VIDEO BANDWIDTH, IF BANDWIDTH AND PEAK DEVIATION IN NOTCH NOISE TESTING

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Summary This paper presents guidelines for conducting notch noise testing of telemetry transmitter-receiver systems. An understanding of the type of FM-FM modulation format which random white noise accurately simulates leads to certain convenient relations between spectral power density, video bandwidth, peak deviation and IF bandwidth. Notch noise measurements were made on video noise in a video limiter to determine the dynamic range required of a system which transmits random white noise faithfully. These measurements were of significant importance because they show that a great deal of excess IF bandwidth is required to transmit random noise spectra. Specifically, it was found that to achieve a 50 db notch noise measurement the system dynamic range may be as much as 10 times greater than the RMS value of the composite signals.

Introduction Since the publication of the "Study of Telemetry Receiver and Recorder Phase Linearity Problems"[1] by Adcom, Inc. four years ago, there has been a great deal of interest in notch noise testing of telemetry receivers, transmitters and even entire telemetry links. An excellent description of the notch noise test is presented in the first section of "Nonlinear Effects in Telemetry Transmitter-Receiver RF Links"[2] by Johnson and Caster of Sandia Laboratories. Basically, the test is conducted by frequency modulating a transmitter with white Gaussian noise. The noise modulated carrier is demodulated by the receiver and hopefully an exact duplicate of the voltage applied to the transmitter is present at the video output of the receiver. The noise power ratio (NPR) is measured by removing a narrow band of the original video noise spectrum and then tuning a narrow band voltmeter to the notched out video frequency at the receiver video output. The noise power ratio is then the db difference between the receiver output before and after the notch filter was applied. Notch noise test equipment is commercially available for conducting these tests.

The white noise test was originally used to measure crosstalk and noise interference in multi-channel telephone links. It is ideally suited for this purpose since telephone communication channels are numerous, narrow band (3 KHz) and of equal bandwidth.

However, FM-FM telemetry formats are varied and may have a variety of subcarrier channel bandwidths. For this reason, the notch noise test can be used to determine the IF bandwidth and transmitter deviations only when the multiplex format is similar to telephone repeater link formats. For other formats, the test may be used to determine whether the equipment is operating properly, but should not be relied upon for setting up modulation parameters.

The Meaning of NPR, SNR and I/S The notch noise test is commonly taken to mean noise power ratio (NPR). However, the NPR can be a measure of receiver signal to noise ratio (SNR), or inband intermodulation levels (I/S) or a combination of the two. Whenever noise power ratios are taken, it is a good idea to also measure the signal to noise ratio. This is done by simply removing the modulation from the transmitter and then recording the db difference between the residual noise at the receiver output from the noise before the notch was applied. This gives an indication whether the NPR is a measure of signal to noise ratio or intermodulation distortion. This difference is illustrated in the 4 sets of data in Figure 1. If the NPR is limited by the signal to noise ratio, the deviation should be increased, whereas if the NPR is much worse than the SNR, the deviation of the transmitter may be decreased in order to improve the NPR. By repeated measurements, the optimum NPR can be found. The purpose of this paper is to present some guidelines for establishing video bandwidth, IF bandwidth and transmitter deviation with a minimum of trial and error to find the optimum NPR.

The Properties of White Gaussian Noise The following discussion will lead us to a better understanding of the nature of the noise signals we are trying to transmit so faithfully. It is important to have some idea what the data looks like before attempting to design a system to transmit it. The term “white” refers to the uniform spectral density of the noise. If we observed this type of video signal with a tuned voltmeter or spectrum analyzer, it would measure equal power at every video frequency. We could characterize it as having a constant power density conveniently expressed in volts per Hz bandwidth. When white noise is applied to a frequency modulator, it produces equal frequency deviations at each video frequency (rate). Knowing this uniform spectral power density and the upper and lower video frequencies, we could calculate the modulation index produced by the video noise voltage at each frequency across the band. A significant consequence of using white noise loading is that the modulation index of the lowest video frequency is typically 5 to 20 times greater than the mod. index produced by the highest video rate. That is to say, no pre-emphasis is present in white noise tests. Since the amount of FM quieting is related to the modulation index3 we expect that at low RF input power levels the highest video frequencies have the poorest SNR and NPR’s while the lowest video frequencies should have the best SNR and NPR. We see this in the bottom curve of Figure 1. This should not be confused with the much emphasized phase linearity problem.[1,2] The NPR would have been flat across the video spectrum if proper pre-emphasis had been employed. Under large input power conditions (typically RF

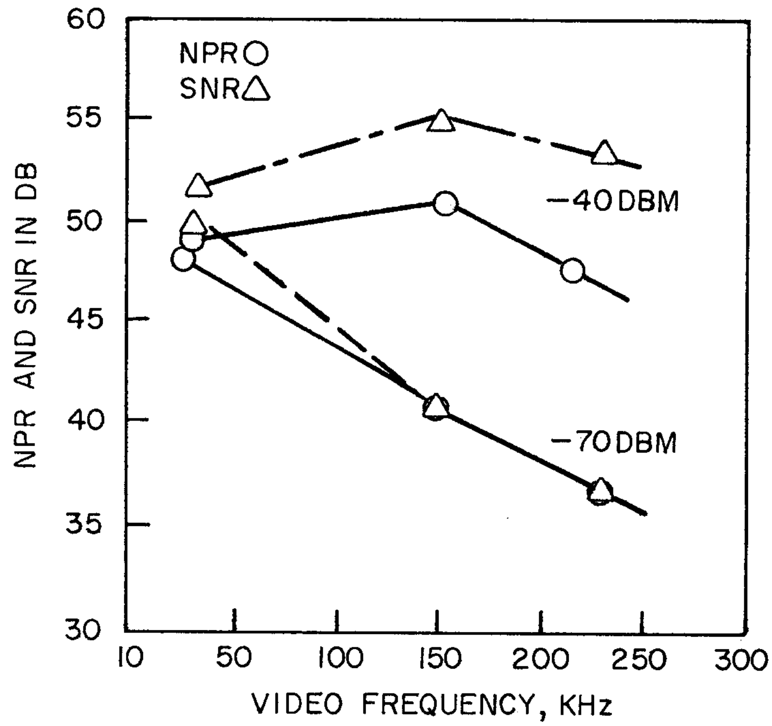

Fig. 1. NPR and SNR Across the Video Band.

power at receiver antenna greater than -40 dbm) NPR is no longer totally dominated by SNR. It is at this point that we are really measuring the intermodulation to signal ratio (I/S) performance which the receiver is capable of producing. Figure 2. also demonstrates this phenomena. Notice how the low SNR present with RF input power of -70 dbm, appears to "push down" the NPR which was achieved with RF power of -40 dbm. All conditions were identical for the two sets of measurements. IF Bandwidth was 3.3 MHz, video bandwidth was 12 to 252 KHz. RF input frequency was 1500 MHz. The IF was a linear phase type which was time delay aligned in the receiver with special equipment recently developed by ACL for this purpose. Clearly from the measurements presented in Figure 1, white noise loading does not represent the optimum simulation of a carefully planned FM-FM format at RF input power levels of -70 dbm (or less).

The second property of the composite baseband video composed of random white noise is its Gaussian amplitude distribution. Random noise generated by reverse-biased diodes is used in Notch Noise Test Sets.[5] This type of noise generator produces random noise whose peak amplitude distribution is Gaussian.[3]

The amplitude of our composite video signal is constantly changing. When applied to a frequency modulator, this ends up as a constantly changing carrier deviation from center frequency. Since the carrier deviation is directly proportional to the amplitude of the applied video signal, it would be desirable to know exactly the amplitude characteristics of the signal.

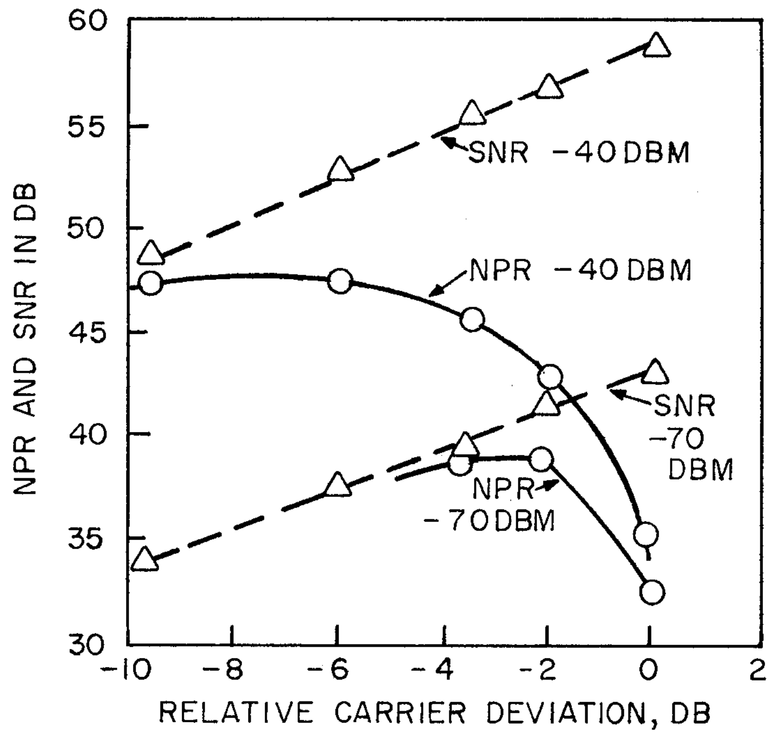

Fig. 2. NPR and SNR vs Carrier Deviation.

The amplitude of Gaussian noise is most easily described by its root means square value (RMS voltage). It can be easily measured with a true RMS voltmeter. Peak detecting voltmeters produce readings typically 6 to 12 db higher than the RMS reading depending upon their time constant. One might inquire why this is so with Gaussian noise. The answer is that Gaussian distributed noise can, theoretically, have any peak voltage value. If one sits at an oscilloscope and observes Gaussian noise which reads 1.0 V RMS on a true RMS voltmeter, one will see 0.5 volt peaks, 5.0 volt peaks and even once in a while 50.0 volt peaks. The peaks can be of any value. The problem with the random peaks being any value is that it is hard to define the peak carrier deviation, a very useful concept in FM. The only helpful guide is to speak of RMS deviation. This is defined as the deviation produced when X volts RMS is applied to a transmitter with modulation sensitivity, $S \frac{\text{KHz peak}}{\text{volt peak}}$

$$Dev_{RMS} \equiv X \cdot S$$

“S” is determined by the Bessel sideband null method and X is monitored by an RMS voltmeter.

Video Limiter Measurements The author has felt ill at ease with the problem of defining the peak deviation produced by random (specially Gaussian) noise.

Theoretically, the peak deviation of any Gaussian noise modulated transmitter is infinite. More important than "what is the deviation?" is the question "what happens if we limit the deviation to some well defined limit?". Does the NPR change? If so, how much does it change? To help answer this, a test was conducted at baseband using a simple two diode video limiter in the line between the noise generator output and the noise receiver input. No amplifiers were used and both ends of the limiter were resistively matched to the impedance of the noise test set. Figure 3 is a plot of NPR versus the ratio of peak to peak limit voltage to RMS voltage applied to the limiter diodes. This graph is useful in determining the dynamic range required of a system which must handle random noise. The results apply very well to baseband equipment and reflect to a lesser extent on IF bandwidth requirements. We see that to achieve a 50 db NPR the peak to peak limit value must be at least 10 times the RMS value. That is to say that a video amplifier must linearly, handle 10 volts peak to peak in order to transmit 1.0 V RMS random noise with a 50 db NPR.

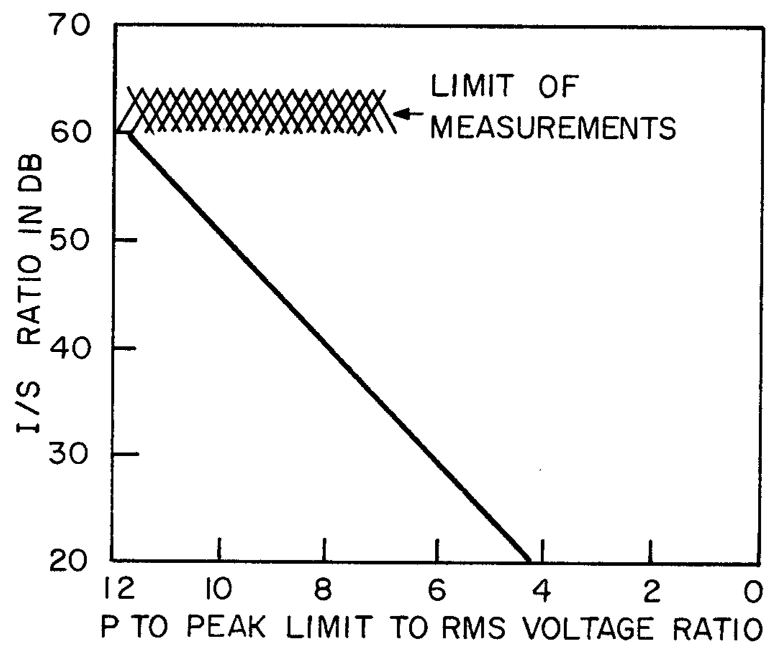

Fig. 3. Dynamic Range Requirements for Noise Voltage.

Characteristics of IF Filters. Since an IF filter is specifically designed to limit the spectrum width of the receiver, it acts in an analogous way on peak carrier deviations as a diode limiter acts on video peak voltages. In an FM receiver, the discriminator following the IF filter produces distorted video signals when the peak deviation exceeds the 3 db IF bandwidth. A linear phase IF filter is better in this respect because it has less selectivity. When followed by a limiter, the useful bandwidth of a poor shape factor IF filter is greater than the useful bandwidth of an equivalent IF filter with a good shape factor. Hence, the linear phase IF not only has the advantage of better time delay linearity characteristic with the attendant improved I/S performance, but the situation is further improved by the fact that its useful bandwidth is actually significantly wider than its nominal 3 db bandwidth. le, a linear phase IF filter is desirable because it doesn't spectrum limit very well. A standard IF with a reasonably flat mid-band time delay characteristic might do about as well as a linear phase IF that is somewhat narrower, if care attention were paid to peak carrier deviation.

IF Bandwidth Requirement There are only two requirements on the IF bandwidth.

1.) It should be wide enough to pass the largest peak transmitter carrier deviation expected.

2.) It must pass all of the significant sidebands generated by the transmitter.

It will be demonstrated that the first criteria is more important than the second in determining the total transmitter deviation appropriate for notch noise testing. Another way of saying this is that given ample signal to noise ratio, I/S measurements will be similar with different video bandwidths if the transmitter deviation is the same in both cases. In actual practice, SNR should be the guiding consideration in determining the relationship between IF and video bandwidth while the relationship between RMS transmitter deviation and IF bandwidth determines I/S performance. See Figure 4. The important feature of this data is that both video bandwidths produced similar NPR curves.

The Relation Between IF and Video Bandwidth One method for determining the IF bandwidth required for a given video (data) bandwidth is to consider the lowest antenna signal level expected and then determine the modulation index required of each subcarrier to achieve a given SNR. From the modulation index the number of significant sidebands is determined thus fixing the required IF bandwidth. As an aid to making these Bessel sideband calculations Figure 5 is presented. It shows the modulation index as a function of the ratio of IF bandwidth video rate for three levels of significant sidebands. Three percent sidebands correspond to sidebands roughly 30 db below the unmodulated carrier, one percent corresponds to -40 db sidebands and 0.3 percent corresponds to sidebands 50 db below the unmodulated carrier. The data was taken from the 6 Bessel Function Table VI of the ITT Handbook, Fourth Edition.[6] The fourth curve was calculated from a convenient formula given in the Fifth Edition,[7] p. 21-9. It is convenient but not as accurate. To insure highest quality data transmission, it seems intuitively correct that the 0. 370 sideband criteria be used. Using Figure 5, the data displayed in Table 1 was generated. This assumes a fully loaded data channel composed of sinusoidal subcarriers with no pre-emphasis and no empty channel guardbands. This is the characteristic of white noise loading. Total RMS transmitter deviation was found by taking the square root of the sum of the squares of the RMS deviation of each subcarrier. This reduces to multiplying the deviation of any subcarrier by $\sqrt{N}$ where N is the number of subcarriers. This is so because each subcarrier has the same deviation in white (nonpre-emphasis) data multiplex. The four video bands are those typically available on notch noise testers. A 750 KHz IF bandwidth was used for purpose of illustration.

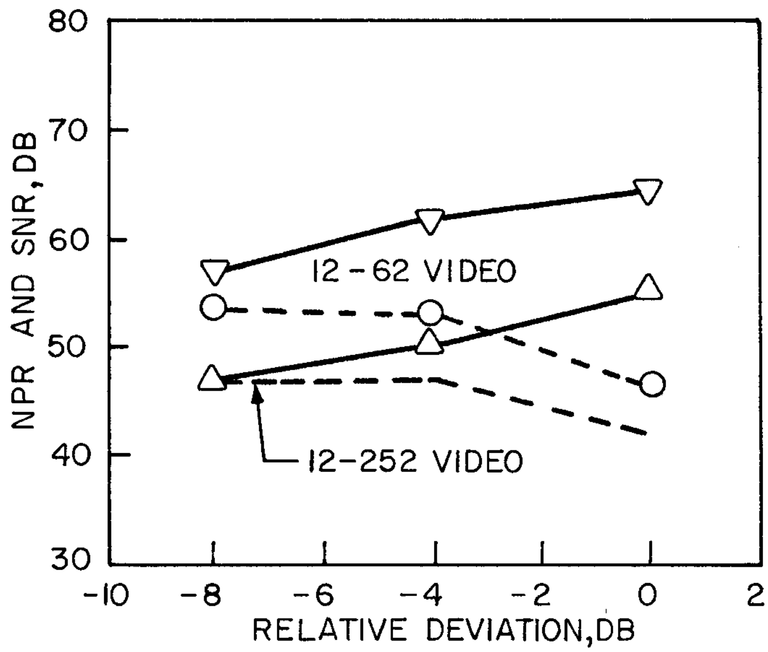

Fig. 4. NPR, SNR vs Transmitter Deviation For Two Video Bandwidths

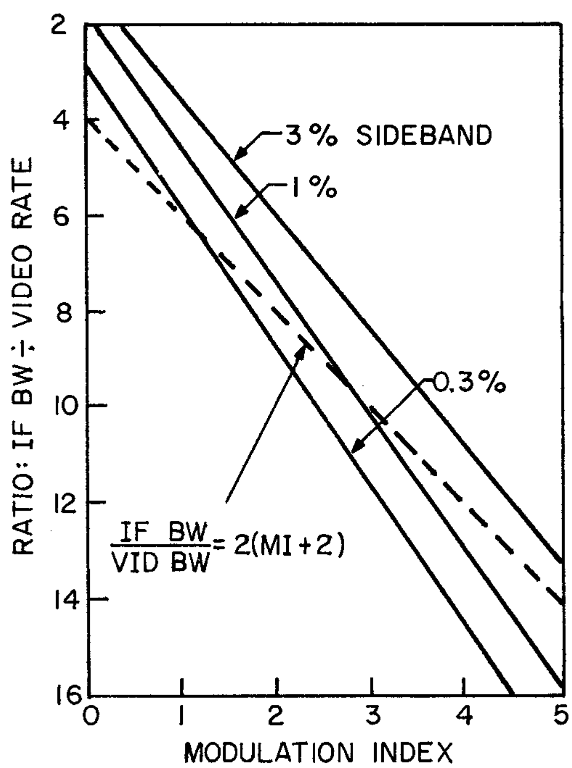

Fig. 5. IF Bandwidth to Video Rate Ratio

vs Modulation Index

Video BW KHz	N = # Ch.	IF BW ÷ Video BW	MI, Highest Rate Sub.	Peak Sub. Dev. KHz	RMS Sub. Dev. KHz	MI of 12 KHz Sub.	RMS Trans. Dev. KHz
12-60	12	12.5	3.3	198	140	16.5	485
12-108	24	7	1.5	162	115	13.5	564
12-156	36	5	0.7	109	77	9.1	462
12-252	60	3	0.1	25.2	18	2.1	138

Table 1. Sample Multiplex Data Based on 0.3% Significant Sidebands.

The purpose of this exercise was to show that in any practical situation (MI ≥ 1.0) the controlling factor is total transmitter deviation rather than a consideration of the significant sidebands. We know that severe distortion would result if a signal with 564 KHz RMS deviation were applied to a 750 KHz IF no matter how good the IF performance was. This is so because the peak deviation of a multichannel composite signal (whether generated from a noise generator or a multiplicity of subcarrier oscillators) is characterized by the Gaussian distribution.[1] With an RMS carrier deviation of 564 KHz, the peak carrier deviation would exceed the 750 KHz IF bandwidth 2076 of the time. The method of determining 201o will be shown in the next section. Clearly we have to establish maximum allowable RMS deviation levels for a number of IF bandwidths which are available and then pick the one which gives a sufficient MI for the data bandwidth required.

Transmitter Deviation and IF Bandwidth One method might be to look at the video limiter data. This would imply that the RMS carrier deviation would be restricted to one-tenth the IF bandwidth to achieve a NPR of 50 db. Experimental evidence shows that matters are only half as bad as this. Fortunately, linear phase IF's are not nearly as good at limiting as diodes are.

The next recourse is to the world of mathematics. If we refer to the Gaussian (or normal) distribution curve such as the one in the ITT Handbook,[7] we find the error or "E" scale. Knowing that I RMS unit corresponds to the 1 point, we can determine the probability that the peak exceeds two or three times the RMS value. This tells us that if the IF bandwidth is six times (± 3~) greater than the RMS carrier deviation, the carrier would deviate outside the 3 db IF bandwidth only 0.3% of the time. Figure 6 is a plot of NPR and SNR in a 1000 KHz IF with 12-60 KHz video bandwidth. This low video bandwidth was used to insure a large modulation index so that the results would not be clouded by insufficient SNR nor confused by the issue of IF time delay linearity. Also shown are the probabilities that the peak carrier deviation is beyond the 3 db bandwidth. Using the criteria that the peak carrier deviation exceeds the 3 db IF bandwidth no more than 0.3% of the time, the RMS carrier deviation levels can be found for a variety of IF bandwidths. Then by working backwards through the tabulations used to develop Table 1, we can determine a usable range of video bandwidths. It should be noted that at any carrier level above approximately -85 dbm best data quality is assured by using the widest receiver bandwidth available. This allows use of the highest modulation index which results in the greatest FM quieting.

IF BW KHz	Max. RMS Carrier Dev.* KHz	Video Band KHz	N = # of 3 KHz Ch.	IF BW ÷ V. BW	Peak Dev. of Sub-Carrier KHz	MI of Highest Sub.	MI of Lowest Sub.
3300	660	12-60	12	55	270	4.5	22.5
		12-156	36	21	156	1.0	13
		12-252	60	13	121	0.5	10
	(825)**	(12-252)			(151)	(0.6)	(12.5)
1500	300	12-60	12	25	122	2.0	10
		12-156	36	9.6	71	0.45	6
		12-252	60	6	55	0.22	4.6
	(375)**	(12-252)			(68.5)	(0.27)	(5.7)
750	150	12-60	12	12.5	61	1.0	5.0
		12-156	36	5	35	0.22	3.0
		12-252	60	3	27	0.11	2.3
	(188)**	(12-156)			(44)	(0.28)	(3.7)
300	60	12-60	12	5.0	24	0.4	2.0

* 1% Excessive Carrier Deviation, Except
** 5% Excessive Carrier Deviation

Table II Modulation Data For Various FM-FM Formats.

Conclusion It is recommended that all NPR tests also include data on SNR. Then meaningful conclusions can be drawn about I/S performance. The tests should be made at large RF power levels (> -40 dbm) in order that I/S performance can be sufficiently evaluated. In order to take advantage of the inherent SNR improvement qualities of wideband FM, modulation indicies for all subcarriers should be greater than 0.5.[4] This coupled with the results tabulated in Table II implies that the best ratio of IF to video bandwidth is about 14 to 1 for highest quality data transmission (NPR's consistently 45 db or more). It was shown that maximum RMS carrier deviation should be held to less than one-fourth the IF bandwidth.

The white noise test could yield more valuable results to telemetry users if the test equipment were modified to account for the presence of subcarrier guardbands and to include pre-emphasis schemes consistent with IRIG standards. If this were done, the test could be used to set up telemetry link modulation parameters for multiplexes involving more than 15 or 20 subcarriers. As the case stands now, the test results may shed only limited light on reality.

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