_m} + 9 \text{ dB} + 10 \log_{10} 3 \left(\frac{D}{\text{BW}_m}\right)^2 +$$
$$\text{Emphasis Improvement (dB)}$$

Where:

C/N = AM Carrier-to-Noise Ratio = Level of the received carrier above the receiver AM Threshold (Exhibit 2).

$10 \log_{10} \dfrac{\text{BWrf}}{2\text{BW}_m}$ is the AM and FM bandwidth correction factor.

9 dB is the conversion to peak-to-peak/RMS from RMS/RMS video S/N.

$10 \log_{10} 3 \left(\dfrac{D}{\text{BW}_m}\right)^2$ is the FM Improvement Factor.

Emphasis improvement is normally +2 dB for standard 525 line C. C. I. R. emphasis.

BWrf is the system RF bandwidth used in the calculation of the receiver AM Threshold (15 MHz).

BW_m is the bandwidth of the modulating signal which is normally 4.2 MHz for video.

D is the peak deviation of the FM carrier, which is 4 MHz in the standard FM system.

EXHIBIT 4

SAMPLE CALCULATIONS

1.   For an AM System

$$\text{Video S/N PP/RMS} = \text{C/N} + 10 \log \frac{BW_{rf}}{2BW_m} + 9 \text{ dB}$$

$$= \text{C/N} + 10 \log \frac{15 \times 10^6}{2 \times 4.2 \times 10^6} + 9 \text{ dB}$$

$$= \text{C/N} + 2.5 \text{ dB} + 9 \text{ dB}$$

$$= \text{C/N} + 11.5 \text{ dB}$$

2.   For the Standard FM System

$$\text{Video S/N} = \text{C/N} + 11.5 \text{ dB (from above)} + 10 \log_{10} 3\left(\frac{D}{B_m}\right)^2 + 2 \text{ dB}$$

$$= \text{C/N} + 11.5 \text{ dB} + 10 \log_{10} 3\left(\frac{4}{4.2}\right)^2 + 2 \text{ dB}$$

$$= \text{C/N} + 11.5 \text{ dB} + 4.3 \text{ dB} + 2 \text{ dB}$$

$$= \text{C/N} + 17.8 \text{ dB}$$

Therefore, the Standard FM System provides a 6.3 dB Video S/N advantage above the equivalent AM System.

3.   As a comparison, the following calculation illustrates the effect on FM improvement when the peak deviation of the FM carrier is reduced to 1 MHz to conserve RF spectrum:

$$\text{Video S/N PP/RMS} = \text{C/N} + 11.5 \text{ dB} + 10 \log_{10} 3\left(\frac{1}{4.2}\right)^2 + 2 \text{ dB}$$

$$= \text{C/N} + 11.5 \text{ dB} + (-7.6 \text{ dB}) + 2 \text{ dB}$$

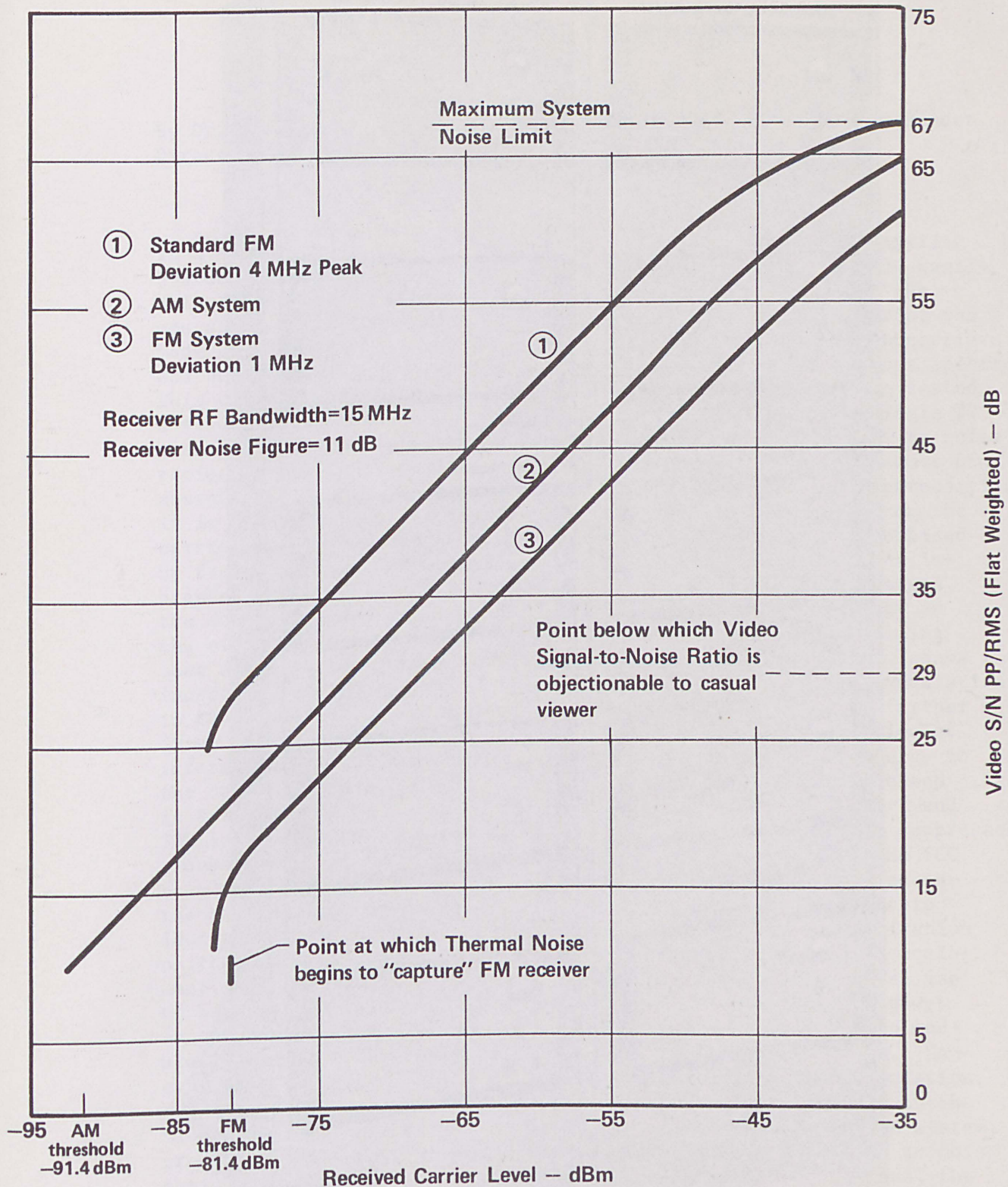$$= \text{C/N} + 5.9 \text{ dB}$$

EXHIBIT 5   VIDEO S/N VS. RECEIVED CARRIER LEVEL

Exhibit 6. MULTICHANNEL CAR BAND SYSTEM