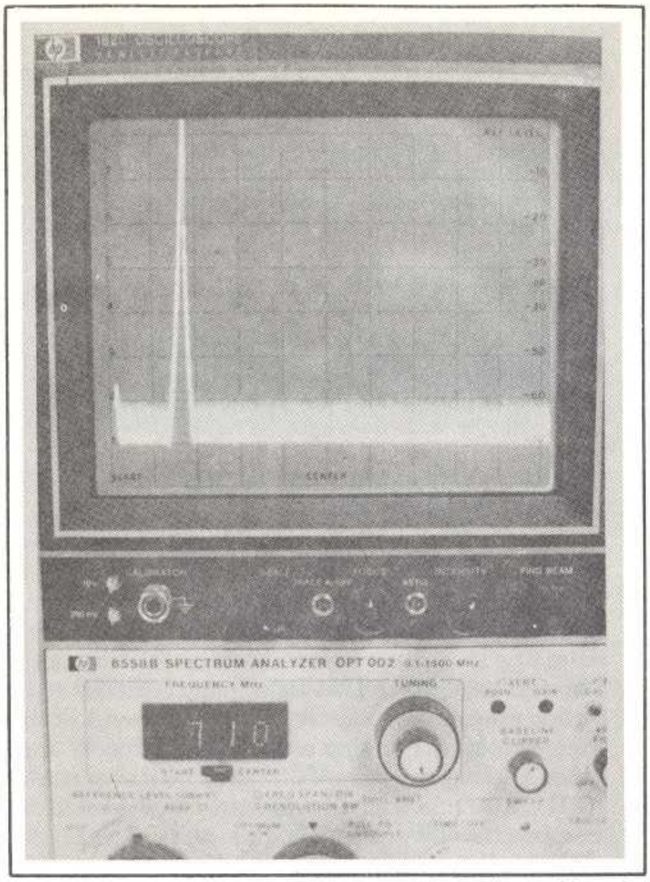

Fig. 1—The trace appearing on a spectrum analyzer shows white noise along the frequency base line. Broad-band noise appears like grass, as if one were looking at a cross-section of thick turf. On a TV picture tube, it appears as snow. From a loudspeaker, it is a frying noise.

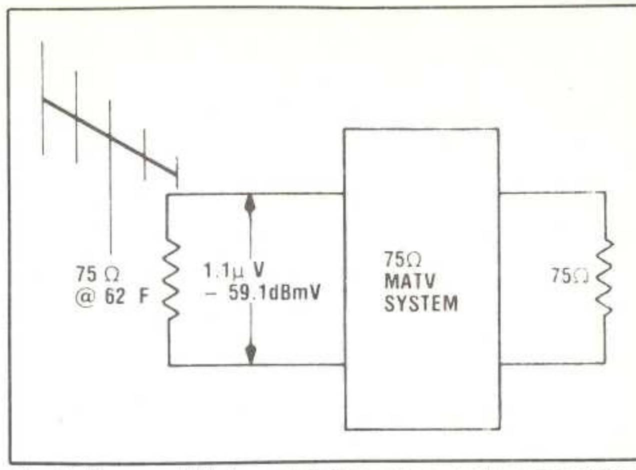

Fig. 2—Diagram of 75-ohm matched impedance MATV system showing that theoretical-minimum thermal-noise voltage is 1.1 μV/ch (−59.1 dBmV) at room temperature.

Noise and Noise Figure

By James E. Kluge*

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How the "noise figure" of an antenna system is determined and what it means to the TV picture quality

■ Noise Figure is the term of measurement that indicates how much noise is contributed by the transistors and/or tubes in the circuitry of an antenna preamplifier or other MATV amplifier. The Noise Figure rating is developed by comparing the device to be measured with a perfect—but non-existent—amplifier that would be able to amplify the input signal without adding any noise of its own.

Antenna Provides Input Signal

Let's start with the input signal, which is generally the voltage developed by the antenna as it intercepts the electromagnetic-wave energy in the air. Looking back 'into' a VHF antenna from its output terminals we see a 75-ohm device. The pre-amplifier input to which the antenna is to be connected also 'looks' like 75 ohms. When we connect the 75-ohm antenna to the 75-ohm input of the preamp, we say they are properly matched for maximum signal-energy transfer from antenna to preamp.

Now suppose that instead of connecting the antenna to the preamp input we simply connect a 75-ohm resistor to the preamp. The preamp doesn't know (and doesn't care) whether its input is terminated by a 75-ohm antenna or a 75-ohm resistor. Since the preamp has no eyes to see with, it doesn't know what's connected to its input, except that the device "feels" like a 75-ohm resistance, which "pleases" the preamp.

Resistors Are Noise Generators

Now, because the resistor is not an antenna, it cannot generate a TV signal voltage at the preamp input.

However, if we look at the voltage at the preamplifier output terminals with an oscilloscope or spectrum analyzer we will see what engineers and technicians commonly call "grass".

This "grass", which is seen at the bottom of the scope in Fig. 1, is comprised of millions of tiny sine waves of infinite frequencies all added together to create a uniform low-level signal across the entire frequency range. The technical name for this "grass" is *white noise*.

It is termed "white" because like white light, which consists of energy at all the frequencies of the visible spectrum, it is comprised of energy at all the frequencies of the RF spectrum.

Electron Motion Generates Noise Voltage

You might ask at this point "Where do all these voltages come from?" It is a phenomenon of nature that in any finite resistance (which includes most known materials) the rate of electron motion in the resistance is a function of the temperature of the material. For this reason, it is termed *thermal noise*. The higher the temperature, the faster the electrons move, and the higher is the white-noise energy and voltage across the resistance. By restricting the frequency bandwidth with such things as filters and measuring instruments we reduce the noise voltages

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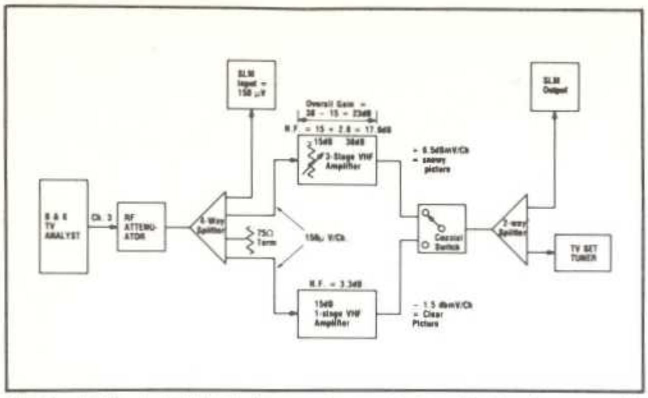

Fig. 3—An illustrated block diagram demonstration of noise-figure vs gain to show how high-gain amplifier with a poor noise figure causes picture-quality deterioration. The moral is: 1) don't try to distribute TV signals less than 1000 μV (0 dBmV) and, 2) use an amplifier having maximum gain more equal to what is required rather than padding down the input of high-gain amplifiers, thus increasing their noise figure.

and thus eliminate the characteristic of white noise.

Mathematical Relationship For Thermal Noise

It may be of interest to know that there is a mathematical formula for the determination of thermal noise. The formula, or equation reveals that any increase in resistance, temperature or bandwidth causes a corresponding increase in the thermal-noise voltage across the resistance. The mathematical expression for this open-circuit voltage is: $E^2 = 4kRT(BW)$. Across a matched load impedance it is: $E^2 = kRT(BW)$. The values are as follows:

E^2 = mean value of the squares of all the individual noise voltages.
k = Boltzmann's constant, named after the physicist who developed this physical constant = 1.38 x 10 −23 Joules/K.
R = resistance (in our case, 75-ohms).
T = temperature of the resistance material in Kelvins (generally considered 290K = 62°F as standard).
BW = frequency bandwidth = 4.2 MHz for TV channels.

Shot-Effect Noise From Transistors

It is also important to mention at this point that up until now, we have been talking only about thermal noise which characterized itself as uniform snow throughout the TV picture or a constant hissing or frying noise from the speaker.

A second source of noise is the transistor. Bias current in transistor and diode junctions generate "shot-effect" noise as well as thermal noise in the base resistance.

Electromagnetic Noise

Other types of noise not generated in the amplifier are: 1) man-made electrical noise from brush-type motors, diathermy machines and auto ignition; 2) atmospheric noise from lightning, corona, and other electrical discharges in the atmosphere characterized by random momentary streaks in the picture or crackling in the speaker; 3) galactic noise (sun spots and solar-flare activity). All these "other" types of noise exist as electromagnetic energy which is generated outside of and picked up by the antenna along with the TV signal.

Noise figure is concerned only with thermal and "shot-effect" noise generated in the amplifier's semiconductor devices and associated resistances. *The major contribution is from shot-noise.*

Minimum Antenna Noise

Noise voltage caused by thermal agitation of electronics in a 75-ohm antenna or terminating resistor is about 1.1 μV/ ch, or −59.1 dBmV at room temperature, as illustrated in Fig. 2. At −25°F it drops to −60 dBmV (1.0 μV) and rises to −58.6 dBmV (1.175 μV) at +140°F. So, for all practical purposes, we can consider the minimum noise voltage in round numbers as 1 μV/ ch, or −60 dBmV across 75 ohms. This means that there will always be a theoretical, bare-minimum noise level of 1 μV/ ch of thermal noise measured anywhere in a 75-ohm system from the antenna to the TV set.

For this reason, the signal voltage generated by the antenna must be sufficiently higher than the noise (and maintained so throughout the system) to provide a snow-free picture at the TV set. A 100 μV (−20 dBmV) signal then provides only a 40-dB signal-to-noise ratio (S/N). This is a marginal signal level which does not provide for amplifier noise, fading and system losses. For this reason, we strive for a minimum 1,000 μV (0 dBmV or S/N = 60 dB) signal level at the antenna and throughout the system until it reaches the TV-set tuner.

Noise Figure Degrades S/N

The noise figure of a good low-noise preamp is typically 4 to 5 dB at VHF and 7 to 8 dB at UHF. A 1,000 μV signal at the antenna has a S/N of 60 dB. A 100 μV signal at the antenna has a S/N of 40 dB. Running these signals through an antenna preamp having a 10 dB noise figure will reduce the S/N to 50 dB for the 1000 μV signal and 30 dB for the 100 μV signal. A S/N of 45 dB is considered an excellent picture with no snow, while a S/N of 30 dB is a marginal-quality picture with objectionable show.

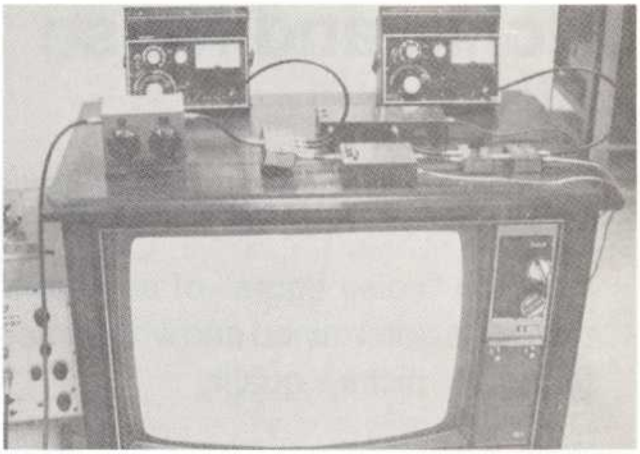

Fig. 4—Photo shows good picture quality resulting from a 150 μV (−16.5 dBmV) signal amplified through a single-stage 15-dB amplifier with a rated N.F of 3.3 dB, which provides the tuner with an 840 μV (−1.5 dBmV) signal.

Now, you can begin to see why noise figure in an antenna preamp is so important in a weak-signal area. The noise figure of a preamp will degrade the S/N by adding shot noise to the signal while it is

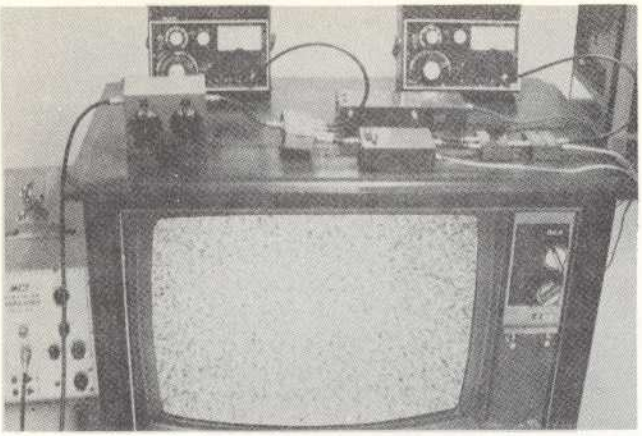

Fig. 5—Photo of a snowy picture resulting from using an amplifier with excessive gain (38 dB) and N.F. rating of 2.6 dB. Input gain control was turned down 15 dB, amplifying the 150 μV input signal 23 dB (or 14 times) to provide the tuner with a 2100 μV (+6.5 dBmV) signal.

undergoing amplification in the transistors. However, if the S/N at the input is excellent (i.e., 45 dB or higher), a good quiet preamp will have little improvement on picture quality.

It should also be understood that the antenna preamp will establish the maximum S/N for the entire system. That is, *the S/N coming out of the preamp can not be improved*—that's it! The most important thing you can do is to *preserve* it.

Any passive (non-amplifying) device causing attenuation or loss in the system is considered to have a noise figure in dB equal to that loss in dB. For example, a 6-dB pad can be considered to have a noise-figure of 6 dB. This is so because it attenuates the signal 6 dB, thereby reducing the S/N by 6 dB. For example, a 6 dB pad ahead of a preamp with a 6 dB noise figure yields an overall noise figure of 12db. This is why it is so important to amplify a weak antenna signal *before* it experiences any attenuation caused by pads, cable, connectors or a mismatch of impedances.

If you have a weak signal, it is best to amplify it up to 0 dBmV with an amplifier having as low a noise figure as possible. In order to preserve the low noise figure of the amplifier there should be a very minimum of loss between the signal source and the input amplifier. If the amplifier has too much gain, pad down the amplified signal *after* the amplifier—not ahead of it. Better yet, choose a smaller amplifier having the right amount of gain. Some distribution amplifiers have a variable gain control that can be used to increase their input-signal handling capability at the input. Attenuating the input signal this way is acceptable in the case of strong or high-level signals, but not for weak ones.

Antennas Considered Noiseless

All antennas are considered to be noiseless and lossless, or, in other words, their noise figure (NF) is 0 dB. They do not attenuate or amplify voltages. The more signal you can get from the antenna, the better your TV picture will be. In contrast to a preamp, a larger antenna will increase the signal without increasing the noise.

Measuring Noise Figure

Noise generated in the transistors and/or tubes of an amplifier appears throughout the various stages and will appear as a single combined noise voltage in the output load. It is accepted practice to refer this noise voltage (or power) back to the input by dividing it by the overall gain of the amplifier. Normally, we refer to noise in terms of power, but in a 75-ohm MATV system we can treat it and measure it as a *voltage* across a 75-ohm matched-load resistance.

Noise figure is measured by terminating the amplifier *input* with 75 ohms and measuring the noise power across a 75-ohm output load. Then a 3-dB matched attenuator is inserted ahead of the load and a 75-ohm calibrated noise generator is connected to the input in place of the terminating resistor. The noise-generator output signal then is increased until the original noise-power reading is obtained in the output load. The noise-generator output then is equal to the noise figure of the amplifier.

This measurement must be made in a shielded enclosure (screen room) so that the noise power reading is the noise generated in the amplifier, and from the calibrated noise generator only—not from direct pickup of extraneous signals and/or noise.

Tuner N.F. Notoriously Poor

TV-set tuners should also be an important consideration regarding picture quality. They are notorious for having poor noise figures (e.g. 15 dB). Therefore, it is important that they be fed at least 100 μV/ch, so that the signal-to-noise ratio at the TV set antenna terminals will be 55 dB or better, for a snow-free picture.

Almost every TV set has a lossy balun between the 300-ohm antenna terminals and the 75-ohm input of the tuner. To make things worse, a 75-ohm coax downlead requires an external balun before connecting to the receiver's 300-ohm antenna input terminals.

For this reason, it is desirable to provide a 75-ohm connector at the rear of the set, and then use a short length of coax to connect it directly to the tuner input. This method not only eliminates the loss in two back-to-back baluns which results in degradation of tuner noise figure but also frequently eliminates leading ghosts caused by direct signal pickup in the short, unshielded 300-ohm line between the antenna connections of the set and the TV tuner.

Summary

Let's summarize the important points made in this article:

* Noise figure indicates the relative amount of noise added by the amplifying devices (i.e., tube or transistors) in an amplifier.
* Noise-figure contribution is mainly shot noise from tubes and transistors.
* The S/N ratio of the signal applied to the receiver's antenna input terminals cannot be improved by the receiver circuitry.
* Use a preamp to compensate for losses in the downlead, splitters, couplers, etc. between the antenna and next amplifier in the system, which in many cases will be the tuner in the TV set.
* Because of poor noise figure of most tuners it is important that you have at least 1000 μV of signal at the TV set to achieve a clean picture. ■