NOISE FIGURE MEASUREMENTS ON DISTRIBUTION SYSTEMS

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ABSTRACT

A technique for measuring the noise figure of a CATV distribution system is discussed, as an alternative to conventional methods of determining carrier to noise ratio. The advantages and disadvantages of both types of measurement are discussed. Suitable instrumentation for noise figure measurement is considered, as well as calibration techniques. Some possible sources of error are identified and analyzed.

INTRODUCTION

As in any communication system, the signal to noise ratio in a CATV system is an important parameter. Due to the complex nature of the television signal, it is common practice to speak in terms of the carrier to noise ratio, to simplify the analysis. The carrier level is taken to be the power of the peak carrier, occuring during the synchronization pulse of the TV signal. Measurements are frequently made with a CW signal of amplitude equal to that of the sync tip.

The corresponding noise power is that delivered by the system over a specified bandwidth. The NCTA standard refers to a 4 MHz bandwidth, although other standards refer to bandwidths as high as 6 MHz.

The ratio of these two powers is the carrier to noise ratio, which is conceptually simple and direct. The carrier power measurement is straightforward, but the noise power measurement can be troublesome. In the CATV industry, a 4 MHz bandwidth is generally used, but it is somewhat arbitrary. The bandwidth must be related to the effective noise bandwidth of the measuring device, which may not be the same as its indicated bandwidth. The detector characteristic is normally defined for coherent signals, and may be somewhat different for noise input. In addition, in a typical situation the system noise power is not much greater than the measuring receiver's noise level. Noise power measurements commonly depend on correction factors supplied by the manufacturer of the measuring equipment, notably its effective noise bandwidth, and the detector noise characteristic. These are seldom independently verified.

It is the intent of this paper to consider the removal of several arbitrary factors from these measurements, by measuring the noise figure of the complete distribution system. We will first review some definitions and techniques.

NOISE FIGURE

Noise figure is a measure of the noise added to a communication system by an amplifier or other system component. At the risk of over-simplification, we will use the terminology of Figure 1 for this discussion.

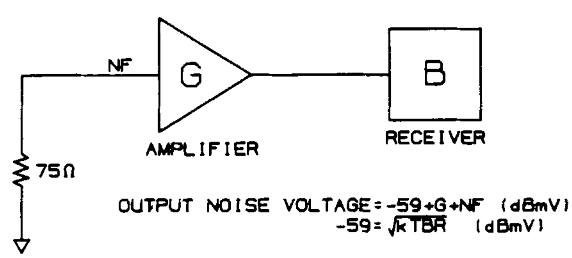

FIGURE 1.

Here G represents the gain of the amplifier and NF its noise figure, both in dB. The familiar -59 figure derives from the Boltzmann constant k, an absolute temperature of 290 K, a receiver bandwidth of 4 MHz, and a 75 ohm impedance.

This glosses over a great deal of important background in noise figure measurement. We assume that all system interfaces are well matched 75 ohm impedances, and that temperature variations (in Kelvin) are not very significant. Practically speaking, these assumptions are justifiable.

In some fields such as satellite communications, the concept of noise temperature is used, wherein a good (low) noise figure is related to a low noise temperature. We will use noise figure here.

An important variation of Figure 1 relates the output carrier to noise ratio C/N to the carrier input level I (dBmV) and the noise figure NF;

$$C/N = 59 - NF + I$$

This is true whether the equation refers to a transistor stage, a trunk amplifier, or a cascade of trunks plus bridger and line extenders. It is a statement of the impact of input level on carrier to noise ratio.

There are a number of ways to measure noise figure. One simple way is to measure the gain of the amplifier, then measure the noise power output, and calculate the noise figure. A similar way is to perform a carrier to noise measurement as described above, and work back to noise figure.

The preferred way to measure noise figure is by reference to a noise generator of known output level. The technique consists fundamentally of adding noise to the system input to the point where the system noise output increases by some measurable amount. By comparing the increase in noise output to the corresponding noise power added, the system noise figure can be determined. Such a measurement can be made with no reference to receiver bandwidth, although the frequency of measurement is a parameter.

Precisely calibrated noise sources are available from a number of suppliers. A diode operated in the reverse avalanche mode is a common mechanism for noise generation, and can be used into the microwave region. Noise output level is calibrated by comparison to a precisely known noise source, typically an actual resistor operated at extremes of temperature. The source may be calibrated in terms of its effective noise temperature in degrees Kelvin, or in Excess Noise Ratio (ENR, dB). The ENR is a measure of how much the noise exceeds the theoretical Johnson noise level, e.g. -59 dBmV.

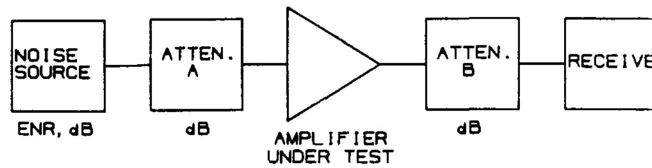

FIGURE 2.

Referring to Figure 2, a noise figure measurement is made by injecting noise into the amplifier input and measuring the resultant increase in amplifier noise output. Several variations are possible:

1. Add the noise and measure the resultant increase in noise power at the receiver.

2. Add the noise and increase the output attenuator at B to produce the original indication on the receiver. This removes the receiver's characteristics from the test.

3. Add noise by adjusting the input attenuator at A until a 3 dB increase in output power occurs.

4. Increase the output attenuator at B by 3 dB, then add noise by adjusting the input attenuator at A until original receiver indication is reached.

These four methods are all variations on what is called the Y factor method. In each case, the formula

$$NF = ENR - A - 10 \log (Y-1)$$

where

$$Y = 10^{B/10} \quad \text{or} \quad B = 10 \log Y$$

applies. Here A is the dB attenuation following the noise source, and Y is the linear power ratio of the output attenuator or detector change. If one of the 3 dB methods is chosen, the factor 10 log (Y-1) disappears. The formula points up the fact that an attenuator at the input to the amplifier degrades the noise figure of that system in like amount. Note that a small change in output power, for a given additive input noise power, is indicative of a high system noise figure rather than a low one.

It is preferable that the ENR of the source be in the same general range as the noise figure being measured. Precision suffers if ENR is less than NF. If ENR is more than about 6 dB greater than NF, the receiver dynamic range may become a factor, and there is no substantial increase in precision.

Noise figure meters automate this measurement process. The current generation of microprocessor based instruments are very sophisticated devices. In addition to being bus controllable, they can calibrate themselves, account for various losses in the device, and simultaneously measure gain. But they all perform Y factor measurements, and are directly dependent on the calibration of the noise source used.

DISTRIBUTION SYSTEM NOISE FIGURE

It is common to describe the carrier to noise of n trunk amplifiers in cascade by the formula:

$$C/N = 59 - NF - 10 \log n + I$$

Generally, the contribution of the bridger and line extenders is minimal, so this formula is approximately true of the entire system. It can be seen that the effect of the cascade is to make the effective noise figure of the cascade equal to

$$NF + 10 \log n$$

relative to the input of the first trunk amplifier. Of course, there is usually a span of cable preceding this first amplifier but this is easily dealt with.

There is no reason not to characterize the total system in terms of its noise figure, from the headend to the last tap. By determining the input levels to the system so defined, the carrier to noise contribution of the distribution system may be precisely determined. This may seem a bit abstract, but it is valid. It should be kept in mind that the noise figure measurement is involved with the system gain, and that the C/N calculation in terms of input levels is closely related to the resulting output levels. Of course, the overall requirement on system carrier to noise is the delivery of a quality signal to the subscriber, and this depends on the signal entering the distribution system as well as the system's noise contribution.

The automatic noise figure meter unfortunately cannot be used if the amplifier output is 10 miles from the input. But the Y factor technique is applicable, and an automatic system for measuring noise figure in this case is certainly feasible.

The proposed method is simple: inject noise into the system from the headend and measure the resulting increase in noise at the system output. Compute the system noise figure by any of the 4 methods indicated above, measure the corresponding system input levels, and determine the carrier to noise ratio. Or, since the system levels at the headend should be tightly controlled, the noise figure itself might become the fundamental performance characteristic. In this way, the arbitrary 4 MHz bandwidth might be kept out of the picture. This may be of increasing value as CATV systems carry other than NTSC video signals.

PREDICTED NOISE FIGURE

What value of noise figure might be expected of a distribution system? If a carrier to noise ratio of 46 dB is expected, and the input level to the distribution system is 32 dBmV, then NF = 59 - C/N + I = 45 dB. This number may seem startingly high, but is consistent with the definitions. The loss of the first span of cable is a major contributor to the value of the system noise figure, as is the 10 log n cascade factor. Note that the typical noise figure of measuring instruments, such as a spectrum analyzer, is about 30 dB.

Some systems have a trunk amplifier as the first element of the system, before the first cable span. In such a case, the system input levels would be lower, corresponding to trunk inputs, and the noise figure would be accordingly better.

If the system is operated with tilted trunk signals, then the low frequency noise figure should ideally be better than that at high frequency by an amount equal to the system tilt, e.g. 6 dB.*

*A note on terminology: this paper observes the NCTA's preferred convention on the use of SLOPE and TILT; TILT refers to signal levels as a function of frequency, whereas SLOPE refers to system gain and loss as a function of frequency. The terms are sometimes used interchangeably, with resultant confusion. Signals are tilted; gains are sloped.

As a practical matter, a test point should be included in these calculations. It is common practice to provide test points, typically a 12 dB coupler, at the headend. So the noise figure viewed through the test point loss will be typically 51 to 57 dB, for low to high frequencies.

NOISE SOURCES

The ENR of the noise source for system noise figure testing should be in the 60 dB range. The sources used with automatic noise figure meters are typically in the 15 dB range, although diode sources up to about 30 dB ENR are readily available. To get to the 60 dB range, amplification must be provided. This is straightforward, for if the ENR of the source is more than about 10 dB greater than the noise figure of the amplifier used, the ENR is simply increased by the gain of the amplifier. Of course, the gain must be known, and the amplifier's frequency response (slope) will modify the output level (tilt) of the noise source. There need be little concern for this amplifier's output capability, since a 60 dB ENR amounts to only a few microwatts of power in a 500 MHz bandwidth. Due caution must be exercised, however, to avoid pickup of extraneous signals.

The ENR of such a boosted source may be measured by direct measurement of its output, or more precisely, by putting the output through a precision attenuator and comparing to the output of a known noise source.

PROCEDURE

The procedure consists of injecting a known level of noise into the system, and measuring the resulting increase in system noise output. As such, it is subject to the same cautions as is the conventional method of measuring carrier to noise ratio. Of course, a signal free area of the spectrum must be used to measure noise output. The receiving instrument must have adequate sensitivity to sense system noise above its own internal noise. Preamplification may be necessary to make the receiver's noise figure sufficiently low. Selectivity may be required to avoid receiver or preamplifier overload. The output attenuator substitution technique is preferable, as it minimizes errors from unknown detector characteristics or insufficient sensitivity.

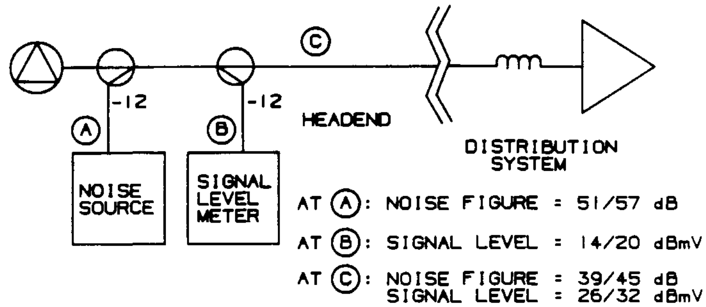

FIGURE 3.

The important point here is that the only field measurement to be made is a difference in system noise output, over a limited dynamic range. This will typically be from 3 to 10 dB. There is no concern for receiver bandwidth, apart from the selectivity which may be needed to avoid receiver overload if heavy channel loading is present. Input mixer overload is a hazard which must be avoided, since the goal is to measure system noise, rather than beats generated in the measuring receiver.

The resolution of this noise output differential impacts the accuracy of the overall measurement. Analysis of the Y factor equation will show that if the noise output difference is 3 dB, then a 0.1 dB error in its measurement will result in a 0.2 dB error in noise figure. At a 6 dB difference, a 0.1 dB error only results in a 0.14 overall error.

Any error in ENR, of course, adds directly to the overall noise figure error. But the ENR of the noise source can be determined with considerable precision, and should not be subject to very much drift, in its headend location. The carrier level error of course also adds directly to the C/N error.

REFINEMENTS

Automatic noise figure meters function by turning the noise source on and off at a rapid rate and measuring the resulting modulation in amplifier noise output. This type of approach might be done at say a 1 Hz rate for system measurements. Some deft manipulation would be required to use the attenuator substitution method. In addition, the ENR of the source might be tilted to track the expected noise figure of the system, so that the differential noise output might be relatively constant across frequency.

It is quite possible that an automatic system could be developed to perform this sort of measurement. All that is really lacking relative to conventional instruments is a means of synchronizing the receiver with the switched noise source.

SOME RESULTS

The figures of Table 1 indicate the results of measurements made on a test cascade of 16 trunk amplifiers plus a bridger. The setup was that of Figure 3. An experimental noise source was used. Its ENR (2) was determined by comparison to an HP 346B noise source, with the aid of the 9870A Noise Figure Meter.

For this test, a Wavetek 3003 signal generator was used as a test carrier source. Its level was adjusted to give a constant carrier to noise ratio at the system output at each frequency (9).

A SAM-I signal level meter was used to measure carrier levels (5), and an HP 8554B spectrum analyzer was used as the noise receiver. Measured carrier to noise data (9) was also obtained from the 8554B.

Noise figures (4) were calculated from ENR's (2) and measured increases in noise output (3) using the Y factor equation described above.

Measured characteristics of the directional coupler test points were used to determine the values of the carrier level and noise figure on the trunk relative to those at the test points (4 / 6 and 5 / 7).

1.	Frequency	55	200	300	400	MHz
2.	ENR	56.5	56.7	56.8	55.9	dB
3.	Increase in Noise Output	10.0	7.5	6.0	4.0	dB
4.	Noise Figure at Test Point	47.0	50.0	52.1	54.1	dB
5.	Carrier Level at Test Point	7.5	11.5	13.5	16.0	dBmV
6.	Noise Figure on Trunk	34.4	37.4	39.5	41.5	dB
7.	Carrier Level on Trunk	19.3	23.3	25.3	27.8	dBmV
8.	Calculated Carrier/Noise	43.9	44.9	44.8	45.3	dB
9.	Measured Carrier/Noise	44.0	44.0	44.0	44.0	dB

Table 1

The values of carrier to noise determined by the conventional measurement technique (9) are in reasonable agreement with the values calculated from system noise figure (8). The maximum difference between the two is 1.3 dB, which is in line with the accuracy of the measuring equipment.

CONCLUSIONS

System noise figure measurement allows the noise contribution of the distribution system to be isolated and analyzed. The portion of the measurement made in the field is relatively simple, and is made over a small dynamic range. Precise level measurements such as ENR and carrier level may be confined to the headend. The technique might be automated. The technique might also be applicable to reverse systems, where carriers are not very predictable.

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