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Useful Concepts Of Frequency Modulation

A non-mathematical discussion of the various ways in which a frequency modulated signal manifests itself and how its characteristics dictate the design of circuits.

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Concept: A mental image of a thing formed by generalization from particulars; also, an idea of what a thing in general should be. (Webster)

A concept is a very personal affair, involving mental images which are subject to infinite variety. The usefulness of a concept is also quite personal; it may even fail to conform with known facts and still be useful. Indeed, a carefully selected assortment of concepts is a powerful addition to the engineer's kit of tools.

The apparent dual personality of frequency modulation is easily observed with common measuring instruments and therefore attracts attention. For example, a sweeping signal which produces a smooth response in a frequency detector circuit may, under certain conditions, fail to excite a response at some sideband frequency. Also, the frequency deviation is not an inherent characteristic of the signal, but sometimes depends on the passive circuits through which the signal is passed.

Modulation

Information is in general transmitted by changing, or modulating, some medium. In communications two aspects of the information are usually transmitted, the amplitude of the modulation signal and the frequency of the modulating signal. In frequency modulation this information is conveyed by changing the frequency of an alternating voltage whose frequency lies well above the highest frequency we wish to transmit as information. Amplitude data is carried as the extent of the carrier frequency change and frequency data as the rate at which the carrier varies above and below its average frequency.

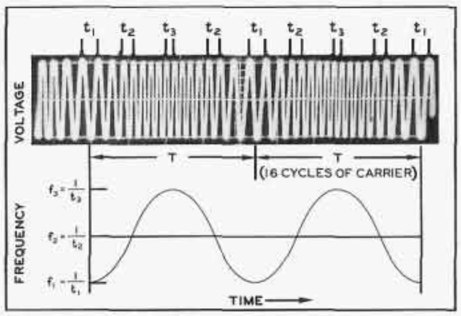

Figure 1. The variation of voltage with time as a signal is deviated ±50 kc about an average frequency of 160 kc by a 10 kc modulating signal.

In amplitude modulation it is conventional to refer to a *carrier* and *sidebands* with the carrier having a single assigned frequency. In the case of frequency modulation, however, the term *carrier* may be thought of literally as meaning the total energy used to carry the information, and as consisting of the vector sum of the center frequency and all of the sidebands. We can of course speak of the average or center carrier frequency. It is also useful to consider the instantaneous carrier frequency at any moment. The frequency swing from the average carrier frequency is called the *deviation*.

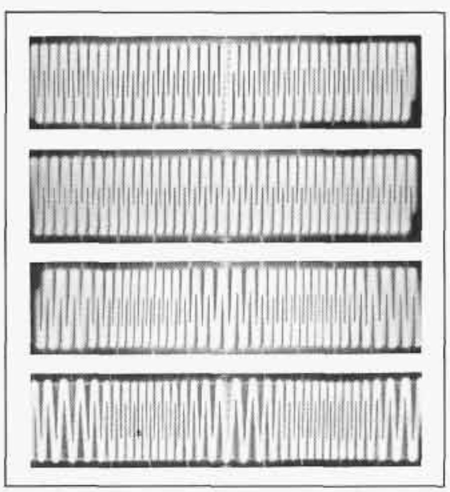

Figure 2. Increasing intensity of cycle- bunching as a 160 kc carrier is frequency modulated by a 10 kc modulating signal to deviations of 25 kc, 50 kc and 75 kc.

Figure 1 is an oscilloscope display of the manner in which the instantaneous voltage of a frequency modulated carrier, having a center frequency of 160 kc, varies with time when deviated ±50 kc by a 10 kc sine wave modulating signal. The frequency and time relationships are shown to illustrate the above terms. Figure 2 is an oscilloscope display of the manner in which the peak deviation conveys *relative* information about several different peak values of modulating voltage.

Sidebands

One might introduce the side frequencies, or sidebands as they are more commonly known, with the rather trite comment that if the peak amplitude or instantaneous frequency of the carrier change, something must have changed them. In fact, the change is proportional to the instantaneous voltage of the modulating signal.

These characteristics are very much like a familiar concept in our daily experience: inertia and force. To suggest that a carrier has inertia may seem a bit far feched. However to change its amplitude or frequency, energy must be added in much the same way as we can change the course of a rolling ball only by adding an *external* force. This added energy, the right amount in the right places at the right time, we call the sideband energy. In the case of frequency modulation, it is a matter of *re-distributing* the original energy, rather than *adding*

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energy as is the case in amplitude modulation. Figure 3 shows how the complexity of the sidebands increases with an increase in the deviation of the carrier frequency from its unmodulated value.

Consider a uniformly rotating flywheel, representing the average frequency of the carrier, on which one spoke has been painted red and carries a direct current from the hub to the rim of the wheel. As the wheel rotates in a counter-clockwise direction, the current will induce a sinusoidal variation of voltage in a fixed conductor located along a diameter. A complete cycle of the alternating frequency will occur for each rotation of the wheel which will have in the process rotated through 2π radians; hence, our concept of *angular* frequency.

If we wish to change or modulate this frequency, we must do something about the speed of the wheel. Specifically, we must apply external accelerating or retarding forces, analogous to sidebands, which combine by vector addition with the original energy of the rotating wheel to raise or lower the output frequency. The amount and distribution of sideband energy will vary with both the rate at which we alter its speed (the modulation frequency) and the amount by which we alter its speed (modulation amplitude) as shown in Figure 3.

About Rotating Sideband Vectors

Our rotating wheel concept showed us that the frequency was directly related to the speed of rotation of the wheel which can be described as rotating so many degrees a second. Therefore, we obtain the concept of frequency modulation as being a form of *angular*, or phase, modulation in which *frequency* is defined as being the *rate of change of phase.*

In order to more readily observe changes in phase, or changes in speed of rotation (frequency), imagine that we climb onto a second wheel rotating at the *average* speed. As the carrier frequency is increased its wheel will appear to speed up counter-clockwise, and vice versa. This concept gives rise to a useful set of vector addition diagrams, shown in Figure 4, which are snapshots taken at the peak of the carrier voltage, distributed throughout the modulation cycle.

The vertical line of unit length is the vector representing the voltage at the average frequency. A pair of sideband voltages is represented by two short vectors of equal magnitude, one rotating faster than the carrier center frequency and the other an equal amount slower than the center frequency. We can determine their net effect by adding up the individual contributing voltages vectorially as shown by the dotted lines, taking first the resultant of the two sidebands and adding it to the carrier center frequency vector to obtain the final resultant voltage magnitude and relative phase angle.

The upper portion of Figure 4a shows the phase of the rotating sideband vectors adjusted with respect to the carrier in such a way that the phase (or frequency) of the carrier remains constant with respect to the wheel on which we are riding but the peak amplitude of the individual cycles of the carrier varies in accordance with the instantaneous voltage of modulating frequency. This effect we call *amplitude* modulation.

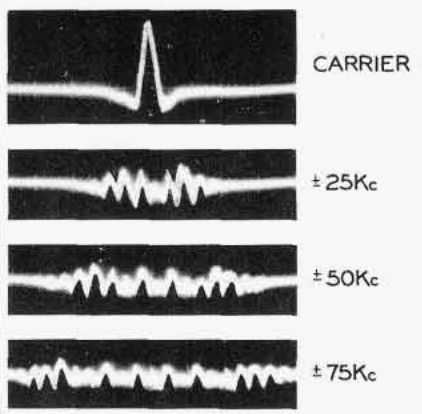


***Figure 3.** Relative sideband spectrum generated by frequency modulating a 60 mc carrier with a 10 kc modulating frequency to maximum deviations of ±25 kc, ±50 kc and ±75 kc (width of trace about ±80 kc).*

If we now pluck off the small cluster of rotating sidebands, rotate this cluster in phase by 90° and tack it back on to the original carrier center frequency, we get a dramatically different result, shown in Figure 4b. Instead of a resultant vector whose relative phase relationship remains fixed and whose amplitude varies, the relative phase of the resultant varies and its magnitude remains reasonably constant. If we now sketch out the peak magnitude of individual cycles in the resulting wave, we see that the end result is the same kind of alternate bunching of individual cycles as was displayed on the oscilloscope for an actual frequency-modulated wave having known characteristics as shown in Figure 1.

It is interesting to note that frequency-modulated transmitters have been based on both of the concepts discussed so far. A reactance tube shifts the resonant frequency of a tuned circuit in accordance with the modulating voltage thus producing directly the waveform demonstrated in Figure 1. Likewise a type of frequency-modulated transmitter actually operates by stripping the sidebands from an amplitude-modulated wave in a balanced modulator, rotating them 90° and adding them back on to the carrier center frequency in the manner shown in Figure 4b. This process is known as "indirect" frequency modulation.[2]

The two portions of Figure 4 indicate an interesting aspect of modulation. Amplitude variations are carried by sidebands in pairs whose vector resultant is in phase addition or cancellation with the average carrier vector. Small phase changes are carried by pairs of sidebands whose resultant is at right angles, or in quadrature, with the average carrier vector. The sine and cosine lend themselves well to the mathematical description of this perpendicular relationship.

The Constant Amplitude Problem

Pure frequency modulation imposes an additional condition on those mentioned above: the rms amplitude of the vector resultant voltage shall remain constant. This requirement demands a complicated assortment of sidebands of proper amplitude, frequency and phase. In Figure 4b only the first pair of sidebands was shown, and the vector resultant was seen to increase in magnitude with increasing change in phase. This unwanted increase can be corrected by the addition of a second pair of sidebands rotated an additional 90° to cancel out part of the amplitude change. The next pair will be rotated still another 90° to act as correction on the first phase shift pair.

Figure 5 shows how successive pairs of sidebands come into play to produce a constant-amplitude resultant peak carrier voltage swinging back and forth about an average value of phase throughout a cycle of the modulating frequency.

If through the use of too narrow a frequency bandpass, some of the outlying sideband components have been attenuated (or to look at it another way, the vector resultant voltage has slid down on the skirts of the amplifier response curve at the extremes of its excursion) the resultant will not have constant amplitude and some of the original sideband energy (or information) will have been lost. The resultant carrier voltage not only varies in amplitude but does not deviate in frequency in accordance with the original signal. This phenomenon occasionally is overlooked Deviation is not an inherently built-in characteristic of a frequency-modulated signal.

While a limiter cannot restore lost peak deviation information, it can restore almost constant amplitude by holding down the peak voltage at the center of the frequency excursion to a level equal to that at wide excursions. The limiting action introduces, in the form of distortion, the missing sidebands in the proper phases and magnitudes required to restore the vector resultant voltage to a constant value; and the following circuits must have sufficient bandwidth to handle these sidebands up to the point of detection. In the case of an interfering signal, the original phase information has not been lost, but only the amplitude needs correction.

The two most common methods for recovering the original information are the resonant coil discriminator in its various configurations which usually operates on a constant amplitude voltage and the so-called linear detector, which can be made reasonably independent of signal amplitude and operates by counting the rate of cycles without the use of resonant circuits. Both respond only to the vector resultant voltage which is the root mean square value of all of the individual voltages present at the input to the detector system at each instant.

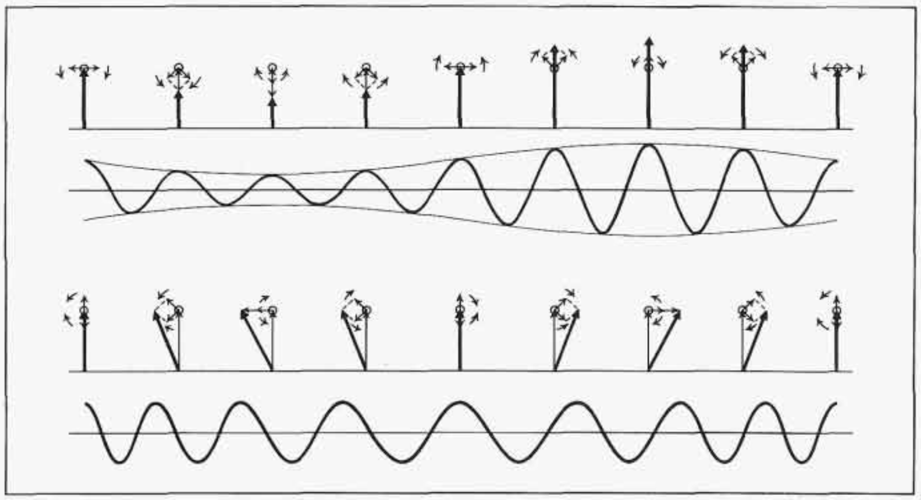


Figure 4. *Amplitude Modulation of a Carrier by the First order Sidebands Compared with Phase (or frequency) Modulation of a Carrier Obtained by Rotating the Pair of Sidebands 90° with Respect to the Initial Carrier Vector, with $\beta = .5$.*

Disappearing Frequencies

If one looks at an *amplitude*-modulated wave with a panoramic frequency analyzer and observes energy occurring only at the carrier frequency and at sideband frequencies spaced by the modulating frequency, one is perhaps not too surprised. However, it can be somewhat surprising to find the same kind of answer for a frequency-modulated carrier which all ones intuition and many measurements demonstrate quite clearly sweeps continuously back and forth throughout the entire frequency range under observation. Since the following exercise is both an interesting experience and a useful tool, may we suggest that the output of a sweep signal generator and the output of a frequency-modulated generator be simultaneously added in a crystal diode circuit whose output contains a RC filter and the result displayed on an oscilloscope whose horizontal trace is synchronized with the sweep signal generator?

Figure 6 is typical of the results obtained under various conditions of modulation frequency and deviation. Two things immediately strike us: first, that the energy occurs only at discreet positions in our frequency spectrum which is clustered rather symmetrically about the center frequency; and secondly, that under some conditions of modulation even these signals, including the one which we are accustomed to associating with the average carrier frequency, disappear. We must hasten to point out that we are here dealing with what the mathematician chooses to call the *frequency domain* rather than the *time domain* previously used in our oscilloscope display. We are in effect taking a cross section of frequency and displaying the energy values averaged over a period of time.

We have previously observed the physical existence of a vector resultant voltage whose instantaneous magnitude varies in approximately a sinusoidal fashion and whose separation between points of corresponding phase on adjacent cycles (a measure of frequency) varies smoothly in accordance with the applied modulating voltage. Figure 5 shows graphically how, by the proper magnitude and phase configuration of these individual voltages or "sidebands", the vector resultant may be caused to have any desired phase relationship at any given instant of time; and therefore how it is possible to cause the vector resultant voltage to sweep over any desired frequency range at any desired rate.

Those Bessel Functions

The "time average" aspect is the essence of either a physical or mathematical approach to the variation of sideband amplitudes. Specifically, the results which we observe by a physical measurement or obtain by a mathematical manipulation do not say that the energy at any given frequency is missing at all times; but only that its time average is zero.

This effect can be analyzed by mathematics using as its point of departure either of the concepts which we have discussed: a continuously-sweeping vector resultant voltage,, or an assortment of sidebands. Using the idea presented

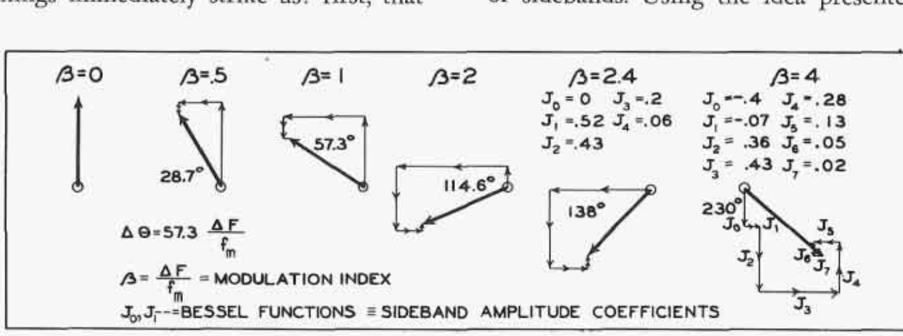
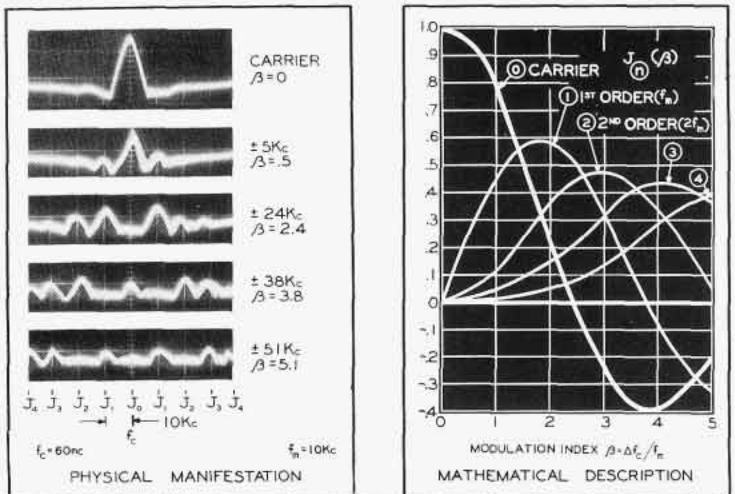


Figure 5. *Generation of a Constant-Amplitude Rotating Vector by Addition of Successive Orthogonal Sideband Pairs.*



FREQUENCY DEVIATION	MODULATION INDEX β	J_0	J_1	J_2	J_3	J_4
0	0	1.0	0	0	0	0
5Kc	.5	.94	.24	.03	0	0
24Kc	2.4	0	.52	.43	.2	.06
38Kc	3.8	-.4	0	.41	.42	.25
51Kc	5.1	-.15	-.32	0	.32	.4

Figure 6. Comparison of the Observed Variations in Strength of the Discrete Signals in a Frequency Modulated Wave with Their Mathematical Description as Provided by Bessel Functions.

by Figure 1, the usual textbook approach sets up an equation involving sines, cosines and phase angles which describes in mathematical symbols the way in which the instantaneous carrier voltage varies as a function of the carrier frequency, the modulating frequency, and the deviation.

The time integration of this equation to get average values leads to a never-ending series of alternating sine and cosine terms whose coefficients are the magnitudes of the successive orders of sidebands, each advanced 90° from its predecessor. The relative numerical values of these coefficients are most conveniently obtained by resort to a mathematical table known as "Bessel Functions", generated at considerable effort from a similar equation. The graph of Figure 6 shows the values of some of the coefficients as a function of the *modulation index,* which is the ratio of the deviation to the modulating frequency. We find that the mathematical formulation has indeed faithfully described the physically observed disappearance of various sideband components, designated as J_0, J_1, J_2, J_3, at critical values of the modulation index.

Having found a satisfactory mathematical description for the wave-form and concept displayed in Figure 1, it should be equally possible to derive a mathematical description of the concept involved in Figures 4 and 5. This has been done by Harvey, Leifer & Marchand[2], in which the authors use a mathematical technique which is the practical equivalent of adding up all of the vector component contributions to the final voltage over a cycle of the modulating frequency, such as might be achieved by a sufficiently large number of graphical solutions. We should not be surprised to find the solution to their equation leading once again to Bessel Functions.

Filters and Sweeping Frequencies

So far all of our physical measurements and concepts have been independent of resonant circuits. However, one of the very interesting characteristics of frequency modulation is associated with the response of a resonant circuit to a swept frequency. Let us assume a reasonably high Q (narrow passband) resonant circuit lying to the side of the average carrier frequency in a region through which the carrier is sweeping. Once again there is more than one way to look at the problem.

The first approach applicable to low repetition rates satisfies our intuitive feeling that it takes time for energy to build up in a resonant circuit, and if the circuit is sharp or the signal sweeping by quickly, only partial response will result. In fact, the peak of the response will not even coincide in resonance with the applied signal.[3] This is a serious difficulty in frequency marking circuits or in the use of fast sweeps on narrow-band amplifiers. Alternately, we might suggest that the highly selective circuit will not accept the high frequency components required to reproduce the sharp leading edge of an impulse of energy and therefore the current cannot rise quickly in the resonant circuit.

At high modulating frequencies a more subtle interpretation of the response of a filter to a swept frequency involves the stored energy.[2] A filter having a passband lying within the deviation range of a frequency-modulated signal has energy applied to it only in short bursts occurring at intervals determined by the modulating frequency and the maximum deviation. Unless the phase of the newly applied voltage has a component lying in phase with the current, no energy will be absorbed by the filter. Once again these relationships are *time* averages and apply at *all* frequencies, as well as at the sideband frequencies and are the basis for part of the derivation in the Harvey-Leifer-Marchand paper previously cited[2].

If the resonant frequency of the filter corresponds to a frequency which we call a sideband frequency, then for most combinations of deviation and modulation frequency there will be an in-phase component of the applied voltage and power will be transferred. The phase of the succeeding pulse of radio frequency energy with respect to the energy stored in the filter depends on how wide the carrier is being deviated and the rate at which it is deviating. For certain critical values the phase of the newly applied voltage will be in quadrature with the current circulating in the resonant circuit and no power will be transferred. The fact that the energy accepted by a narrow band filter does occasionally go to zero at the frequency of the carrier and the various orders of sidebands is a very useful tool.[4] It enables us, for example, to determine when the modulation index has reached a certain value as shown in Figure 6; and knowing the modulation frequency, we can determine the deviation.

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Use Of Smith Charts For Converting RX Meter Readings To VSWR And Reflection Coefficient

ROBERT POIRIER, *Development Engineer*

In a previous Notebook article, Fall 1954, issue number 3, page 7, it was mentioned that impedance measurements could be made at remote distances from the RX Meter along known lengths of 50 ohm co-ax. In this case the results obtained at the RX Meter must be transformed either by means of the Smith Chart or transmission line equations—for the ideal case

$$Z_i = Z_o \frac{Z_l \cos \beta l + jZ_o \sin \beta l}{Z_o \cos \beta l + jZ_l \sin \beta l} \qquad (1)$$

where Zi = Impedance at βl distance in radians from
Zl = Load impedance
and Zo = Characteristic impedance of the interconnecting transmission line.

and for the general case,

$$Z_i = Z_o \frac{Z_o \cosh \gamma l + Z_l \sinh \gamma l}{Z_l \cosh \gamma l + Z_o \sinh \gamma l} \qquad (2)$$

where $\gamma =$ the complex propagation constant:

$$(R + j\omega L)\ (G + j\omega C)$$

For distributed resistance, R; inductance, L; conductance, G and capacity C; per unit length for the general case.

It is the purpose of the present article to illustrate the use of the Smith Chart solutions of the transmission line equations with a view to obtaining the values of reflection coefficient ρ and VSWR from RX meter readings.

Preparation of Data

The Smith Chart is usually a plot of impedance or admittance with the rectangular coordinates curved into circles and contained within a unit circle of which the polar coordinates are reflection coefficient, $\rho = \frac{V\ \text{refl.}}{V\ \text{inc'd}}$ and phase angle, βl in the ideal case. The RX meter reads directly in terms of parallel resistance, R_p, and either + capacity, C, equal to the capacity in the test circuit or — capacity equal to the capacity required to resonate the inductance in the external circuit at the test frequency; neither value will plot directly onto the Smith Charts. To plot the RX Meter readings it is necessary to—

1. Evaluate the parallel reactance

$$X_p = \frac{1}{\omega C_p}$$ (where the + sign of C_p shall denote equivalent parallel capacity and the — sign of Cp shall denote equivalent parallel inductance.)

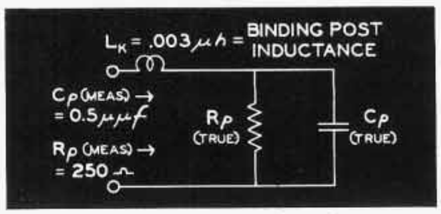


Figure 1. Equivalent Circuit of Sample Measurement.

2. Transform R_p and X_p to either rectangular admittance coordinates;

$$G = \frac{1000}{R_p} \text{ millimhos and}$$

$$B = \frac{1000}{X_p} = 1000\omega C_p \text{ millimhos,}$$

or rectangular impedance coordinates;

$$R_s = \frac{R_p X_p^2}{R_p^2 + X_p^2} \qquad (3)$$

$$\text{and } X_s = -\frac{R_p^2 X_p}{R_p^2 + X_p^2} \qquad (4)$$

where Q and the — sign of Xp results from the convention that inductive reactance is considered positive and capacitive reactance is considered negative.

3. Plot G and B or R_s and X_s directly onto a Smith Chart having appropriate coordinates.

For plotting on Smith Charts with normalized coordinates the following additional conversions are indicated:

$$\text{Resistance component} = \frac{R_s}{Z_o}$$

$$\text{Reactance component} = \frac{jX_s}{Z_o}$$

$$\text{or, Conductance component} = \frac{G}{Y_o}$$

$$\text{Susceptance component} = \frac{jB}{Y_o}$$

where Zo and Yo may be any source impedance or admittance respectively. These conversions are likely to be found printed on the normalized Smith Charts.

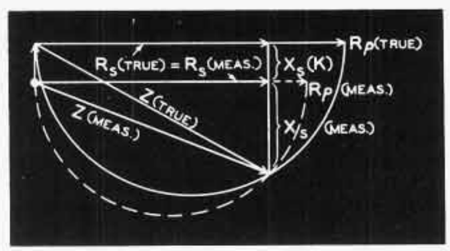


Figure 2. Impedance Circle Diagram of Figure 1.

EXAMPLE: Consider a 270 ohm ½W carbon resistor measured on the RX Meter at a frequency of 225 megacycles per second. The RX Meter readings in a typical case could be $R_p = 250\Omega$, $C_p = +0.5\ \mu\mu f$. The only source of error to be considered in this case is the series inductance of the binding posts, and for a first approximation this may be neglected. The binding post inductance may be best accounted for as follows: Consider the equivalent circuit of the measurement and the impedance circle diagram in Figures 1 and 2 below. From the circle diagram it is recognized that R_s (True) = R_s (Meas) so that R_s may be computed directly from (3)

$$R_s = \frac{R_p X_p^2}{R_p^2 + X_p^2} = \frac{250 \times 2.0 \times 10^6}{6.25 \times 10^4 + 2.0 \times 10^6} = 243\Omega$$

From (4)

$$X_s\ (\text{Meas}) = -\frac{R_p^2 X_p}{R_p^2 + X_p^2}$$

$$= \frac{-6.25 \times 10^4 \times 1.41 \times 10^3}{6.25 \times 10^4 + 2.0 \times 10^6} = -42.6\Omega$$

Also from the circle diagram (Fig. 2) it is seen that

$$Xs\ (True) = Xs\ (Meas) - Xs\ (K)$$
$$= -42.6 - \omega Lk = -46.9\Omega.$$

Now let us suppose that this considered resistor is to be connected as a load for a 300Ω signal source and it is desired to predict the reflection coefficient and/or VSWR on a 300Ω transmission line connecting the source to the load. R_s (True) and X_s (True) may be normalized by $\frac{Rs}{300\Omega}$ and $\frac{Xs}{300\Omega}$ respectively. The normalized resistance component, 0.81 and reactance component −j0.156 are plotted directly on a normalized Smith Chart (expanded scale) as shown in Fig. 3. The reflection coefficient, ρ, that is the ratio of the voltage reflected to the voltage transmitted is equal to the length of the radius vector from the center of the Smith Chart to the plotted impedance. In this example $\rho = 0.13$. The reflection coefficient in terms of power,

$$\frac{P\ refl.}{P\ inc'd} = \left(\frac{V\ refl.}{V\ inc'd}\right)^2 = 0.017$$

Additionally, a return loss may be expressed as:

$$10 \log \frac{P\ inc'd}{P\ refl.} = 10 \log \frac{1}{.017} = 17.7db$$

and a transmission loss, expressing in db the incident power which is not absorbed by the load, may be written as:

$$10 \log \frac{P\ inc'd}{P\ abs'd}$$

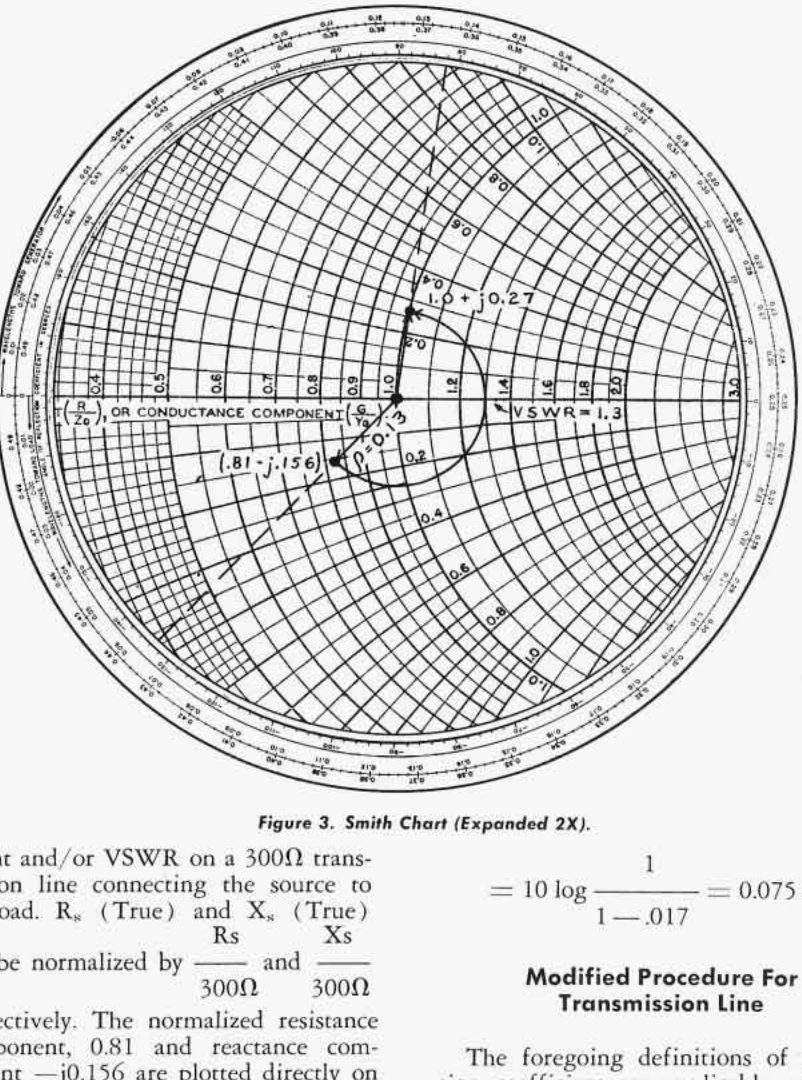


Figure 3. Smith Chart (Expanded 2X).

$$= 10 \log \frac{1}{1 - .017} = 0.075\ db$$

Modified Procedure For Transmission Line

The foregoing definitions of reflection coefficient are applicable whether a transmission line is involved or not. Now let us further suppose the Z (true) (normalized) = .81 − j.156 was measured at one end of a transmission line and that the other end of the transmission line was terminated in an unknown load to be determined. Let the transmission line be measured and found to be 0.3 wavelength long. VSWR on a transmission line is defined as the ratio of the maximum voltage to the minimum voltage; viz,

$$\frac{V\ inc'd + \rho\ V\ inc'd}{V\ inc'd - \rho\ V inc'd} = \frac{1 + \rho}{1 - \rho}$$

On a Smith Chart the reflection coefficient for a given load is a radially scaled constant so even though the now unknown load is not represented by .81 − j156 we can use $\rho = 0.13$ previously obtained and find,

$$VSWR = \frac{1 + 0.13}{1 - 0.13} = 1.3$$

which in db is written,

$$20 \log VSWR = 2.28\ db$$

Except in the ideal case, however, this is an approximation which is very good for short (in terms of wavelength) low loss transmission lines.

As previously stated the Smith Chart' provides a ready solution to the transmission line equations (1) and (2). In the ideal approximation the impedance at any point along a transmission line may be found by rotating the constant radius vector around the center of the Smith Chart the βl distance between the known and the unknown in the direction indicated on the chart. For our example $\beta l = 0.3$ wavelength; the impedance was represented by 0.81 − j.156 measured at what may be considered the input end of the transmission line. To find the impedance at the load end, the radius vector is rotated 0.3 wavelength toward the load (counter clockwise direction) as shown in Fig. 3. The true impedance at the load end of the line is read from the Smith Chart as 1.0 + j0.27 per unit ohms. Since the reference unit in this case was 300Ω, Z = 300 + j81. It is also of interest to note that in crossing the horizontal axis of the Smith Chart to the right of center, the radius vector denotes a pure resistance point of maximum impedance. It is also a point of maximum voltage and minimum current. Since,

$$V\ max. = V\ inc'd\ (1 + \rho)$$

$$\text{and, } I\ min. = \frac{V\ incd}{Zo}(1 - \rho)$$

$$Z\ max. = \frac{V\ max.}{I\ min.} = Zo \frac{1 + \rho}{1 - \rho}$$

$$\frac{Z\ max.}{Zo} = VSWR$$

That is to say the per unit impedance denoted on the horizontal axis of the Smith Chart to the right of center is equal to VSWR, and we read from Fig. 3, VSWR = 1.3 as obtained previously.

Reference: P. H. Smith "Transmission Line Calculator" Electronics Jan. 1939.

Frequency Calibration Of Q Meter Type 260-A

SAMUEL WALTERS, *Editor, The Notebook*

Two of the principal reasons for checking the frequency calibration of the 260-A are (1) replacement of the oscillator tube and (2) a desire to obtain more accurate inductance readings. The former involves an adjustment on only one frequency band since all bands are affected in the same direction and approximately in the same degree. On the other hand, an inductance reading of greater accuracy than factory tolerances may require a correction curve for more accurate use of the F dial*.

Each of the eight frequency ranges has two calibration adjustments, a threaded magnetic core for the inductance of the tuned circuit and an adjustable piston type trimmer condenser for varying the capacitance of the tuned circuit. The former is used to establish frequency calibration at the low frequency end of the range and the latter to establish calibration at the high frequency end. The threaded magnetic core is adjusted at the factory and is then sealed in its coil form with a high Q lacquer to prevent movement. This adjustment should not be disturbed.

In addition to the adjustments for each range there is a variable plate trimmer condenser (C-129) for adjustment of the circuit minimum capacitance when the oscillator tube is replaced. Continuous tuning of each range is handled by the two-section variable capacitor whose sections have been pre-calibrated to follow a standard capacitance vs. rotation curve. No further adjustments of the plates should be necessary or attempted without a clear knowledge of the interdependence of all eight ranges. If adjustments are absolutely necessary, however, the outer rotor plates are slotted to provide minor corrections. For ranges 10-23 mc and 23-50 mc, adjust the 13 plate section; for ranges 300-700 kc, 700-1700 kc, 1.7-4.2 mc and 4.2-10 mc, adjust the 25 plate section; for ranges 50-120 kc and 120-300 kc, adjust both sections. In making these adjustments, care should be taken that rotor to stator plate spacings are not less than 0.015 inches.

Oscillator Re-Calibration Following Tube Change

As previously pointed out, re-calibration is necessary on only one band following a replacement of the oscillator tube.

A 10 mc crystal calibrator, such as the Ferris Calibrator, Model 33A, is recommended. However, standard broadcast stations may be used satisfactorily in place of a crystal calibrator.

To calibrate the oscillator proceed as follows (see photo):

1. Remove the screws around the edge of the top and front panels and the 3 screws from the bottom of the instrument. The entire front panel and top can now be gently lifted out of the cabinet. As noted in the Figure, the shaft of the plate tuning condenser, C-129, extends beyond the top oscillator shield wall. The piston type trimmers can be easily reached through the access holes in the oscillator casing.

2. Turn on the Q Meter and allow instrument to warm up for 30 minutes.

2. Connect the rf input terminals of the crystal calibrator to the LO and GND terminals of the Q Meter.

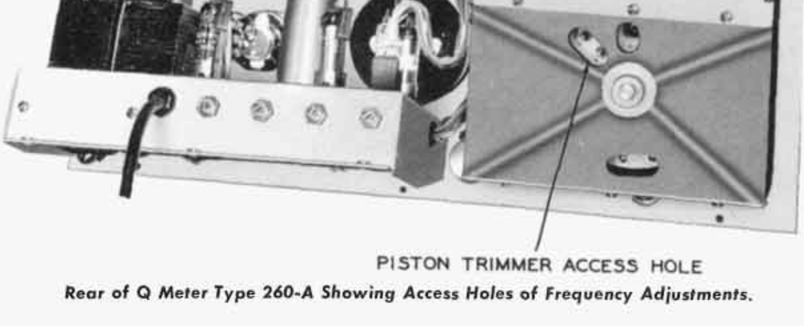
3. Adjust the calibrator to 10 mc.

4. Switch the frequency range to the 4.2 - 10 mc range. Set the *Megacycle* dial to exactly 10 mc.

5. Adjust the XQ controls for a reading of 1.0 on the *Multiply Q By* Meter.

6. Carefully adjust C-129 until a zero beat is heard in the calibrator headset.

Standard broadcast stations in the neighborhood of 700 kc or 1500 kc can also be used in conjunction with a radio receiver to calibrate the oscillator. The upper ends of either the 300 - 700 kc or 700 - 1700 kc ranges may be used to zero beat the Q Meter oscillator with the station carrier.



Rear of Q Meter Type 260-A Showing Access Holes of Frequency Adjustments.

Correction Curve

Should it become necessary to read the dial with an accuracy greater than factory tolerance, a correction curve plotting dial reading error against dial reading can easily be made. Using a crystal calibrator similar to the Ferris Model 33-A one can re-calibrate any range through the use of the built in multivibrator circuit, which in the case of the Ferris calibrator is locked by the 100 kc oscillator. Fundamentals of 50, 25, 20, 10 kc are thus made available to check the 50-120 kc range.

The general procedure outlined above should be followed. A pair of phones may be plugged into the output jack of the Calibrator so that beats between the Q Meter oscillator and the standard frequencies of the Calibrator can be heard.

It must be remembered that the accuracy of the correction curve is a function of the number of points checked, type of calibrator used and, of course, the skill of the operator.

**Although the C dial calibration is also important, the F dial has a greater influence on the over-all tolerance except at the low settings of the C dial. See Fall, 1955, issue No. 7 of The Notebook on "Calibration of the Internal Resonating Capacitor of the Q Meter."*

EDITOR'S NOTE

The public sees the engineer as a gnome-like creature, a sort of electronic sorcerer conjuring up electronic devices so complex that even he is startled when they work. Oblivious to the surrounding world, he plods daily from his laboratory cubicle to his home submerged in abstruse engineering problems 'til he reaches his front door where he makes

an outward show of normalcy. With an effort that produces mental fatigue he greets his wife with a perfunctory peck and his kids with a dutiful pat on the head (mixing up their names if he happens to have more than one), and enters the bosom of his family in a trance-like state from which he does not emerge 'til safely ensconced once again in his familiar world of electronics. His only "social activity," it is believed, is periodically attending meetings where technical papers full of solemn nonsense are intoned by other engineers of mien as grave as his own.

This of course is gross exaggeration. Worse. It is a myth and difficult to lay. Part of the difficulty can be attributed, we fear, to the engineers themselves. Too often the only view the public obtains of engineers or their work is in the photographs that appear in the newspapers from time to time showing an engineer at an instrument replete with dials, meters, switches, etc. The caption might say: "John Smith, development engineer for the Whynot Company, demonstrating the operation of an electric pretzel bending machine," but this belies the attitude of the engineer who, far from appearing to demonstrate anything, sits frozen in solemn disbelief of the entire proceeding. This, of course, engenders in the viewer a feeling only of pity for the engineer and a morbid curiosity for the instrument which has apparently placed its inventor in a hypnotic state.

The fact is however, despite such superficial appearances, the average engineer is a human being in the accepted (non-anthropological) sense of the word, e.g., a social being. He is a joiner. It is true he is usually a member of technical societies where "shop talk" is the rule. But that is also true of a horse breeding organization or any other homogeneous group with intellectual, economic or other interests in common.

For the benefit of that segment of the general public that may see this publication as well as for that group of engineers whose self esteem may be under a cloud because of the "queer bird" looks of the uninformed, we shall scan the professional and avocational interests of the group here at BRC with the sure knowledge it is typical of the engineering field as a whole.

Our president, Dr. Downsbrough is a member of the Board of Trustees of the Riverside Hospital here in Boonton, N. J. in addition to his membership in the Scientific Apparatus Makers Association (SAMA) where he serves as a member of the Electronics Committee. He and his family pursue the interesting hobby of Gliding, his wife holding the U. S. distance record for women. Frank G. Marble, our vice-president, is active in the Little League, a baseball organization for the pre-teen agers. He also serves as Chairman of the Exhibitors Advisory Committee of the IRE. W. Cullen Moore, our Engineering Manager, is the Scout Master in his home town as well as the Secretary of the New Jersey Chapter of the IRE. Our engineers, exclusive of their professional activities, have as motley a collection of hobbies and activities as one could find anywhere — amateur cartoonists, photographers, cabinet-makers, science fiction devotees, astronomers, Civil Air Patrol activities, and a host of others.

These multifarious interests are, we firmly believe, representative and characterize the engineering profession in general as well rounded and imaginative, ingredients essential to all creative vocations and healthy citizenship.

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