NOISE MEASUREMENTS FOR A CATV SYSTEM-C/N,S/N,Phase Noise

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INTRODUCTION

A study of the theoretical calculations of noise in a CATV system and the methods to measure the noises is presented.

This paper is focused on the effect of phase noise on the signal-to-noise ratio (S/N). It is well known that excessive phase noise will degrade the S/N but lack of understanding of the exact relationship between phase noise and S/N causes unneccessary confusion about the importance of phase noise. It is the purpose of this paper to clarify the significance of phase noise and provide a detailed calculation and measurement method for phase noise and its conversion to S/N.

I. CARRIER-TO-NOISE-RATIO

Carrier-to-noise ratio (C/N) is defined as the power ratio of the unmodulated carrier to the noise in the communication channel. In the CATV system, the noise is mainly white noise (thermal noise). The white noise of each component of the CATV system will accumulate when they are cascaded. To specify the degree of noise containmination of a piece of equipment, the term Noise Factor (f) is used. The f of a piece of equipment represents the increase in C/N of a signal which passes through that equipment. The f can be written as follows:

$$f = \frac{C/N\ (output)}{C/N\ (input)} \qquad [eq.1]$$

Note that the f and C/N's in eq. 1 are numerical ratios. If a system is noiseless, then the f will be 1. Noise factor f should not be confused with the noise figure F which is defined as the logrithm of noise factor F = 10* log (f) and is specified in db. Noise figure is more familiar than noise factor but for most noise power calculations noise factor is more practical.

It is often more convenient to use the term "equivalent input noise" to describe the noise contribution. The noise at the output of a piece of equipment is contributed by the noise accompaning the input signal plus the noise generated by the equipment itself. The self-generated noise can be treated as a kind of noise that occurs at the input of the equipment and the equipment is treated as noiseless. In this way, the output C/N can be calculated easily once the equivalent input noise is known. The equivalent input noise (Pn) is given by : (note 1)

$$Pn = Pn(in) + (f-1)kTB \qquad [eq.2]$$

where Pn (in) is the power of the noise that accompanies the signal, f is the noise factor of the equipment, K is the Boltzmann constant (1.38E-23), T is the absolute temperature (290 at room temperature) and B is the bandwidth (4 Mhz for standard baseband video).

Note that eq. 2 is a formula for noise power addition so that both the input noise power and the noise power generated by the noise factor should have the dimension of watts instead of dbmv or dbm.

Table 1 provides a conversion for dBmV (dB relative to one millivolt at 75 ohms) and watts. Table 2 is the conversion for noise factor and watts.

The idea of equivalent input noise is very helpful to calculate the C/N. For example, suppose the input signal level is +30dBmV and C/N is 70dB and this signal is going through an equipment with 10 db Noise Figure and we want to know the C/N at the output.

First the signal power of +30dbmv is calculated as 13.33 uW, the noise power of -40dbmv is calculated as 1.333 pW. The noise generated by the 10 db noise figure is equal to 0.144 pW so that the total input noise is 1.477 pW and C/N at output is 69.6dB.

If the noise figure is increased to 30dB, the equivalent noise power will be 16 pW, the total noise becomes 17.33 pW and C/N becomes 59 dB.

If the input C/N is 50dB, in other words, input noise power is 133 pW; the output C/N will be also 50 dB when the noise figure is 10 dB and 49.5 dB when the noise figure is 30dB.

Compared with the other noise parameters, C/N is relatively easy to measure. A spectrum analyzer or signal level meter can do the job with good accuracy.

A sophisticated spectrum analyzer such as the HP8568B is especially convenient for C/N measurement. The noise floor level can be automatically measured in 1Hz resolution with no need for IF filter, detector response and LOG amp correction. However, the spectrum analyzer noise floor correction is needed when the noise floor measured is less than 10 dB above the noise floor of the spectrum analyzer. This correction is required not just for spectrum analyzers, but for all RF level measuring equipment when used to measure equipments with low noise floor levels like headend modulators.

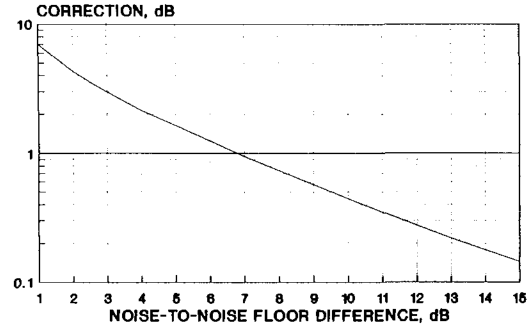
To determine the correction factor, the difference of noise floor level with and without the equipment under test should be measured. The correction factor can be read from the noise floor correction chart in figure 1. If the noise floor difference is less than 3 dB, in other words, the signal being tested has lower noise than the spectrum analyzer, a low noise pre-amplifier should be used to boost the signal level or the input attenuation of the spectrum analyzer should be reduced. However, care must be taken not to overdrive the analyzer or meter as the resulting compression can produce an artificially low reading.

The noise power measured in a 1 Hz bandwidth should be converted to 4 Mhz video bandwidth. The conversion is 10* log (4000000) which is equal to 66 dB. The C/N, in dB, can be calculated as follows:

C/N = carrier level - noise level (dbmv/Hz) - 66 + correlation [eq. 3]

FIGURE 1

CORRECTION CHART FOR NOISE FLOOR



For example, a typical Jerrold C5M modulator output at CH 2 is to be measured for C/N. As shown in figure 2, the carrier level is 58 dBmv and the noise floor level is -75.6 dbmv. The noise floor level difference is only 7 db so that a correction factor of 0.9 dB is needed. The C/N is calculated as follows:

C/N = 58 - (-75.6) - 66 + 0.9 = 68.5 dB

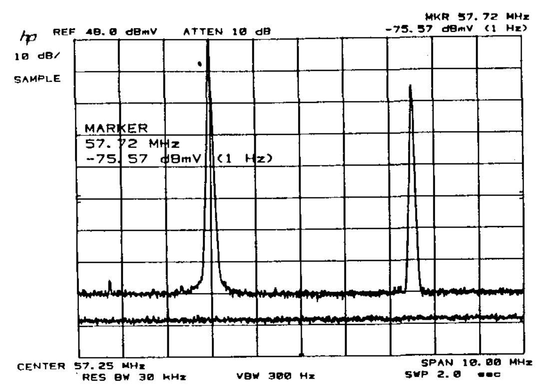


FIGURE 2

C/N MEASUREMENT FOR C5M

The C/N measurement is a very straightforward and accurate way to determines the degree of containmination of the carrier after passing through a system or a piece of equipment. But for the person who receives the signal at the end of the communication system, it is the quality of the video signal, instead of the carrier, that is of concern. In other words, video signal-to-noise ratio (S/N), instead of C/N, should be used to judge the performance of the system. Fortunately, since the carrier is AM modulated by the video signal, the noise floor is directly converted to baseband video noise so that we are able to calculate the S/N from the C/N. The conversion of C/N to S/N needs to be corrected , however, if phase noise prevails. This will be discussed in the following section.

II. SIGNAL-TO-NOISE-RATIO

A carrier modulated to 87.5% by a 100 IRE flat field video signal is shown in figure 3. It is clear that the full power of the carrier only occurs during the sync period while the video signal is carried at a lower power level. For a 100 IRE flat field signal the carrier power for the video is only 12.5% of the full power carrier . This is the case because the synchronization signal is more important than the video signal. If a picture can not be synchronized, it can not be watched no matter how clean the video signal is. It is also the reason that positive sync instead of negative sync is adopted.

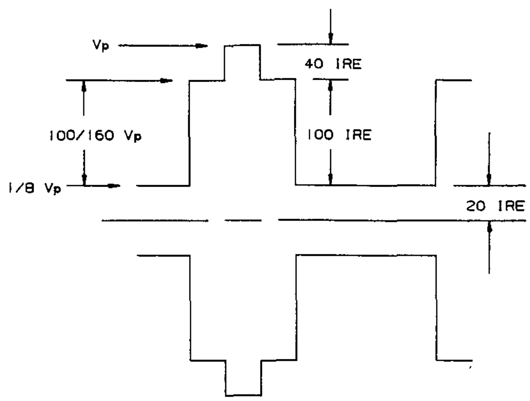


FIGURE 3
100 IRE FLAT FIELD MODULATION 87.5%

It is evident that the C/N measurement, which measures the full power carrier vs. noise, will yield a higher value than the S/N measurement which measures a fraction of the full carrier power vs. the same noise.

In order to calculate the equivalent signal-to-noise ratio, it is assumed that the signal level to the TV demodulator is high enough to overcome the noise figure of the TV tuner so that the noise contributed by the demodulator is negligible. It is further assumed that the Nyquist slope of the demodulator is accurate so that the 6 Mhz RF channel is equivalent to a 4 Mhz baseband video channel. These assumptions are valid in most cases. Assume also that the noise in the RF channel is white noise only and the phase noise of the carrier is low enough not to affect the measurement.

Suppose the carrier peak level is Vp and the noise power is Pn, the Carrier to RMS noise ratio (C/N), by definition, can be written as:

$$C/N = 10 * \log\left(\frac{Vp*Vp/2}{Vn*Vn}\right) \qquad \text{[eq.4]}$$

The video S/N is defined as the ratio of the 100 IRE video level to the rms noise level. In a 75 ohm system, it is equivalent to the ratio of the peak-to-peak power of 100 IRE video level to the rms noise power. As in figure 3, the peak carrier level is 160 IRE which is equal to 8/7 * (100 IRE + 40 IRE). So the video level is equal to Vp*100/160 and S/N is

$$S/N=10 * \log\left(\frac{Vp^2 * (100/160)^2}{Vn^2}\right) \qquad \text{[eq.5]}$$

so that

$$C/N=S/N + 10* \log\left((160^2 / 100^2)*2\right)=S/N + 7.1 \text{ dB} \qquad \text{[eq. 6]}$$

According to the NTC-7 video test standard (note 4), three filters are needed for video noise measurement. Two filters, the 4.2 Mhz low-pass filter and the 10 Khz high-pass filter, must be in use at all times. The noise power measured with only these two filters is called the unweighted noise. A weighting filter, which simulates the visual response of human eyes to white noise, may be used and the noise measured with the weighting filter is called the luminance weighted noise. Noise below 10 Khz, like hums, is usually periodic and should be measured as peak-to-peak. This type of low frequency periodic noise is treated seperately from the random white noise.

It should be noted that the S/N calculated in eq. 6 is unweighted. With a luminance weighting filter, the S/N is improved by 6.8 dB from the unweighted S/N (note 2). As a result, C/N is almost equal to S/N with a weighting filter.

$$C/N = S/N \text{ (luminance weighted)} + 0.3\text{dB} \qquad \text{[eq.7]}$$

Eq. 7 is based on the assumption that the RF noise sidebands above and below the picture carrier are coherent so that they add directly. For a CATV modulator, the RF noise floor is normally much lower than that of typical video sources so that the modulated RF noise sidebands are coherent. In such a case, equation 7 accurately relates C/N and S/N. In cases where the noise phase is not coherent above and below the picture carrier, as with broadband distribution system noise, the equation is modified to

C/N = S/N (luminance weighted) [eq.7a]

Refer to the paper described in Note 2 for the derivation.

To measure the S/N, a demodulator is required. The Tektronix demodulator 1450 is a typical precision TV demodulator for accurate S/N measurement. The S/N of that demodulator is specified as 60dB min and the equivalent S/N with luminance weighting filter is 67dB. Typically, the S/N of the Tek 1450 with luminance weighting filter is about 70 dB.

The equipment setup for S/N measurement of a headend modulator is shown in figure 4. The video noise can be measured by using either an AC RMS meter and a set of filters or the automatic video test equipment, such as Tektronix 1980 Answer system or the Tektronix VM700 video measurement set. When the automatic video measurement equipment is used, it is important to make sure that the modulation depth on the test modulator is exactly 87.5 %. The modulation depth is not a concern when an AC RMS meter is used to measure the noise because the video signal has to be removed from the modulator anyway.

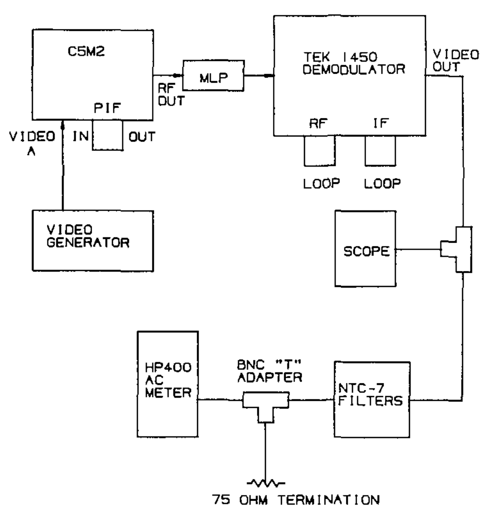


FIGURE 4
TEST EQUIPMENT SETUP FOR S/N MEASUREMENT

If the Answer system is used, the S/N measurement can be done quickly by typing a simple command. The Answer shows the S/N in four different ways --- unweighted, luminance weighted, chromance-weighted and low frequency peak-to-peak noise.

The Answer system, however, can not measure the low frequency peak-to-peak noise accurately. Such a system cannot separate the tilt and random low frequency noises from the hums and other periodic low frequency noises and measures the total low frequency peak-to-peak disturbance. A 1% tilt will cause the Answer to show -40 db low frequency noise. Some automatic test systems such as the VM700 have a function to correct the error due to tilt and the result is more accurate.

If an RMS meter and filters are used for S/N, it is wise to make the high-pass filter switchable (as we will see later). The HP3400A AC meter is good for the video noise measurement. The S/N can be read directly from the HP3400A AC meter by adding 0.7 dB to the noise level measured in db. This correction is needed because the meter 0 db reference is equal to 1 mw/600 ohm (775 mv) while the signal level 0 db reference is 714 mv.

The conversion of C/N to S/N by eq. 6 is found to be very accurate. If there is a discrepancy between C/N and S/N measurements, it is caused by either spurious signals or the phase noise of the carrier. The effects of spurs depends upon the location of the spurious signal. But how does the phase noise affect the S/N measurement?

III. Phase Noise

Phase noise is a general term used to describe the phase perturbation of a signal. Depending on the rate of the perturbation, the phase can have several characteristics, such as white phase, flicker phase, white FM and flicker FM. Phase noise is inherent to any oscillator and it is strongly affected by the Q of the oscillator. For example, a crystal oscillator has lower phase noise than an L-C oscillator due to the high Q of the crystal. Phase noise can be measured and specified in several ways, such as time variance, single-sideband power density or residual FM. In CATV systems, residual FM is probably the most easily and commonly used approach to the phase noise.

The residual FM of a carrier indicates the total power of the phase noise. In other words, the total phase noise power can be represented by a noisy FM modulation with deviation equal to the residual FM. The higher the residual FM, the more the carrier phase jitters. Residual FM can be measured directly by using a modulation analyzer such as the HP8901A, which characterizes the residual FM by measuring with different baseband filters. The alternative is to measure the single-side-band (SSB) noise power density with a spectrum analyzer and calculate the residual FM from the noise power density. As we will see later, the SSB noise power density is the better way for residaul FM measurement due to limitations of the modulation analyzer.

In a television receiver, FM noise of the picture carrier is converted to amplitude noise by the Nyquist slope of the demodulator. Refer to figure 5 and suppose the FM noise causes the carrier to jitter by f(KHz). After the Nyquist slope, the noise becomes amplitude jitter of f/750 %. Since the phase noise is random, it must be measured in rms.

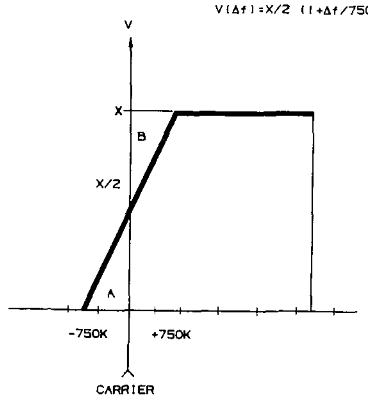


FIGURE 5
TV RECIEVER NYQUIST RESPONSE

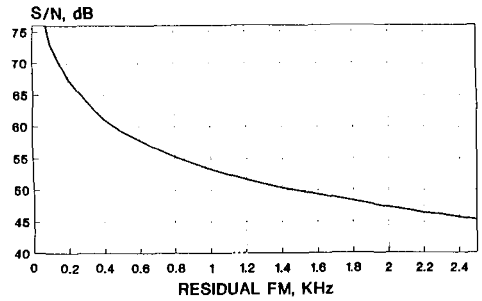
The S/N caused by the phase noise can be calculated as:

$$S/N = 20 * \log \left(\frac{Vp*100/160}{Vp* f/750} \right) \quad \text{[eq.8-a]}$$

$$S/N = 53.4 \text{ dB} - 20 * \log f(\text{KHz}) \quad \text{[eq.8-b]}$$

Eq. 8-b, plotted in figure 6, provides a conversion chart of residual FM to S/N.

FIGURE 6
RESIDUAL FM TO S/N CONVERSION CHART



Eq. 8-b and the chart show that a phase noise with residual FM of 1 KHz is equivalent to an AM noise that produces a S/N of 53.4 dB, and that 100 Hz residual FM produces a S/N of 73.4 dB. Since the amplitude noise caused by the phase noise will add to the noise floor, the total system noise is the sum of the two noises. For example, if the S/N requirement of the headend is 60 dB and the C/N is 68 dB, then the phase noise must be less than 400 Hz. The 400 Hz value can be used as a rule of thumb to judge the phase noise performance of CATV headend frequency agile equipment.

The basic process for measuring the residual FM with the HP8901 is simple. Connect the test signal to the HP8901 and choose the FM function in AVE mode. Since video S/N is always measured with a 10 Khz HPF, the residual FM also has to be measured with a 10 Khz HPF. The HP8901, unfortunately, only has 50 and 300 Hz HPF's and 3KHz, 15KHz and 20 KHz LPF's. So the residual FM can only be measured approximately and indirectly by this method.

First measure the residual FM with all the filters OUT and the residual FM measured is noted as f1. Then measure the residual FM with the 15KHz LPF IN and note the residual FM as f2. The residual FM with a 15 KHz HPF can be calculated as:

$$f\ (res) = \text{sqrt}(\ f1^2 - f2^2\ ) \qquad \text{[eq.9]}$$

f1: residual FM measured without filter
f2: residual FM measured with 15 Khz LPF
f(res): residual FM within the bandwidth 15 Khz to 200 Khz

Due to the bandwidth limitation of the filters of the HP8901, we can only measure residual FM from 15 Khz to 200 KHz. Since the Nyquist slope covers +/- 750 KHz about the carrier, the phase noise between 200 KHz and 750 KHz can not be measured by using HP8901. The phase noise in this region, depending on the SSB noise power slope, may or may not contribute to the final residual FM. In general, the total residual FM is higher than the residual FM calculated from eq.9. As a result, eq. 9 can show excessive residual FM but cannot obtain the actual residual FM.

The only way to find out the real residual FM is to measure the phase noise SSB power density and calculate the residual FM from it. The process, unfortunately, is very time consuming and error prone.

The residual FM, by definition, can be written as (note 4) :

$$f_{res}^2 = 2 * \int_{fa}^{fb} f_m^2 * L(f_m)\, df_m \qquad \text{[eq. 10]}$$

$$L(f_m) = K * f_m^x \qquad \text{[eq. 11]}$$

where f_{res} is the residual FM,

f_a, f_b are the bandwidth corners of residual FM,

$L(f)$ is the phase noise power density in dbc/hz,

f_m is the deviation frequency,

x is the slope of the sideband and usually is a negative integer like 0,-1,-2, etc., and

K is a constant.

The process for obtaining the total residual FM is illustrated by the following example: For a typical Jerrold model C5M modulator , the residual FM measured with the modulation analyzer is 202 Hz without filters and 160 Hz with a 15 Khz LPF so that the residual FM between 15 Khz and 200 Khz is calculated from eq.9 as 123 Hz. The residual FM between 200 Khz and 750 Khz is calculated as follows:

Refering to Figure 7, the carrier level is recorded as 4.5 dBm. It is clear from the figure that between 200 KHz and 750 KHz the SSB noise power follows the slope of f**-2. (noise power level reduces by 6db/octave). The level of noise at 200 KHz is -113.9 dBm/Hz. Since the noise level at 200 KHz is only 11db above the analyzer noise floor, a correction factor of 0.3 dB is needed. The resulting noise power density L(200Khz) is -113.9 -0.3 -4.5 = -118.7 dBc/Hz which is equal to 1.34E-12.

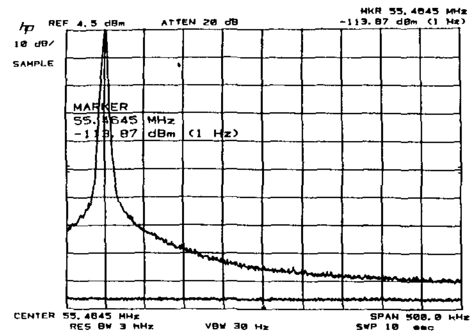


FIGURE 7
NOISE SIDEBAND MEASUREMENT

The constant K can be calculated from eq. 11 as:

$$K = L(200KHz) * 200KHz^2 = 1.34E-12 * 200000^2 = 0.0536$$

The residual FM can then be calculated from eq. 10,

$$f_{res}^2 = 2 * \int_{200E3}^{750E3} f_m^2 * \frac{K}{f_m^2}\, df_m$$

$$f_{res} = \text{sqrt}\ (\ 2 * 0.0536 * (750000 - 200000)\ ) = 243\ \text{Hz}$$

Therefore, the total residual FM from 15 Khz to 750 Khz is equal to

$$f_{(total)} = \text{sqrt}\ (\ 243^2 + 123^2\ ) = 272\ \text{Hz}$$

The total residual FM calculated above can be used to calculate the equivalent unweighted S/N. The luminance weighted S/N can be calculated from the weighted residual FM as follows:

$$f_{(total,\ weighted)} = \text{sqrt}\ (243^2 * 0.7 + 123^2 * 0.9\ ) = 228\ \text{Hz}$$

A weighting filter correction factor of 0.7 is used for 200 to 750 KHz and a factor of 0.9 is used for 15 to 200 KHz. These two factors are needed to predict the effect of the luminance weighting filter which is a kind of low pass filter. The numbers 0.9 and 0.7 are obtained experimentally and by calculating the approximate response of the filter.

The equivalent S/N due to the residual FM can be obtained by using the conversion chart in figure 6 and it is found to be 66.2 dB.

Continuing the above example, the Jerrold C5M2 frequency agile modulator has 228 Hz weighted residual FM and 68.4 dB C/N from the example of section 2. The S/N is the sum of 66.2dB (due to phase noise) and 68.1 dB (due to noise floor). Since the difference between 66.2 dB and 68.1 dB is 1.9 dB, referring to figure 1, the sum will be given by subtracting 2.2 dB from the smaller number. So the result is 64 dB. When the S/N of the modulator was measured by using Tektronix 1450, the result was 63 dB. The discrepancy can be ascribed to the contribution of the demodulator's noise floor which is 70 dB and is only 6 dB above the noise floor of the modulator S/N, causing a 1 dB degradation.

If a modulation analyzer is not available, the residual FM between 15 KHz and 200 KHz has to be measured and calculated from the phase noise SSB power density spectrum. The procedure is similar to the residual FM mesurement between 200 KHz and 750 KHz as shown in the above example.

First, the corners, or break points of the phase noise sideband spectrum slope should be identified and the noise level at each corner should be measured in dBc/Hz. Then the slope should be measured and used to calculate the constant K in eq. 11 and the residual FM in eq. 10. The constant K will not be the same for different slopes so that the residual FM associated with each segment must be calculated seperately and added by :

$$FM_{(res)} = \mathrm{sqrt}\ (f1^2 + f2^2 + f3^2 + \ldots.) \qquad [\text{eq. } 12]$$

f1,f2,f3 are the residual FM calculated for each different slope.

The calculation process for the exact residual FM is very tedious. To simplify the calculation, the conversion charts in figure 8 and 9 can be used to find the approximate residual FM from the SSB noise power density directly. Figure 8 and 9 are for weighted residual FM only.

To use these charts, the noise power level at 200 Khz offset should first be measured in dBc/Hz. Then the slope below and above 200 Khz should be decided. Figure 8 is the conversion chart for noises between 15 Khz and 200 Khz and figure 9 is the chart for noise between 200 Khz and 750 Khz. There are four curves in each chart for slopes 0, -1, -2 and -3. The residual FM can be read directly from these charts. For example, the noise power level at 200 Khz offset of a typical C5M2 is measured -119 dBc/Hz and the slopes are -2 both above and below 200 Khz. The residual FM, according to the chart, is 132 Hz for the noise between 15 Khz and 200 Khz, and 195 Hz for the noise between 200 Khz and 750 Khz. So the total residual FM, by eq. 11, is 235 Hz. This result is close to what we calculated before (228 Hz). The accuracy of the approximation depends on the judgment of the noise side-band slope. Usually, the slope is -3 (for -9dB/oct), -2 (for -6dB/oct) or -1 (for -3 dB/oct). For a few cases the slope is measured as -7dB/oct or -8 dB/oct). For these cases, the slopes can be approximated as -2.3 and -2.6 and the residual FM can be read between the lines -2 and -3.

FIGURE 8

WEIGHTING FACTOR = 0.9

(for F = 15 KHz to 200 KHz)

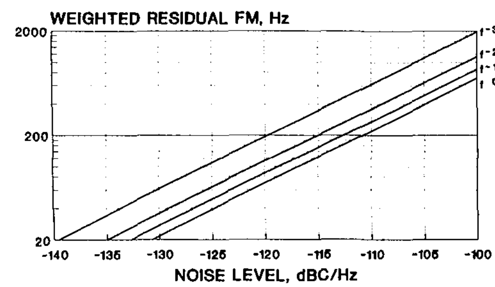
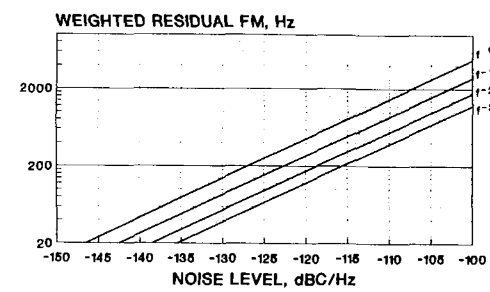


FIGURE 9

WEIGHTING FACTOR = 0.7

(for F = 200 KHz to 750 KHz)



IV. LOW FREQUENCY PHASE NOISE

The residual FM measured with 10 KHz LPF shows the amount of low frequency phase noise which is not included in the S/N measurement. The rms low frequency phase noises should be added to the low frequency peak-to-peak S/N. Subjectly, the low frequency noise is not like white noise which appears as grains in the picture. The low frequency phase noise looks like flickering horizontal bars due to its long period.

The low frequency video S/N can be measured very easily using the rms meter and filters. By toggling the ON/OFF switch of the 1Ø KHz HPF, the S/N difference between filter ON and OFF is the low frequency noise. For our sample C5M the residual FM measured with the 1Ø KHz LPF was 16Ø Hz, which from Fig. 6 corresponds to 69.8 dB low frequency S/N. Alternately, the S/N measurement with 1Ø KHz HPF is 64 dB and without the 1Ø KHz HPF is 63.3 dB. The difference of Ø.7 dB results from the low frequency S/N which can be found from Fig. 1 to be 63.3 + 8.2 = 71.5 dB. The results of the phase noise calculation and the S/N measurement are reasonably close.

Many subscriber converters and low cost CATV/MATV frequency agile modulators have low frequency S/N worse than 5Ø db due to phase noise. Theoretically, the low frequency noise should be suppressed by the AGC system of the TV/demodulator if the noise is within the bandwidth of the AGC. But for some noisy equipments, the noise jitters so rapidly that the phase noise appears in the TV picture. To look for the low frequency noise, a flat field 1Ø IRE test pattern can be used. This pattern gives a very low intensity picture so that the contrast and brightness of the TV monitor should be turned to maximum. The noise can be readily seen if the ambient light is lowered and appears as flickering horizontal bars.

The phase noise can be seen more easily if a waveform monitor is available. Set the monitor to display 2 video fields (2V) and look at the sync region of the video waveform where the phase noise can be seen as low freqeumcy ripples.

The low frequency phase noise will be accumulated when equipment such as satellite receivers, modulators, FM links and subscriber converters are cascaded. In a practical CATV system, the subscriber converter is the major contributor to low frequency phase noise while the others are negligible.

V. COMPARISON

To verify the phase noise theory and calculations, four CATV/MATV frequency agile modulators were used to compare the theory with actual measurements. The noise side band spectrums of these modulators, brands "A" through "D", are shown in figures 1Ø through 13.

FIGURE 10 BRAND A

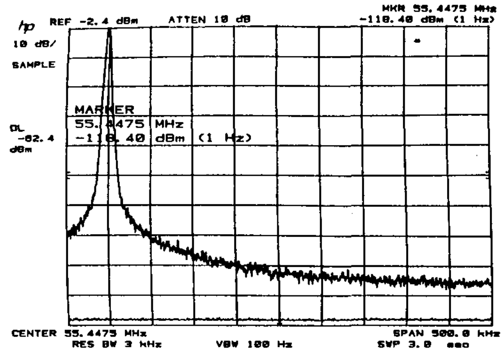


FIGURE 11 BRAND B

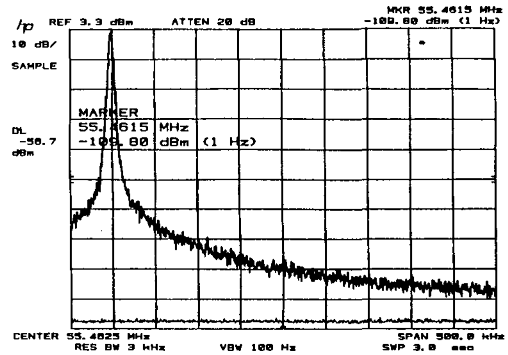


FIGURE 12 BRAND C

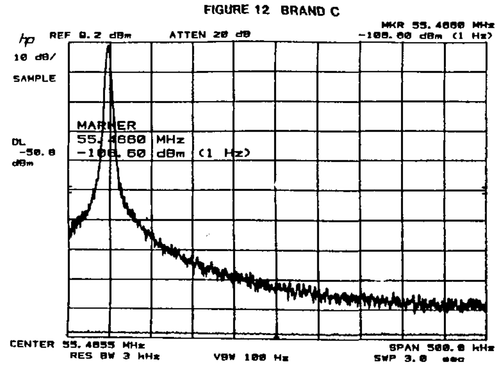
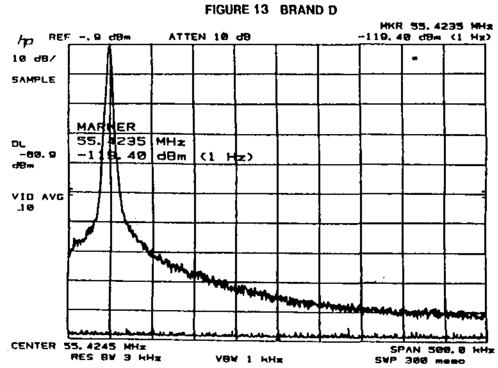


FIGURE 13 BRAND D



For these modulators, the S/N are measured first by using the rms meter and demodulator. Then the measured S/N is compared with the S/N calculated from the C/N and residual FM. Figures 8 and 9 were used to calculate the residual FM from the SSB noise power at 200 Khz offset.

The spectrum analyzer can be set up in such a way that the slopes and the SSB noise power at 200 Khz offset can be measured easily. As in figure 10, the span is set at 500 Khz so that each division is 50 Khz. The carrier is set one division from the left edge so that 200 Khz is located at the center of the screen. The SSB power at 200 Khz offset and the carrier level should be measured, converting the noise power to dbc/Hz.

The slope above 200 Khz can be found by measuring the level difference between the center and the point one division from the right edge (400 Khz offset). The slope below 200 Khz can be found by measuring the level difference between the center and two divisions to the left (100 Khz offset). This slope can be double checked by measuring the level difference between 100 Khz offset and 50 Khz offset which is one division to the left of 100 Khz offset.

The results of the calculations and measurements for the modulators are listed in the following table.

Brand	C/N	L(200Khz)	slope above	slope below	S/N (res. FM)	Total S/N	Measured S/N
A	54.7 dB	-116.2 dBc	-1	-2	60.0 dB	53.3 dB	53.8 dB
B	58.2 dB	-112.0 dBc	-2	-2	59.2 dB	55.7 dB	56.1 dB
C	61.7 dB	-115.8 dBc	-2	-3	60.8 dB	58.1 dB	58.0 dB
D	58.4 dB	-118.1 dBc	-2	-2	65.1 dB	57.3 dB	57.5 dB
C5M	68.6 dB	-118.9 dBc	-2	-2	66.2 dB	64.0 dB	63.0 dB

From these measurements we know that the calculated S/N values are very close to the measured S/N. The accuracy of the calculation is better than the authors expected. As mentioned earlier, the accuracy is decided by the judgment of slopes. If the slope is not an exact integer value then an error might occur due to approximation. It may also be necessary to compensate for the spectrum analyzer's phase noise. The phase noise power of HP8568 at 200 Khz offset is specified as 125 dbc/Hz but typically it is about 128 dBc/Hz. If the measured phase noise is below 118dbc/Hz, a correction similar to the noise floor correction in the C/N measurement (see section II) should be used.

The above measurements illustrate how phase noise can significantly degrade the S/N of a system and therefore, the subjective noise performance. As mentioned earlier, the phase noise is inherent to any oscillator and greatly affected by the Q of the oscillator. The block diagram of a frequency agile modulator system is shown in Figure 14. The modulator consists of two parts, the baseband to IF conversion and the IF to RF conversion. In the IF to RF conversion, two high frequency oscillators are needed to convert the IF to the desired channel output. The first oscillator is a fixed frequency oscillator and the second oscillator is a variable frequency oscillator (VCO) with its frequency controlled by a PLL. Since the second oscillator must cover a wide frequency range, the Q is usually low and contributes most of the phase noise. The resonant circuit of the VCO usually consists of a fixed inductor and a variable capacitor that results in the -2 phase noise slope. So if the oscillator is clean, the phase noise should follow a -2 slope. But in some cases the oscillator transistor has extra noises, especially in the low frequency region. This noise is called flicker noise and causes the close-in noise to have a -3 slope as with brand "C"

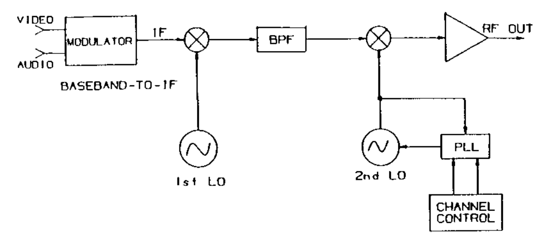


FIGURE 14 BLOCK DIAGRAM FOR FREQUENCY AGILE MODULATOR

The noise floor of the oscillator buffer and amplifiers following the second mixer should be as low as possible. This noise floor will be added to the phase noise spectrum of the oscillator. In brand "A", the phase noise slope became -1 above 200 KHz offset because of the noise floor of the RF output amplifiers.

The noise figure of the oscillator should be as low as possible. The phase noise level is directly affected by the noise figure of the oscillator. Every dB improvement of the oscillator noise figure will improve phase noise by a dB. Brand "B" is an example wherein the phase noise slope is good but the oscillator itself is too noisy.

The phase noise spectrum of brand "D" was the best among the frequency agile modulators to be tested so far. The noise slopes are -2 both below and above the 200 KHz offset and the level is as low -118 dBc/Hz.

CONCLUSION:

The C/N measurement does not completely characterize the noise performance of a CATV system. A S/N measurement is absolutely necessary for this purpose. With subscriber converters and new generation frequency agile headend modulators , the S/N can be degraded by phase noise. A high quality modulator will reduce this degradation to the minimun. For Jerrold's model C5M, with phase noise included, the typical S/N is about 64 db as required for negligible system degradation. The phase noise is not necessarily a problem for CATV systems but must be carefully considered in the design and selection of frequency agile equipment.

Note 1: MODERN COMMUNICATIONS AND SPREAD SPECTRUM, by George R.Cooper and Clare D. McGillerm, published by McGraw-Hill Company.

Note 2: THE RELATIONSHIP OF S/N IN A VHF CABLE SYSTEM TO THE S/N IN THE VIDEO SYSTEM, by Mike Jeffers, 7/85.

Note 3: TEKTRONIX 1450-1 TELEVISION DEMODULATOR INSTRUCTION MANUAL.

Note 4: NTC-7 REPORT

Note 5: DIGITAL PLL FREQUENCY SYNTHESIZERS, by Ulrich L. Rohde, published by Prentice Hall Co.

CONVERSION TABLE FOR dBmV AND POWER

dBmV	Power (W)	dBmV	Power (W)	dBmV	Power (W)
60.0	0.133E-01	20.0	0.133E-05	-20.0	0.133E-09
59.0	0.106E-01	19.0	0.106E-05	-21.0	0.106E-09
58.0	0.841E-02	18.0	0.841E-06	-22.0	0.841E-10
57.0	0.668E-02	17.0	0.668E-06	-23.0	0.668E-10
56.0	0.531E-02	16.0	0.531E-06	-24.0	0.531E-10
55.0	0.422E-02	15.0	0.422E-06	-25.0	0.422E-10
54.0	0.335E-02	14.0	0.335E-06	-26.0	0.335E-10
53.0	0.266E-02	13.0	0.266E-06	-27.0	0.266E-10
52.0	0.211E-02	12.0	0.211E-06	-28.0	0.211E-10
51.0	0.168E-02	11.0	0.168E-06	-29.0	0.168E-10
50.0	0.133E-02	10.0	0.133E-06	-30.0	0.133E-10
49.0	0.106E-02	9.0	0.106E-06	-31.0	0.106E-10
48.0	0.841E-03	8.0	0.841E-07	-32.0	0.841E-11
47.0	0.668E-03	7.0	0.668E-07	-33.0	0.668E-11
46.0	0.531E-03	6.0	0.531E-07	-34.0	0.531E-11
45.0	0.422E-03	5.0	0.422E-07	-35.0	0.422E-11
44.0	0.335E-03	4.0	0.335E-07	-36.0	0.335E-11
43.0	0.266E-03	3.0	0.266E-07	-37.0	0.266E-11
42.0	0.211E-03	2.0	0.211E-07	-38.0	0.211E-11
41.0	0.168E-03	1.0	0.168E-07	-39.0	0.168E-11
40.0	0.133E-03	0.0	0.133E-07	-40.0	0.133E-11
39.0	0.106E-03	-1.0	0.106E-07	-41.0	0.106E-11
38.0	0.841E-04	-2.0	0.841E-08	-42.0	0.841E-12
37.0	0.668E-04	-3.0	0.668E-08	-43.0	0.668E-12
36.0	0.531E-04	-4.0	0.531E-08	-44.0	0.531E-12
35.0	0.422E-04	-5.0	0.422E-08	-45.0	0.422E-12
34.0	0.335E-04	-6.0	0.335E-08	-46.0	0.335E-12
33.0	0.266E-04	-7.0	0.266E-08	-47.0	0.266E-12
32.0	0.211E-04	-8.0	0.211E-08	-48.0	0.211E-12
31.0	0.168E-04	-9.0	0.168E-08	-49.0	0.168E-12
30.0	0.133E-04	-10.0	0.133E-08	-50.0	0.133E-12
29.0	0.106E-04	-11.0	0.106E-08	-51.0	0.106E-12
28.0	0.841E-05	-12.0	0.841E-09	-52.0	0.841E-13
27.0	0.668E-05	-13.0	0.668E-09	-53.0	0.668E-13
26.0	0.531E-05	-14.0	0.531E-09	-54.0	0.531E-13
25.0	0.422E-05	-15.0	0.422E-09	-55.0	0.422E-13
24.0	0.335E-05	-16.0	0.335E-09	-56.0	0.335E-13
23.0	0.266E-05	-17.0	0.266E-09	-57.0	0.266E-13
22.0	0.211E-05	-18.0	0.211E-09	-58.0	0.211E-13
21.0	0.168E-05	-19.0	0.168E-09	-59.0	0.168E-13

dBmV = decibels relative to 1 millivolt in a 75 ohm system

TABLE 1

CONVERSION TABLE FOR NOISE FIGURE, NOISE FACTOR, AND NOISE POWER

Noise Figure	Noise Factor	Noise Power (W)
49	79432.8	0.127E-08
48	63095.8	0.101E-08
47	50118.7	0.802E-09
46	39810.7	0.637E-09
45	31622.8	0.506E-09
44	25118.9	0.402E-09
43	19952.6	0.319E-09
42	15848.9	0.254E-09
41	12589.3	0.202E-09
40	10000.0	0.160E-09
39	7943.3	0.127E-09
38	6309.6	0.101E-09
37	5011.9	0.802E-09
36	3981.1	0.637E-10
35	3162.3	0.506E-10
34	2511.9	0.802E-10
33	1995.3	0.319E-10
32	1584.9	0.254E-10
31	1258.9	0.201E-10
30	1000.0	0.160E-10
29	794.3	0.127E-10
28	631.0	0.101E-10
27	501.2	0.801E-11
26	398.1	0.636E-11
25	316.2	0.505E-11
24	251.2	0.401E-11
23	199.5	0.318E-11
22	158.5	0.252E-11
21	125.9	0.200E-11
20	100.0	0.158E-11
19	79.4	0.126E-11
18	63.1	0.994E-12
17	50.1	0.786E-12
16	39.8	0.621E-12
15	31.6	0.490E-12
14	25.1	0.386E-12
13	20.0	0.303E-12
12	15.8	0.238E-12
11	12.6	0.186E-12
10	10.0	0.144E-12
9	7.9	0.111E-12
8	6.3	0.850E-13
7	5.0	0.642E-13
6	4.0	0.477E-13
5	3.2	0.346E-13
4	2.5	0.242E-13
3	2.0	0.159E-13
2	1.6	0.936E-14
1	1.3	0.414E-14
0	1.0	0.000

TABLE 2