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# Determination Of Metal Film Thickness

**A non-destructive electronic method applicable to combinations of coating and basis materials, at least one of which must be a conductor.**

ANTS PIIP, *Development Engineer*

The measurement of the thickness of thin films, of the order of $10^{-3}$ inches or less, has always been one of the major problems for the coating industry, whether it be a question of metallic films on a metal basis (e.g., such as are produced by electroplating); or metallic films on an insulator; or an insulating film on a conducting carrier.

There has been a deeply felt need for a reliable, rapid, simple, non-destructive method for obtaining absolute or comparative thickness readings on the majority of film-basis combinations. Hitherto available methods lack one or more of these desirable characteristics.

Thickness measurements have been based on the following methods: mechanical, chemical, electrochemical, optical, X-ray and beta ray scattering; magnetic, electrical conductance, and last but not least, eddy-current properties.

### Description of Available Methods for Measuring Plating Thickness

*Mechanical:* Mechanical methods involving the use of a micrometer or similar device are useful in a limited number of cases: the specimen is measured at the identical spot before and after plating. Obviously, the shape of the specimen has to be suitable for such a measurement, and the thickness of the deposit has to be appreciable.

The chemical, electrochemical and optical methods are definitely destructive.

*Chemical:* The majority of the chemical methods can be reduced to a determination of the weight of coating metal per unit area. They involve the following steps: measurement of area, stripping the plating with a reagent that leaves the basis unaffected; direct determination of coating material lost through stripping by means of weighing the specimen before and after stripping, or a determination by appropriate quantitative chemical analysis or colorimetry of the amount of coating material gone into solution. For rough checks, the dropping method can be used in certain cases: a prescribed stripping reagent is made to drip under controlled conditions on the piece to be tested, and the time noted until the basis becomes exposed.

***Figure 1. The author shown measuring plating thickness of a capacitor frame.***

*Electrochemical:* Electrochemical plating thickness measurement is actually a deplating operation of a known area. The number of coulombs (ampereseconds) required to expose the basis metal is a measure of the amount of material removed, as stated by Faraday's electrochemical law. The sharp change in deplating cell voltage that occurs when the basis metal is introduced into the electrolyte is used as an indicator.

*Optical:* For optical methods the specimen is mounted in a clamp or protective medium (usually a thermosetting plastic), sliced accurately, the cut polished, etched and measured either under a microscope or projected at known magnification.

*X-ray and Beta ray:* X-ray and beta ray techniques require quite elaborate instrumentation. Neither of these two methods is necessarily destructive for the specimen to be measured.

The following methods are all non-destructive, and should properly be called comparators, since none of them is capable of yielding an absolute measurement without recourse to precalibrated standards. Likewise, they are sensitive to the geometry of the specimen.

*Magnetic:* The magnetic methods obviously are limited to combinations where at least one of the components, either the basis or the coating, is ferromagnetic (e.g., steel, iron, nickel). Generally, they are based on measuring the force necessary to pull a small magnet off the specimen. In the case of a non-magnetic coating on steel or iron, this force decreases with increasing coating thickness. With nickel on a non-magnetic base, the force is the higher the thicker the plating. Readings depend on the smoothness and surface

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conditions of the coating, on the geometry of the test piece, on magnetic properties of the material, and local composition of the material; also, the magnetic properties of plated nickel vary widely with the plating process used.

*Electrical Conductance:* Instruments based on the direct measurement of the electrical conductance of the plated specimen are applicable only when the conductivities of the coating and basis materials differ appreciably. The probes

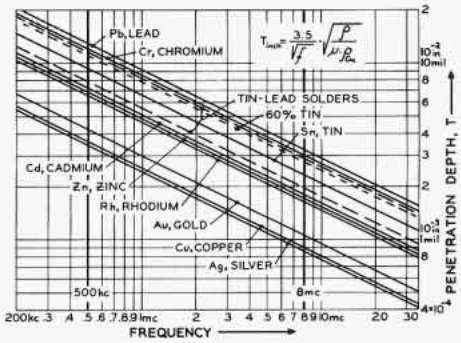


***Figure 2. Penetration depths (in inches, T) of the most common plating materials.***

associated with this type of instrument require good electrical contact at 4 points (2 for current injection, 2 for voltage pickup.) A hybrid method has also been used, utilizing a combination of thermal conductivity and generated thermoelectric voltage.

### Eddy-Current Method

The method described below is the one employed in the instrument shown in Figure 1.

When a conductor is brought into the field of a coil excited by an alternating current, eddy-currents are induced that circulate in closed loops in the conductor. The eddy-currents generate an electromagnetic field, which in turn induces an electromotive force in the exciting coil that tends to oppose the original current in it, thereby changing its impedance. The effect on the coil is equivalent to having introduced an additional "reflected impedance" in the coil circuit.

The amount by which the coil impedance changes depends on a number of factors: the electrical and magnetic properties of the conductor, its configuration, the coil-conductor spacing, the geometry of the coil, and the frequency.

For the sake of simplicity, let us consider the case of a plane, infinite, homogeneous conductor close to the coil and normal to the coil axis. We observe the following phenomena:

Bringing the coil closer to the conducting plane decreases the reactance and increases the effective resistance of the coil. The relative reduction of the reactance depends mainly on the ratio of coil diameter to the spacing from the conductor and is quite independent of the material of the conductor — provided this is non-ferromagnetic. The increase in resistance, however, depends not only on the coil spacing, but also on the conductivity of the conductor.

Keeping the coil spacing and conductor material constant, but varying the thickness of the conducting sheet, we notice that the reflected impedance of the coil follows the increase of the conductor thickness only up to a certain thickness, called the "penetration depth" beyond which eddy-currents do not appreciably penetrate into the metal. The penetration depth, T in inches, can be expressed as

$$T = \frac{3.5}{\sqrt{f}} \sqrt{\frac{\rho}{\mu \rho_{Cu}}}$$

where: f = frequency in cycles/second

$\frac{\rho}{\rho_{Cu}}$ = ratio of resistivity of conductor to that of copper,

$\mu$ = permeability of conductor.

Figure 2 illustrates the dependence of current penetration depths on frequency and conductivity for a variety of metals.

Changes in thickness can be detected by observing the coil parameters only if the conductor is not thicker than T; after that its effect is the same as if it were infinitely thick. T is smaller for materials with high conductivity (low resistivity), ferromagnetic materials have very small penetration depths.

In the case of conductive coatings on conductors, the reflected impedance depends on the conductivities of the basis and coating and the thickness of the coating, with the coil spacing and frequency being kept constant. The relationships between reflected impedance and the properties of the composite conductor become quite complex, but it can be easily established, that

1. Changes in coating thickness are detectable only if the thickness of the coating is not more than the penetration depth in it, approximately, and an appreciable portion of the total eddy-currents circulate in the basis metal. If the coating thickness is larger than the penetration depth, practically all eddy-currents are confined to the coating metal and variations of its thickness have negligible effect on the distribution of the eddy-currents.
2. Combinations of the same basis material with coatings of different metals, but of the same thickness, result in different changes in reflected impedance, referred to that on the bare basis. These changes are larger, if the coating and basis conductivities differ by a larger ratio, since a much larger fraction of the total eddy-currents is confined in the coating than in the case where both the coating and basis are very close in their conductivities.

The foregoing discussion is applicable to magnetic materials as well, if we take into account that the "surface conductivity" is a function of permeability and frequency as well as bulk conductivity.

Having discussed the general properties of eddy-currents, we find that they offer a possibility for measuring film thickness of all three kinds: conducting films on conductors through detecting changes in current distribution; conducting films on non-conductors by variations in the total amount

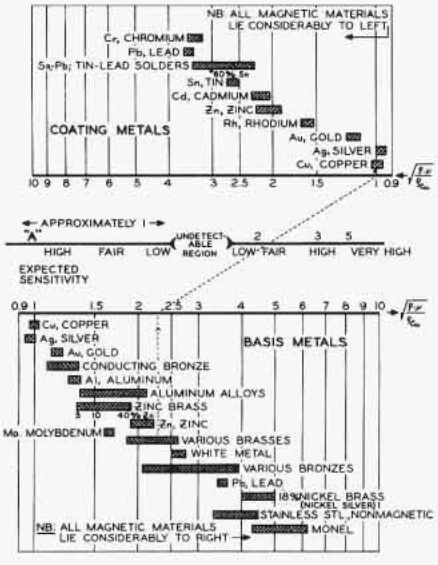


***Figure 3. Frequency parameter "A" and expected sensitivity as functions of basis and plating materials.***

of eddy-currents in a film thinner than the penetration depth; and non-conducting films on sufficiently thick (more than the penetration depth) conductors by the increased spacing of the coil from the basis. We can also conclude that eddy-currents offer a means for sorting metals according to their conductivities.

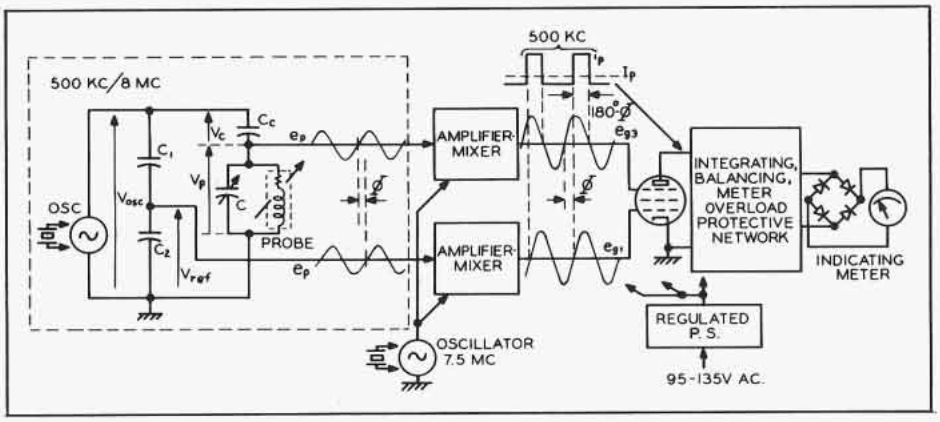


***Figure 4. Functional block diagram of the Metal Film Gauge, Type 255-A.***

Various techniques using the eddy-current principle have been used in the testing of materials, including measurements of film thickness. F. Forster in Germany, a pioneer in the field; Brenner and his associates at the National Bureau of Standards, and the Atomic Energy Commission are only a few who have made contributions in this field.

### Determination of Suitable Test Frequency, and Expected Measurement Sensitivity for Conducting Films on Various Basis Metals

Irrespective of the kind of instrument to be used or the changes of probe impedance it responds to, the test frequency should be chosen accordingly to the thickness of the coating and composition of the film-basis combination to be measured. Quite generally, a thinner coating requires use of a higher frequency. Also, coatings of lower conductivity should be measured at a somewhat higher frequency than those of higher conductivity for comparable plating thickness on the same basis metal.

These relationships can be visualized more easily if we study Figure 3, a nomograph prepared in conjunction with Figure 2 for the choice of test frequency. A factor "A" for each combination of the more common coating and basis metals is obtained by dropping perpendiculars from the boxes pertaining to the coating and basis metals to the appropriate base lines of the nomograph, and joining these points by a straight line. "A" is then found at the intersection of this straight line with the center line. This figure represents the desirable ratio between penetration depth in the coating metal and maximum expected coating thickness.

Let us assume it is desired to measure 1 mil ($10^{-3}$ inches) of silver plating on a yellow brass of average composition. For this combination, we find A is approximately 2. Consequently, we should choose a test frequency such that the penetration depth in silver will be of the order of 2 mils. From Figure 2, this is obtained at a frequency of 1.5 mc. A frequency somewhat lower, e.g., 500 kc, will increase the maximum measurable thickness, but some loss of sensitivity is to be expected on very thin coatings. A higher test frequency, e.g., 8 mc, will prevent us from measuring up to the full 1 mil thickness although we get better sensitivity on very thin platings.

### Considerations for the Design of an Eddy-Current Film Thickness Gauge

The eddy-currents induced by the coil in the conductor circulate in the latter and diminish in amplitude as one goes deeper into the material, and also with distance from the coil along the surface. This decrease of the amplitude of the eddy-currents with distance from the coil determines the diameter of the coil which must not be more than about ½ the smallest linear dimension of the surface to be measured.

Since variations of reflected impedance depend on the ratio of coil diameter to mean spacing from the conductor, the coil should be flat and very close to the specimen if sufficient sensitivity is to be obtained.

In general, variations of the resistance component of the reflected impedance are characteristic of the conductors in the coil field, and we want this variation to be as large as possible in relation to the resistance of the coil proper for good sensitivity. Therefore, a high-Q coil is indicated. The sensitivity can be increased furthermore if the probe is made the inductance in a resonant circuit operating at or near resonance.

The spacing of the probe coil to the conductor (or their relative angular orientation, which is equivalent to a change of mean spacing) exerts a major influence on the reflected impedance. Therefore, means should be provided to guarantee that the spacing and orientation of the probe coil are always kept constant in use.

Phase changes are less affected by slight variations in probe spacing and orientation and reasonable surface imperfections (such as scratches, dirt, scale), than functions which also involve the magnitude of probe impedance. Phase changes are also relatively independent of voltage levels.

A careful study of the coating-basis combinations commonly encountered in the plating art, and the coating thicknesses thereof, shows that 500 kc and 8 mc are suitable test frequencies, which together provide a continuous range of thickness measurements of about 20:1 for any given combination of plating and basis material.

### Metal Film Gauge, Type 255-A

Figure 1 shows the Metal Film Gauge Type 255-A which was designed to meet the requirements outlined above.

Fundamentally, the instrument consists of an oscillator driving probe and reference phase circuits. The probe circuit is made resonant at the oscillator frequency with the probe placed on the basis material. Both the probe signal and the reference signal are impressed, after suitable amplification and amplitude limiting, on the grids of a gated-beam phase detector tube. The plate current of the phase detector varies in accordance with the phase difference between the probe and reference signals, and actuates the indicating meter. The meter has easily interchangeable scales which can give a direct reading on any plating-basis combination and obviate the need for separate calibration curves. Two complete probe assemblies go with the instrument, one for 500 kc and one for 8 mc. The probe coils are approximately ¼ inch in diameter, making possible measurements on flat samples over ½" across.

A more thorough understanding of the operation and design of the instrument can be obtained by referring to a functional block diagram, Figure 4, and

$V_{osc}$ = const = $V_p + V_c$; oscillator tank voltage

$V_{ref}$ = const, in phase with $V_{osc}$; reference voltage

I — current through $C_c$ coupling capacitor and probe circuit.

$V_p$ — voltage across probe circuit.

$V_c$ — voltage across coupling capacitor $C_c$ lagging 90° behind I

$\varphi$ — phase angle of probe circuit.

$\phi$ — phase angle between $V_{ref}$ and $V_p$

$\theta = \phi_1 - \phi_0$ = change of phase angle between $V_{ref}$ and $V_p$ due to a change of the phase angle of the probe circuit. ($\theta$ is the angle by which conduction angle of phase detector changes).

Subscript 0 — at probe resonance, $\varphi_0 = 0$

Subscript 1 — with detuned probe.

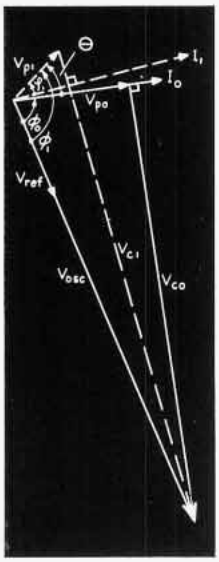


***Figure 5. Vector diagram of the 255-A probe circuit.***

the vector diagram of the probe circuits, Figure 5.

The test frequency, either 500 kc or 8 mc, is generated in a crystal-controlled oscillator which can be switched to either of these frequencies. Since the limiting and phase detection circuits operate at 500 kc, a 7.5 mc heterodyne oscillator frequency is provided for mixing with the 8 mc signals from the high frequency probe and reference phase circuits when in use.

The output of the oscillator is applied across the series combination of a coupling capacitor and the probe circuit which together effectively form a phase shifting network (Fig. 5). The probe is resonated by a variable air capacitor. A fraction of the total oscillator voltage, in phase with it, is used as the reference signal. With the probe resonated, there exists a certain phase difference $\phi$ between the probe and reference signals which are fed to the grids of two identical limiter amplifier-mixer heptodes, whose plate circuits are tuned to 500 kc. On the 500 kc range, the heptodes function as straight amplifiers. However, on the higher frequency (8 mc) range the heptodes are made to act as mixers and to yield 500 kc signals in their outputs, transposing the phase difference $\phi$ from 8 mc to 500 kc.

The outputs of the heptode stages are impressed on the first and third grids of a gated beam limiter-phase detector tube, type 6BN6. The amplitudes of these grid signals have been made sufficiently high so as to cause saturation, thus making the phase detector quite insensitive to any changes in signal amplitudes. The average plate current is a linear function of the phase difference.

The plate circuit of the 6BN6 is made part of a dc bridge containing facilities for bucking out the quiescent plate current (at probe resonance), an overload meter protection circuit, a sensitivity control providing constant meter damping, and a full wave bridge rectificer, to make the meter reading unidirectional no matter how the basis and coating conductivities are related to each other. Full scale meter deflections, at full sensitivity of the instrument, correspond to phase angle changes of the order of 4°.

The sample cards carry a piece of the basis material and specimens of known plating thickness on this basis material together with the appropriately calibrated meter scale and are inserted in the holder in such a way that the calibration comes against the edge of the transparent meter case, thus making the instrument direct reading in thickness. The encapsulated probe coil is carried on a spring loaded plunger.

### Properties and Advantages of the Metal Film Gauge

The 255-A is an instrument capable of detecting small differences in the surface conductivities of metals, or of small variations in the metal-to-probe spacing. It becomes a direct reading instrument when standards of known thickness and composition are used for calibration.

Since both the conductivity and permeability can show considerable variations, depending on the local composition of the material, its heat treatment and previous history (work hardening, etc.) care must be exercised that the calibrated standards really are representative of the material encountered in the subsequent measuring process.

The absolute accuracies obtainable with the instrument depend on the accuracy with which the thicknesses of the standards are known. The instrument by itself is capable of distinguishing between film thicknesses differing only by a few percent of the thickness corresponding to full scale, when used at the correct frequency.

To use the instrument for absolute thickness measurements at least two identical sets of standards of at least three thicknesses should be made up. One of the standard sets is measured by some other means for the actual plating thickness, and the other mounted on a sample card together with a piece of bare basis metal. All the standard samples are measured in succession at the appropriate frequency and the corresponding readings on the 0-100° scale plotted on graph paper as a function of film thickness. After drawing a smooth curve through the four points (three readings and zero), a calibration curve is obtained. This curve can be transferred to the sample card and is used to measure the thickness of work pieces having the same materials and falling within the thickness range of the calibration. The calibrating and measuring techniques described above are in principle applicable to all three kinds of film basis combinations.

Moderate amounts of curvature and slight differences in basis conductivities of the specimen can be compensated by a modified operating technique.

In addition to film thickness determinations, the instrument can be used for sorting materials according to their conductivities. The main balancing ("Set Basis") control can be calibrated directly in conductivities, and the instrument used as a null device.

In measuring film combinations involving at least one ferromagnetic component, the instrument readings can under certain conditions become ambiguous, but this ambiguity can be eliminated by a proper choice of frequency.

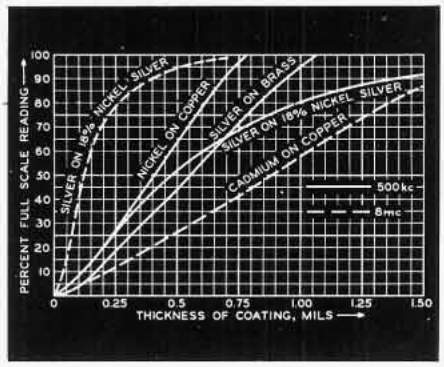


***Figure 6. Typical samples of calibration curves.***

### THE AUTHOR

Ants Piip joined the engineering staff of Boonton Radio in the fall of 1954. His background covers work in naval electronics and ultrasonics in Tallinn, Estonia; development and research in the electronics laboratory of "AGA", Stockholm (ultrasonics, radiobeacons, special instruments); semi-conductor test equipment for Sylvania, and a miscellaneous experience in allied engineering fields. He received his EE from the Royal Institute of Technology in Stockholm (1950) and his MEE from Notre Dame (1953) where he subsequently taught and did additional post graduate work in physics.

# A Method Of Measuring Frequency Deviation

JAMES E. WACHTER, *Project Engineer*

There are in use today several methods of measuring the frequency deviation of a frequency modulated signal. Most of these methods require the use of specialized equipment such as linear FM detectors and panoramic frequency analyzers. However, there is one method which, although not the least time consuming, is both straight forward and accurate, requiring the use of commonly available laboratory equipment. This method is known by various names, probably the most used of which is "The Bessel Zero Method". As this name implies, it is related to the Bessel functions, the zero-order Bessel function $J_0$ in particular. The fact that the zero-order function passes through zero amplitude at certain points, which correspond to discrete modulation indices, forms the useful basis for the method.

The equation of a sinusoidal signal can be expresed as

$$e = A_c \cos(\omega_c t + \theta) \qquad (1)$$

where $A_c$ is the maximum amplitude of the carrier and $\omega_c$ is the angular frequency of the carrier. With a sinusoidal modulating signal and assuming $\theta = 0$, a frequency modulated signal can then be expressed as

$$e = A_c \cos\left(\omega_c t + \frac{\Delta\omega_c}{\omega_m} \sin \omega_m t\right) \qquad (2)$$

where $\omega_m$ is the angular frequency of the modulating signal and $\Delta\omega_c$ is the peak angular frequency deviation of the carrier.

$$\frac{\Delta\omega_c}{\omega_m} = \frac{\Delta f_c}{f_m} = B = \text{modulation index.} \qquad (3)$$

Expanding equation 2 results in

$$e = A_c [\cos \omega_c t \cos(B \sin \omega_m t) - \sin \omega_c t \sin(B \sin \omega_m t)]. \qquad (4)$$

It can be shown that [1]

$$\cos(B \sin \omega_m t) = J_0(B) + 2J_2(B) \cos 2\omega_m t + 2J_4(B) \cos 4\omega_m t + \ldots. \qquad (5)$$

and

$$\sin(B \sin \omega_m t) = 2J_1(B) \sin \omega_m t + 2J_3(B) \sin 3\omega_m t + \ldots\ldots \qquad (6)$$

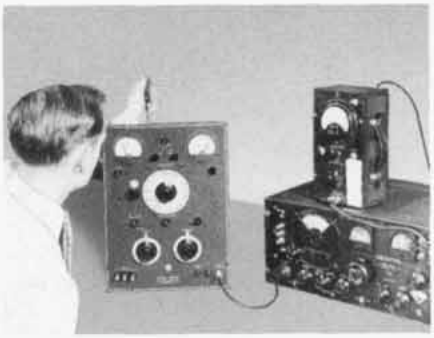

***Figure 1. The author checking the frequency deviation of the Signal Generator, Type 202-B.***

where the coefficients $J_n(B)$ are Bessel functions of B. On substituting equations 5 and 6 in equation 4 there results

$$e = A_c [J_0(B) \cos \omega_c t + J_1(B) \cos(\omega_c + \omega_m)t - J_1(B) \cos(\omega_c - \omega_m)t + J_2(B) \cos(\omega_c + 2\omega_m)t + J_2(B) \cos(\omega_c - 2\omega_m)t + \ldots..] \qquad (7)$$

which is the expression for sideband frequencies of a frequency modulated signal. It will be noted that there are possible an infinite number of sideband frequencies and that each sideband is spaced from the carrier by integral multiples of the modulating frequency. Also, it may be seen that the amplitude of the carrier decreases from a value of unity in the unmodulated condition to $J_0(B)$, which is zero for some values of B, during modulation. A graphical representation of equation 7 for B = 25 is given in Figure 2.

In employing the Bessel zero method, a heterodyne type receiver is tuned to the unmodulated carrier frequency of the source to be tested so that a beat frequency of some several hundred cycles is obtained, which can be monitored with earphones or a voltmeter. If some loss in measurement sensitivity can be tolerated, a crystal frequency calibrator may be substituted for the receiver, providing that the carrier frequency of the source is a harmonic multiple of the calibrator frequency. As a carrier is frequency modulated by a single frequency, the beat frequency will be observed to disappear at several points as the amplitude of the modulating signal is increased. As previously stated, these null points correspond to specific modulation indices, the first five of which are:

2.4048
5.5201
8.6537
11.7915
14.9309

These five points are graphically illustrated by the curve of the zero-order Bessel function in Figure 3. The modulation index being the ratio of frequency deviation to modulating frequency (equation 3), it becomes apparent that knowing the indices at which the carrier is zero and knowing the modulating frequency, the frequency deviation at each carrier zero is readily determined.

As an illustration, let us take a value of 10,000 cps for the modulating frequency. As the amplitude of the modulating signal is increased, nulls will be obtained at the deviation frequencies of 24.1, 55.2, 86.5, 117.9 and 149.3 kc.

It is well to bear in mind that in order to perform this test with any degree of success, it is necessary that the modulating frequency be considerably greater than the beat frequency being monitored. This is so because the sidebands of a frequency modulated signal are spaced at intervals equal to the modulating frequency (see figure 1). If such is not the case and the ratio of modulating frequency to beat frequency is, for an extreme case, only of the order of 2 to 1, the possibility exists of beating with the first side-band frequency rather than the carrier. If unknown to the operator this will produce erroneous results, since the side-bands, like the carrier, pass through points of zero amplitude at particular modulation indices (see Figure 3).

The accuracy to be expected from this method is dependent upon the accuracy of the modulating frequency and how well the nulls can be defined. For example, let us assign a value of $\pm 0.5\%$ as the accuracy of the modulating frequency. Holding the modulation index constant, this $\pm 0.5\%$ is applied directly to the frequency deviation. Further, let us assume that the sensitivity of our system is such that the smallest amplitude beat-frequency we can detect is 40 db below the beat-frequency signal due to the unmodulated carrier. Because

the receiver signal amplitude remains constant, the amplitude of the beat frequency varies directly as the amplitude of the carrier frequency of the source under test. If we arbitrarily assign a value of 1 to the amplitude of the beat-frequency due to the unmodulated carrier, we may interpolate directly from a table of zero-order Bessel functions [1] to determine the definition of the nulls. Now, 40 db below 1 is 0.01, which we

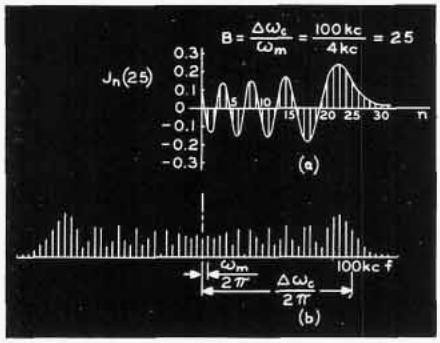


***Figure 2. Bessel functions and frequency spectrum for $f_m$ = 4 kc and $\Delta f_c$ = 100 kc.*** [2]

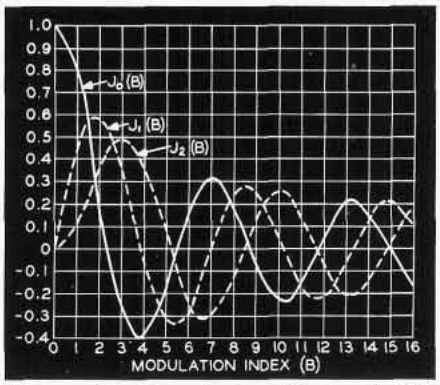


***Figure 3. Bessel functions of the first kind.***

can locate in the table in the vicinity of the first zero point. If what we believe to be 0 is actually 0.01, then the modulation index we obtain is approximately 2.38 instead of 2.4048, or an error of about 1.0%, which if the Bessel curve is assumed linear in the vicinity of zero, is possible on either side of zero, or ±1.0%. For this case, if we hold the modulating frequency constant, this error too is applied directly to the deviation frequency. Taking both errors into account, for this example the maximum possible error in determining the deviation frequency at a modulation index of 2.4048 is ±1.5%. Because the slope of the zero-order Bessel curve decreases as it passes through zero at higher modulation indices, the maximum possible error in determining frequency deviation will increase slightly with higher modulation indices.

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# RF Calibration of the Sweep Signal Generator Type 240-A

**SAMUEL WALTERS,** *Editor, The Notebook*

It sometimes becomes necessary to recalibrate the rf circuit of this generator because of changes in frequency determining components, tube aging, etc. These changes will normally cause a frequency variation of no more than 2 or 3%. Changes larger than this usually indicate serious circuit problems which re-calibration will not overcome.

The parameter most likely to affect the frequency stability is the dc reactor biasing current which is an integral part of the saturable reactor method used in this instrument for generating a sweep frequency.* This method has many advantages such as a wide sweep range, good stability and accuracy, inherently non-microphonic operation and a linear sweep. However, it introduces another variable into the oscillator circuit besides the conventional L & C: a specially shaped saw-toothed current that drives each of the five saturable reactors (one for each range). The saw-toothed current is super-imposed in the sweep condition on the dc reactor current, which provides the proper inductance at the center frequency. This dc current may change in value should some frequency determining component in the power supply through aging or some other reason change its value, thus affecting the frequency.

### Discussion Of Marker System Used In Calibration

The 240-A has a self-contained means of calibration through the use of a zero beat type marker system. As shown in Figure 1, a harmonics generator produces a set of crystal-controlled reference frequencies. A front panel control permits the choice of harmonically related reference frequencies at the fundamental frequencies of 2.5 mc, 0.5 mc or 0.1 mc. The rf sample output in cw or sweep condition heterodynes with the related frequencies in a mixer stage to produce audio frequency beat notes or "birdies", as they are sometimes called.

The table below designates the variable resistors which control the reactor bias current and thus the cw and center sweep frequencies for each range. All of the variable resistors are located in a circle around the switch at the front right hand corner of the sweep chassis (see Figure 2). In all cases turning the resistor element in a *clockwise* direction causes the frequency to *increase.*

| Freq. Range (MC) | Res. (CW Operation) | Res. (Sweep Operation) |
|---|---|---|
| 4.5 to 9.0 | R 540 | R 533 |
| 9.0 to 18.0 | R 538 | R 531 |
| 18.0 to 35.0 | R 537 | R 527 |
| 35.0 to 75.0 | R 535 | R 526 |
| 75.0 to 120.0 | R 534 | R 525 |

### Recalibration Procedure

### A. Sweep Operation Adjustment

1. Connect the *Sweep Out* terminal posts to the horizontal input of an oscilloscope.
2. Connect shielded cable from the *Composite Signal Out* BNC jack to the vertical input of the oscilloscope. No rf detector is required.
3. Turn the *Crystal Marker* switch to the 2.5 mcs position.
4. Turn the *CW-Sweep* switch to *Sweep.*
5. To avoid any error caused by scope non-linearity, turn the scope horizontal gain all the way down. Center the resulting vertical line on the scope face, this point will mark the position on the scope of the center

of the sweep. Restore the scope horizontal gain to normal. Tune the signal generator so that one of the markers or "birdies" is at the center of the sweep. Decrease the signal generator sweep width until only one marker appears and retune the frequency as required to center the marker.

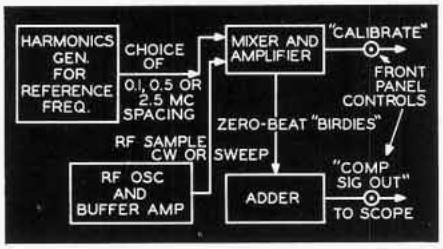


***Figure 1. Block diagram of circuits used in RF calibration of the 240-A.***

6. The frequency on the dial should be a multiple of 2.5 mcs within the ±1% tolerance of the instrument. If it is beyond the tolerance, set the dial on the frequency and center the marker on the sweep display by adjusting the proper resistor (see table) while observing the precautions listed below.
7. Identify the frequency read on the dial with some frequency determining instrument such as a receiver or grid dip meter to insure that calibration was made to the correct multiple of 2.5 mcs. This should be done whether or not a recalibration adjustment was necessary.

### B. CW Operation Adjustment

1. Plug a pair of headphones into the front panel jack marked *calibrate* and adjust *Center Frequency* control knob for a zero beat. If the use of an oscilloscope is preferred, connect a shielded cable from the *Composite Signal Out* BNC jack to the vertical input. Use the internal horizontal sweep on the oscilloscope to display the zero beat.
2. Turn the *CW-Sweep* switch to *CW*.
3. Turn on the 2.5 mcs crystal marker and adjust the frequency dial to obtain a zero beat.
4. The frequency indicated should be a multiple of 2.5 mcs within the ±1% of the instrument. If it is beyond the tolerance, set the dial on the frequency and adjust the proper resistor for zero beat.
5. Identify the frequency.

#### Precautions

The following precautions should be observed:

1. Leave the dust cover intact but remove the bottom plate.
2. Operate the instrument in its normal vertical position. Set the instrument on the bench so that it hangs over the front sufficiently to allow access to the resistors with a screw driver from the bottom.
3. Use a screwdriver with an insulated handle and a protective insulated sleeve on the shaft. This is recommended to prevent accidental shorting of the dc voltage on the resistor control to chassis ground.
4. Allow 1 hour warmup before attempting any recalibration.
5. Wait five minutes when changing frequency ranges to allow proper "settling".
6. Before making any adjustments in the *Sweep* position of the *CW-Sweep* switch, turn sweep width control fully clockwise and wait five minutes.

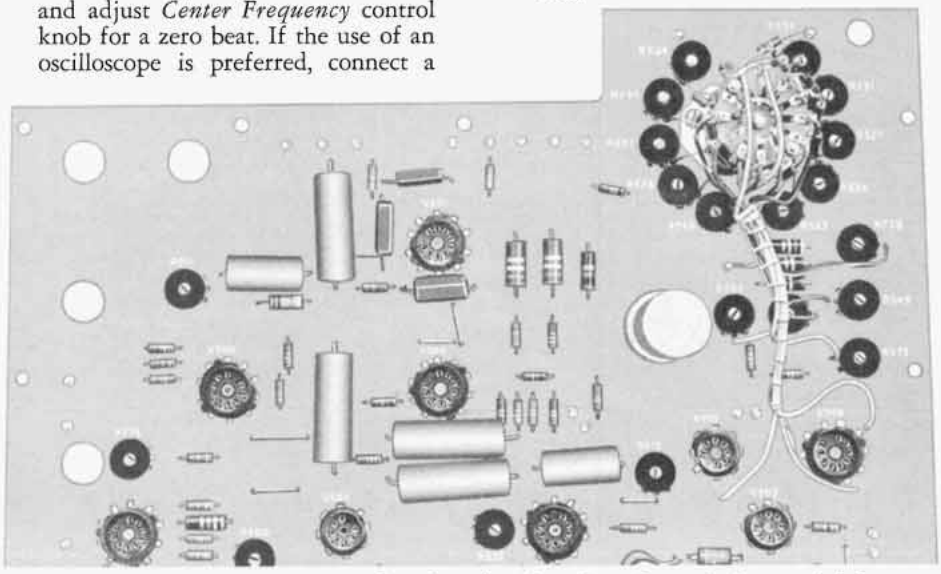

***Figure 2. Sweep generator chassis, showing location of the variable resistors which control the CW and center sweep frequencies.***

### NOTE FROM THE EDITOR

The annual trek East each Spring to see a picture in the round of electronic progress and exchange views presents the opportunity to talk of other things, "of shoes — and ships — and sealing wax — of cabbages — and kings," things that may appear irrelevant but are actually germane.

Industrial growth, for example, is rooted in local history. Such disparate articles as cannonballs and Q meters, although produced almost two centuries apart and separated even further in function, are linked by threads of politics, geography, even geology.

In our town of Boonton we can follow the threads back to the American Revolution when the iron in its soil provided the main source of cannon balls for Washington's Army. More than once, while posted at Morristown, about ten miles distant, Washington visited the works to inspect the processes on army contracts. One of the roads the Revolutionary Army traveled between Morristown and Pompton Plains was through old "Boonetown" and legend records that the town was included among the many places where our indefatigable first president spent a night (at the home of a Colonel Ogden, who reputedly gave "Boonetown" its name in honor of Thomas Boone, Governor of New Jersey, in 1760)

Colonel Ogden at this time was the owner of the great metal slitting mills at Boonetown (now lying 60 feet under the Jersey City Reservoir at nearby Parsippany — see photo) and one of the Revolutionary Army's prime sources of military supplies. He ran considerable risk before the war in the operation of his iron works since it was unlawful to manufacture iron in the Colonies. He tried to conceal it by building a harmless grist mill in front and over it. However, word reached the authorities and Governor William Franklin (a son of Benjamin) came to inquire into a report that Colonel Ogden was flouting His Majesty's authority. A stout partisan of the belief that "a bumper of good liquor will end a contest quicker than justice, judge, or vicar," Colonel Ogden wined and dined the governor 'til the inner man glowed and the discerning eye turned myopic. Governor Franklin's subsequent report bristled at the "slander" that Colonel Ogden was making bootleg iron, and hailed him as one of "your Majestie's loyal subjects".

Prior to the Revolution, Boonton was a quiet spot of great natural beauty, nestling in an area of lakes, streams and forests. Lenni-Lenapes or Delaware Indians were the first known settlers in

this area which they called Parsippanong ("where the brooks leap down the hills").

The Indians were called by the Whites after the Indian name of the river by which they dwelt; hence the Whippanongs, the Pomptons, the Rockawacks, the Parsippanongs, the Minnisinks and the Musconetcongs — the suffix "ong" meaning water and the remainder of the word describing the exact kind of water.

At or about 1700 the Indians sold their land which took in the entire northwestern territory of New Jersey and migrated to Pennsylvania and Ohio. The purchasers were a group of White proprietors of West New Jersey, most prominent among whom was William Penn who acquired approximately 4,000 acres in this area. They in turn broke the property into smaller areas and sold them to resolute settlers.

During most of the 19th century Boonton's progress depended almost solely on its Iron Industry whose fortunes waxed and waned with the times until the 1870's. In this period a double calamity broke the back of the Industry and prostrated the economy of the town — a national depression that coincided with the discovery of cheap surface ores. Many efforts were made to re-industrialize the area: silk works, hat company, soft goods industry, varnish factory, even a doll and toy company were established. None took solid root until a chemist, Edwin Scribner, started a business in 1891 that was destined to bring prosperity to the town, lure technicians, engineers and factory workers here and make Boonton's name synonymous with progress in the field of molded plastics, electronics and precision instruments the world over.

The Boonton Rubber Company, as it was known, made the first commercially

***Cradle of the Iron Industry, on the site of the old Forge, where cannon balls were made for the Revolutionary Army. This site is now 60 feet under the waters of the Jersey City reservoir.***

molded parts of Bakelite, which were sold to the Weston Electrical Instrument Company; thus Boonton became the birthplace of molded plastics. Today there are three firms in Boonton engaged in the molded plastics industry.

The burgeoning radio industry in the early 1920's created a great demand for molded parts, presenting technical problems whose solution gave birth to an important new industry. It was found that the available molded material which could be used at dc and audio frequencies became too lossy at radio frequencies; so engineers were brought in to make and test new materials. These pioneers of the radio art devised new electronic devices to assist them in their work and, in so doing, they developed circuits and instruments which were an innovation to the art. And thus was born in the Boonton area a new electronic instrument industry beginning with the founding in 1922 of the Radio Frequency Laboratories. There followed in relatively rapid succession and keeping pace with the development of the radio industry, Aircraft Radio Corporation, 1928; Ballantine Laboratories, 1932 (established by Stuart Ballantine, a foremost authority in his field); Ferris Instrument Company, 1932; and in 1934 William D. Loughlin, one of the original RFL staff, formed the Boonton Radio Corporation and concentrated on the development of measuring equipment which was in great demand by the radio industry. Measurements Corporation, the latest addition to the growing electronic family of this area, followed in 1939.

Early contributions of this group to the electronic art included amplifier circuits, single-control broadcast receivers, automatic volume control circuits, high sensitivity airborne receivers, throat microphones and broadcast station antenna systems. Later developments produced amplitude modulation signal generators, vacuum tube voltmeters, "Q" meters, field strength meters, pulse generators, sweep frequency signal generators and many other instruments invaluable to the electronic industry and the armed services.





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