

"DESIGNING 18 CHANNELS OF LOCAL DISTRIBUTION SERVICE USING FILTERED PULSE WIDTH MODULATION"

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I. Introduction

The Federal Communications Commission, in supporting the dockets for the "Local Distribution Service" (LDS), has awakened a slumbering billion-dollar giant for cable operators in urban and rural areas. This new air-link, CATV service, provides a communications highway of electromagnetic energy which can accommodate a vast number of services, to fill an array of social needs. LDS will not only be an entertainment and advertising service, important as they are to society, but it will also provide information, education, community awareness, and political expression on an economical basis. LDS, as authorized, not only solves the urban problem, but provides the vehicle for taking existing systems in rural and suburban areas, and allows them to extend their services economically to contiguous small communities, jumping highways, crossing rivers, surmounting terrain barriers, and doing so for a fraction of the cost of cables. To understand one of the techniques proposed for this service, this paper is a full disclosure as to how the Quasi-Laser Link System functions.

II. General Considerations

The Quasi-Laser Link System, incorporating the proprietary technique of Filtered Pulse Width Modulation (FPWM) provides a flexible, economic, and workable means of transmitting multi-channel TV signals in a local distribution system as well as over longer haul systems requiring several hops. The FPWM technique makes possible improvements over systems using other modulation means. It does not have the limitations of Amplitude Modulation (AM) which requires extreme system linearity and lacks noise immunity.

For AM systems, these factors require the use of high power devices in order to obtain moderate linear power outputs, and also require wider physical separation between systems causing poor use of the frequency spectrum - space

geometry product, and place economic hardships on users requiring more than single TV channel transmission.

The Quasi-Laser Link System does its signal processing at low levels and then generates the high level transmitted signal in stages not requiring amplitude linearity so that they can be used at maximum power output and maximum efficiency. It is a system which can be used anywhere in the high frequency domain. The performance when transmitting many channels of TV information in a single transmitter has been demonstrated. System simplicity is best in the higher frequency ranges (millimeter and above) where the possibility of allocating more transmission bandwidth exists; however, much of the advantage of the FPWM technique can still be maintained in the currently allocated bands. Because the FPWM system is able to operate at lower signal-to-noise ratios than less noise immune systems, it makes possible the use of longer point-to-point transmissions or the use of multi-hops.

III. General Technical Considerations

The FPWM transmits as pulse width modulation the composite information content of a number of frequency multiplexed television channels, normally within NTSC standards (Fig. 1). The individual channels from locally generated sources or off the air, are combined and down-converted to the spectral region starting at approximately 6 MHz and extending upwards in frequency in accordance with a number of channels being multiplexed.

Two systems of down conversion have been operated in demonstration links. In one case, the composite of channels 7 - 13 are translated to the frequency band 6 - 48 MHz, with channels 2 - 6 remaining approximately in their present location. In the second approach, each channel is translated on an individual basis to a location appropriate to it. To all intents and purposes, this is identical to the technique employed in sub-band transmission in present CATV cable installations. This combination of frequency multiplexed channels results in an output signal voltage whose instantaneous phase and amplitude is the vector sum of the individual channel signals and contains frequency components equal to the highest frequency in the baseband. This instantaneous voltage is fed to modulator circuitry such as to generate a train of pulses whose width is directly related to the instantaneous voltage.

In one configuration of this system, the pulse width varies from one nanosecond corresponding to the least positive voltage to 0.95 nanoseconds corresponding to the highest possible voltage for the case where three channels of television are in the baseband. For five channels, the pulse width varies from one nanosecond to .9 nanoseconds and for twelve channels from one nanosecond to .84 nanoseconds.

The average pulse spacing is equal to the average pulse width such that the average power in the pulse train closely approximates one half of the peak power. The width of the resultant train of pulses has a one-to-one relationship with the instantaneous voltages. These pulses are then limited to insure they are all of equal amplitude and are used to switch the output of a carrier determining oscillator from the "On" to "Off" stage in accordance with the rise and fall of the pulses. The resultant signal has a spectrum consisting of a carrier, the first upper-side band, the first lower-side band, a second upper-side band, a second lower-side band, etc. The spectrum is then filtered by an appropriate microwave filter structure, such as to pass only the first upper-side band.

For operation in the 12.7 to 12.95 GHz band, the carrier oscillator is at a frequency such that the upper first sideband falls within the authorized band and is centered at the assigned frequency. The signal is further amplified to the required transmitter output level by means of a traveling wave tube of a standard variety.

The radiated spectrum after filtering and amplification consists of a frequency varying signal which results from the pulse-width variation of the first modulation step. This spectrum has the general form and distribution associated with frequency modulation, and transmission of this spectrum is treated in a manner identical with the transmission of a frequency modulated carrier.

Two types of receivers have been used in this system (Fig. 2). In the first type, the received signal is amplified with a tunnel diode amplifier followed by a traveling wave tube, both of which are operating in the transmitter frequency band, with a filter limited bandwidth equal to that of the transmitter output spectrum. A solid state circuit network is then utilized to obtain an instantaneous voltage corresponding to the pulse width of the train of pulses present in the IF. The signal which results is identical to that which was used in the transmitter to produce the original train of pulses. The output signal is the instantaneous vector sum of the frequency multiplexed television band such that a standard VHF television receiver is capable of separating out the signals, and displaying them in a manner identical to that used to receive transmissions along CATV cables.

The second type of receiver consists of a balanced mixer and local oscillator at the input to immediately convert the incoming signal from the transmitter to an intermediate frequency. In this configuration, the receiver noise figure is approximately 6 dB higher than that which has been achieved with a tunnel diode input.

In this system, the signal-to-noise ratio presented at the input to the television receiver is a function of the signal-to-noise carrier, and the variation in the pulse width is used to create the transmitted spectrum. For a given carrier-to-noise ratio, the wider the deviations of the pulse widths, the larger the signal-to-noise ratio presented at the television receiver for each of the television channels. Typical tests links have shown signal-to-noise ratios at the input to the television receiver in excess of 48 dB for carrier-to-noise ratios of 34 dB for 12-channel operation.

IV. Theoretical Considerations

Since FPWM is a spectrum, which is the generalized form of an FM wave, after the first upperside band is filtered out, and amplified for transmission, the resultant signal may be analyzed, as if it were, in effect, FM. The FM formulations derived in the literature can be applied with analyzing this form of transmission.

It is possible to get a better signal-to-noise ratio in an FPWM system than in an AM system with the same transmitter power. To achieve this advantage, however, it is necessary to use a wider range of pulse widths to represent the instantaneous voltages being transmitted. This, of course, requires more bandwidths. The improvement in signal-to-noise ratio, by using wider bandwidths, is obtained by increasing the modulation index:

$$M = \frac{\Delta p}{f_b [4p^2 - (\Delta p)^2]} \quad (1)$$

Where

p = mean pulse width in microseconds

Δp = change in pulse width (max.-min.)

f_b = highest baseband frequency in MHz

With this definition, it is possible to now use formulas associated with frequency modulation to analyze the performance of FPWM. In the following analysis, ΔX is used to define the spectral distribution within the first sideband that is given by the relationship:

$$\Delta X = \frac{\Delta p}{4p^2 - (\Delta p)^2} \quad (2)$$

ΔX corresponds to the peak frequency deviation in ordinary FM.

A. VIDEO SIGNAL-TO-NOISE RATIO

1. Amplitude Modulation

Amplitude Modulation (AM) may be used to transmit video information. A typical video waveform is shown in Fig. 3 with the vertical axis calibrated in terms of carrier amplitude. The video signal is clamped so that the transmitter power is at its maximum power P on the sync tips. The peak white level is then adjusted to 0.143 of the peak voltage.

The video is usually transmitted using vestigial sideband modulation (VSB). Such a system has the same noise performance as a double sideband (DSB) system having the same signal power and noise spectral density, providing the proper VSB filter is chosen. For this situation, the input signal-to-noise ratio in the channel bandwidth will be smaller for the DSB system since its noise bandwidth is larger. The differences of the several possibilities are summarized in Table I. These signal-to-noise ratios are for white noise in the appropriate bandwidth.

2. Frequency Modulation

Frequency Modulation (FM) is frequently used in microwave satellite or point-to-point television transmission systems. The video signal-to-noise ratio for FM is derived in terms of the RF carrier-to-noise ratio.

For an FM system operation above threshold with sinusoidal modulation:

$$(S/N)_{\text{out}} = \frac{3P (\Delta X)^2}{2 N_o (f_m)^3} \quad (3)$$

Where

$(S/N)_{\text{out}}$ = output signal-to-noise ratio

P = received signal power

N_o = (single-sided) noise power spectral density

ΔX = peak pulse width deviation spectrum

f_m = video bandwidth

Note that Eq. (3) does not depend explicitly on the total bandwidth W . However, W must be large enough to pass the FM signal undistorted. Also, $\frac{P}{N_o W}$ must be

large enough so that operation is above threshold. Eq. (3) will now be expressed in terms appropriate to TV transmission.

The video signal power is defined as the peak-to-peak video squared:

$$S_{p-p} = (V_{p-p})^2 \quad (4)$$

This is done because the peak levels are defined by system constraints while averages are dependent on picture content.

Assuming sinusoidal modulation

$$V_{p-p} = 2\sqrt{2} V_{rms} \quad (5)$$

then

$$S_{p-p} = 8V_{rms}^2 = 8S \quad (6)$$

therefore

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 12 \frac{P (\Delta X)^2}{N_o f_m^3} \quad (7)$$

Furthermore, the video signal is clamped so that $f = f_c + \Delta X$ on sync tips, and the deviation is adjusted so that $f = f_c - \Delta X$ for peak white level. Then the peak-to-peak frequency deviation F_{p-p} is:

$$F_{p-p} = 2 \Delta X \quad (8)$$

The minimum bandwidth required at RF (or IF) is then:

$$\begin{aligned} W &= 2 (\Delta X + f_m) = F_{p-p} + 2 f_m \\ &= 2 f_m (1 + M) \end{aligned} \quad (9)$$

where M = modulation index

The input signal-to-noise ratio is then:

$$(S/N)_{in} = \frac{P}{N_o W} = \frac{P}{N_o (F_{p-p} + 2 f_m)} \quad (10)$$

Substituting (8) and (10) in (7) we get:

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 24 M^3 (S/N)_{in} \frac{(F_{p-p})^3}{f_m^3} \left(1 + \frac{2f_m}{F_{p-p}}\right) \quad (11)$$

$$\left(\frac{S_{p-p}}{N}\right)_{out} = 24 M^3 (S/N)_{in} \frac{(1+1)}{M} \quad (2-10) \quad (12)$$

If the input signal-to-noise (SNR) is referred to the information (video) bandwidth rather than the RF bandwidth:

$$(S/N)_{in} = (M + 1) (S/N)_{in} \quad (13)$$

(video
bandwidth)

then

$$\left(\frac{S_{p-p}}{N} \right)_{out} = 24 M^2 (S/N)_{in} \quad (14)$$

(video bandwidth)

The output signal-to-noise ratios are for peak-to-peak video waveforms and unweighted "triangular" noise spectrum. They differ by a factor of eight from standard results because of the different definition of signal power.

3. Sample Calculation

FM

Let us calculate the "worst case" (in the highest channel) unweighted output signal-to-noise ratio of a 12 channel FM multiplexed television link operating at 12 GHz, with a bandwidth of 250 MHz and a transmitter power of $\frac{10}{12}$ watts per channel:

$$N_o = \frac{-194 \text{ dB.W}}{\text{Hz}} \quad (10 \text{ dB Receiver Noise Figure})$$

$$W = 250 \text{ MHz}$$

$$\Delta X = 47 \text{ MHz}$$

$$f_m = 78 \text{ MHz}$$

$$P_t = \frac{10}{12} \text{ W/channel} \times 12 \text{ channels} = 10 \text{ W}$$

$$G_t = 35 \text{ dB transmitting antenna gain}$$

$$G_r = 35 \text{ dB receiving antenna gain}$$

$$L_p = 145 \text{ dB, path loss}$$

where

$$\begin{aligned}
 P_r &= P_t + G_t - L_p + G_r \text{ (in dB)} \\
 P_r &= +10 \text{ dBW} + 35 \text{ dB} - 145 + 35 \text{ dB} \\
 P_r &= -65 \text{ dBW} \\
 N_o &= -194 \frac{\text{dBW}}{\text{Hz}} + \frac{84 \text{ dB}}{(250 \text{ MHz})} = -110 \text{ dBW} \\
 M &= \frac{47}{78} = 0.6
 \end{aligned}$$

$$\left(\frac{S_{p-p}}{N} \right)_{\text{out unweighted}} = 24M^2 \frac{(S)}{(N)}_{\text{in}}$$

$$\left(\frac{S_{p-p}}{N} \right)_{\text{out}} = 24 (0.6)^2 \frac{(S)}{(N)}_{\text{in}} = 8.7 \frac{(S)}{(N)}_{\text{in}}$$

$$\begin{aligned}
 \left(\frac{S_{p-p}}{N} \right)_{\text{out}} &= S_{\text{in}} - N_{\text{in}} + 10 \log 8.7 \\
 &= -65 \text{ dBW} + 110 \text{ dBW} + 9.4 \text{ dB} \\
 &= 54.4 \text{ dB}
 \end{aligned}$$

If a 30 dB fade occurred the SNR would still be 25 dB -- quite an acceptable level for many observers.

Now let us calculate the performance of an AM system with single channel capability (6GHz bandwidth).

AM (VSB)

$$\begin{aligned}
 N_o &= -194 \frac{\text{dBW}}{\text{Hz}} \\
 W &= 6 \text{ MHz} \\
 P_t &= \frac{10}{12} \text{ w/channel} \times 1 \text{ channel} = 1 \text{ W} \\
 P_r &= P_t + G_t - L + G_r \text{ (in dB)} \\
 &= +0 \text{ dBW} + 35 - 145 + 35 = -75 \text{ dBW} \\
 N_o &= -194 + \frac{68 \text{ dB}}{6 \text{ MHz}} = -126 \text{ dBW}
 \end{aligned}$$

$$\left(\frac{S}{N}\right)_{\text{out unweighted}} = -75 + 126 = 51 \text{ dB}$$

IV. Theoretical Conclusions

Using the special definition of SNR for video modulated FPWM systems, even a modest modulation index (0.6) has been shown to produce a 3 dB advantage over a vestigial sideband single channel AM system. Additionally, we have calculated the unweighted (triangular) signal-to-noise ratio which puts the FPWM system at a disadvantage since most of the FPWM noise contribution is at high frequencies. Subjectively high frequency noise is much more tolerable to the average observer so that an additional 4 to 10 dB can be claimed for FPWM, depending on which weighting networks are used in making the comparison. Since AM noise is flat, the weighting network has little effect on system SNR.

We believe we have demonstrated that a 12 channel multiplexed FPWM system with an M of 0.6 can match the performance of a single channel AM system. The obvious equipment simplicity of a multiplex arrangement as opposed to a channel-by-channel transmission method cannot be overlooked. Furthermore, the entire question of amplitude linearity in point-to-point microwave radio systems is so overriding that AM has not been seriously considered heretofore even where it might appear to provide improved performance or reduced bandwidth.

In this type of system, the cross-modulation resulting from the link is a function of the symmetry of the modulation and the demodulation circuitry. If the translation from instantaneous voltage to pulse width is the identical conjugate of the translation from pulse width to instantaneous voltage, the cross modulation at the receiver will be identical to that achieved by combining the television channels in the frequency multiplexing circuitry. This has been shown to be the situation for the case where the television channels are translated into the sub-band, and then translated back at the receiving end. For these channels, the cross-modulation measured, when the down-converter is connected directly to the up-converter, is identical to that measured when the intervening air link is inserted into the system. The cross modulation was measured using the NCTA standard method of square wave modulated carriers. For channels 2 - 6, the cross-modulation was less than -60 dB, which was the limit of the measuring equipment.

The FPWM system must be measured for its cross-modulation as a total link, including the "On-Off" switching which is used to drive the carrier oscillator. As a result, the ability to measure the cross-modulation is limited by the maximum signal-to-noise ratio, which can be achieved in the overall system.

With available components, this limit is 60 dB. As a result, the square waves which must be detected on the unmodulated channel carrier are less than the residual noise level, and can therefore not be measured. Specialized instrumentation to probe into the noise to measure the residual cross-modulation is currently under investigation.

For multi-hop systems, required increase in signal level or antenna gain is a function of the number of hops in the identical manner to that of a standard FM network. Since no modulation or demodulation is required in the intermediate link of the network, the cross-modulation remains unchanged for a multi-hop link.

Pre-emphasis of the frequency multiplexed baseband signal can be used to equalize the signal-to-noise ratios at the television receiver. In one 12-channel configuration, the equalization was adjusted such that a signal-to-noise ratio of 54 dB was achieved at both ends of the baseband, such that even the highest up-converted signals in the normal VHF television band (channel 13) all met this signal-to-noise ratio level.

V. System Description

A. Quasi-Laser Link Transmitter (Fig. 1)

The Quasi-Laser Link transmitter has two principal sub-systems. They are a signal compiler, and a pulse-width modulator.

1. Signal Compiler

The function of the signal compiler is to accept VHF, UHF or internally generated video signals and frequency translate them into sub-band channels starting between 5 and 6 MHz. If it is desired to transmit for example 10 TV channels, then the modulation signal will occupy the frequency range from 6 to 66 MHz. The output of the signal compiler is the sum of individual signal voltages in each channel:

$$\begin{aligned} (1) \quad v_o(t) &= v_1(t) + v_2(t) + \dots + v_n(t) \\ (2) \quad v_o(t) &= \sum_{n=1}^n v_n(t) \end{aligned}$$

where v_n has the form:

$$(3) \quad v_n = v_{cn} \cos W_{cn} t \quad v_m(t)$$

when $v_{cn} \cos W_{cn} t$ is the translated carrier in channel n and $v_m(t)$ is the corresponding composite modulating waveform including video and sound. The output of the signal compiler is applied to the pulse generating circuitry of the modulator.

2. Pulse-Width Modulator

The instantaneous pulse-width is determined by the instantaneous applied control voltage. Ideally, the characteristic is such that a change in the control voltage will cause a proportional departure from the average pulse-width. This can be expressed as:

$$(4) K_v(t) = \frac{1}{T(t)} \quad \text{where} \quad \text{is pulse-width}$$

Within the deviation region where the relationship holds the output pulse-width will exactly follow the output voltage variations of the signal compiler. The calculation of the exact spectrum produced is extremely difficult because of the random nature of the signals in each channel.

The pulse-width modulated train is used to key (switch "On-Off") the carrier determining oscillator. The result of this keying is a train of microwave signals which are pulse width modulated. The spectrum which results from this processing consists of a carrier, and a pair of first sidebands. Then there are higher order sidebands which are harmonics of the first sidebands and are a result of the pulse modulation. Fortunately, all of the information contained in the modulating wave is present in either the upper or lower first sideband (they are really exact replicas of the modulating spectrum) so that only one first sideband needs to be transmitted. It is not even necessary to send the carrier wave, although this does result in equipment simplification in the receiver. The name Filtered Pulse Width Modulation comes from the ability to filter out redundant or unnecessary modulation products and still retain the essential information for faithful reproduction of the input television signals at the system output. The filtering is accomplished before and in the TWT amplifier, so that the transmitted signal is the first upper sideband.

B. Quasi-Laser Link Receiver (Fig. 2)

A typical Quasi-Laser Link receiver configuration consists of a local oscillator, mixer and IF amplifier. The received signal is fed to the first detector circuit where it is translated to an intermediate frequency by mixing it with a locally generated signal such that the transmitted signal which is single-sideband suppressed-carrier, appears in the IF band. The first detector output is a frequency modulated wave whose average frequency is centered in the IF band. The signal is amplified, limited, and then applied to a demodulator, the output of which is the multiplexed television signal formed in the signal compiler of the transmitter.

The function of the receiver's de-compiler is to filter and frequency translate these signals to their required locations in the VHF television channel allocations for transmission over cable distribution systems.

VI. Experimental Results

The experimental evaluation of the FPWM technique has been conducted under experimental authorization KB2XFL and KB2XGW issued to Chromalloy American Corporation. As was noted in an earlier report ¹, tests were performed at all the assigned frequencies, 18.5 GHz, 30.0 GHz, 39.3 GHz, and 42 GHz.

The tests confirmed the expectation that the FPWM technique is carrier frequency insensitive, performing in essentially the same manner at all four frequencies. The major test effort was then conducted at 18.5 GHz.

The overall performance of the system, when transmitting multiple TV channels such as in the LDS application, was evaluated. Television channels 7-13 were down-converted in the transmitter compiler from their regularly assigned frequencies to the sub-band frequencies indicated. They were up-converted in the receiver decompiler back to their regular frequencies for reinsertion into the distribution system.

Experiments on the test link were also made using the TV channels on frequency (no down-conversion & up-conversion). When the seven New York TV channels (covering a frequency band of 54-216 MHz) were used, the pulse-width modulation occupied a bandwidth of 1 GHz.

Other tests were made to determine the output signal quality under varying combinations of multiple channel transmission. The video signal-to-noise ratio at the output of the FPWM system is the measure of system quality. The signal level is that of the carrier only, and the noise is the sum of the idle noise and intermodulation products. The experimental receiver always used a full 500 MHz bandwidth so that it could receive full spectrum transmission. For the limited bandwidth tests, an improvement in carrier-to-noise ratio (C/N) could have been achieved by reducing the receiver bandwidth to that required for the spectrum being transmitted.

The output signal-to-noise ratio is dependent upon the input signal-to-noise ratio and the length of the transmission path.

The FPWM technique is capable of producing a 20 dB improvement in the detected video S/N ratio over the C/N ratio at the input to the receiver. Operation was simulated for different ranges by means of suitable attenuators. The data taken for a carrier-to-noise ratio at the receiver of 34 dB (equivalent to 15 miles range) was better than 48 dB for 12-channel operation.

¹/Appendix B of Petition for Reconsideration in Part in the matter of Amendment of Part 74, Subpart J, of the Commission's Rules and Regulations Relative to Community Antenna Relay Stations.

It should be noted that even at a carrier-to-noise ratio of 19 dB, all the signals are marginally acceptable or better. When the received signal is increased to produce a C/N of 34 dB, all twelve channel outputs are providing excellent picture quality. At C/N of 46 dB, even better quality pictures are feasible.

A. Other Experimental Results: The seven New York TV channels, covering a frequency band of 54 through 216 MHz were transmitted in place with good picture quality being maintained. In order to make a more stringent evaluation, five channels of video programming were combined to form the wide spectrum signal. The VHF-TV channels 2, 4, and 5 were used directly, and VHF-TV channels 9 and 11 were translated into the slots for channels 3 and 6 respectively. The detected signal-to-noise ratio at the input to the TV set for each channel is tabulated below. The signal measured was that of the carrier only. The noise level was the highest level in the channel, determined by searching the band with a field strength meter. The noise measured is the total of idle noise plus cross-modulation, and as such results in the poorest ratio in each channel.

TV Channel	S/N + x mod.	
2	45.2 dB	
3*	47.0 dB	*Channel 9 translated
4	45.0 dB	**Channel 11 translated
5	47.5 dB	
6**	48.0 dB	

The experimental results indicate a significant fade margin available insuring satisfactory operation during adverse weather conditions.

From extensive tests under varying atmospheric conditions, it was determined that the FPWM technique is not frequency sensitive, giving essentially the same performance at the four assigned frequencies. It was therefore decided to concentrate the experimental effort at 18.5 GHz. A new air link was established over a 1.5 mile line of sight path. The transmitter was located at The New York Times printing plant at 64th Street and West End Avenue, and the receiving site was in The Times Tower at 43rd Street and Broadway in New York City. This link was maintained over a period from May, 1969 through November, 1969, logging a total of 750 hours of operation.

In this instance, three channels of video information were transmitted by multiplexing VHF-TV channels 2, 4 and 5 directly. The input signals were adjusted to produce identical output signal-to-noise ratios at the input to the TV sets, and the detected signal-to-noise ratios in the three channels are shown below. The measurements were made in the same manner as described previously:

TV Channel	S/N + mod.
2	57 dB
4	57 dB
5	57 dB

The transmitter TWT amplifier had a power output of 1 Watt. Both the transmitting and receiving antennas were 3' parabolic dishes. This combination results in a range capability far in excess of the 1.5 mile path length. The effective path length was increased to 15 miles by use of attenuators. Because of the advantage of the Filtered Pulse Width Modulation technique in the presence of noise and fading, this link continually performed in a satisfactory manner. Transmission maintained during major rainfalls resulted in no degradation in the received picture quality, including September 3, 1969 when the rainfall during the 24-hour period exceeded 3.32 inches.

Other combinations of channels are shown in Table III.

Table IV shows the variation in signal-to-noise ratio as a function of time of day, and shows a comparison of the performance of the headend equipment with down-converter when fed directly to the up-converter receiving equipment, and the resultant performance a short time later through the Quasi-Laser Link System. Typical spectrums are shown in Figures 4 and 5.

While all the foregoing data reflects a system test with only 12 channels, earlier tests have been run with as many as 32 channels. Based on these results, 18 channels of CATV is compatible with all the presently allocated bandwidths for LDS.

VII. Conclusion

The system we have described has complete versatility, and removes the lid on the number of services and applications possible in a locality; all beamed to rooftop, down-converter, and then, by intra-building or inter-home cabling, into existing black and white or color television receivers.

Systems like the Quasi-Laser Link give promise to a bright new prosperous era for television service. It is for those of us within the industry with vision to harness the potential of the Local Distribution Service, and bring it to fruition.

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TABLE I

SNR for AM Television Systems

Modulation	Channel Bandwidth W	$(S/N)_{in}$	$(S/N)_{out}$	$\frac{(S/N)_{out}}{(S/N)_{in}}$
DSB	$2f_m$	$\frac{p}{2N_o f_m}$	$\frac{p}{N_o f_m}$	2
VSB	$f_m + \Delta$	$\frac{p}{N_o (f_m + \Delta)}$	$\frac{p}{N_o f_m}$	$1 + \frac{\Delta}{f_m}$
SSB	f_m	$\frac{p}{N_o f_m}$	$\frac{p}{N_o f_m}$	1

where:

 f_m = Video bandwidth p = Signal power (peak RF or video power, including the white-level d.c. offset) Δ = Bandwidth of the vestigial sideband N_o = Single-sided noise power density W = Channel bandwidth

TV CHANNEL	ORIGINAL FREQ. IN MHz	CONVERTED FREQ. IN MHz	S/N AT INPUT TO TV SET			
			C/N-19 db	C/N-34 db	C/N-34db equalized	C/N-46 db
2	54-60	54-60	27	43	48.5	70
3	60-66	60-66	27.5	46	48.5	61
4	66-72	66-72	26	44	49.0	58
5	76-82	76-82	23	41	54.0	69
6	82-88	82-88	23	41	53.0	53
7	174-180	5.75-11.75	30	41	46.0	50
8	180-186	11.75-17.75	23	40	46.5	50
9	186-192	17.75-23.75	23	43	47.0	53
10	192-198	23.75-29.75	25	43	45.0	50
11	198-204	29.75-35.75	20	40	46.0	52
12	204-210	35.75-41.75	29	45.5	46.5	50
13	210-216	41.75-47.75	30	41	47.0	51

TABLE II INDIVIDUAL CHANNEL OUTPUT S/N RATIO FOR DIFFERENT C/N RATIOS MEASUREMENTS FOR EACH C/N RATIO MADE AT DIFFERENT TIMES.

NUMBER OF CHANNELS TRANS.	INPUT C/N dB	TV CHAN.	FREQUENCY MHz	OUTPUT VIDEO S/N Db
2	46	5 6	76-82 82-88	56 60
3	46	2 3 4	54-60 60-66 66-72	55 55.5 57
3	46	11 12 13	29.75-35.75 35.75-41.75 41.75-47.75	49 49.5 49.5
3	46	10 11 12	23.75-29.75 29.75-35.75 35.75-41.75	49 49.5 51.5
3	46	9 10 11	17.75-23.75 23.75-29.75 29.75-35.75	52 51.5 52
5	46	2 3 4 5 6	54-60 60-66 66-72 76-82 82-88	59 56 54 54.5 56
5	46	9 10 11 12 13	17.75-23.75 23.75-29.75 29.75-35.75 35.75-41.75 41.75-47.75	47.5 46 44 44 48
6	46	2 3 4 5 6 7	54-60 60-66 66-72 76-82 82-88 174-180	50 48 45 46.5 44.5 47

Receiver band width 500 MHz

TABLE III OUTPUT VIDEO S/N RATIO FOR VARIOUS COMPILE COMBINATIONS

HEADEND EQUIPMENT

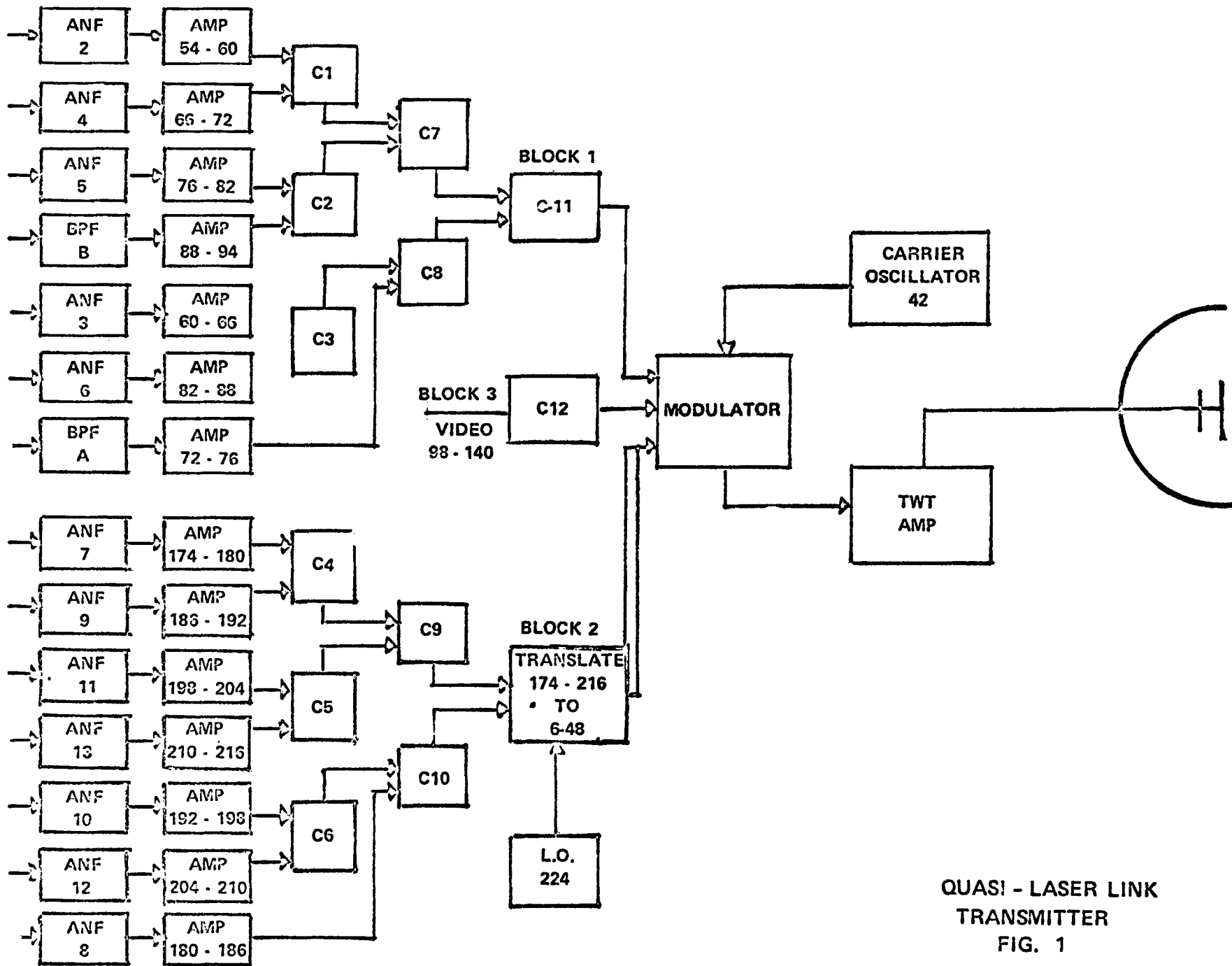
QLL SYSTEM

CHANNEL NO.	TEST 1 S/N	TEST 2 S/N	TEST 1 S/N	TEST 2 S/N
2	52	60	48	52
3	53	60	48	53
4	61	64	50	61
5	56	63	50.5	56
6	54	60	53	54
7	51	54	44	54
8	54	55	43	54
9	52	55	47	52
10	48	54	46	48
11	49	52	46	49
12	47	54.5	46	47
13	51	55	50	51

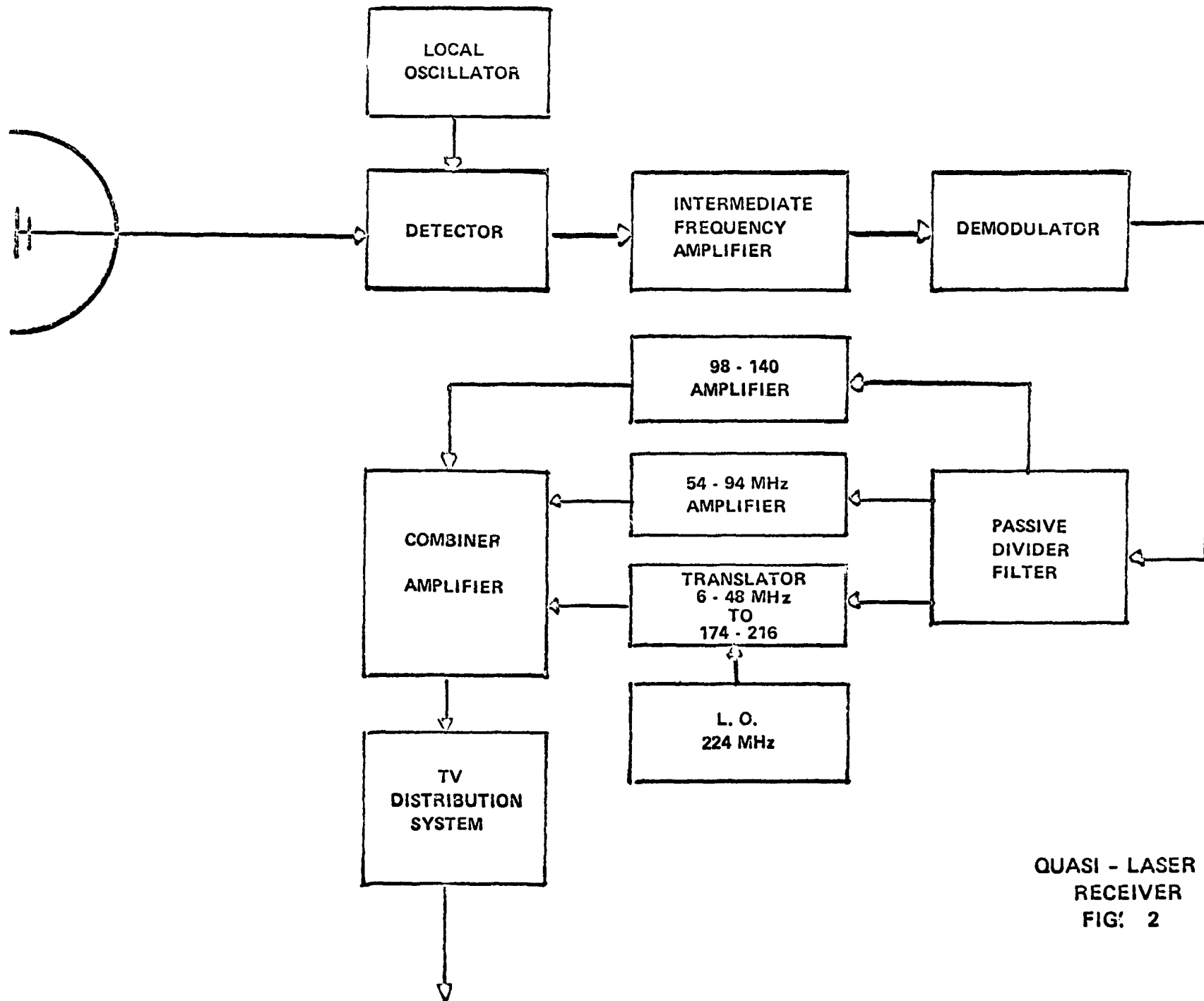
Subband

C/N for QLL = 33db

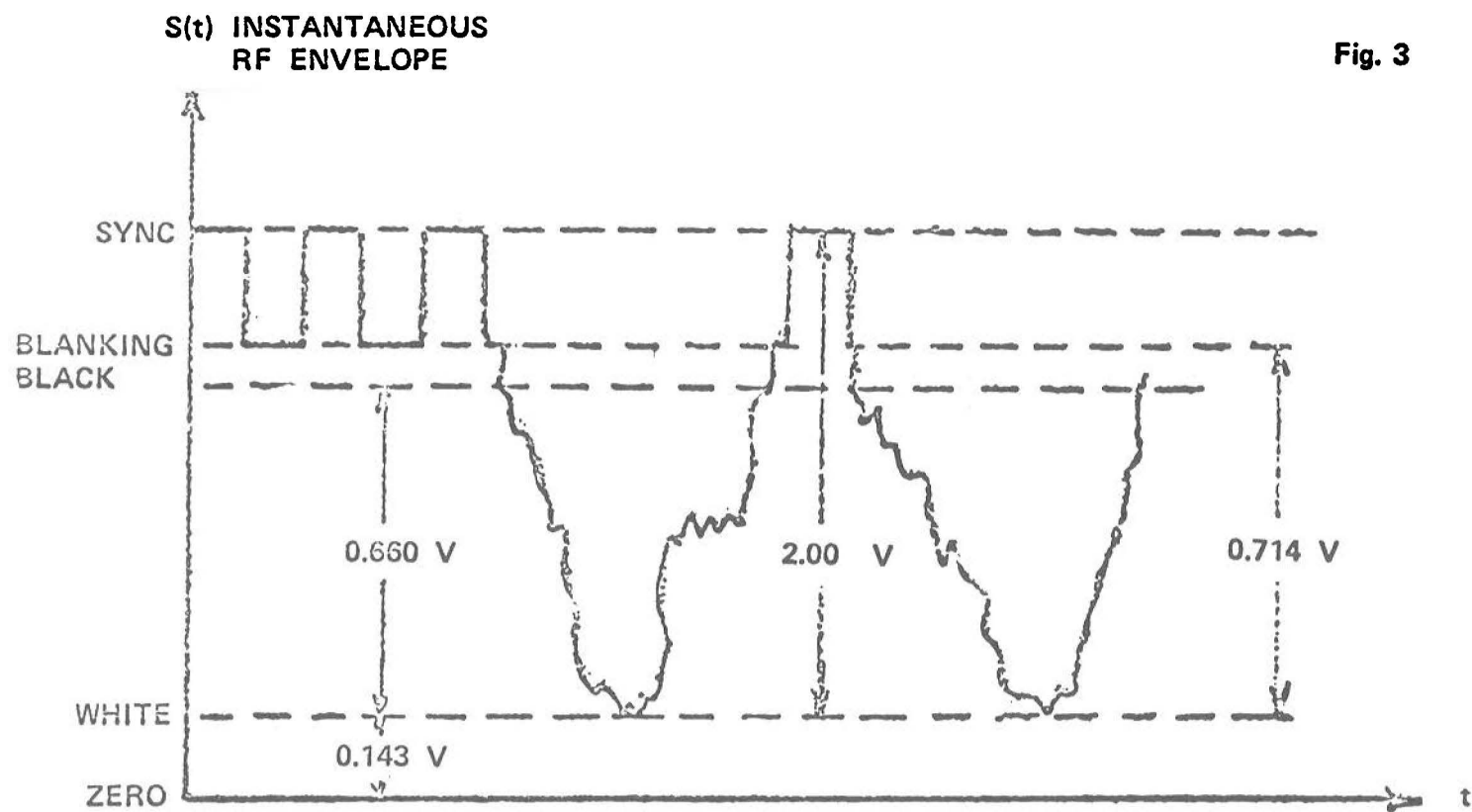
TABLE IV COMPARISON OF HEAD END AND QLL PERFORMANCE



QUASI - LASER LINK
TRANSMITTER
FIG. 1



QUASI - LASER LINK
RECEIVER
FIG. 2



NOTE:- Amplitudes Refer to Video Modulating Voltage
and is Normally 1.0 volts Peak to Peak

FIG. 3 - Television composite signal waveform, amplitude modulation.

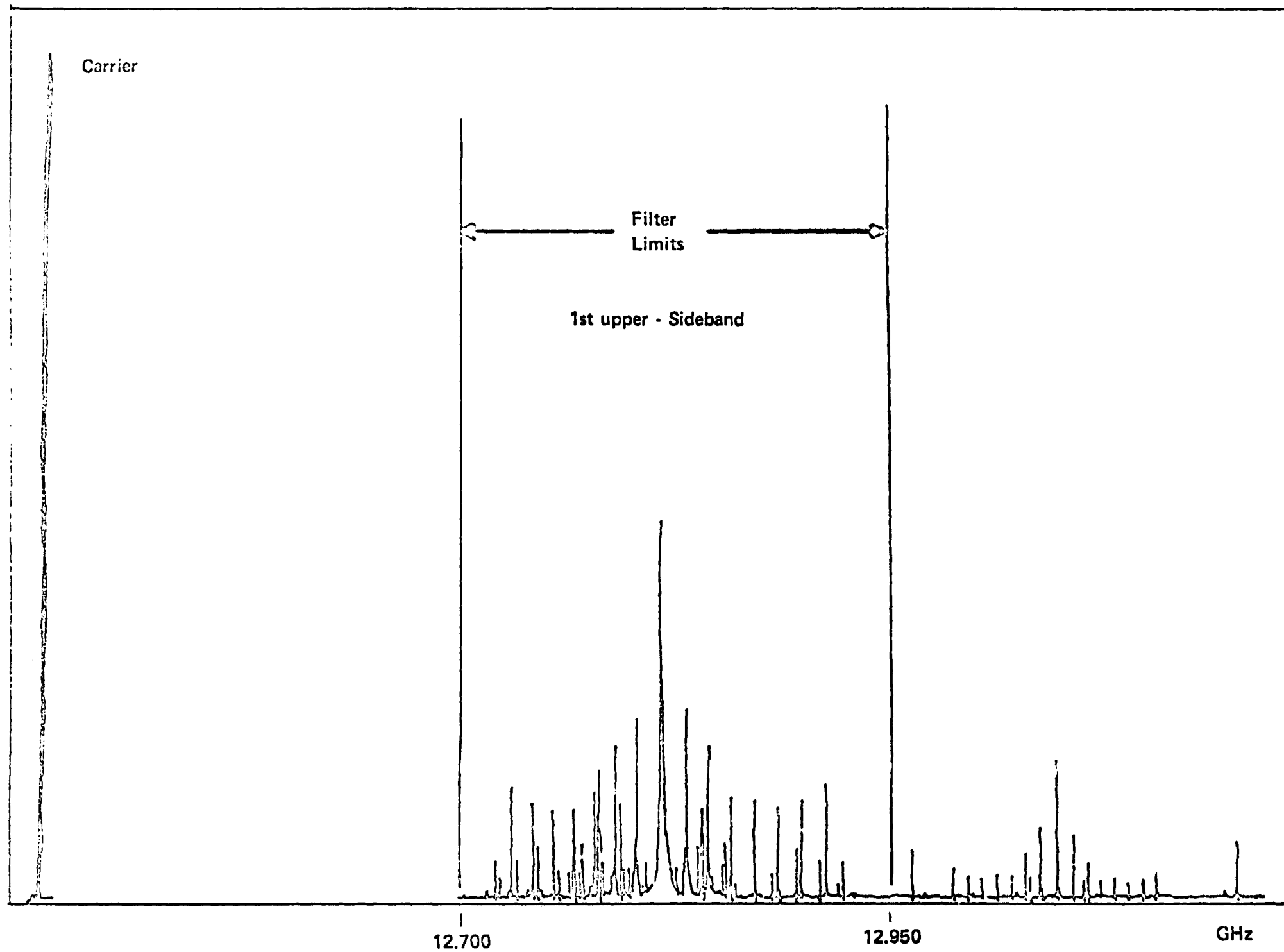


Fig 4 - Upper Half of Pulse Width Modulated Spectrum

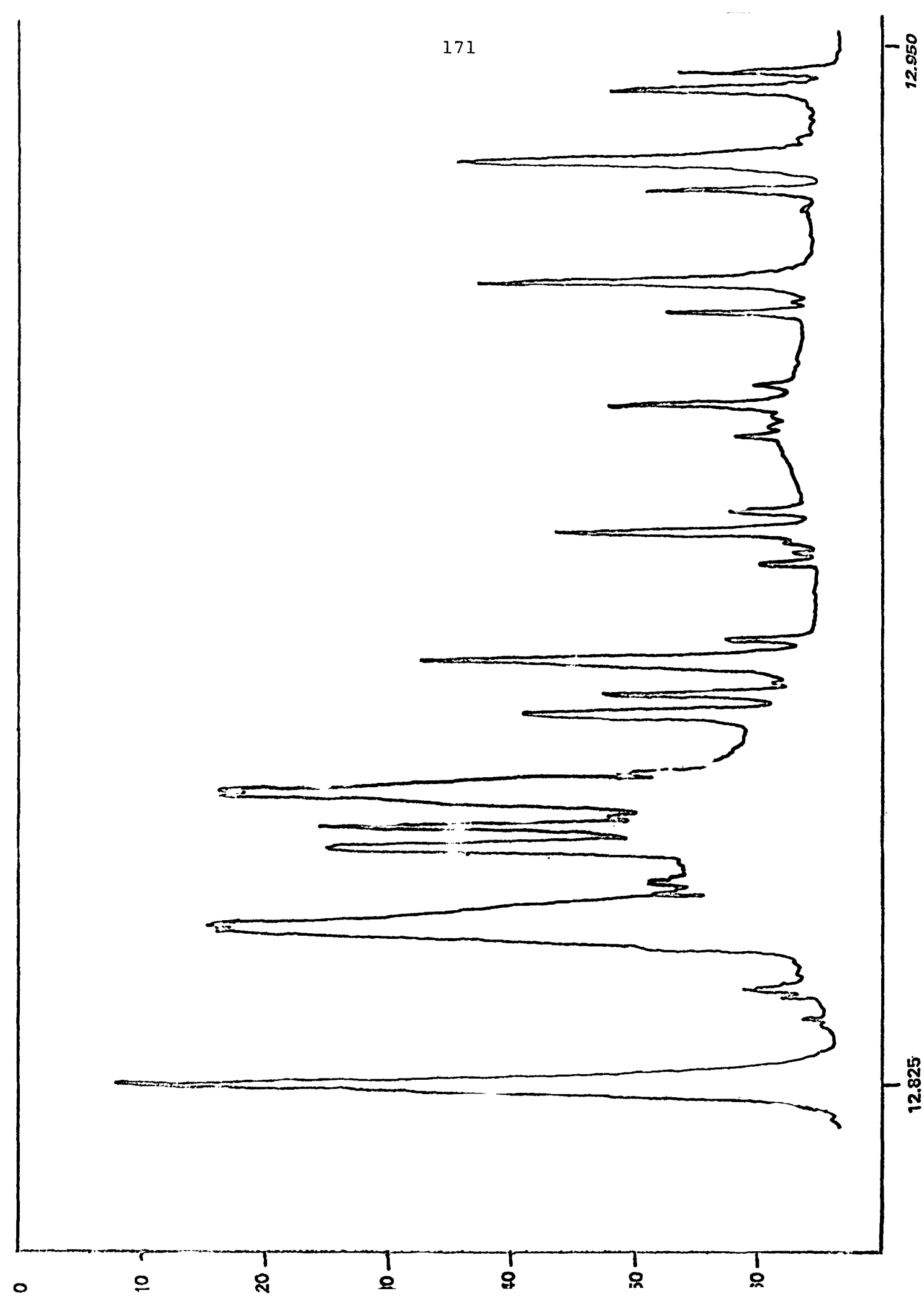


Fig. 5 - Upper Half of First Sideband FPMW Spectrum

DISCUSSION

Dr. Vogelman: Any questions?

Mr. Hub Schlafly: Hub Schlafly, TelePrompter. I have two questions. One is the data that you presented data that is equivalent to the proposed rulemaking at the Commission--is that equivalent to the system that has been identified in the proposed rulemaking as in terms of modulating bandwidth and RF bandwidth?

Dr. Vogelman: This all fits into 250 megahertz but is done at $18\frac{1}{2}$ gigahertz.

Mr. Schlafly: So it was a 12 channel system in a RF bandwidth of 250 megahertz.

Dr. Vogelman: 250 megahertz, but at $18\frac{1}{2}$ gigahertz.

Mr. Schlafly: What is the index of modulation of the multiplex (tape fadeout) signal as the Commission calls it--that first side band? Do you have a figure on that?

Dr. Vogelman: Well, I can tell you what the variation in widths are. The variations in widths run about 16%. In other words, the fattest to the thinnest pulse is 16%.

Mr. Schlafly: I understand the variations. That would be restricted in order to get the information into the 250 megacycles of CARS bandwidth.

Dr. Vogelman: Right.

Mr. Schlafly: But do you have a figure of what that modulation is or what the modulation index is because that's really the factor that determines performance, is it not, in an FM system?

Dr. Vogelman: Well, it depends on how you define this in terms, I don't know how you translate quickly from one to the other, but I would guess that if you have a base band which is 72 megahertz wide using Carson's Rule this index of modulation is about .8.

Mr. Schlafly: I applied Carson's Rule. I'm not sure that that applies on low index modulation FM systems. But if I took 114 megahertz, as you have indicated, to the Commission and FM

multiplex set for 250 megahertz RF spectrum, I come out with about 0.1 index of modulation.

Dr. Vogelman: If that signal were noise, you're right. But it's not.

Mr. Schlafly: Okay, thank you.