The *Lenkurt.*

OCTOBER 1970

DEMODULATOR

communications yardsticks

A yardstick is a measure of a system's quality, quantity, and performance. The often requested discussion of logarithmic units used to measure the quality of transmission systems is reprinted here with the addition of the metric units used internationally to measure absolute quanities. The results of the Demodulator survey are also being published at this time as a measure of performance.

Descriptive terms used in the telecommunications industry range from the infinitesimal — 1/1,000,000,000,000 watts/cm^2 the power rating for conversational speech — to the enormous — 6,000,000,000 hertz, the frequency of a typical microwave radio. Such a span would be unwieldy if simplifying expressions had not been established.

Powers of Ten

The first step to simplicity is a shorthand notation which expresses numbers as powers of ten. We know that 10 x 10 = 100 can be written 10^2. Likewise, 10 x 10 x 10 = 1000, or 10^3. By definition, an exponent of three means the number 10 is used as a multiplier three times. A frequency of 6,000,000,000 hertz then becomes 6 x 10^9 hertz (6 GHz).

Note that 10^1 = 10 and 10^0 = 1. Numbers smaller than one can also be treated using powers of ten. By definition, 10^{-1} is the same as $1/10^1$, or 1/10. In this way, the power rating for typical conversational speech, 1/1,000,000,000,000 watts/cm^2, can be written 10^{-12} watts/cm^2.

When discussing two relative values, it is sometimes convenient to use the term *orders of magnitude.* This is another way of expressing powers of ten. That is, one order of magnitude (10^1) is 10 times as much, two orders of magnitude (10^2) is 100 times as great, etc. Simple division indicates that a supersonic plane flying 1500 miles per hour (2500 km per hour) is 100 times faster than a man jogging at 15 miles per hour (25 km per hour). So, it can be said that the plane is two orders of magnitude faster than the man. Notice that orders of magnitude are really concerned with the exponent of the number.

Logarithms

All the numbers in these examples use the same "base." number of ten. If we treat the exponent of the base number separately, another useful shorthand is achieved, called *logarithms.* In 100 = 10^2, the logarithm of 100 is two. That is, the common logarithm (abbreviated $\log_{10}$, or just log) is the power to which the base ten must be raised to produce the number. The written form is log 100 = 2.

The use of logarithms simplifies many forms of complicated calculations. Remember that to multiply like numbers (the number ten is used here to relate to common logs), it is only necessary to *add* their exponents ($10^2 \times 10^3 = 10^5$); to divide, subtract exponents ($10^5 \div 10^3 = 10^2$). Logarithms are used in the same way. Multiplications and divisions involving large numbers may be carried out by adding or subtracting the corresponding logs. In fact, any series of events involving multiplication or division, if expressed logarithmically may be handled by addition or subtraction. This is particularly valuable in the telecommunications industry, where a variety of measurements are necessary to describe the qualities of a signal as it passes through the system. Voltages, currents, and powers are measured; noise identified; and losses assessed. These are all made easier by the use of the logarithmic yardstick.

Decibels

The basic logarithmic yardstick in communications is the decibel, derived from the less practical unit, the bel, named in honor of Alexander Graham Bell. A decibel is a tenth of a bel.

Early experimentation proved that a listener cannot give a reliable estimate of the absolute loudness of a sound. But, he can distinguish between the loudness of two different sounds. However, the ear's sensitivity to a change in sound power follows a logarithmic rather than a linear scale, and the decibel, dB, has become the unit of measure of this change. The relationship between any two power values can be calculated in decibels as:

$$dB = 10 \log \frac{P_1}{P_2}.$$

If P_2 is larger than P_1, the dB value will be negative; therefore, it is convenient to designate P_1 as the larger power.

It should be emphasized that a given number of decibels is always the relationship between two powers, and not the absolute power value itself (Figure 1). For example, the gain in an amplifier, or the attenuation of a pad, can be expressed in decibels without knowledge of the input or output power of the device – just the change.

Decibels	Power Ratio
1	1.259
2	1.585
3	1.995
4	2.512
5	3.162
6	3.981
7	5.012
8	6.310
9	7.943
10	10.0
20	100.0
30	1000.0
40	10,000.0

Figure 1. Decibels and power ratios are related on a logarithmic basis.

dBm

Frequently, however, it is convenient to represent *absolute* power with a logarithmic unit. One milliwatt is generally accepted as the standard reference for such purposes in the telephone industry, and signal powers can be written as being so many dB above or below this reference power. When this is done, the unit becomes dBm, in the expression:

$$dBm = 10 \log \frac{P_1}{P_2}$$

where P_2 is one milliwatt (10^{-3} watts).

By adding a definite reference point, dBm becomes a measurement of absolute power, rather than just a ratio, and can readily be converted to watts. A measurement of 10 dBm indicates a signal ten times greater than 1 milliwatt, or 10 milliwatts; 20 dBm is 100 times greater than 1 milliwatt, or 100 milliwatts. A 15-dBm signal applied to an amplifier with a 10-dB gain will result in a 25-dBm output. Or, a standard test tone (0 dBm) will be measured as −15 dBm after passing through an attenuator of 15 dB.

It is important to note at this point that most meters used in the telephone industry are calibrated for measurements of voltage appearing across a 600-ohm termination (standard transmission line impedance). If the circuit to be measured is of a different impedance than that for which the meter was calibrated, the indicated power level will be wrong, and a correction factor must be taken into account. Using the relationship of $P = E^2/R$, the following correction factor is formulated:

$$dB = dB_{(indicated)} + 10 \log \frac{600 \text{ ohms}}{\text{circuit impedance}}.$$

For example, a +6-dB reading across a 500-ohm line is calculated:

$$\begin{aligned} dB &= 6 + 10 \log \frac{600}{500} \\ &= 6 + 10 \log 1.2 \\ &= 6 + 0.792 \\ &= 6.792 \text{ dB}. \end{aligned}$$

Level Point

In most telephone systems, the toll switchboard is defined as the Zero Transmission Level Point (0 TLP), and the levels of both signal and noise at other parts of the system are usually referred to that point. A point in the transmission system where a signal has experienced a 16-dB attenuation relative to the toll switchboard is known as the −16-dB level point. Note that *level* used this way is purely relative and has nothing to do with actual power – a signal of any power will be down 16 dB at the −16-dB level point. When a standard test tone is transmitted over the circuit, its power in dBm at any point is numerically equal to the level in dB at that point.

dBm0

Another term, dBm0, is used to refer measured power back to 0 TLP, and has useful significance in system planning. Measurements adjusted to dBm0 indicate what the power would have been, had it been measured at 0 TLP. For example, a tone measured at the −16-dB level point with a meter reading of +8 dBm, is equal to +24 dBm0.

In addition to dBm, there are a number of other logarithmic units used in the telephone industry which are expressed as dB above or below some reference power. One of the most common of these is dBrnc, used in the measurement of noise.

Noise Measurement

The Bell Telephone Laboratories and the Edison Electrical Institute did original research to determine the transmission impairment caused by noise interfering with speech. A large number of listening tests were made with different tones introduced as interference. The degree of interference was determined by comparing the power of each interfering tone with the power of a 1-kHz tone that created the same degree of interference.

A power of 10^{-12} watts, or −90 dBm, was selected as the reference power because it was found that a 1-kHz tone at this power has a negligible interfering effect. Any noise power encountered that was greater than this could be given a positive value in dB above reference noise, or dBrn.

These first measurements were made with the deskstand-type telephone offered in the 1920's, known as the Western Electric Type 144. From these measurements, curves were plotted – called weighting curves.

dBa

Later, an improved handset, Western Electric type 300, (F1A weighting) came into general use, exhibiting a more uniform frequency response. Listener tests indicate that the new instrument gave approximately 5-dB improvement over the 144. Rather than change existing standards, a new reference noise power of −85 dBm (3.16 x 10^{-12} watts) was introduced. This also necessitated a change in the units, resulting in the adoption of dBa – decibels adjusted.

dBrnc

When the new 500 type handset was put into service in the 1950's, another line weighting was introduced, called C-message weighting. Since the new equipment was an improvement over the old, an even higher reference power would have been required to express equal interfering effects with equal numbers. But this might have resulted in some unrealistic "negative" values of noise interference. So the reference power was returned to −90 dBm, and the units dBrnc – decibels, reference noise C-message weighted.

Weighting curves (Figure 2) for each handset compare interfering effects for various frequencies and are referred to an interference of 1 kHz. Noise measuring sets are frequency weighted in the same way so that meter readings obtained are meaningful in terms of what the ear detects. That is, the instrument does not measure noise intensity alone, but takes into account the frequency of the noise and how the particular frequency affects the ear.

Since there is no weighting effect on a 1-kHz tone, straightforward conversion between dBa and dBrnc is possible by comparing reference power. A 1-kHz signal having a power of 0 dBm yields 90 dBrnc. But, because weighting networks attenuate other frequencies differently, a uniform 3-kHz band of noise (flat or white noise) will not be measured the same as a 1-kHz tone. White noise at 0 dBm will produce a noise reading of 82 dBa and 88 dBrnc. Approximate conversion is then accomplished by adding 6 dB to the dBa value:

$$dBrnc = dBa + 6.$$

For instance, using an instrument F1A weighted, a reading of 20 dBa would be equivalent to 26 dBrnc. The conversion factor is due to the 5-dB difference in noise reference power and an approximate 1-dB difference in weighting over the voice band.

At the present, dBrnc is more convenient to use than dBa.

Psophometric Weighting

Circuit noise expressed in units established by the CCITT (International Telegraph and Telephone Consultative Committee) is gaining

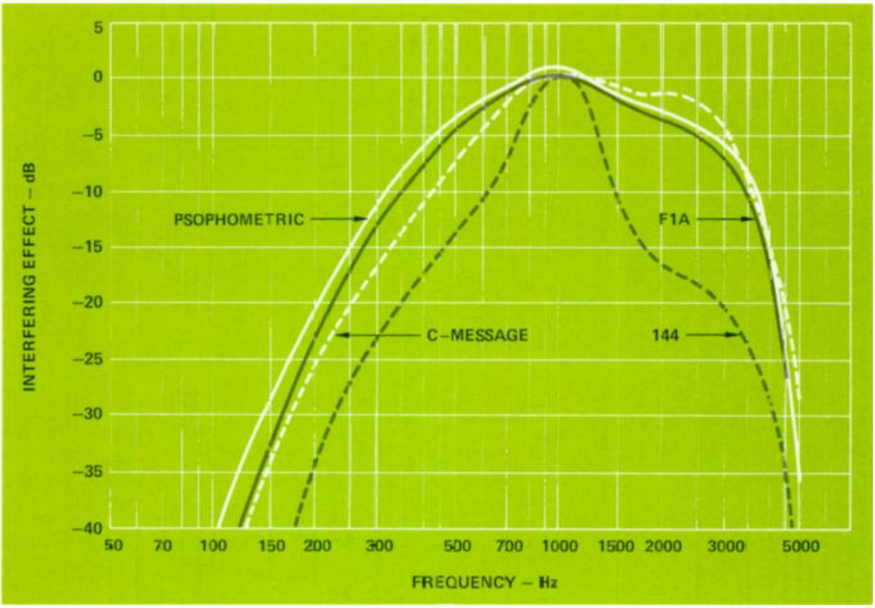

Figure 2. Weighting curves, based on listener response, show the relative interfering effect of noise on speech. All curves are referred to 1000 Hz except psophometric, which is based on measurements at 800 Hz.

recognition throughout the world. This international unit is linear rather than logarithmic and is in terms of picowatts (10^{-12} watts) of power, psophometrically weighted – pWp. (Psophometric is from the Greek word psophos, meaning noise.)

The reference level, 1 pWp, is the equivalent of an 800-Hz tone with a power of −90 dBm, or a 3-kHz band of white noise with a power of approximately −88 dBm. The shape of the psophometric curve is essentially identical to the F1A curve and similar to the C-message curve. Approximate conversion may be made as follows:

dBrnc = 10 log pWp.

Note that these terms all have absolute reference values of 10^{-12} watts, and are customarily written dBrnc0 and pWp0 to relate the measurement to 0 TLP.

Signal-to-Noise

Occasionally the term signal-to-noise ratio (S/N) is encountered. The term, usually expressed in dB, indicates the number of dB the signal is above the noise. To obtain dBrnc0 from S/N, it is only necessary to calculate how many dB the signal is above the reference noise power. The corrected reference (as mentioned previously for 3-kHz white noise) is −88 dBm for flat noise channels. Conversions are therefore:

dBrnc0 = 88 – S/N
S/N = 88 – dBrnc0
S/N = 88 – 10 log pWp0.

When it is necessary to measure speech or program volume in a transmission system, a dB meter or voltmeter is not adequate. The complexity of the program signal, as compared to pure sine waves, will cause the meter needle to move erratically, trying to follow every fluctuation in power. This would obviously be difficult to read, and has no worthwhile meaning.

Volume Units

To provide a standardized system of indicating volume, a special instrument was created. Called a VU meter, it measures *volume units*, abbreviated VU. The VU meter is calibrated to read 0 VU across a 600-ohm line with a signal of 1 milliwatt (0 dB) at 1 kHz. The scale is logarithmic and reads VU above and below this zero reference. The instrument is not frequency weighted in any way, and while not designated for the purpose, it will read single frequencies directly in dBm. Its prime function, however, is to indicate the volume of complex signals in a way corresponding to the response of the ear. The reading is not instantaneous, but a value somewhere between the average and the peak value of the complex wave due to the meter's damping characteristic.

Other Units

Various other logarithmic units are used in the telephone and communications industries to conveniently compare like values. Crosstalk coupling in telephone circuits is indicated in dBx, or dB above reference coupling, and may be measured with a noise measuring set such as used to obtain dBrnc. Reference coupling is defined as the difference between 90 dB loss and the actual coupling. Two circuits having a coupling of –40 dB could be said to have a coupling of 50 dBx.

Decibels may take on many other absolute values depending on their reference. Whereas dBm is a unit of power referenced to 1 milliwatt, dBw (referenced to one watt) is equal to 30 dBm. Similarly, dBk are decibels referenced to 1 kilowatt.

Likewise, dBv for industrial use is defined referencing 1 volt. However, in writing the equation for such a measurement, it is necessary to observe the following relationship:

$$dBv = 20 \log \frac{E_1}{E_2}$$

where E_2 equals one volt. The log of the voltage ratios is multiplied by 20, rather than 10 as in the power ratios, expressing the squared relationship of voltage and power ($P = E^2/R$). It is assumed that all measurements are across the same impedance.

Another form of decibel unit related to voltage is referred to as dBv/600 and is read directly from a dBm-voltmeter calibrated at an impedance of 600 ohms.

Speech energy is commonly rated in terms of the intensity level of the speaker's voice measured 1 meter from his mouth. The standard Reference Acoustical Power, 0 dBrap, is defined as 10^{-16} watts/cm^2.

Other terms come into use in broadcasting: dBu, with 1 microvolt (10^{-6} volts) as the reference, and dBj, referred to 1000 microvolts (10^{-3} volts). Both are measurements of signal intensity or receiver sensitivity. Any number of logarithmic units could be devised to suit special purposes, using decibels referred to some standard unit of power – voltage or current.

As the need for different calibrations and reference points arise, new yardsticks will be defined for ease of calculation.

Measure	SI Unit	Derived Units
Length	meter (m)	area - - (m^2) volume - - (m^3)
Time	second (s)	frequency - - hertz (H)
Mass	kilogram (kg)	
Temperature	kelvin (K)	
Electric Current	ampere (a)	

Figure 3.

Prefix	Symbol	Multiplier
tera	T	1,000,000,000,000 = 10^{12}
giga	G	1,000,000,000 = 10^{9}
mega	M	1,000,000 = 10^{6}
kilo	k	1,000 = 10^{3}
hecto	h	100 = 10^{2}
deka	da	10 = 10^{1}
deci	d	0.1 = 10^{-1}
centi	c	0.01 = 10^{-2}
milli	m	0.001 = 10^{-3}
micro	μ	0.000 001 = 10^{-6}
nano	n	0.000 000 001 = 10^{-9}
pico	p	0.000 000 000 001 = 10^{-12}
femto	f	0.000 000 000 000 001 = 10^{-15}
atto	a	0.000 000 000 000 000 001 = 10^{-18}

Figure 4.

Conversion Factors

inches x 25.4	= millimeters
feet x 0.3848	= meters
miles x 1.61	= kilometers
pounds x 0.454	= kilograms
millimeters x .0394	= inches
meters x 3.28	= feet
kilometers x 0.621	= miles
kilograms x 2.21	= pounds

Figure 5.

Absolute Quantity

The yardstick adopted by the communications industry to measure absolute quantitites is really a meterstick divided into centimeters instead of inches. The metric scale is part of the SI (international standards) units used to simplify and clarify numerical communication between countries.

The basic SI units and their abbreviations are shown in Figure 3. The prefixes shown in Figure 4 are added to these basic units to indicate the magnitude.

Since some English units are still prevalent and at times more familiar, conversion factors are offered to ease the transition to SI units. Figure 5 gives conversion factors for the two systems.

The equipment needed to provide world-wide communication is available and by adopting SI units the needed language is also provided.

Demodulator Survey Results

The Demodulator's performance was measured by the survey sent out in March. Four different readership areas were studied – who, where, what, and how.

The "who" distribution (Figure 6) closely correlates with the 1960 readership, except for a slight increase of readers in the manager and technician categories.

Although the job classifications did not change drastically, there was a marked change in "where" the readers are employed. An increased percentage of the readership is employed in areas with peripheral concern in the telephone industry and a more direct involvement with the broader concept of communications. Figure 7 shows the change in job classification over the 1960 distribution.

While the readers' job classifications may be blurring, the readers are definitive about "what" they want to read. Specific information about the newest forms of communication described in applied rather than theoretical terms is in greater demand than broad and general discussions of communications and systems design. The most popular topic was satellites (not in the 1960 survey). Figure 8 shows the total distribution compared with the 1960 results.

The greatest measure of performance was gained from the "how" section of the survey, in which a clear majority indicated preference for style, page size, and subject treatment as they are presently being handled.

The *Demodulator* is flexible and will change to stay abreast of technology and readership interests.

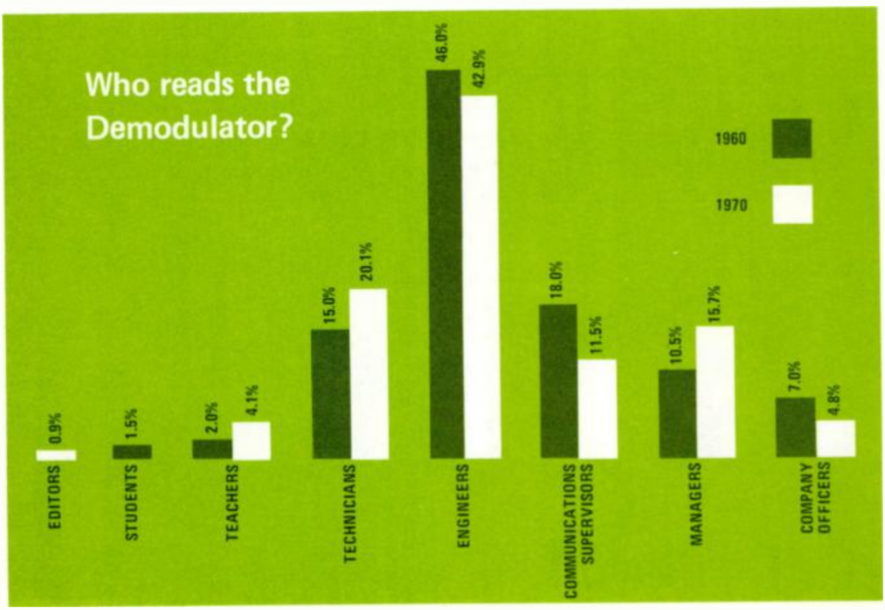

Figure 6.

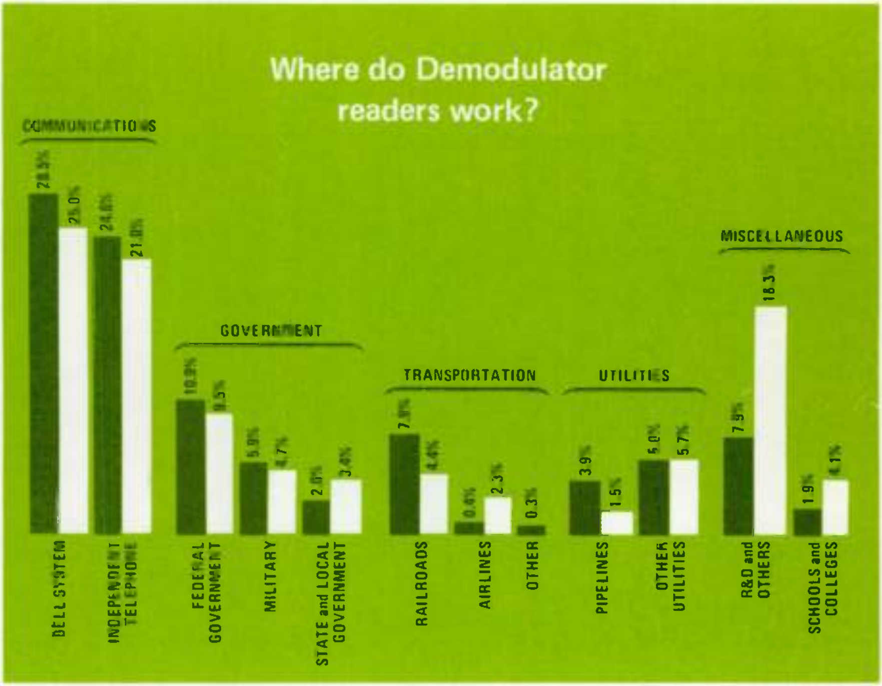

Figure 7.

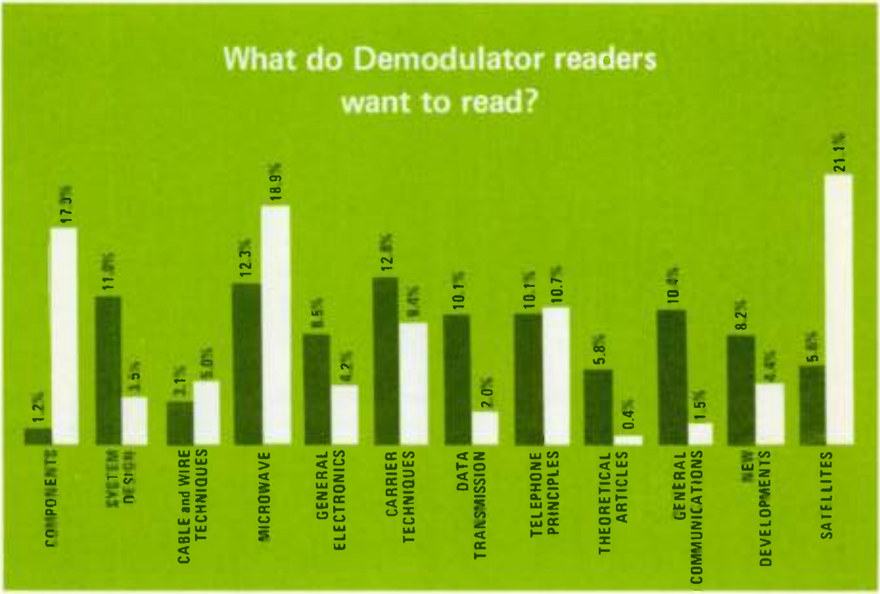

Figure 8.

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