GTE LENKURT

DEMODULATOR

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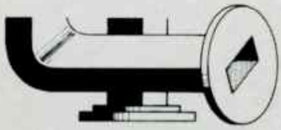


One of the most important considerations in any transmission system is the behavior of the transmission line. At microwave frequencies, waveguide is the most efficient path for transferring electrical energy from one point to another over relatively short distances.

Waveguide can be broadly defined as a structure that allows energy in the form of electromagnetic waves to be transferred from one point to another over a particular route; this, of course, excludes broadcast energy, which does not properly travel through what is commonly meant by "structure." A cord supplying 60-Hz power to an appliance is thus a type of waveguide, in that it "guides" energy from a source to a load. More commonly, however, the term "waveguide" is used only in reference to the hollow metallic conductors employed in high-frequency applications, while lower-frequency conductors are called simply "transmission lines." This convention will be followed in this discussion.

Wavelength Considerations

At relatively low frequencies, both the wavelength and period of a signal are large. For example, the wavelength of a 3-kHz signal would be 100 kilometers (62 miles), and the period would be on the order of 10^{-3} second. At 10 GHz, however, the wavelength would be 3 centimeters (1.17 inch), and the period on the order of 10^{-10} second. A transmission medium that represents a negligible fraction of a wavelength at a low frequency can thus represent several wavelengths at a higher frequency: a fifty-meter (164.04-foot) transmission line would be small compared to a 100-km wavelength, but a fifty-meter waveguide would be more than a thousand 3-cm wavelengths long.

This relationship is of particular importance because a transmission medium that is very short compared to wavelength allows absolute values of voltage and current to be ascertained at any point in time. Such a medium can, therefore, be generally treated as a two-port network, upon which ordinary ac circuit analysis techniques can be used. When the length of the transmission medium approaches a significant fraction of a wavelength, however, it becomes increasingly difficult to obtain absolute voltage and current values, until the voltage/current analysis techniques must be completely abandoned at microwave frequencies. It must also be noted that, unlike transmission lines, microwave waveguides, being hollow-pipe type structures, have lateral dimensions that are also relatively large compared to the wavelength.

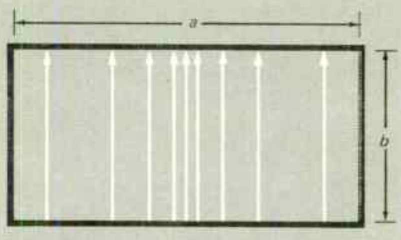
The lateral dimensions of a waveguide determine its cross-sectional shape; a circular waveguide is identified by its diameter, a rectangular waveguide by large (*a*) and small (*b*) dimensions. Rectangular waveguide has historically been the most widely used, and conveniently illustrates the general principles that apply to all waveguides.

Modes in Rectangular Waveguides

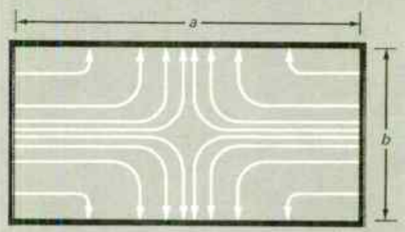
In free space, the electric and magnetic fields that comprise an electromagnetic wave are always perpendicular to one another and to the direction of wave propagation (the general direction of power flow) at any instant in time. When a wave travels through a waveguide, however, the confinement forces one of the fields, but never both, to have a component that is parallel to the direction of propagation (a longitudinal element).

For every wave, there is a number of possible field configurations. These configurations are referred to as the operating "modes" and are determined by the operating frequency and the lateral dimensions of the waveguide through which they travel. There are two fundamental classes of modes that may appear in a waveguide. In one class, the "transverse electric" (TE) mode, the electric field is everywhere perpendicular, or transverse, to the direction of propagation and the magnetic field has a longitudinal element. In the other class, it is the magnetic field that is transverse and the electric field that has a longitudinal element; this is the "transverse magnetic" (TM) mode.

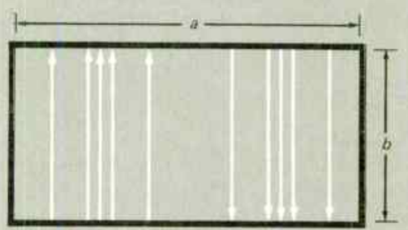
Each mode is identified by a set of two subscripts that, generally, relate to the number of half-wave field variations occurring across the guide's lateral dimensions. The first subscript indicates the number of half-wave variations of the field intensity across the wide (a) dimension of a rectangular waveguide. The second subscript denotes the number of half-wave variations across the narrow (b) dimension. In Figure 1A, for example, the electric field intensity varies from zero to a maximum level and back to zero across the wide dimension; across the narrow dimension there is no variation in electric field intensity. This represents the $TE_{1,0}$ mode. Figure 1B illustrates the $TE_{1,1}$ mode, in which there is one variation across each dimension, and Figure 1C shows the $TE_{2,0}$ mode. (The field configurations in waveguides are represented graphically by "field lines" that represent



A. IN THE $TE_{1,0}$ MODE, THERE IS A SINGLE HALF-WAVE VARIATION OF ELECTRIC FIELD STRENGTH ACROSS THE WIDE DIMENSION.



B. IN THE $TE_{1,1}$ MODE, THERE IS A SINGLE HALF-WAVE ELECTRIC FIELD STRENGTH VARIATION ACROSS BOTH THE WIDE AND NARROW DIMENSION.



C. IN THE $TE_{2,0}$ MODE, THERE ARE TWO HALF-WAVE (ONE FULL-WAVE) ELECTRIC FIELD STRENGTH VARIATIONS ACROSS THE WIDE DIMENSION.

Figure 1. Graphic representations of field configurations use "field lines" to show relative strength. The closeness of the lines indicates how strong the field is at any point in time.

the field vectors. The strength of the field is indicated by the proximity of the lines: where the field is weakest, few lines appear; where the field is strongest, the lines are close together.)

Depending upon the relationship of a and b dimensions to wavelength, more than one mode may be able to propagate through a given waveguide. This is not normally desirable, because when two or more modes are present within one guide they tend to interfere with one another and distort the transmission characteristics of the guide. Also, because the energy to sustain the modes comes from a single source, dividing it among several modes decreases the power available for signal transmission.

The physical laws controlling the electromagnetic wave establish conditions that must be met for energy transmission to occur. Each mode, for example, has a "cutoff wavelength" (λ_c), or "cutoff frequency" (f_c), that determines the point at which it can no longer exist within a waveguide. Energy at wavelengths above λ_c (below f_c) is greatly attenuated, while energy below that point is freely transmitted. The exact wavelength at which this cutoff occurs for any mode is a function of the lateral dimensions, and can be found for any rectangular guide by:

$$\lambda_c = \frac{2}{\sqrt{(m/a)^2 + (n/b)^2}}$$

where m is the first subscript of the mode being considered, n is the second subscript, and a and b are the wide and narrow dimensions, respectively. As shown in Figure 2, the cutoff wavelength of the $TE_{1,0}$ mode can be simplified to $2a$; that is, the length of a wave can be no more than twice the width of the guide if the $TE_{1,0}$ mode is to be propagated. The $TE_{0,1}$ mode cutoff wavelength is $2b$, making it the only low-frequency competitor of the $TE_{1,0}$ mode. From this, it can be seen that the $TE_{1,0}$ mode has the longest cutoff wavelength of all modes. It is, therefore, the dominant mode in rectangular waveguides, and is the most used because it can be allowed to propagate freely while other modes are suppressed.

OPERATING MODE	CUTOFF WAVELENGTH
$TE_{1,0}$	$2a$
$TE_{0,1}$	$2b$
$TE_{2,0}$	a
$TE_{1,1}$ OR $TM_{1,1}$	$\frac{2ab}{\sqrt{a^2+b^2}}$

a = WIDE DIMENSION
b = NARROW DIMENSION

Figure 2. Cutoff wavelengths for various modes in rectangular waveguide.

Suppression of all but the dominant mode can be accomplished by careful selection of lateral dimensions. Since the operating frequency — and wavelength — are known, it is a relatively simple matter to select a guide whose a dimension is greater than a half, but less than a whole, wavelength. The b dimension can then be chosen to be approximately one-half the width. These dimensions are small enough to prevent higher order modes from forming, and set a cutoff wavelength that is sufficiently above the operating wavelength not to interfere with transmission.

Polarization

As has been indicated, the electric and magnetic fields comprising an electromagnetic wave are always at right angles to one another at any instant in

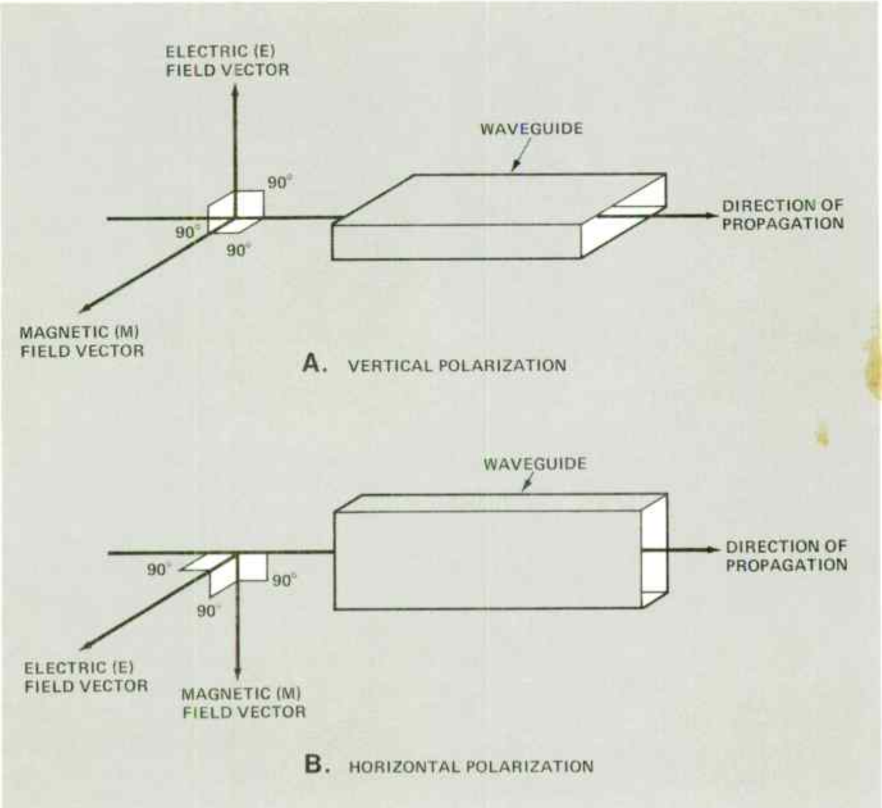


Figure 3. The polarization of an electromagnetic wave is determined by the orientation of the electric field component.

time. By definition, the polarization of the wave is determined by the orientation of the electric field component. If this component is perpendicular to the earth, the wave is said to be "vertically polarized"; if the electric field is horizontal, the wave is "horizontally polarized" (see Figure 3).

When a wave's electric field orientation remains constant in time and space, it is further said to be "linearly polarized." If, however, the electric field undergoes a 90° change of direction in each quarter-cycle of time, or quarter-wavelength of distance, the wave is "elliptically polarized." "Circular polarization" is achieved when the electric field magnitude of an elliptically polarized wave remains constant as it rotates.

Polarization is of importance in the consideration of waveguides because it allows selectivity in the transmission and reception of microwave energy. A horizontally polarized wave, for example, has no vertical component; if it were transmitted, only a similarly oriented receiver could properly detect it. A receiver using 90° polarization with respect to the transmitted wave (a "cross-polarized" condition) would receive a greatly attenuated signal. This makes possible the operation of two cross-polarized microwave radio systems over one route without undue interference between them.

Circular Waveguides

Although rectangular waveguide has appeared in the great majority of microwave applications, there are still uses for other cross-sectional shapes. One of the most commonly utilized of these other shapes is circular.

When, for example, the distance from a microwave radio transmitter/receiver to an antenna is relatively short, rectangular guide can be used for both the horizontal (from equipment to tower base) and vertical (from tower base to antenna radiating element) sections of the run. Systems employing long tower runs, however, cannot tolerate the high insertion loss (total power lost through reflection and attenuation) of a long rectangular waveguide section, especially if the transmitter has relatively low output power. For these systems, circular guide, which has a much lower insertion loss, is commonly used for the vertical section.

Circular waveguide also has an advantage over rectangular in systems employing cross-polarized antennas: rectangular guide cannot support both vertical and horizontal polarization simultaneously and would thus require separate vertical runs for each polarization; circular guide allows propagation of cross-polarized waves, and can thus reduce the number of vertical runs required.

The same general rules that control propagation of electromagnetic energy in a rectangular structure hold for circular waveguide, but in a more complex manner. For example, the lowest frequency signal that can propagate through a circular guide is determined by the guide's diameter; the diameter, that is, establishes a cutoff wavelength. The definition of this wavelength, however, is a more complex mathematical formula than that for a rectangular guide, and results in the mode/diameter relationships shown in Figure 4. As can be seen from these relationships, the $TE_{1,1}$ mode is dominant because it has the longest cutoff wavelength, and can thus propagate when other modes are suppressed. This differs from rectangular waveguide, in which the $TE_{1,1}$ is a higher order mode, because the geometrical significance of the subscripts is different: in circular waveguide mode notation, the first subscript indicates the number of full-wave electrical field variations around the circumference, and the second subscript denotes the number of radial variations (see Figure 5).

OPERATING MODE	CUTOFF WAVELENGTH
$TE_{1,1}$	1.706 *d*
$TM_{0,1}$	1.306 *d*
$TE_{2,1}$	1.028 *d*
$TE_{0,1}$	0.820 *d*

d = DIAMETER

Figure 4. Cutoff wavelengths for various modes in circular waveguide.

The $TE_{1,1}$ mode is generally used in circular waveguide applications not only because of its greater cutoff wavelength, but also because its electric and magnetic field configuration most closely resembles the $TE_{1,0}$ mode in rectangular guide and thus simplifies the interface considerations (see Figure 6). The $TE_{1,1}$ mode also lends itself most readily to propagation of circularly polarized electromagnetic waves, and can operate using both vertical and horizontal polarization (see Figure 7).

Elliptical Waveguide

If a circular waveguide is deformed so as to give it an elliptical cross-

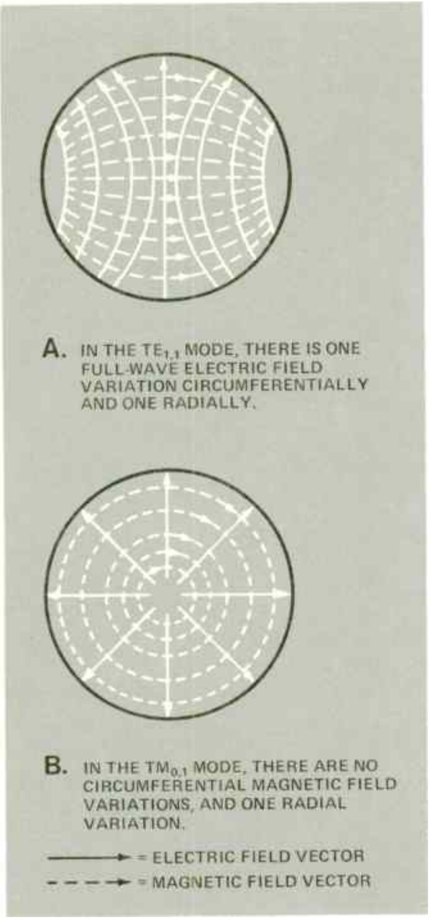


Figure 5. The field strength variations in circular waveguide occur in relation to the circumference and radius.

section, the transmission of energy through it will usually be affected. In general, the mode configuration being propagated divides into two components that travel through the guide with different phase velocities and attenuation (see Figure 8A). However, a mode having circular symmetry, such as the $TE_{1,1}$ mode, does not undergo this splitting (see Figure 8B), but propagates in essentially the same manner whether the guide is elliptical or circular.

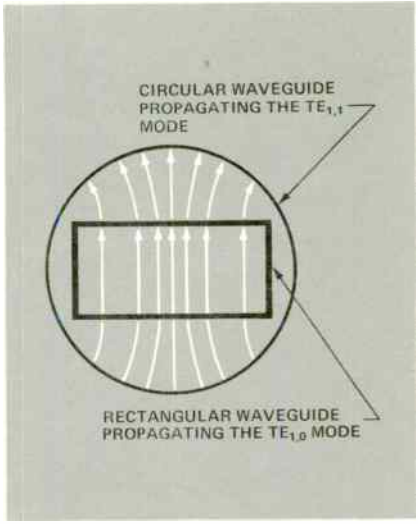


Figure 6. The $TE_{1,1}$ mode in circular waveguide resembles the $TE_{1,0}$ mode in rectangular waveguide closely enough to make coupling from one to the other relatively simple.

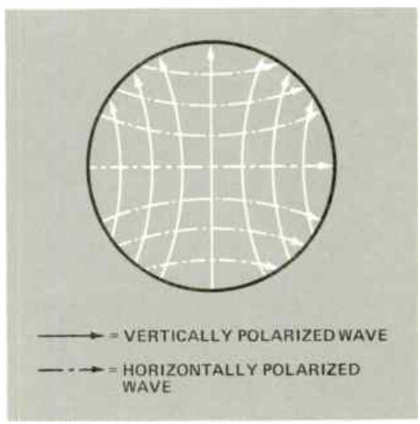


Figure 7. Circular waveguide can support cross-polarized waves, particularly when both propagate in the $TE_{1,1}$ mode.

Elliptical waveguide mode notation is similar to that of circular guide. There is, however, an additional preceding subscript indicating whether the wave is "even" (*e*) or "odd" (*o*).

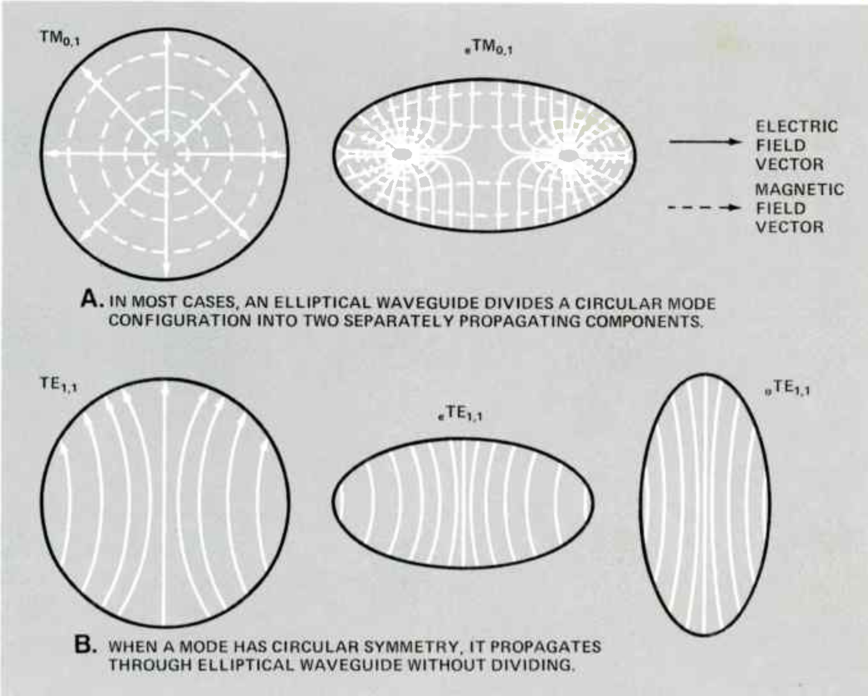


Figure 8. Modes in elliptical waveguide derive from those propagating in circular guide.

This convention derives from the mathematical functions defining the fields in an elliptical structure, and relates to the axis of deformation: a vertically oriented guide propagates "odd" waves, a horizontally oriented guide, "even" waves.

Mode Filters

When microwave energy is being propagated through a waveguide, discontinuities (bends, damaged components, circular-to-rectangular transitions, etc.) can cause modes other than the desired one to form. Careful selection of lateral dimensions can generally reduce the effects of such spurious modes by making it impossible for them to remain in existence. If a higher-order mode is being used, however, the dominant mode would continue to propagate once it formed, and would interfere with the desired mode. In circular waveguide, there is also the problem of the dominant and next-higher modes having cutoff wavelengths that are very close. Both of these problems can be solved in several ways, but the mode filter generally represents the most economical solution.

The two most common types of mode filters are resistive and constrictive. A constrictive mode filter consists of a section of circular waveguide that tapers from one diameter to a smaller one and back. This type of filter reflects the higher-order modes by establishing a point at which only the dominant mode's wavelength can pass. The major problem with constrictive filters is that the reflected energy may become "trapped" and continue to reflect back and forth in the section of guide preceding the filter, producing even greater interference with the desired mode. A more effective and less expensive filter is the resistive type.

A resistive mode filter is basically a discontinuity that is purposely introduced into a waveguide to absorb the energy present in any but the desired mode. If, for example, the $TE_{2,0}$ mode is to propagate through a rectangular guide (an uncommon, but possible, arrangement), the dominant $TE_{1,0}$ mode can be removed by placing a thin piece of conducting material in the center of the wide dimension. At this point, the $TE_{1,0}$ electrical field would be maximum and the $TE_{2,0}$ field minimum; the $TE_{1,0}$ energy is thus short-circuited and the mode stopped from propagating, while the $TE_{2,0}$ mode is undisturbed (see Figure 9).

If the $TE_{1,1}$ mode propagates through a circular guide, the $TM_{0,1}$ mode is the most likely spurious mode to form if the guide's diameter is carefully selected to begin with. A resistive mode filter can remove the unwanted field configuration. In this case, a short piece of conducting material is placed along the axis of the guide, in effect changing that portion into a short section of coaxial cable that does not support the $TM_{0,1}$ mode.

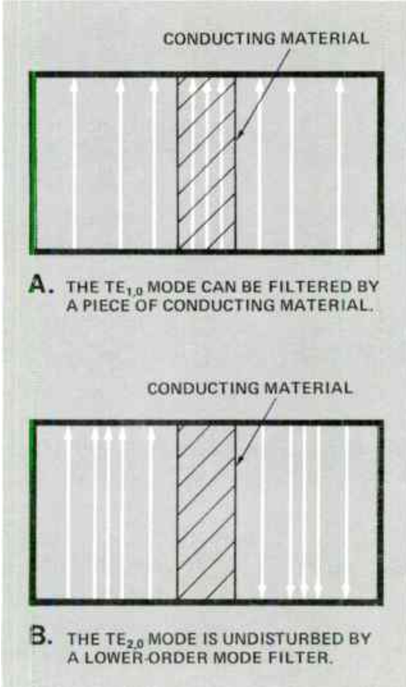


Figure 9. When a higher-order mode is to be propagated, a resistive mode filter can be used to suppress the dominant mode.

Waveguide runs form transmission links between microwave radio equipment and antennas. As such, they are an essential part of a microwave system. Defects in a run are difficult to locate and expensive to rectify, so as much care must be exercised in the planning, selection and installation of the components in a waveguide run as is taken in engineering the elements that it will link.

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Logarithmic Units of Measure

Logarithmic units are used extensively in the telecommunications industry to define the qualities and functions of transmission circuits, especially in relation to the wide variety of power ratios considered.

The logarithm, or "log," of a quantity is the exponent of the power to which a base number must be raised to produce the quantity; that is, (base number)$^{\log}$ = (quantity). Since, for example, $2^4 = 16$, then 4 is the log, to the base 2, of 16. Similarly, since $10^2 = 100$, the log of 100, to the base 10, is 2. The base 10 is by far the most widely used, so numbers in that base are referred to as "common" logarithms. The subscript 10 is usually eliminated and the form becomes $2 = \log 100$, with the base 10 understood.

The use of logarithms is advantageous in many forms of complicated calculations. Because they are basically exponents of powers of ten, logarithms allow addition, subtraction, multiplication and division to replace multiplication, division, raising to powers and extracting roots, respectively. Any series of events involving multiplication or division can therefore be handled by simple addition or subtraction, if expressed logarithmically. This is particularly valuable in the telecommunications industry, where a variety of measurements, some involving very large numbers, is necessary to describe the properties of a signal as it passes through a system.

Decibels

It has been shown that the volume of a sound must change by about 25 percent before the human ear can detect the difference. For example, the power output of an audio amplifier delivering eight watts would have to rise to ten watts in order for the ear to note an increase in volume. To produce another discernable volume increase, the output would have to rise to at least 12.5 watts. Such changes in hearing response follow a logarithmic, rather than linear, scale; any practical unit used to express power gains or losses in communications circuits should also vary logarithmically. The decibel (dB) is the basic unit for measuring such power changes.

The decibel is defined by the expression:

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

where if P_2 is the larger power the ratio is a positive number of dB's, and if P_2 is smaller than P_1 the ratio is in negative dB's. A given number of decibels is therefore always the relationship between two powers, and is not an absolute value by itself (see Figure 1). The gain or loss of a circuit or component can thus be expressed without defining the input and output quantities. A 16-dB attenuator, for example, will always reduce a signal by 16 dB, regardless of the absolute value involved.

Frequently, however, it is convenient to know the relationship between signal (or noise) power at some point in a circuit or system and a fixed,

dB	POWER RATIO	dB	POWER RATIO
0	1.00	10	10.0
0.5	1.12	15	31.6
1.0	1.26	20	100
1.5	1.41	25	316
2.0	1.58	30	10^3
3.0	2.00	40	10^4
4.0	2.51	50	10^5
5.0	3.16	60	10^6
6.0	3.98	70	10^7
7.0	5.01	80	10^8
8.0	6.31	90	10^9
9.0	7.94	100	10^{10}

Figure 1. The decibel by itself is always a ratio, and never an absolute value.

known quantity. In this case, the relationship is generally expressed as so many dB above or below a reference power.

dBm

The most common reference power in the telecommunications industry is one milliwatt (10^{-3} watt). When this reference figure is used, the unit of measure is dBm ("decibels referred to one milliwatt"), which is defined by the expression:

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

where P_2 is one milliwatt. Adding a definite reference point makes dBm a measure of absolute power rather than just a ratio, and it can be readily converted to watts. For example, "+10 dBm" indicates a signal ten times greater than one milliwatt, or ten milliwatts; "+20 dBm" is 100 times greater than one milliwatt, or 100 milliwatts (the unit is logarithmic, not linear, so 20 dBm is not simply twice 10 dBm). A +30-dBm (one-watt) signal applied to an amplifier with 10 dB gain results in a +40-dBm output, while a standard 0-dBm (one-milliwatt) test tone would be measured at −15 dBm after passing through a 15-dB attenuator.

Although dBm expresses a certain amount of absolute power, it has little meaning in a transmission system unless the gain or attenuation at the measurement point is also specified. Gain and attenuation likewise have significance only if a reference level is defined for the system, allowing any point to be described in terms of dB above or below the reference. The point at which the reference appears is designated the "zero transmission level point" (0 TLP). The 0 TLP, which is also known as a "reference transmission level point" (RTLP), is defined as the point in a system at which a standard 0-dBm test tone would have an absolute value of one milliwatt (0 dBm). The relative levels of all other points in the system are determined by the algebraic summation of the gains and losses between the 0 TLP and the point being considered.

dBm0

The point in a transmission system where a signal has experienced X amount of gain or attenuation in decibels relative to the 0 TLP is called the "relative transmission level," or "dBr," point. A 0 TLP is thus also a 0-dBr point. "Level" in this context is purely relative and has nothing to do with actual power; rather, it shows the difference between the point at which a measurement is taken and an established zero point: a signal of any power at a 0 TLP is reduced by 20 dB at a −20-dBr point. When the actual power measured in dBm at a relative transmission level (dBr) point is referred to a 0 TLP, it is converted into dBm0, where the "0" indicates that the level is measured at, or referred to, a point of zero relative level (a 0 TLP). The relationship of dBm and dBm0 is:

$$\text{dBm0} = \text{dBm} - \text{dBr}$$

where dBm is the actual measured power, dBr is the relative transmission level at the measurement point, and dBm0 is the power level referred to a zero transmission level point.

For convenience, measurements converted to dBm0 can be seen as indicating what the power would have been if it had been measured at the 0 TLP. For example, a tone having an actual −9-dBm level measured at a −16-dBr point is equal to +7 dBm0; that is, in order to be at −9 dBm after 16 dB attenuation the signal would have had to be +7 dBm at the 0 TLP, or +7 dBm0.

The dBm0 unit is especially useful in checking system operation. In Figure 2, for example, a 0-dBm standard test tone appears at point A, allowing it to serve as a 0 TLP where, by definition, the relative transmission level is 0 dBr. At point B, the tone has undergone attenuation of 6 dB; point B is thus a −6-dBr point. An absolute power of −6 dBm measured at B equals 0 dBm0. Any other value would indicate excessive attenuation.

The units dBm and dBm0 generally refer to the total power measured at a given location. Noise level is also of considerable interest in the telecommunications industry, and there are several logarithmic units used in its measurement.

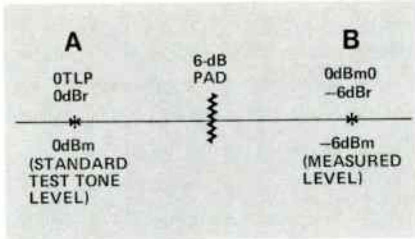

Figure 2. To verify proper system operation, the level of any point, in dBm0, should numerically equal the absolute power, in dBm, at the 0 TLP to which it is referenced.

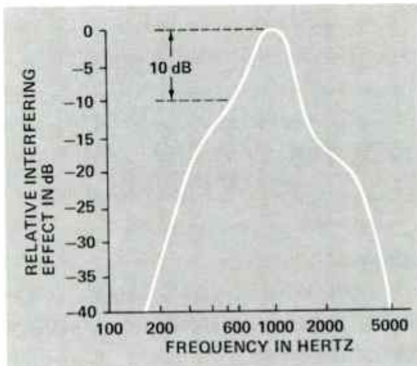

Figure 3. The 144-weighted curve compares frequencies within a vf band with a 1-kHz reference.

dBrn

In the early days of telephony, tests were made to develop a unit of measure for noise interference. These tests took into account the capabilities of the human ear and the efficiency of the telephone equipment used. Plotting the test results on a graph produced a "weighting curve" (see Figure 3) that showed how much each frequency in a voice-frequency (vf) band interfered with a conversation compared with a reference of 1 kHz, which had been found to produce more interference than any other frequency. For example, a 600-Hz tone caused 10 dB less interference than a 1-kHz tone of the same amplitude. The characteristics shown on such a curve permitted objective test instrument measurements to approximately parallel the results of subjective tests made by human observers.

Since any noise or tone superimposed on a conversation has an interfering effect, it is desirable to express all such quantities in positive numbers. To accomplish this, a power of 10^{-12} watt, or −90 dBm, at 1 kHz was originally selected as the reference power, because such a tone was found to have negligible interfering effect.

Any power capable of producing interference would thus have a positive effect with respect to the reference, and could be expressed in "dB above reference noise," or dBrn (see Figure 4). A noise measurement of 30 dBrn, for example, would indicate a power level of –60 dBm (30 dB above the –90-dBm reference noise level).

dBa

These early experiments were made with Western Electric Type-144 handsets, so the graph came to be called the "144 weighting curve." Later, an improved handset, the F1A, came into general use. When the listener tests were repeated with this equipment, the "F1A weighting curve" was produced. Interference measured with F1A weighting was 5 dB higher than with the 144 weighting. That is, a 1-kHz tone at –85 dBm was found to have the same interfering effect with F1A weighting as a 1-kHz signal at –90 dBm with 144 weighting. Rather than change the existing standard, however, a new reference level of –85 dBm was established for use with the F1A instrument, and a new unit of measure, the dBa ("decibels above reference noise, adjusted"), was adopted. A noise measurement of 30 dBa, using the F1A weighting, therefore indicated a power level of –55 dBm (30 dB above the reference noise level of –85 dBm).

dBrnc

When the 500-type handset was put into service in the 1950's, another set of weighting curves, called "C-message weighting," was introduced. Since the new equipment improved on the old,

POWER	WATTS IN POWERS OF TEN	dBm (dB REFERRED TO 1 mW)	dBrn (dB ABOVE 144-WEIGHTED REFERENCE NOISE)	dBa (dB ABOVE FIA WEIGHTED REFERENCE NOISE)	dBrnc (dB ABOVE C-MESSAGE-WEIGHTED REFERENCE NOISE)	pWp (PICO-WATTS, PSOPHOMETRICALLY WEIGHTED)
10W	10^{1}	+40	130	125	130	10^{13}
1W	10^{0}	+30	120	115	120	10^{12}
100mW	10^{-1}	+20	110	105	110	10^{11}
10mW	10^{-2}	+10	100	95	100	10^{10}
1mW	10^{-3}	0	90	85	90	10^{9}
100μW	10^{-4}	–10	80	75	80	10^{8}
10μW	10^{-5}	–20	70	65	70	10^{7}
1μW	10^{-6}	–30	60	55	60	10^{6}
.1μW	10^{-7}	–40	50	45	50	10^{5}
.01μW	10^{-8}	–50	40	35	40	10^{4}
.001μW	10^{-9}	–60	30	25	30	10^{3}
100pW	10^{-10}	–70	20	15	20	100
10pW	10^{-11}	–80	10	5	10	10
				0		
1pW	10^{-12}	–90	0	–5	0	1

Figure 4. Noise power measurements are related to a minimum reference power, allowing them generally to be expressed as positive interference values.

the power of a tone had to be even higher to produce an interfering effect, so the reference noise power would have had to be increased. In circuits with very low noise, however, this could have resulted in unrealistic "negative" values of noise interference, so the reference was returned to −90 dBm and the unit became "decibels above reference noise, C-message weighted" (dBrnc).

Because it is a single-frequency tone, the 1-kHz reference has all of its power concentrated at one point in the vf spectrum; that is why a 1-kHz signal having a power of one milliwatt (0 dBm) produces 85 dBa, or 90 dBrnc, of interference. With a 3-kHz band of random noise (white, or flat, noise), however, the power is spread uniformly over the spectrum, and this changes the level of interfering effect. The interference produced by white noise having a power of 0 dBm is only 82 dBa (approximately 88 dBrnc), so when measurements are taken in white, or flat, noise circuits the reference noise power is −82 dBa, or about −88 dBrnc, depending upon weighting. An approximate conversion from dBa to dBrnc can be accomplished by adding 6 dB to the dBa value:

$$\text{dBrnc} = \text{dBa} + 6\ \text{dB}$$

where the conversion factor is due to the 5-dB difference in noise reference power and an approximate 1-dB difference in weighting over the vf spectrum.

Psophometric Weighting

In Europe and many other parts of the world, circuit noise is expressed in units established by the CCITT (International Telegraph and Telephone Consultative Committee). The basic unit, which is linear rather than logarithmic, is in terms of power measured in picowatts (10^{-12} watt), psophometrically weighted (pWp). ("Psophometric" derives from two Greek words and literally means "noise measurement.") The reference level, 1 pWp, is the equivalent of an 800-Hz tone with a power of −90 dBm, a 1-kHz tone with a power of −91 dBm, or a 3-kHz band of white noise with a power of approximately −88 dBm. In the United States, system noise is typically expressed in terms of dBrnc; internationally, it is more common to refer to "picowatts per kilometer." Approximate conversions can be made by:

$$\text{dBa} = 6 + 10 \log \text{pWp}$$
$$\text{dBrnc} = 10 \log \text{pWp}$$

As with the total power measurement, it is often desirable to refer an absolute noise power measurement to a known quantity at a different location. The zero transmission level point is again used for this purpose. The units referenced to the 0 TLP become dBa0, dBrnc0 and pW0p.

Summing dB Powers

Expressing gain or loss in terms of decibels allows the overall performance of a system to be found by simple algebraic summation rather than more complicated multiplication or division: 30 dBm + 10 dB = 40 dBm is another way of saying one watt multiplied by ten is ten watts. Summing the powers of two separate signals expressed in logarithmic form, however, is more complex. For example, one milliwatt + one milliwatt = two milliwatts, but 0 dBm + 0 dBm = 3 dBm; twice as much power, that is, represents a 3-dB increase (this is an approximation, since log 2 = .30103, but is in error by only about one-third of one percent and is thus widely accepted). Figure 5 provides a simple means of summing powers expressed logarithmically. In this figure, P_a and P_b represent two powers whose summation is P_s; P_a is always taken as the larger of the two.

COLUMN 1 $(P_a - P_b)$	COLUMN 2 $(P_s - P_a)$	COLUMN 1 $(P_a - P_b)$	COLUMN 2 $(P_s - P_a)$
0	3.0	8	0.6
1	2.5	9	0.5
2	2.1	10	0.4
3	1.8	12	0.3
4	1.5	14	0.2
5	1.2	16	0.1
6	1.0	18	0.07
7	0.8	20	0.04

Figure 5. An addition table is convenient when summing powers expressed logarithmically.

To sum two powers, calculate $P_a - P_b$ and locate the resulting value in Column 1. Then simply add the corresponding value in Column 2 to P_a to obtain the desired sum, P_s. For example, to add +12 dBm (P_a) to +10 dBm (P_b), subtract 10 from 12. Locate the result, 2, in Column 1; the corresponding value in Column 2 is 2.1, which is added to P_a: +12 dBm + 10 dBm = +14.1 dBm.

Other Units

Various other logarithmic units are used in the telecommunications industry. Crosstalk coupling in telephone circuits, for example, is indicated in dBx, or "dB above reference coupling." Reference coupling is defined as the difference between 90 dB loss and the amount of actual coupling. Two telephone circuits having a coupling of −40 dB could be said to have a coupling of 50 dBx.

Decibels may also take on many other absolute values, depending upon the particular reference. While dBm is a unit of power referred to one milliwatt, dBw is power referred to one watt; 0 dBw thus equals +30 dBm. Similarly, dBk is power referred to one kilowatt, and dBv is defined referring to one volt. In writing the equation to define this unit, however, the following relationship must be observed:

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

where E_2 = one volt. The log of the voltage ratio is multiplied by 20, rather than 10 as in power ratios, to allow for the square relationship between voltage and power.

In the broadcast industry, the terms dBu, with one microvolt as the reference, and dBj, referred to 1000 microvolts, are widely used as measurements of signal intensity or receiver intensity, illustrating the versatility of logarithmic units, which can be made to suit special purposes by establishing a standard power, voltage or current reference.

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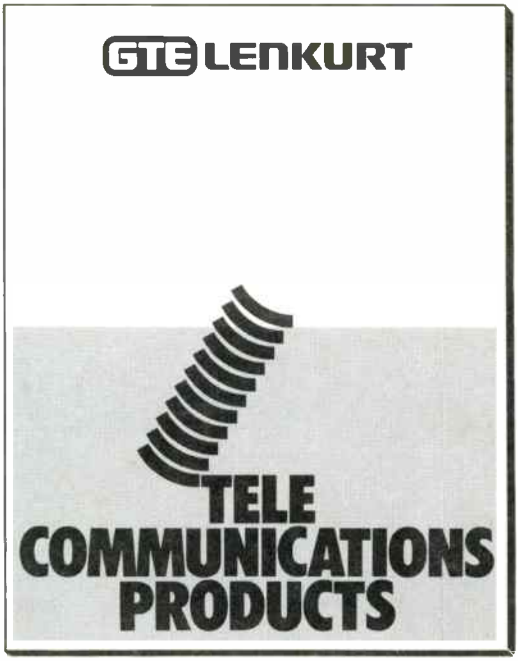

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