Topics in broadband modulator/demodulator design for video transmission

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1. Abstract

In a standard broadband video signal distribution system, performance degradations are caused by the system's power and bandwidth limitations. To minimize these distortions and to take advantage of the capabilities that the system offers, the best type of modulation must be selected for the application at hand .

2. Background

Traditionally,video (along with accompanying audio or data) has been used in consumer applications and entertainment.The distribution systems used to transmit these signals include over-the-air broadcast channels, CATV, satellite and lately, fiber optic links.

One of the key properties of baseband video is that most of the information it carries is concentrated in the low frequency portion of the signal spectrum. Since any distortion in this portion of the spectrum is highly visible to the human eye, the design of a high quality composite broadband video transmission system present challenges at almost every level. Any artifacts introduced by the video processing or transmission must be very low (minimum of 60 db below the signal path) or else the distortions become clearly visible.

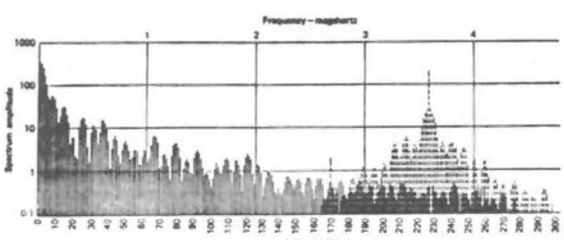


Figure 1: Composite luminance - chroma spectrum

Both the luminance and the chroma video information have periodic line spectra with a period equal to the line scanning frequency. The chroma information is modulated in quadrature on a subcarrier with frequency (approximately 3.58 Mhz) chosen to permit distortionless interlacing with the luminance line spectrum. Aural carrier, positioned 4.5 Mhz away from thr video is however only 920 Khz away from the color subcarrier.

3. Transmission channels

An NTSC baseband TV signal occupies a nominal bandwidth of 4.2 Mhz. For over the air and CATV transmission, the baseband video is VSB-AM modulated onto a carrier, while the audio baseband signals are FM-modulated onto a separate carrier 4.5 Mhz away from the video carrier frequency and at a level 15 db lower than the video carrier level. After multiplexing the video and the audio carriers, the total occupied transmission bandwidth is 6 Mhz.

a) Broadband distribution trunks

The topology of a typical CATV coaxial cable broadband distribution system includes a main trunk path length extending from several miles to several tenths of miles with amplifier boosters located every 1-2 miles. Subscribers are hooked to the main trunk via branches extending from the main trunk into the customer premises.

The key limitation of a typical CATV distribution system results from the degradation caused by the cable and the associated booster amplifiers. They limit the level and the number of the transmitted carriers as well as the achievable cable plant bandwidth. Extensive work has been performed to determine the number of carriers and their level , the noise accumulation and the second and third order intermodulation products generated as a result. Present state-of the art distribution amplifiers have a bandwidth of 550 Mhz, and can handle up to 55 high level VSB-AM signal carriers with a worst case commercial quality of 45 db C/N over the channel bandwidth.

b) Broadband distribution supertrunks

Broadband distribution supertrunk is a broadband communication link connecting typically two (sometimes more) multisource headend centers together.

For broadband supertrunk signal transportation it is imperative to be able to deliver video transparently (with virtually no system-added degradation) from geographically separated locations to distant (tens of miles away) headends.Typical CATV distribution systems having the usual number of repeater amplifiers cannot easily or inexpensively achieve this goal.

The topology of a supertrunk include path lengths extending from several miles to several tents of miles with one or more branches along the way. Because of the very high video signal performance required of a supertrunk, the number of video channels each supertrunk is required to carry is of a secondary importance only.

Coaxial cable - based supertrunks must use booster amplifiers in order to maintain the proper signal levels and CNR at all of the path sections. To guarantee, that after a cascade of booster amplifiers the required SNR at the farthest receiver location can be maintained , FM modulation is frequently selected . With the proper modulation index chosen for optimum SNR improvement versus bandwidth expansion , large improvements factors can be achieved at the expense of the number of channels which the system can support.

Fiber optic supertrunk distribution systems offer wide bandwidth with low losses and very small size and weight. Many fibers can be packed into a small space, permitting easy future expansion, excellent communication security and rapidly dropping equipment cost. Because of these properties, the system designer can select the frequency plan, the modulation method and the number of fibers offering the best and the most economical way of packing the number of required channels into a broadband supertrunking signal distribution system.

For long haul paths especially, the benefits derived from a broadband fiber optic supertrunk distribution system can be substantial - both in up front cost as well as in maintenance. Because FM modulation can offer large SNR improvement factors and the associated bandwidth expansion can easily and inexpensively be accommodated in a fiber optic link, a broadband fiber optic supertrunk can support a large number of high quality video channels inexpensively and economically.

With the rapid development of cost - effective optical sources and fiber technology, the use of fiber optic links as transmission media offers an attractive and cost-effective approach to distribution of high quality signals. It would allow the system designer to take full advantage of the wide bandwidth and of the insensitivity to EMI. Most importantly, no booster amplifiers would be required for links as long as 25 miles.

4. Modulator design for broadband trunk systems

Typically, the design objectives for a high-quality broadband distribution trunk system are set to guarantee that it will provide:

a) High quality of the delivered video and audio,
b) Reduced or no sensitivity to EMI,crosstalk etc.
c) No adverse environmental effects
d) Low equipment and installation cost
e) Low maintenance cost

A block diagram of a typical VSB-AM modulator is shown in Figure 2.

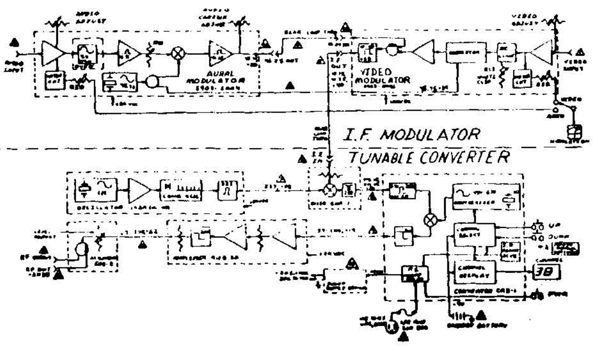
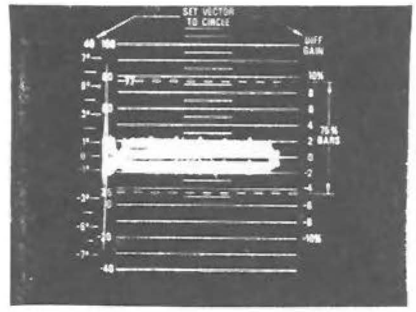


Figure 2: VSB-AM modulator block diagram

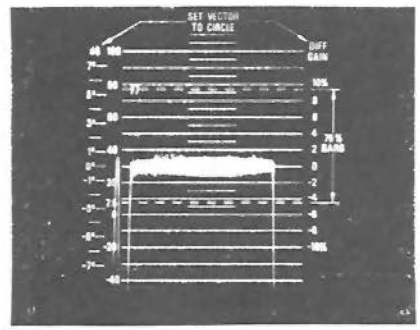
The modulator accepts baseband video and audio signals and generates the composite RF signal. Various performance specifications are imposed on the modulator to insure a high quality transmission of the baseband TV signals.

a) VSB-AM video performance with no noise present

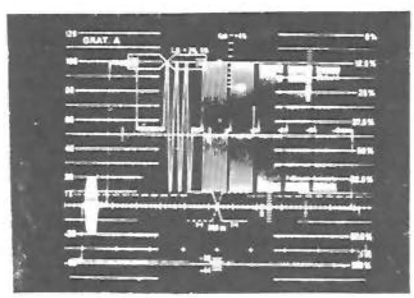
To evaluate the video performance of a system, standard test waveforms are applied to the video input and the degradations caused by the system are recorded.



Differential phase



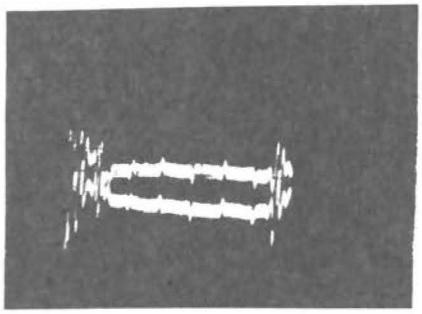
Differential gain



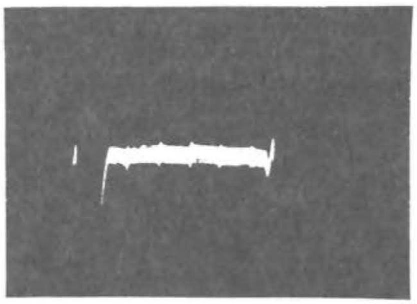
Multiburst test

Figure 3: Examples of standard video test waveforms

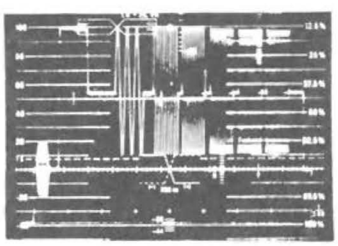
The response of a Catel CTM-20 VSB-AM video modulator to the test waveforms in Figure 3 is shown in Figure 4.



Differential phase



Differential gain



Multiburst test

Figure 4 CTM-20 VSB-AM video modulator response

A discussion and interpretation of the results reveals a wealth of information about the performance of the system.

Widely accepeted guidance standards for video transmission equipment quality are the RS-250-B standards, used extensively by the video broadcast industry.

Examples of selected short-haul (from few feet to 20 miles) RS-250-B system performance specifications are shown below:

RS-250-B Specifications

Differential gain	2.0%
Differential phase	0.5^0
Short time distortion	2.0%
Video freq. response	0.15db

The differential gain variations indicates how much the transmission gain varies with variations of the input amplitude (expressed as a percentage of maximum gain).

Differential phase expresses the maximum phase change between any two levels of the luminance signal.

The short time distortion is defined as the distortions of the time components from 0.125 to 1 microseconds and indicates the flatness of the group delay with frequency.

More tests (not shown here) are required to fully characterize the video performance. For example, the chrominance to luminance linear and nonlinear distortions are characterized by the chrominance/luminace gain inequalities, chrominance/luminance intermodulations and chroma delay relative to the luminance. Other tests such as chroma non-linear phase and gain characterize the phase distortions as a function of frequency by the modulator (more detailed explanations can be found in Reference 1).

For example, the results achieved with a broadcast quality TV modulator CTM-20 can be read from Fig. 4.

CTM-20 results

Differential gain	1%
Differential phase	0.5^0
Short time distortion	1.5%
Video freq. response	0.1db

To achieve such high performance it is imperative to design every portion of the modulator chain very carefully. Not only the frequency flatness but the return loss and match (16 db min) at each point must be well preserved, the filters frequency response and group delay must be flat, the video modulator DC response and clamp circuits must maintain the operating point to a fraction of a percent.

The frequency conversion circuits (especially output converters oscillators, mixers and IF filters must provide a flat frequency response and group delay over the conversion range, they must not introduce spurious signals and must not introduce crosstalk from the chroma or audio into the luminance channel (See Ref. 3).

b) VSB-AM performance with noise present

A signal is delivered to its final destination - a broadcast or CATV system customer - by way of transmission over the broadband trunk distribution system.

For 87.5% VSB-AM modulation, an approximate expression (Ref.5) of the (unweighted) video S/N_0 as a function of the C/N_0 is given by,

$$S/N_{0\,(p\text{-}p/rms)} = C/N0_{(rms/rms)} - 4.1 \text{ db} \quad (1)$$

Adding noise weighting improvement (6.8 db-Ref.1), the weighted S/N0w becomes,

$$S/N_{0w\,(p\text{-}p/rms)} = C/N_{0(rms/rms)} + 2.7 \text{ db} \quad (2)$$

As the VSB-AM modulated signals are transmitted, their carrier-to-noise ratio decreases with the trunk length.

Further decrease in the C/N_0 is expected at the customer premise location due to no-ideal receivers. It can be shown (Ref.6) that for a receiver with a noise figure F, gain $G_{(db)}$, received level $X_{(dbmv)}$ and input $C/Ni_{(db)}$, the output C/N_0 in 4.2 Mhz bandwidth becomes

$$C/N_{0(db)} = [G+X]_{db} - [GX/(C/N_i) + kTo(F-1)]_{db} - 10Log(4.2x10^{6)} \quad (3)$$

For example, at -6 dbmv and a noise figure of 10 db, for input C/Ni of 43, 46 and 49 db, the output C/N_0 becomes 40.15 , 41.45 and 42.3 db - a C/N loss of 3 - 7db.
Therefore, high S/N_0 ratios for VSB-AM signals can be only be achieved with high C/N_i.

Very good insight of how this modulation method compares with others and in particular with optimum modulation methods can be demonstrated in the following paragraphs.

c) Optimum system performance

If we define the optimum communication system to be the one in which no information is lost, from the Shannon system's capacity theorem the S/N_0 is given by

$$S/N_0 = \{1 + (fm/B)(C/Ni)\}^{(B/fm)} - 1 \quad (4)$$

in which f_m is the highest modulation frequency (4.2 Mhz for video signals) and B is the channel bandwidth.

Plots of the S/No vs C/Ni is shown in Figure 5.The curve clearly demonstrates the S/No advantages of bandwidth expansion modulation methods, since they trade power for bandwidth exponentially.

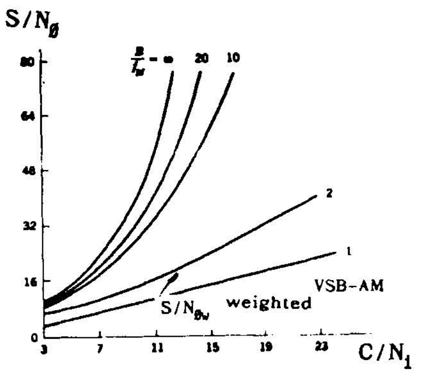


Figure 5 S/No (unweighted) of an optimum communication system

If the design objective is a broadband supertrunk system, to achieve the much higher video S/No required, FM modulation method is almost universally selected.

5. FM video for supertrunks

a) FM video performance with no noise present

To evaluate the video performance of an FM system, standard test waveforms shown in Figure 3 are applied to the input of a Catel FM modulator WFMS 3000 and the degradations caused by the system are recorded. in Figure 7.

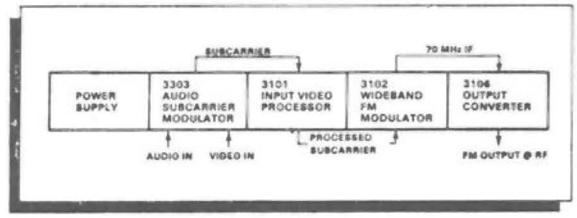
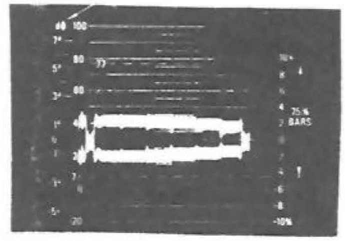
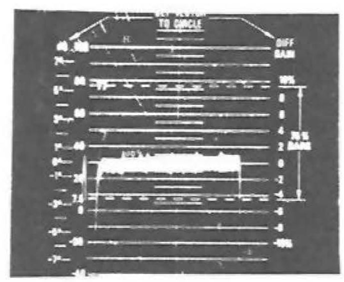


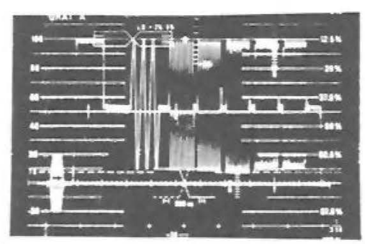
Figure 6 WFMS 3000 FM modulator



Differential phase



Differential gain



Multiburst test

Figure 7 Catel WFMS 3000 modulator response

b) FM system performance in the presence of noise

If analog FM modulation is used to transmit video, we can define the weighted output SNR_{ow} (Ref.2) of a video-modulated carrier as a function of the input (C/N)IF, the modulation index β,the IF bandwidth B_{if}, and the highest baseband video frequency F_m as follows

$$SNR_{ow} = [3\beta^2 Bif/(2Fm)] + (C/N)_{IF} + W \qquad (5)$$

Where $(C/N)_{IF}$ is measured in the IF bandwidth and

$$B_{if} = 2 \times (\Delta F + Fm) \qquad (6)$$

B_{if} is the Carson's rule bandwidth and the modulation index is

$$\beta = \Delta F/Fm \qquad (7)$$

where ΔF is the peak deviation of the video carrier and W is the video weighting improvement resulting from using preemphasis and deemphasis (3.6db with CCIR-405-1 characteristic) , CCIR noise weighting (11.5db) and P-P/RMS conversion (9db).

Note that ΔF is the peak deviation of the carrier by a **sinusoidal** signal with no preemphasis included.Other deviation definitions, used by equipment manufacturers (including Catel) include **sync tip to peak white deviation** $\Delta F_{st\text{-}pw}$. It can be shown (Ref. 4) that the two deviation definitions are related as follows:

$$\Delta F = \Delta F_{st\text{-}pw} / (2x0.3) \qquad (8)$$

If we refer the noise generated by the receiving equipment to the input, the carrier to noise ratio C/N becomes

$$(C/N)_{IF} = Pr/(kT^0_{eq} x B_{IF}) \qquad (9)$$

Where k is the Boltzman constant, T^0_{eq} is the equivalent noise temperature given by:

$$T^0_{eq} = T^0_0 x(F-1) \qquad (10)$$

in which T^0_0 is the ambient noise temperature (300^0K) and F is the noise figure of the receiver.

To estimate the theoretical achievable performance of an FM video modulation system, the SNR_{ow} will be calculated with the following assumptions:

Carrier deviations :

$\Delta F_{st\text{-}pw}$ = 4Mhz , 6Mhz

(corresponding to ΔF = 6.67Mhz, 10Mhz)

IF Bandwidth B_{IF} = 30 Mhz, 40Mhz

Worst case NF : 20 db

Worst received power : -24 dbm

Substituting in equations (5) to (10), the SNR_{ow} becomes:

For $F_{st\text{-}pw}$=4Mhz and IF bandwidth=30Mhz, SNR_{ow} = 72 db.

For $F_{st\text{-}pw}$=6Mhz and IF bandwidth=40Mhz, SNR_{ow} = 75 db.

Although not shown in the analysis, it has been demonstrated that FM can reject interference from other sources including adjacent FM channels, intermods, crossmods and any other interference not coherent with the in-channel video. This feature permits the system designer to select the modulation to cost-effectively design high performance multichannel video FM systems over broadband supertrunks

Early multichannel FM video systems using peak carrier deviation of 1.6 Mhz and RF bandwidth of 16 Mhz have been used in coaxial cable supertrunks and achieved S/N_0 improvement factors of 10 db over the C/N_i.

With the appearance of cost-effective high performance fiber optic transmitters and receivers and single mode fibers, it become economical to build high performance broadband supertrunk fiber systems. With these systems, it become possible to accomodate more channels and to achieve longer distances without repeaters.

Examples of present state-of -the art high performance wide deviation video FM systems can carry up to 16 channels, each 40 Mhz wide with multiple subcarriers at a distance to 40 km and achieve 65 db video S/No per channel.

Shown in Figure 8 is measured performance of 12 channel video FM fiber optic-based system delivered by Catel.

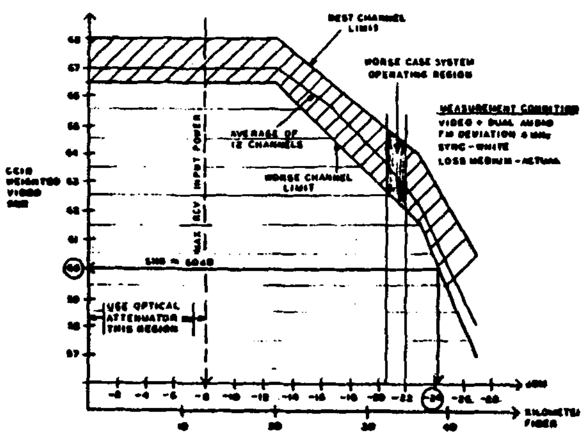


Figure 8: S/No of a 12 channel FM system over a signle mode fiber media

The chart shows that worst case of 60 db S/No per channel at 40 km distance can be achived with worst case received power of -24 dbm and dual audio channels.

6. Flexibility of video FM systems

Because of their high performance, video FM system can also be quite flexible.

For example, the system can be easily adapted to transmit data. Since multi-level PCM data is a video-like signal, PCM multiplexers can be readily interfaced (as shown in Fig.ure 9) with the FM modulator and demodulator permitting high data rate signals to be transmitted over broadband networks.

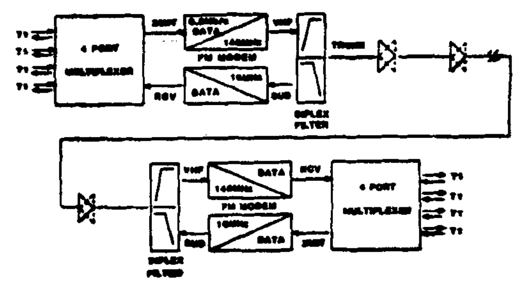


Figure 9: PCM multiplexer interfaced to an FM system

Other type of complex signals (such as BTSC - stereo audio signals) can be conviniently and efficiently carried as subcariers above the audio subcarrier signals.

Even the most complex scrambled signals can be transmitted over an FM system. Converting the scrambled RF signal into a subcarr-like signal and then modulating it permit preservation of the properties of the scrambled signal and does nor require decoding and encoding for supertrunk distribution. Since the modulation is AM/FM however, the FM advantage is lost and the C/N of the scrambled signal is only 3 db better than before downconversion and FM modulation.

7. Comparison to an optimum system

It is instructive to plot the S/No performance of an FM demodulator and compare it with the optimum system performance (shown in Fig.12).

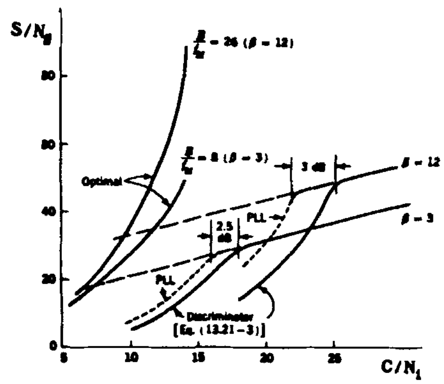


Figure 12 Comparison of FM demodulator performance to the optimum system performance

The results are quite interesting. It can be seen that although large FM improvement factors can be obtained for wide carrier deviations by the baseband video, audio and data, the FM system is quite inefficient when compared to the optimum system - especially at high C/Ni! Unfortunately however,although Shannon theorem gave us the bound on the achievable optimum system performance, it did not specify what is this system!

May be it is a digital video system? What type of digital modulation/coding scheme should we use to achieve this bound? Future research will determine this question.

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Dr. Mircho A.Davidov has received his PH.D. in 1981 from the University of Southern California and Msc and Bsc in 1976 and 1974 respectively from Tel Aviv University.

Dr. Davidov presently directs all of the engineering activities at Catel Telecommunications Inc. developing products in the areas of FM modulators and demodulators for video transmission, VSB-AM modulators and demodulators, FDM-FM fiberoptics transmitters and receivers and frequency translators for LAN data signals.

He was Director of Corporate Research at Oak Industries from 1981-1985. His responsibilities at Oak included developing systems for securing the transmission of high quality video signals. He worked for Honeywell and Brunswick Corporations between 1979-1981 and was responsible for development of RF communication systems for wireless monitoring of energy and control systems and wireless transmission of language translations. Between 1976-1979 he was a consultant to LinCom Corporation in Los Angeles, performing studies in the area of PLL, synchronization and signal processing for satellite communications.Between 1970-1976 he was an engineer for the Israeli Governmental Communication Office,designing circuits for the International Telephone,Telegraph and Telex lines. Between 1967 and 1970 he managed a military communication lab designing communication equipment for the Israeli Defence Forces.

He was an assistant professor at Cal State Northridge in 1981 and teaching assistant between 1974-1979 at Tel Aviv University and the University of Southern California. He speaks 5 languages fluently and is a member of IEEE.

Dr. Davidov has numerous publications and 7 patents pending.