the Lenkurt Demodulator

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NOISE

Noise is probably one of the most expensive discommodities in the history of communication. Billions of dollars are spent annually to design, construct, and maintain facilities for overcoming the interfering effect of noise. Always present, stemming from any of a thousand sources, noise is the principal enemy of communication. This article discusses noise, its nature, and how it is measured.

Across a crowded room one may have trouble being understood, even when speaking in a loud voice. When the room is empty, the same voice may seem too loud. What has obscured communication? In both cases the same amount of speech power was present to carry the message. The signal was there, but the interference prevented it from being identified by the listener.

In communications, interfering disturbances are called *noise,* even though the interference may be electrical, rather than auditory in nature. A signal represents a certain degree of order or pattern. During transmission, disorganizing forces constantly damage the signal and tend to reduce it to a meaningless jumble of random energy. When a signal is transmitted, it begins to lose strength and clarity immediately. If this is allowed to go too far, the signal will eventually become lost in the background noise, thus destroying communication. The signal is always at a disadvantage because it constantly undergoes attenuation, whereas noise is generated afresh at almost every point in the transmission path, so that it is always present, always at "full strength."

Sources of Noise

The very nature of the universe gives rise to noise. Noise is generated in the flow of electricity through a conductor as electrons collide with some of the molecules of the conducting material. As the temperature of the conductor is increased, noise also increases as more of the electrons collide with the more agitated molecules of the conductor. The amount of noise generated is directly proportional to the temperature of the conductor.

In electron tubes, transistors, or other semiconductors, noise is generated by the *randomness* of electrons or other current carriers. Electrons boil off a cathode irregularly: "holes" or electrons slide through the lattice of a semiconductor randomly, taking different paths and varying amounts of time to travel from one electrode to another, thus adding to the noise in the circuit. This type of noise also increases as temperature rises. Since electricity consists of individual particles or charges rather than being a perfectly smooth homogeneous fluid, noise is bound to arise in connection with the flow of electricity.

Another fundamental source of noise is called *black body radiation,* and is of interest primarily in radio transmission. All objects in the universe radiate energy over a broad spectrum. The most perfect radiator of energy would also be the most perfect absorber. Thus, a perfectly black body—capable of neither transmission nor reflection—would be the ideal radiator. The hotter an object, the more energy it radiates, and the higher the wavelength at which most of the energy is radiated. For instance, objects at room temperature radiate some energy at microwave frequencies, but most of the radiation from such objects is at very long infra-red wavelengths. Similarly, most of the sun's energy is radiated as visible light and ultraviolet rays, and most of the energy released during the first flash of a nuclear bomb consists of X rays and gamma rays.

Although the radio energy emitted by objects at moderate temperatures is very slight, some sensitive microwave receivers can detect a man as he crosses a field of snow by the extra microwave radiation that he emits! All radiation of this kind contributes to the background noise that must be overcome in radio communication.

The various types of noise based on thermal agitation or radiation are sometimes called *resistance noise, thermal noise, Johnson noise,* or *white noise.* The term white noise refers to the fact that white light has a uniform distribution of energy across the visible spectrum. Similarly, thermal or Johnson noise is uniformly distributed across the bandwidth spectrum. This uniform distribution is caused by the great variety of noise sources, and the extremely wide range of energy levels of the electrons and molecules that actually generate the noise.

Johnson noise has been found to be directly proportional to bandwidth and temperature, regardless of the source of the noise. Actual calculations of the noise power to be found in an electrical circuit or detected by a radio receiver follow the relationship

$$\textit{noise power} = kTB \textit{ watts}$$

where

k is Boltzmann's constant (1.37×10^{-23} joule per degree),

T is absolute temperature in degrees Kelvin (0° C. = 273° K.), and

B is the bandwidth in cycles per second.

Thus, if a highly directional microwave antenna were connected to a suitable receiver having a bandwidth of 8 megacycles and pointed at an object the temperature of the sun (which has a surface temperature of about 6,000° K.), noise power of 1.6×10^{-11} watt, or -78 dbm would be received. The same microwave receiver, if pointed at a man, would receive 3.4×10^{-14} watt or -105 dbm of noise power. Radio astronomers are now using this technique to uncover many new facts about other planets and other galaxies, by using very sensitive microwave equipment to measure noise temperature.

Microwave receivers of the type normally used in telephone and industrial communication are unsuitable for the measurements described above because of the great amount of noise introduced by the receiver itself, which would mask the thermal noise present. Typical microwave receivers used in communications introduce from 10 to 100 times as much noise as is picked up by radiation. That is, the noise figure of these receivers will range from 10 to 20 db. When using parametric amplifiers or

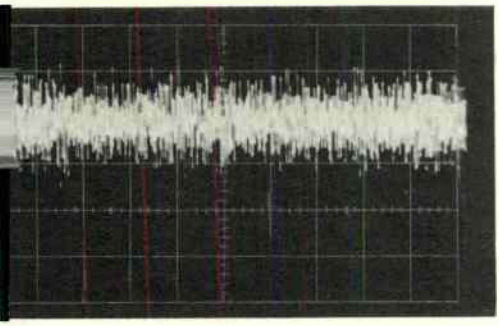

Figure 1. "White" noise as it appears in communication channel. Other names for white noise include background noise, random noise, *and* fluctuation noise.

masers in the receiver input circuit, noise figures as low as 3 to 4 db have been achieved at 6000 megacycles. Noise figures of less than 1 db have been reported at VHF and UHF frequencies. Such low noise performance becomes quite important in systems which employ tropospheric scatter to span long distances at higher frequencies. In such a case, the scatter signal may be at such a low level that receiver noise becomes an important limiting factor in the performance of the system.

In microwave receivers, considerable noise is introduced by electron tubes, particularly the first intermediate-frequency amplifier. Other major contributors of noise are diodes used in the mixer, and noise sidebands from the local oscillator—if a balanced mixer is not employed. In addition, impedance mismatch between antenna, waveguide, or mixer can distort the signal, resulting in increased noise. Intermodulation or non-linear distortion also adds to the noise which the signal must overcome.

Although there is little that can be done about noise originating outside the communications system, much progress is being made in reducing noise that originates within the system itself. Such new developments as masers, parametric amplifiers, and tunnel (or Esaki) diodes promise new standards for transmission performance.

Impulse Noise

An increasingly important type of interference is known as *impulse noise.* Unlike thermal noise, impulse noise is sporadic and may occur in bursts, rather than being uniformly distributed. Impulse noise consists of discrete impulses which occur on the circuit as the result of any of several causes. Some types of impulse noise are natural, being caused by lightning, aurora borealis, or other such electrical disturbances. Increasing amounts of impulse noise are man-made. Ignition noises, power lines and their associated switching are strong offenders. In telephone offices, impulse noise may be very great, due to dialing and switching impulses which are induced or otherwise coupled into transmission paths.

Figure 2 compares a speech signal and a typical noise impulse. Both traces are to the same scale; the speech signal level was approximately -20 dbm. Note that the amplitude of the noise impulse is greater than the maximum speech amplitude. These photographs also suggest why impulse noise hardly disturbs speech. A speech sound must be sustained to be understood, since the tone and other qualities of the speech are determined by a succession of waves over a continuing period of time. Noise impulses are too brief to produce a serious disturbance to speech. On the other hand, although noise impulses are usually of very short duration, they may have very great amplitude. Data pulses do not have the redundancy which permits speech to be understood in the presence of large amounts of interference. As a result, a burst of noise which would hardly harm a syllable, could ruin a punched card or similar block of information.

The advent of "Data-phone" or similar dial-up data transmission services make the problem of impulse noise much greater. As data transmission rates increase (in a given bandwidth), the transmission becomes much more vulnerable to impulse noise, mostly because the data pulses are shorter and more nearly like the noise impulses. Even though noise impulses may be very brief, much shorter than the data pulses, they can cause serious interference by causing filters and other tuned elements in a communications channel to "ring." The resulting oscillations may interfere with the signal and cause errors.

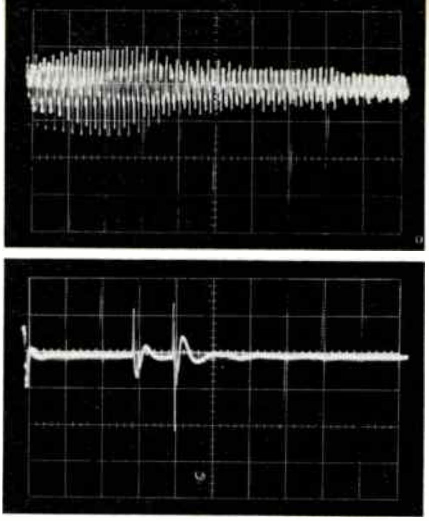

Figure 2. Comparison of speech and noise impulse recorded from actual telephone circuit. Speech sample is the word "two." Note slight ringing following each noise impulse.

Noise Measurements

In order to establish performance standards for communications systems, it is necessary to be able to measure the interfering effect of noise. This is different than measuring the amplitude or power of the noise, since noise seems to create more interference at some frequencies than at others. Because the "wave-shape" of noise is entirely different than that of speech or music, the ear reacts differently to noise than to speech. In telephone circuits, the type of receiver used has an effect on the amount of interference that a given amount of random noise will produce.

In establishing noise measurement standards, the interfering effect of noise was simulated by comparing the interference provided by a 1000-cycle tone at a reference level, with other frequencies. The levels of the other frequencies were adjusted until they were estimated to have the same interfering effect as the 1000-cycle tone. In all tests, a carefully prepared recorded conversation was used to test the interference. A weighting curve such as shown in Figure 4 was obtained. When a filter or weighting network having these characteristics is used in connection with a "flat" meter, the meter will give a direct measure of the actual interference produced on voice circuits by the noise. Line weighting should not be used when measuring interference on data circuits, since the weighting represents human response when using a certain type of instrument.

At the time of the first tests, the Western Electric Type 144 handset was the most widely used handset in the United States. Later, this instrument was replaced with the Type F1A, and new response curves were obtained by similar tests. It is important to note that the weighting curves do not represent the frequency response of the telephone receiver, but combine the effect of the receiver and the listener's subjective reaction to the interference.

Although the F1A handset has been replaced with newer equipment, the characteristics of the newer equipment (even from different manufacturers) are in close agreement with those of the F1A handset. For all practical purposes, the F1A curves may be used for noise measurements on circuits where more modern equipment is used. The F1A curve became an international standard in 1946 when the C.C.I.F. (Comité Consultatif International Téléphonique, or International Consultative Committee on Telephony) adopted it as a standard for use in measuring noise on international circuits.

Noise Units

In the United States telephone industry, the reference power level for noise measurements was standardized at 10^{-12} watt, or 90 db below 1 milliwatt at 1000 cycles per second. At the time this standard was established, the 144 handset was in general use and noise was measured in decibels above the reference power level (using the weighting network), and were called "dbRN" or decibels above reference noise. With the introduction of the F1A handset, which was about 5 db more sensitive than the 144 handset, the reference level was raised to -85 dbm so that established standards would still be meaningful. Measurements made with the F1A weighting network were in terms of "dba" or decibels adjusted.

The term dba has come into general use as the unit of interfering noise in telephone communications systems, even where Type 144 handsets are used. To be strictly accurate, the weighting network used should be named when specifying noise levels in dba. However, handsets with F1A characteristics are so nearly universal today that the qualifying statement "F1A weighted" is usually dropped. Whenever the term dba is used without reference to the type of weighting, F1A weighting is implied.

Figure 3. A typical noise measuring set used for determining noise characteristics of communications channels. Instrument permits noise measurements under wide range of conditions and with any of several line weightings.

European Noise Units

In Europe and many other parts of the world, units established by the C.C.I.F. are used to express circuit noise. The principal units of measurement, which are linear rather than logarithmic as in the U.S.A., are called *psophometric emf* and *psophometric voltage*. In addition, the *picowatt* is sometimes used to express noise power. A picowatt = 10^{-12} watt or -90 dbm.

The psophometric emf is the electromotive force (or voltage) generated by a source having an internal resistance of 600 ohms and no internal reactance, which, when connected across a standard receiver having 600 ohms resistance and no reactance, produces the same sinusoidal current as an 800-cycle generator of the same impedance.

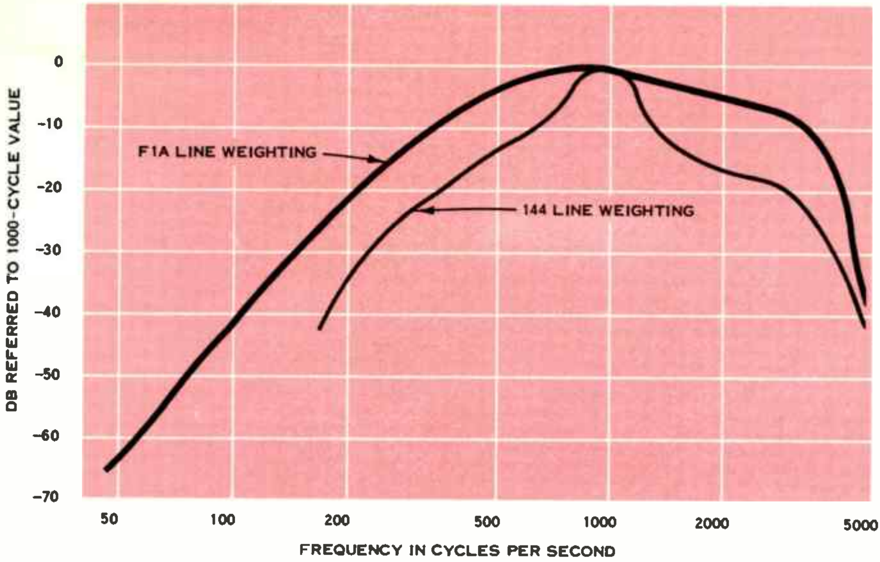

Figure 4. Weighting curves show the relative interfering effect of noise on speech when using either Type 144 or F1A handsets or their equivalents. F1A curve is international standard.

Psophometric voltage is defined as the voltage which would appear across a 600-ohm resistance connected between any two points in a telephone circuit. This value is one-half the psophometric emf since the latter is essentially the open circuit potential necessary from a source to produce the psophometric voltage if the source has a 600-ohm internal resistance. Figure 5 illustrates the relationship between psophometric emf (E) and psophometric voltage (V).

These noise units are measured by a *psophometer*. This unit includes a weighting network equivalent to the F1A network used in the U.S.A. Aside from the calibration of the meter, there is no essential difference between a noise measuring set, such as used in the U.S.A., and a psophometer. Although the psophometric units are in terms of voltage, load resistance or impedance is carefully specified. Figure 6

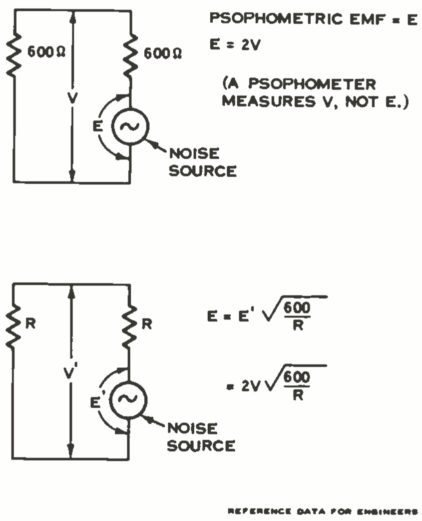

Figure 5. Psophometric noise is measured or calculated in volts (or milli-volts) under conditions shown here.

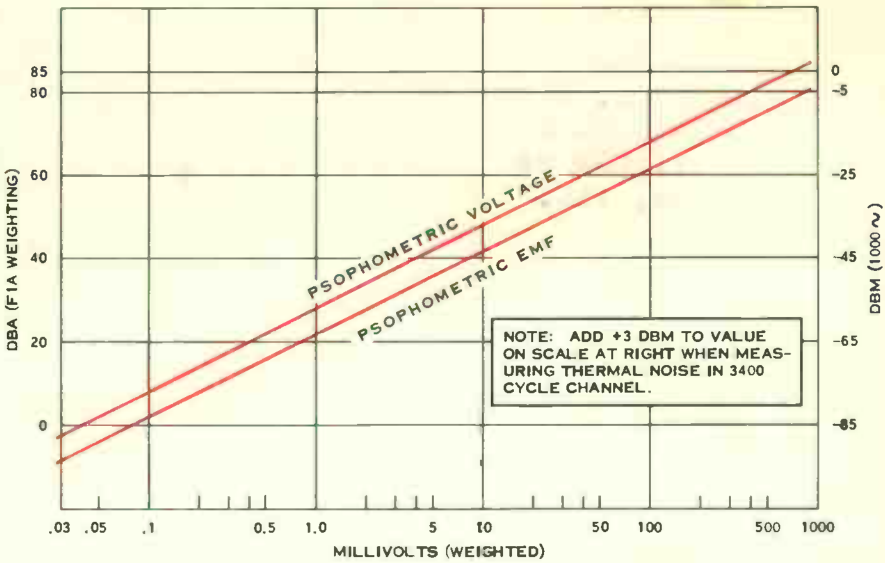

Figure 6. Comparison of dba and psophometric noise values. Dba is logarithmic unit, while psophometric noise values are linear.

compares dba and the C.C.I.F. standard psophometric units.

Impulse Noise Measurements

Since impulse noise may be quite sporadic in its occurance, it does not generate a "noise power" in the sense that thermal noise does. Although thermal noise may be measured with conventional instruments such as noise measuring sets and voltmeters, these instruments are unsuitable for measuring impulse noise. One reason is that impulses last too short a time for the instrument to register. Another is that pulse amplitudes at one instant don't necessarily indicate the maximum pulse amplitudes that may be encountered. Because of this uncertainty, most impulse noise figures are estimates of the highest pulse amplitude that will occur. The estimates, in turn, are based on noting the highest amplitude which occurs in a given period of time—the longer the better.

One instrument used for such measurements is known as an *impact meter.* This device amplifies the impulse and charges a capacitor. The charge on the capacitor is directly proportional to the impulse amplitude. A vacuum tube voltmeter constantly indicates the charge. Thus, the meter reading will indicate the highest amplitude which occured after the measurement began. Determining the impulse noise characteristics may take on the aspects of a statistical survey! ●

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3. *Reference Data for Radio Engineers, Fourth Ed.,* International Telephone and Telegraph Corp.; 1956

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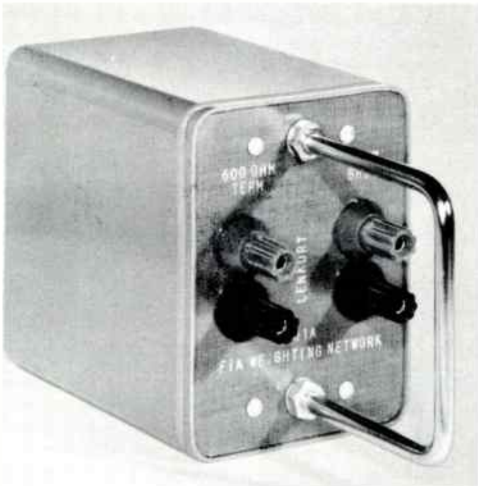
F1A Line Weighting Network



Lenkurt produces a line weighting network which adapts any high-quality vacuum tube voltmeter to measure F1A-weighted noise down to about 10 dba, thus eliminating the need for expensive noise measuring sets for many routine measurements.

Form 601A-P4 provides a detailed description of this network, and may be obtained from Lenkurt or Lenkurt distributors.

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