M-1990

HEWLETT · PACKARD

415B

STANDING WAVE INDICATOR

M-1990

OPERATING AND SERVICING MANUAL

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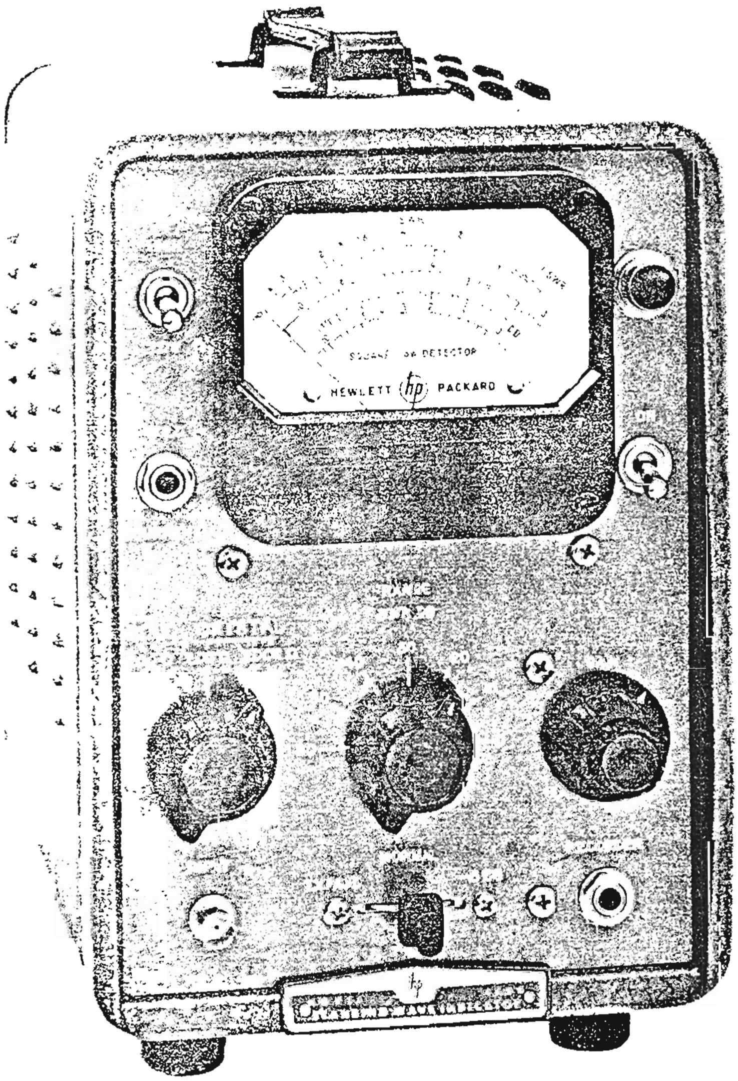
OPERATING AND SERVICING MANUAL

FOR

MODEL 415B

STANDING WAVE INDICATOR

SERIAL 4183 AND ABOVE



275 PAGE MILL ROAD, PALO ALTO, CALIFORNIA, U.S.A.

415B002-4

SPECIFICATIONS

FREQUENCY:	1000 cps ±2%. Other frequencies 315 to 2020 cps available on special order.
SENSITIVITY:	0.1 μv at a 200 ohm level for full scale deflection.
NOISE LEVEL:	Less than 0.03 μv ref. to input operated from a 200 ohm resistor at room temperature.
AMPLIFIER Q:	25 ± 5.
CALIBRATION:	Square law. Meter indicates SWR, db.
RANGE:	70 db. Input attenuator provides 60 db in 10 db steps. Accuracy ±0.1 db per 10 db step. Maximum cumulative error ±0.2 db.
SCALE SELECTOR:	"Normal", "Expand", and "-5 db".
METER SCALES:	SWR 1-4, SWR 3-10, Expanded SWR 1-1.3, db 0-10, Expanded db 0.2.
GAIN CONTROL:	Adjusts to convenient reference level. Range at least 10 db.
INPUT:	"Bolo" (200 ohms). Bias provided for 8.4 ma bolometer of 1/100 amp fuse; or 4.3 ma low current bolometer.
	"Crystal". 200 ohms for crystal rectifier.
	"200,000 ohms". High impedance for crystal rectifier as null detector.
RECORDER OUTPUT:	Jack provided for recording milliammeter having 1 ma full scale deflection, internal resistance of 1500 ohms or less.
INPUT CONNECTOR:	BNC.
POWER:	115/230 volts ±10%, 60 cps, 55 watts. Other frequencies on special order.
DIMENSIONS:	Cabinet Mount: 7-1/2" wide, 11-1/2" high, 12-1/4" deep. Rack Mount: 19" wide, 7" high, 11-3/4" deep.
WEIGHT:	Cabinet Mount: Net 13 lbs., Shipping 19 lbs. Rack Mount: Net 18 lbs., Shipping 30 lbs.
ACCESSORIES FURNISHED:	41A-16E Cable Assembly.
ACCESSORIES AVAILABLE:	415B-42B Plug-in Filter 315-700 cps. 700-2020 cps.
	AC-16D Cable Assembly, 44 inches of RG-58/U 50 ohm coaxial cable terminated at one end only with a UG-88/U Type BNC male connector.
	AC-16K Video Cable Assembly, 4 feet of RG-58/U 50 ohm coaxial cable terminated at each end with UG-88/U Type BNC male connectors.

CONTENTS

SECTION I
GENERAL DESCRIPTION

1-1 INTRODUCTORY

In high frequency applications, standing-wave measurements are the customary means of investigating the impedance match of transmission systems, various types of terminations such as antennas and loads, and other high-frequency devices such as connectors, transitions, etc. The Model 415B Standing Wave Indicator is a laboratory-quality instrument designed primarily for use in making accurate standing-wave measurements in conjunction with a suitable detector probe and slotted coaxial and waveguide sections. The 415B can also be used as a detector in bridge circuits and for other applications requiring a very sensitive fixed-frequency indicator.

1-2 DESCRIPTION

The Hewlett-Packard Model 415B Standing Wave Indicator is a highly sensitive, fixed-frequency electronic meter calibrated to indicate directly both voltage and power standing-wave ratios when used with square law detectors such as crystal diodes and barretters. Expanded meter scales are provided for easy reading of extremely small increments. The highly accurate input RANGE switch permits range-to-range reading without loss of accuracy. Because of the low noise level in the 415B, measurement of signal levels to below 0.1 microvolt is possible.

A front panel selector switch adapts the input circuit of the 415B to either a crystal diode, a barretter or a high impedance signal source. For barretters, the correct bias current is automatically supplied through the input jack, the current value being selected by a toggle switch for either of two different barretter resistances in common use.

The 415B responds to a single frequency only, 1000 cycles per second. The frequency may be changed in the field by installing a new plug-in filter tuned to the desired frequency, no further adjustment being required. Plug-in filters tuned to frequencies between 315 and 2020 cycles are available from the Hewlett-Packard Company, on special order.

Provision is made in the Model 415B for passing the meter current through an external recorder. This current can also be used to operate earphones or an oscilloscope.

1-3 ELECTRICAL CHARACTERISTICS

The Model 415B Standing Wave Indicator is designed and calibrated to measure a signal obtained from square-law devices such as crystal diodes (at low signal levels) and barretters; however, it may also be used as a peak or null indicator in conjunction with linear signal sources. The indicating meter is calibrated to indicate standing wave ratio directly in vswr and in db and includes expanded scales for very accurate readings of small increments. The range-to-range accuracy is within ±0.1 db between each range. The maximum sensitivity of the 415B (when set for CRYSTAL or BOLO operation) is 0.1 microvolt for full scale meter deflection. The noise level is less than 0.03 microvolt as referred to a signal obtained from a 200 ohm resistor connected to the input jack. Useful measurements may be made down to the actual noise level.

The sensitivity of the 415B is varied 10 db steps over a range of 60 decibels by the front panel RANGE switch. The GAIN control provides a further adjustment of the sensitivity over an approximate 12.5 decibel range to obtain a convenient meter reading for any input signal level. The EXPAND-NORMAL-5 DB switch selects an expanded meter scale when desired and in the -5 db position shifts the meter reading downscale by 5 db so that readings normally read from a down scale position can be read up scale on the next lower step on the RANGE switch.

The internal impedance of the 415B as seen at the INPUT jack is either 200 ohms, or 200,000 ohms as selected by the BOLO-CRYSTAL-200,000 selector switch. When set to BOLO, a d-c bias of approximately 8.4 milliamperes is automatically applied to a 200-ohm barretter connected to the INPUT jack.

A toggle switch on the front panel changes the bias current to approximately 4.3 milliamperes. The BOLO CURRENT jack on the front panel permits the bias current supplied to the external barretter to be monitored by an external meter and decreased by insertion of added series resistance.

The frequency of the 415B as supplied from Hewlett-Packard Company is 1000 cycles per second ±2% with a bandwidth of approximately 38 cycles at the half power points. The selectivity of the tuned amplifier is determined by a single plug-in filter having an effective Q between 20 and 30.

The frequency of the amplifier may be changed without adjustment by installing a new filter tuned to the desired frequency. The RECORDER jack on the front panel provides sufficient signal current to operate a 1 milliampere recorder (or other indicating device) having an input resistance of 1500 ohms. The current through the recorder is the same current that flows through the vswr meter.

The 415B operates on 115 volt or 230 volt, 60 cycles a-c power and consumes 55 watts of power. The instrument is normally supplied with a 1 ampere "Slo-Blo" fuse. For 230 volt operation use a 0.5 ampere fuse.

1-4 APPLICATIONS

The hp Model 415B Standing Wave Indicator has been specifically designed for use with the hp series of Slotted Lines and Detector Mounts. A complete series of Slotted Line equipment for impedance and swr measurements in coaxial and waveguide transmission systems is available to cover the entire frequency range from 500 mc to 18 kmc. Also available is a convenient line of waveguide and coaxial Detector Mounts for the range from 10 mc to 12.4 kmc. Table 1-1 shows the various Hewlett-Packard instruments for these services arranged by frequency coverage.

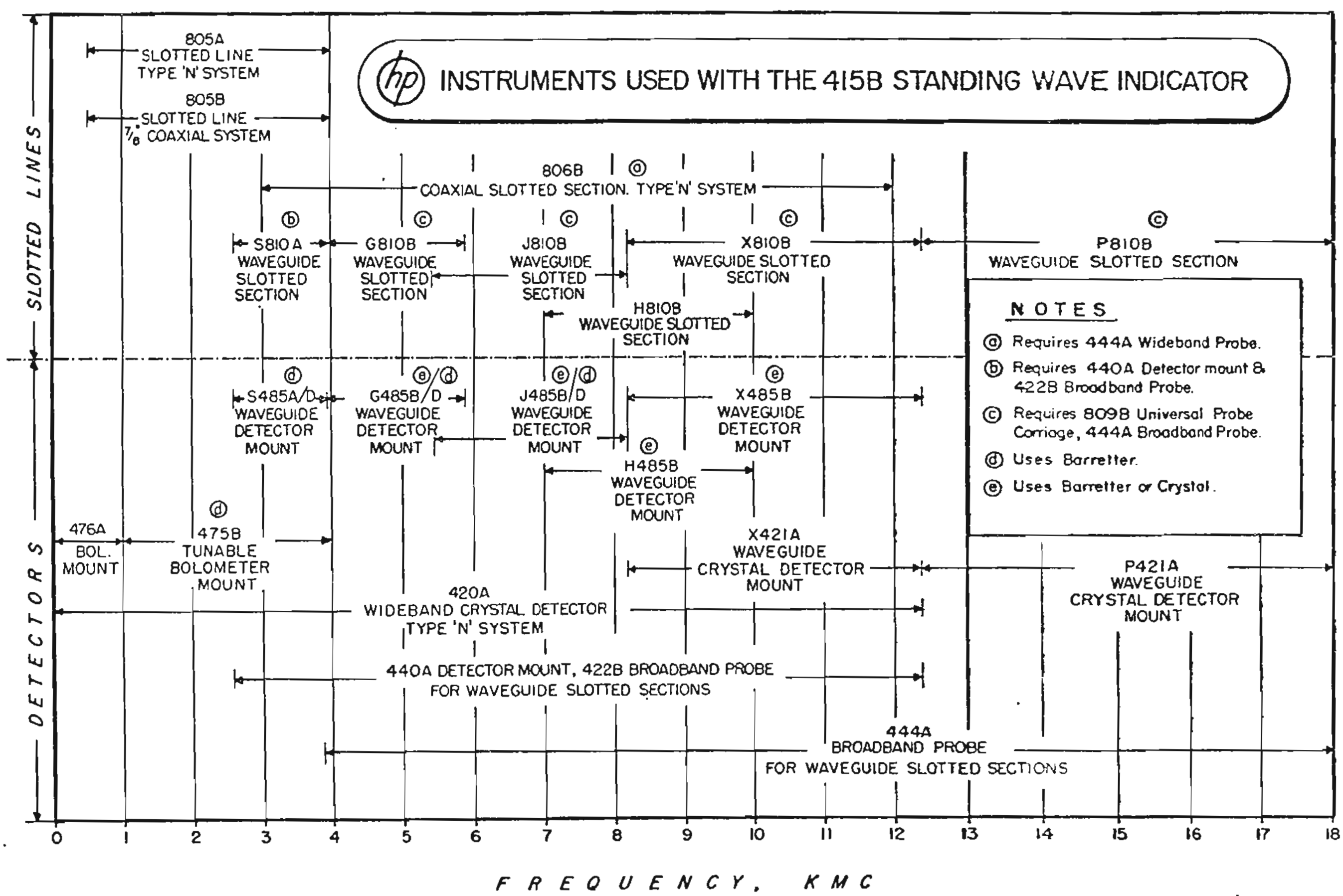


Table 1-1. Suitable hp Microwave Equipment for Slotted Line Measurement arranged by frequency range

SECTION II
OPERATING INSTRUCTIONS

2-1 INTRODUCTION

This section contains complete operating instructions for the Model 415B Standing Wave Indicator, test set-up instructions, measurement possibilities and measurement precautions. Because the accuracy of standing wave measurement depends largely on measurement techniques, considerable attention should be given to the various measurement discussions, Low VSWR, High VSWR, Precautions with Detectors, etc. The material in this section is outlined below:

2-2 INSTALLATION

The 415B Standing Wave Indicator has been rigidly tested and inspected before being shipped and is ready for use when received. When the instrument is unpacked, it should be carefully inspected for damage received in shipment. If any damage is found, follow the procedure outlined in the "Claim for Damage in Shipment" paragraph on the last page of this instruction book.

The Model 415B is a portable measuring instrument designed for table top use, or in the rack-mounting model, for permanent installation in a standard relay rack. No special installation instructions are required other than to assure that the ventilating louvers are not obstructed.

When shipped from the Hewlett-Packard factory, the 415B is connected for operation on 115-volt power. If the 415B is to be operated on 230-volt power, the power transformer primary winding must be rewired as shown in the schematic diagram at the end of the manual.

2-3 REQUIRED SIGNAL SOURCE

The signal sources used with the 415B Standing Wave Indicator are of two common types; signal generators and variable frequency klystron tubes. To be used with the 415B, the signal source must be capable of 1000 cycle per second amplitude modulation and should generate up to 0.1 milliwatt of power. Since shf oscillator circuits for the most part use reflex klystrons (which are incapable of sinusoidal amplitude modulation without serious frequency modulation) it is common practice to key the modulating electrode of the klystron from a square-wave generator to obtain 100% square-wave modulation of the signal source. The frequency of the square wave must then be tuned accurately to 1000 cps (to the frequency of the 415B).

For most flexible and versatile operation the signal source should indicate power output and should contain an accurately calibrated output attenuator. Figure 2-1 illustrates a typical test set-up using such a signal generator.

When using a variable frequency klystron tube as a signal source connected directly to waveguide or coaxial sections a suitable attenuator should be used between the klystron and the guide to prevent reflections and to control the signal level from the klystron. In this application the power supply used to power the klystron tube must supply the 1000 cycle modulation or must be capable of being modulated from an external source of square waves.

The 415B is basically a very high gain amplifier driving a meter. Precautions applicable to any high gain system must be considered in operation of the instrument. If the signal source is pulse modulated, care must be taken that the 415B is not overloaded,

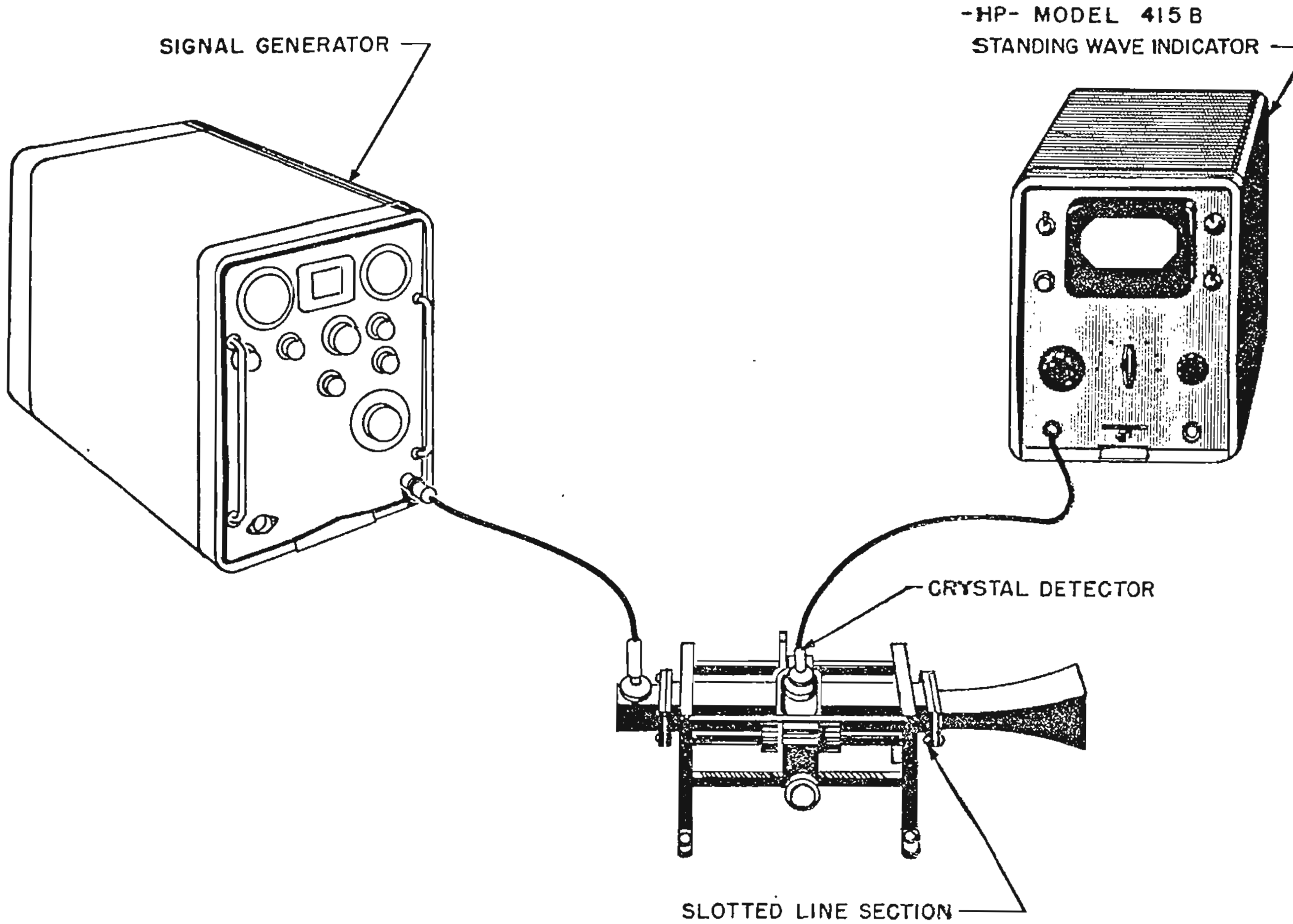


Figure 2-1. Test Setup

as this will result in severe errors. If pulse modulation is used, the duty cycle should be not less than approximately 40%. Since the 415B input in the 200Ω CRYSTAL position is through a transformer, short pulse type signals can give trouble due to ringing and overload effects. For these reasons it is recommended that only square-wave modulation be used, if at all possible.

2-4 MEASUREMENTS

The Model 415B Standing Wave Indicator can be used to measure the magnitude and phase of the reflection coefficient of any r-f load. This information is obtained by measuring the magnitude of the standing wave and the position of its minimum or maximum. From a knowledge of the reflection coefficient, all other information pertaining to the load can be easily calculated.

Basically, the measurement of standing wave ratio consists of setting a pick-up probe in a slotted section at a position of maximum voltage and then setting the gain of the standing wave indicator so that a reading of 1.0 is obtained at this position. The probe is then moved along the line section until a minimum voltage point is reached. The standing-wave ratio can then be read directly from the standing-wave indicator scale. This is a basic and straight-forward method of making an swr measurement which, under certain conditions, may lead to relatively large errors. These errors, along with techniques for minimizing them, are discussed later in this section.

In many cases a knowledge of the standing-wave ratio is sufficient as this is a direct measure of the mismatch of the load. There are nevertheless some cases, particularly in design and development, where a greater knowledge of the load is required, and this can be obtained by measuring the position of the minimum in the standing-wave pattern (probe carriages are usually equipped with an accurate scale and indicator for this purpose). The minimum is usually not used directly, but is compared to the position of the minimum when some known load (for

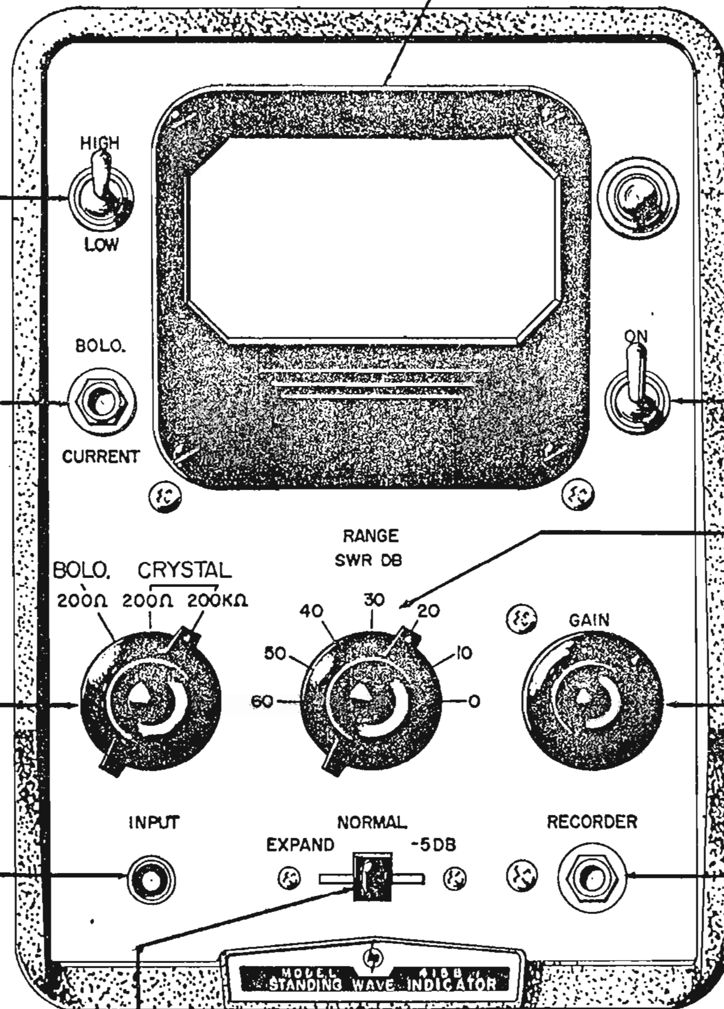


Figure 2-2. Controls and Terminals Diagram

convenience usually a short circuit) is placed at a reference point in the line. The detailed instructions for such measurements are given in paragraphs 2-12 to 2-14 on impedance measurements.

2-5 HOW TO OPERATE THE 415B

As a precaution to prevent possible damage to low current barretters, always set bias current switch to LOW before turning on the instrument.

a. Connect the 415B Standing Wave Indicator to a nominal 115-volt a-c power source, turn the power switch to ON and allow instrument to warm up.

b. Set the input selector switch for the type of detector that is to be used with the standing wave indicator.

c. Connect the INPUT jack to the detector or other signal source to be used.

d. Set the SWR-DB RANGE switch to obtain an up-scale reading on the vswr meter.

e. Peak the meter reading by adjusting the modulation frequency of the signal source.

f. If reading swr from a slotted section, move the probe along the line to obtain a peak on the vswr meter.

g. Set the GAIN control to obtain an exact full-scale reading on the vswr meter.

h. Move probe along the slotted section to obtain a minimum reading, if necessary reducing the SWR-DB RANGE switch setting to maintain an up-scale reading.

i. Read the vswr, which is now indicated directly on the 415B.

Examples - refer to Figure 2-3.

1) If at the minimum the 415B reads 1.3 on the uppermost scale (solid pointer line in Figure 2-3), the vswr would be 1.3 to 1.

2) If the reading at the minimum is lower than 3 on the uppermost scale (dashed pointer line A in Figure 2-3), set the SWR-DB RANGE switch to the next range and read the indication on the second vswr (3 to 10) scale. In this case the reading is 3.25 (dashed pointer line B).

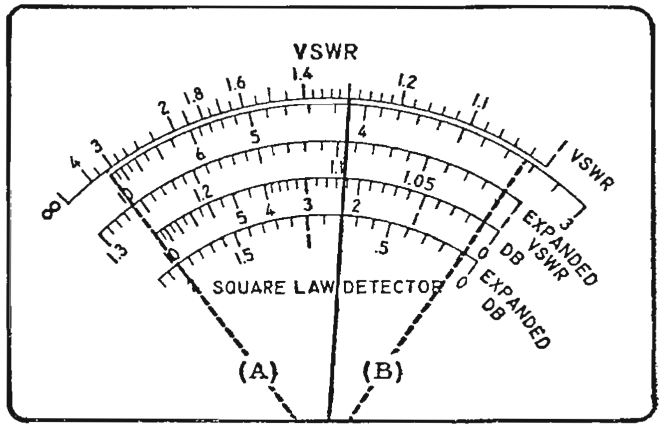


Figure 2-3. Detail of Meter Face

3) If the SWR-DB RANGE switch has to be changed by two ranges the scale shifts twice, back to the top scale again; however, the full-scale reading is now 10 instead of 1.

4) If the vswr is 1.3 or less it can be read on the EXPANDED VSWR scale after the lever switch on the front panel is set to EXPAND. When the lever switch is set to EXPAND, the meter pointer will "pin" downscale and must be reset to full-scale by increasing the meter sensitivity using the GAIN control and/or the SWR-DB RANGE switch.

5) The standing wave ratio is also indicated in decibels on the DB and EXPANDED DB scales. Swr's of less than 2.2 can be read on the EXPANDED DB scale.

A graph of swr in decibels vs. voltage standing wave ratio is shown in Figure 2-4.

PRECAUTIONS

Both the BOLO. and RECORDER jacks on the front panel of the 415B receive the three-circuit 1/4 inch diameter "tip-ring sleeve" phone plug supplied with the instrument. Do not use the standard two-circuit phone plug in these jacks. To do so will short an internal voltage circuit to ground in either jack. In both jacks the sleeve connection is grounded to the instrument chassis and is not used as part of the output circuits; the ring and tip provide the connections to the appropriate signal circuit and must not be grounded externally.

An external recorder connected to the RECORDER jack on the 415B must have approximately 1500 ohms resistance. If the recorder has higher resistance it can be shunted so the total resistance connected to the

RECORDER jack on the 415B is 1500 ohms. If the recorder resistance is lower than 1500 ohms, resistance must be added in series with the recorder. In addition the recorder input terminals must be isolated from ground.

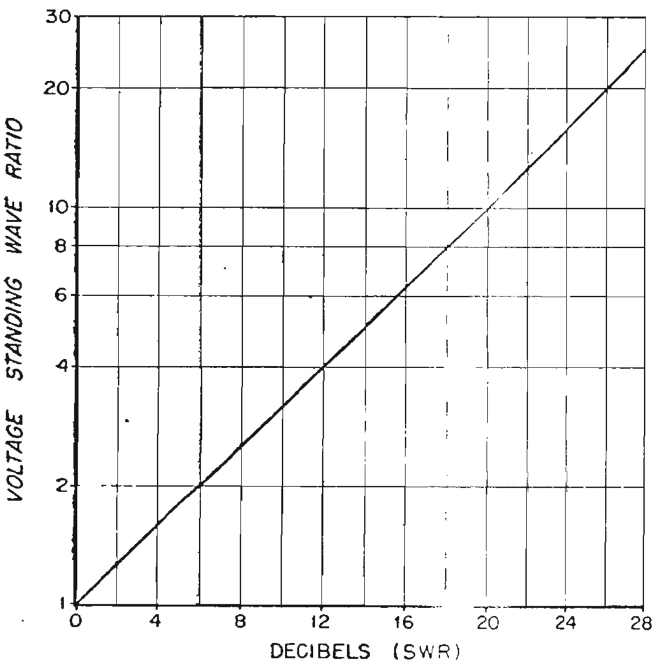


Figure 2-4. Graph Showing Standing Wave Ratio in DB vs. VSWR

2-6 PRECAUTIONS WHEN USING CRYSTAL DETECTOR

There are precautions to be observed concerning all crystal detector elements. The limitations of these devices are well known and will be mentioned only briefly. Crystal diodes exhibit a departure from the ideal square-law response for which standing-wave indicators are calibrated. This departure tends to occur when the r-f power level exceeds a few microwatts, or when a reading of full scale on the 30-db range of the standing wave indicator with the GAIN control set to maximum is obtained.

If the quality of a crystal detector is in question, its performance may quickly be checked against a signal generator having an accurately calibrated attenuator. The step-by-step procedure for making such a check follows. Any new crystal being used for the first time should be thus checked, as there is often a significant variation between one crystal and another.

To check a crystal detector using a calibrated signal source, proceed as follows:

a. With the equipment in operation, adjust the detector to obtain a full-scale reading on the 30 db-range of the standing wave indicator (GAIN control set to maximum).

b. Accurately reduce the output of the signal generator 10 decibels by its attenuator.

c. Set the SWR-DB RANGE switch to the 40-db range. The meter on the standing-wave indicator should again read full-scale, thereby showing a decrease of 10 decibels. A deviation from full-scale indicates a departure from square-law characteristics at the higher level.

d. Adjust GAIN control on standing-wave indicator, if necessary, to again obtain a full-scale reading with the SWR-DB RANGE switch set to the 40-db range.

e. Again reduce the signal generator output to 10 db by means of its attenuator.

f. Set the SWR-DB RANGE switch to the 50-db range. The meter should again read full-scale, indicating a reduction of signal strength of 10 db. If the reading differs noticeably from that on the attenuator of the signal generator, a lower signal level should be used or another crystal detector should be tried.

2-7 DETECTOR PROBE PENETRATION

A general rule in slotted line work is that the penetration of a sampling probe into the line should be held to a minimum. However, this rule is so generally disregarded that it is one of the major sources of errors in standing wave measurements.

Since the sampling probe must extract some power from the line in order to supply the detector and indicating device, it is to be expected that the probe can have an effect on the fields within the line. This effect usually becomes greater as probe penetration is increased. The probe can be considered as an admittance shunting the line. In practical work this admittance is kept small by coupling as loosely as possible (small penetration) and by using a signal source having a power output in the order of a milliwatt or more.

If the coupling between the probe and line is not small, the shunt admittance introduced by the probe will cause the measured vswr to be lower than the true vswr and will shift both the maxima and minima from their natural positions. In general, the shift in the maxima and minima will not be equal, but will depend upon the shunting admittance of the probe. In one special case where the susceptance of the load is zero, there is no shift of maximum or minimum. A minimum will suffer less shift than the maximum. The impedance along a line varies from a maximum at a voltage maximum to a minimum at a voltage minimum. The effect of the probe conductance is to lower these line impedances, and the effect will be greater at a voltage maximum than at a voltage minimum.

An exception to the minimum-penetration rule occurs when it is desired to examine in detail a minimum point in a standing wave of high ratio (see paragraph 2-9, "High VSWR's", for example of this form of measurement). For this work a greater probe penetration can be tolerated than otherwise because the minimum corresponds to a low-impedance point in the line. However, the minimum should be definitely small (high vswr) before tolerating substantial probe penetration.

It is more desirable to locate a voltage minimum than a voltage maximum since the effect of probe loading on the minimum is less than on the maximum. However, location of the minimum in a low standing wave ratio by a single measurement is usually inaccurate since the minimum is generally quite broad. A more accurate method of locating the minimum is to obtain the position of probe at two equal output readings on either side of the minimum and then average these two readings.

Besides absorbing power and affecting the standing-wave pattern as a shunting element in the line, the probe will also cause reflections in the line. These reflections will travel towards the generator. If the generator is not matched, they will be reflected down the line toward the load.

2-8 PRECAUTIONS WITH SIGNAL SOURCES

Signal sources can introduce at least three undesirable characteristics that will affect slotted line measurements. These include presence of r-f harmonics, frequency modulation, and spurious signals. Signal sources used for standing wave measurements should have relatively low harmonic content in their output. The standing wave ratio at a harmonic frequency may be considerably higher than at the fundamental. Spurious frequencies in the signal source are also undesirable, for, unless very slight, they will obscure the minimum points at high vswr values. Figure 2-5 shows plot of an swr pattern made with signal source producing unwanted f-m.

Instances are common where the presence of r-f harmonics has led to very serious errors in vswr measurements. Such harmonics are usually present to an excessive degree only in signal sources that have coaxial outputs. Coaxial pickups of a broad-band type will often pass harmonic frequencies with greater efficiency than the fundamental. In waveguide systems, signal sources such as internal cavity klystrons have a more or less fixed coupling and in addition do not have pickups extending into the tuned cavity to cause perturbations of the cavity fields. Consequently, the harmonic problem is generally limited to coaxial systems. Harmonics become especially troublesome when the reflection coefficient of a load at a harmonic frequency is much larger than at the fundamental frequency — a common condition. When the harmonic content of the signal source is high, the large reflection coefficient of the load at the harmonic frequency can cause the harmonic standing wave fields to be of the same order of magnitude as the fields at the fundamental frequency. Thus, a device having a vswr of 2.0 at the fundamental frequency will often have a vswr of 20 or more at the second harmonic frequency. If such a device is driven from a signal source having, say, 15% second harmonic content, the peaks of the standing waves of second harmonic will be about one-forth the amplitude of the peaks at the fundamental frequency. Figure 2-6 shows a typical swr pattern obtained when the r-f signal contains harmonics.

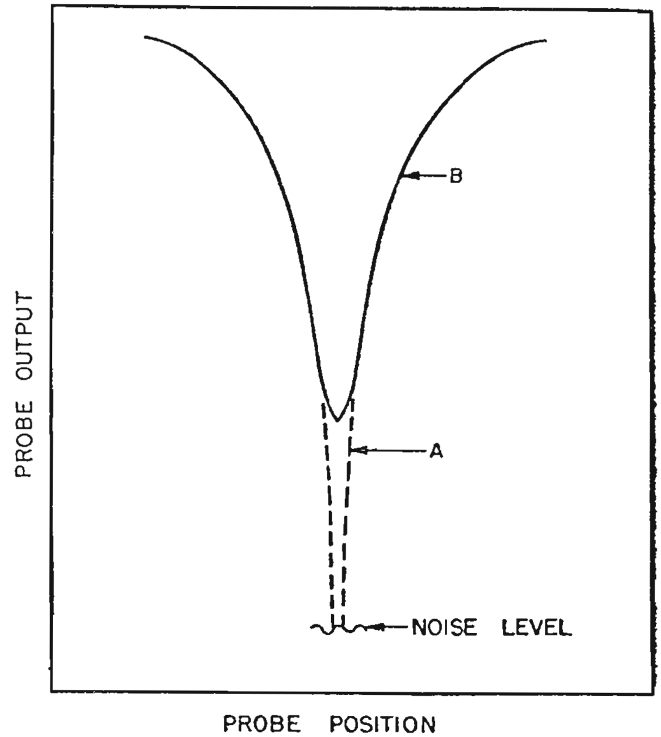


Figure 2-5. High Standing Wave Ratio Pattern
(A) Free of FM
(B) With Moderate FM

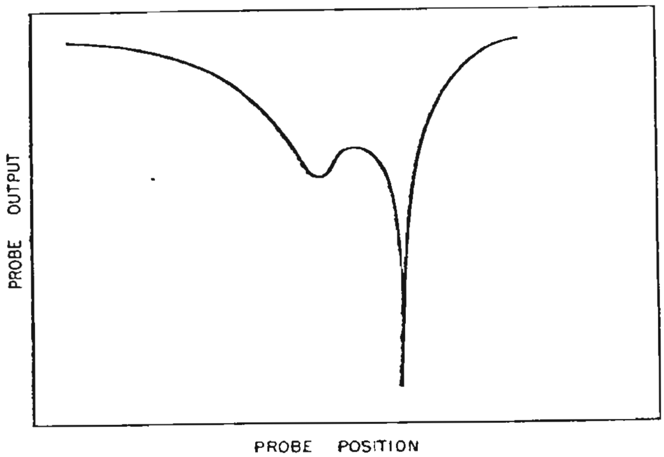


Figure 2-6. Typical Pattern of High VSWR to Spurious Frequency in Signal Source

2-9 HIGH VSWR'S

The straightforward measurement of vswr with conventional methods is generally applicable when measuring nominal vswr's up to the range of 10-12, but at higher vswr's special considerations are desirable.

When the vswr is high, the coupling of the probe must be high if a reading is to be obtained at the minimum. This requirement may result in a deformation of the pattern when a maximum is measured, with the consequent error in the reading. In addition to the error caused by probe coupling, there is danger of the error caused by a change in detector characteristics as the r-f energy increases to a much higher level.

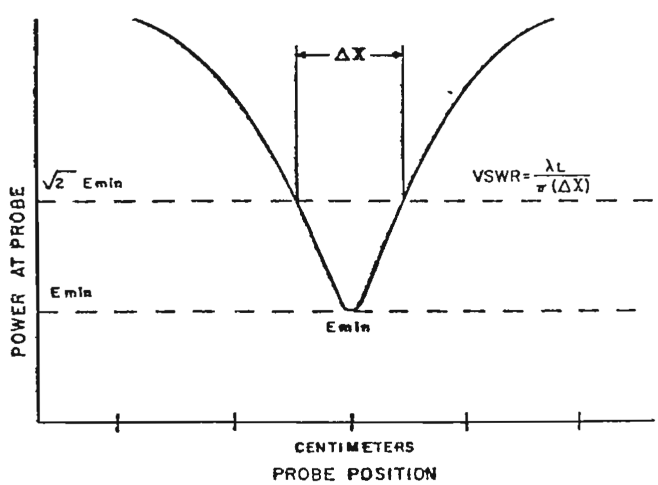


Figure 2-7. Graph Showing Double Minimum Method for Computing VSWR

There is available for measuring high vswr's a method that is accurate within approximately 1% down to the region where conventional methods can be used. This method is the twice-minimum-power method and is predicted on the approximation of a high-ratio power standing-wave pattern to a parabola in the vicinity of a minimum. (See Figure 2-7)

In the twice-minimum method it is only necessary to establish the electrical distance between the points that are twice the power amplitude of the minimum. The vswr can then be obtained by substituting this electrical distance into the expression

$$\text{VSWR} = \frac{\lambda\ L}{\pi\ (d_1 - d_2)}$$

Where λL is the guide wavelength in cm and d_1 and d_2 are the locations of the two twice-minimum points, also in cm.

NOTE: It should be noted that the value referred to in this method is the twice-power value. If a standing wave indicator such as the 415B calibrated for use with a square-law detector is used, or if a linear receiver is used, the voltage ratio of the two readings will be 1.4:1. If a linear voltage indicator is used with a square-law detector, the voltage indication of the twice-power point will be twice that of the minimum.

For this method of reading vswr, the probe penetration should be sufficient to give a clear reading of the minimum. For this work a greater probe penetration can be tolerated than otherwise because the minimum corresponds to a low-impedance point in the line. However, the minimum should be definitely small (high vswr) before tolerating substantial probe penetration.

2-10 LOW VSWR'S

When a sampling probe is lowered into a slotted section it gives rise to reflections from the probe itself. Reflections from the probe travel back toward the generator, and what happens there depends upon the match between the generator and the line. If the generator is mismatched, these reflections are again reflected, this time toward the load. When the probe is moved under these conditions, the phase of the reflections is changed, leading to errors. Since the reflection from the generator is a second-order effect, it only becomes important when measuring low vswr's in the order of 2 or less, in which case it is desirable to achieve a moderately good match between generator and load. Probe reflections, of course, should be kept as low as possible by minimizing probe penetration.

Accurate measurement of the position of the minimum, when the vswr is low, becomes difficult because of the broadness of the minimum. When the precise location of the minimum is desired, it is helpful to establish points on each side of the minimum that have the same value. By averaging the location of these points, the minimum can be located with greater accuracy than with a direct measurement. The locations of equal-amplitude points are more easily established because of their higher slope.

2-11 IMPEDANCE MEASUREMENT RULES

Some rules of thumb that are helpful in making slotted line measurements are:

The shift in the minimum when the load is shorted is never more than ± one-quarter wavelength.

If shorting the load causes the minimum to move toward the load, the load has a capacitive component.

If shorting the load causes the minimum to shift toward the generator, the load has an inductive component.

If shorting the load does not cause the minimum to move, the load is completely resistive and has a value Z_0/VSWR.

If shorting the load causes the minimum to shift exactly one-quarter wavelength, the load is completely resistive and has a value of Z_0 x VSWR.

When the load is shorted, the minimum will always be a multiple of a half-wavelength from the load.

Shifts in voltage minima resulting from various types of loads are illustrated in Figure 2-8.

2-12 IMPEDANCE MEASUREMENT PROCEDURE

The technique for performing actual impedance measurement is as follows:

a. Connect the load under test to the slotted section and measure the vswr and the position of the minimum in the standing wave pattern.

b. Replace the load with a short at the load end of the slotted line.

c. Determine the new minimum position with the line shorted.

d. The normalized load impedance may be computed by the formulas below. Refer to Figure 2-9.

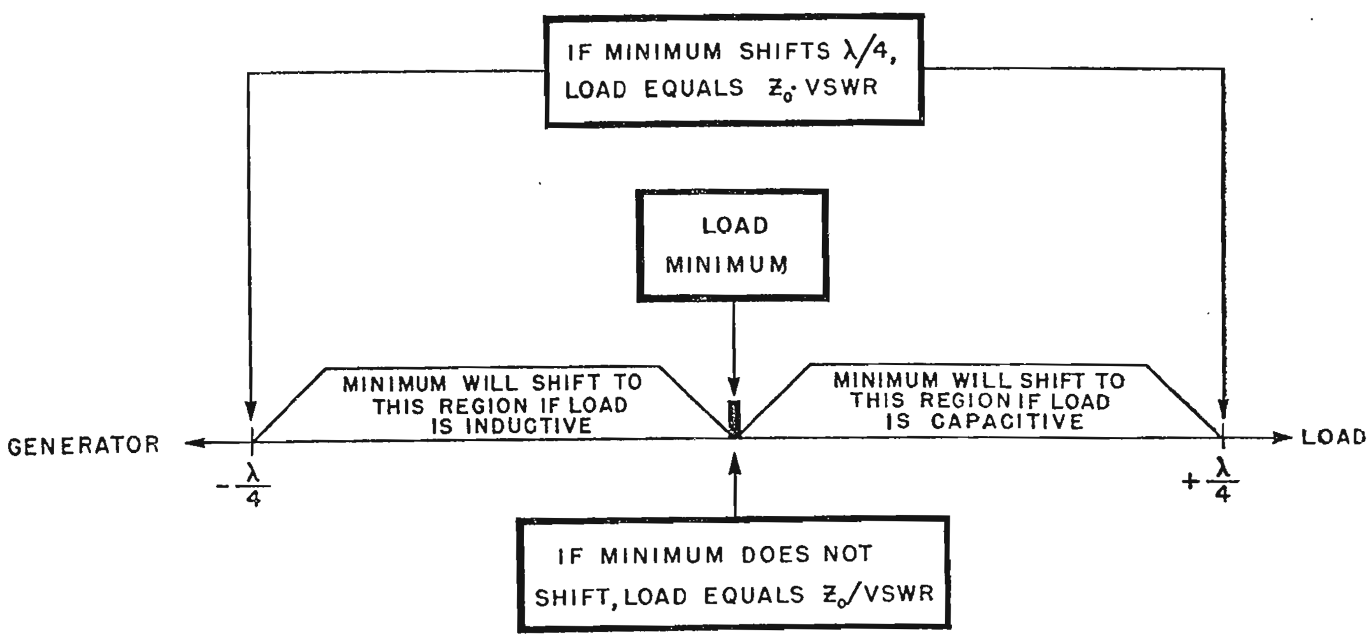


Figure 2-8. Summary of Rules for Impedance Measurement

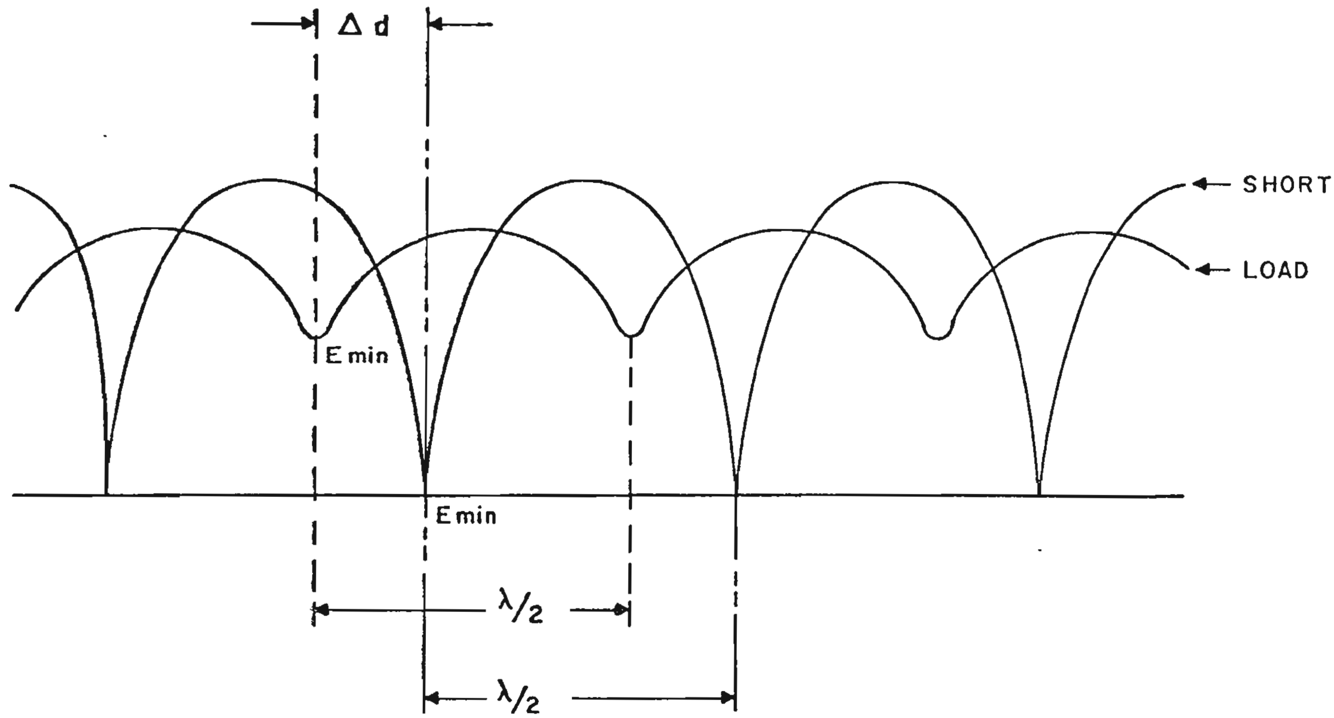


Figure 2-9. Graph Showing Standing Wave Patterns with a Load and Short

$$zL = \frac{1 - j\,(VSWR)\,\mathrm{Tan}\,X}{(VSWR) - j\,\mathrm{Tan}\,X}$$

Where: $X = \dfrac{180^\circ\,(\pm\,\Delta\,d)}{\frac{\lambda}{2}}$

And: $\pm\,\Delta\,d$ = Shift in centimeters of the minimum point when the short is applied.

Δ d takes a positive (+) sign when the minimum shifts toward the load.

Δ d takes a negative (-) sign when the minimum shifts toward the generator.

$\frac{\lambda}{2}$ = One-half line or guide wavelength. It is the distance in centimeters as measured between two adjacent minima.

These calculations are based upon the assumption that no losses occur in the transmission system. For laboratory set-ups where the line lengths are short this assumption is customary. It is also assumed that the Z_0 for the lines is entirely resistive.

2-13 IMPEDANCE MEASUREMENT AND THE SMITH CHART

When data is obtained from slotted line measurement, one of the most indispensable tools and certainly the simplest to use, is the Smith Chart. This chart represents an impedance coordinate system so arranged that the variable quantities in impedance relationships are conveniently displayed for the solution of transmission line problems. *

The values of resistance and reactance shown on the Smith Chart in Figure 2-10 are based upon the normalized values. The normalized impedance, resistance or reactance is obtained by dividing the actual value by the characteristic impedance of the line. For example, if the actual impedance of a 50 ohm transmission line were found to be 100 ohms at some point, the normalized impedance would be 2.

The circles on the Smith Chart tangent to bottom of the chart are circles of constant and normalized resistance.

---

* Smith, P.H. "Transmission-line Calculator" Electronics, Jan. 1939, McGraw-Hill.

Ragain, G.L. Ch. 2, Vol. 9 M.I.T. Rad. Lab. Series, 1948, McGraw-Hill.

The straight line forming the vertical diameter of the chart is the line of zero reactance. To the right and left of this line are seen lines which curve away from the zero reactance line. The curved lines to the right are the lines of positive reactance $\frac{+jX}{Z_O}$.

The curved line to the left are the lines of negative reactance, $\frac{-jX}{Z_O}$.

For example, the impedance point of a line terminated by its characteristic impedance would be the center of the chart (with a normalized resistance of 1.0 and no reactive component).

In another example of actual impedance calculation:

$$ZL = 5 + j\,25 \text{ ohms}$$

Normalized for a 50 ohm line would be:

$$zN = 0.1 + j\,0.5$$

2-14 PROCEDURE FOR SMITH CHART CALCULATIONS

The step by step procedure for employing the Smith Chart when solving transmission line problems is outlined below. It should be understood that there are various methods employed for entering the Smith Chart with data obtained from the slotted line, and that the method outlined in this section has been found practical and simple.

a. Set up slotted line in system.

b. Measure vswr in manner described in section 2-5.

c. Determine wavelength of transmission line (λ L). Paragraph 2-8 showed that the distance as measured on slotted line between two adjacent minima was equal to one-half the wavelength of the line.

d. Find a convenient minimum point.

e. Replace load with short.

f. Measure Δd (the shift in centimeters of the minimum point with the short applied).

g. Determine the number of wavelength of shift ($\Delta\ \lambda$).

$$\Delta\lambda = \frac{\Delta d}{\lambda L}$$

h. Starting at center of Smith Chart draw circle with vswr as radius. Read vswr on zero reactance line down from center.

i. Enter the Smith Chart at the top and proceeding in a direction of probe movement (either toward the load or toward the generator) when the load was replaced by a short to the quantity $\Delta\lambda$ established in step g.

j. Draw a line to the center of the chart from the $\Delta\ \lambda$ point.

k. The intersection of this line and the vswr circles is the normalized impedance.

l. It is important that the convention be followed of first finding the minimum reference with the load on the line and then sliding the probe to the new minimum when the line is shorted. Should it be necessary to establish the shorted minimum point first, the Smith Chart would be entered with $\Delta\ \lambda$ in a direction opposite to the direction of probe movement. That is, the probe movement toward the load would be entered on the chart in a direction toward the generator.

m. An example will clarify this procedure.

The vswr is measured as 3.3.

The distance between two adjacent minima is 15 cm. Therefore, the wavelength of the line is 30 cm (λL).

A convenient minimum is located at 22 cm.

The line is shorted.

The minimum point shifts to 19 cm (toward generator).

$$\Delta d = 22 - 19 = 3 \text{ cm}$$

$$\Delta\lambda = \frac{\Delta d}{\lambda L} = 3/30 = 0.1 \text{ wavelength}$$

Construct vswr circle on Smith Chart. See Figure 2-10.

Construct radius to wavelength shift point. See Figure 2-11.

Read impedance at intersection at point A on Figure 2-12. Normalized impedance equals .44 + j 0.64.

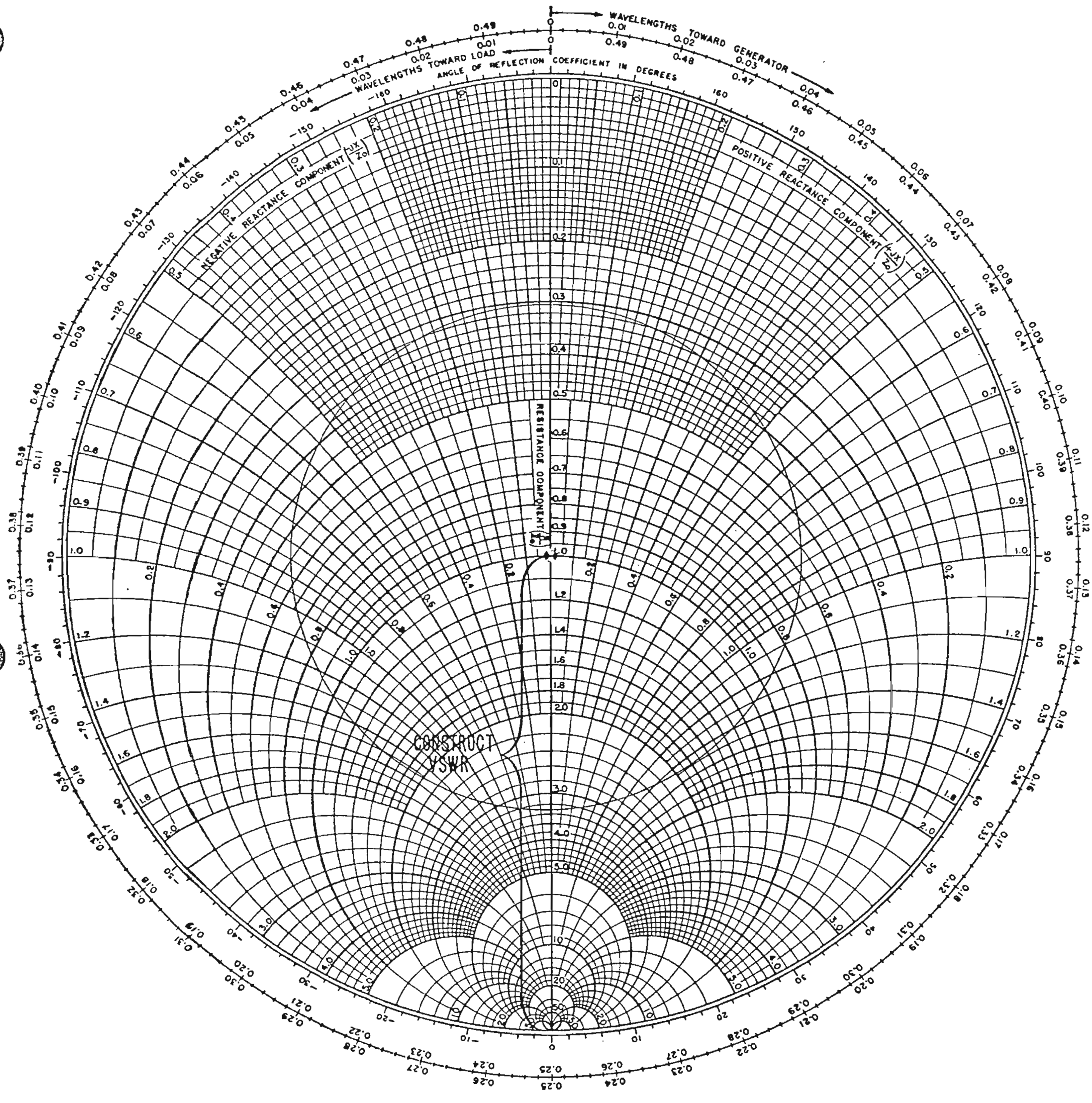


Figure 2-10. Smith Chart with Constructed VSWR Circle, VSWR = 3.3

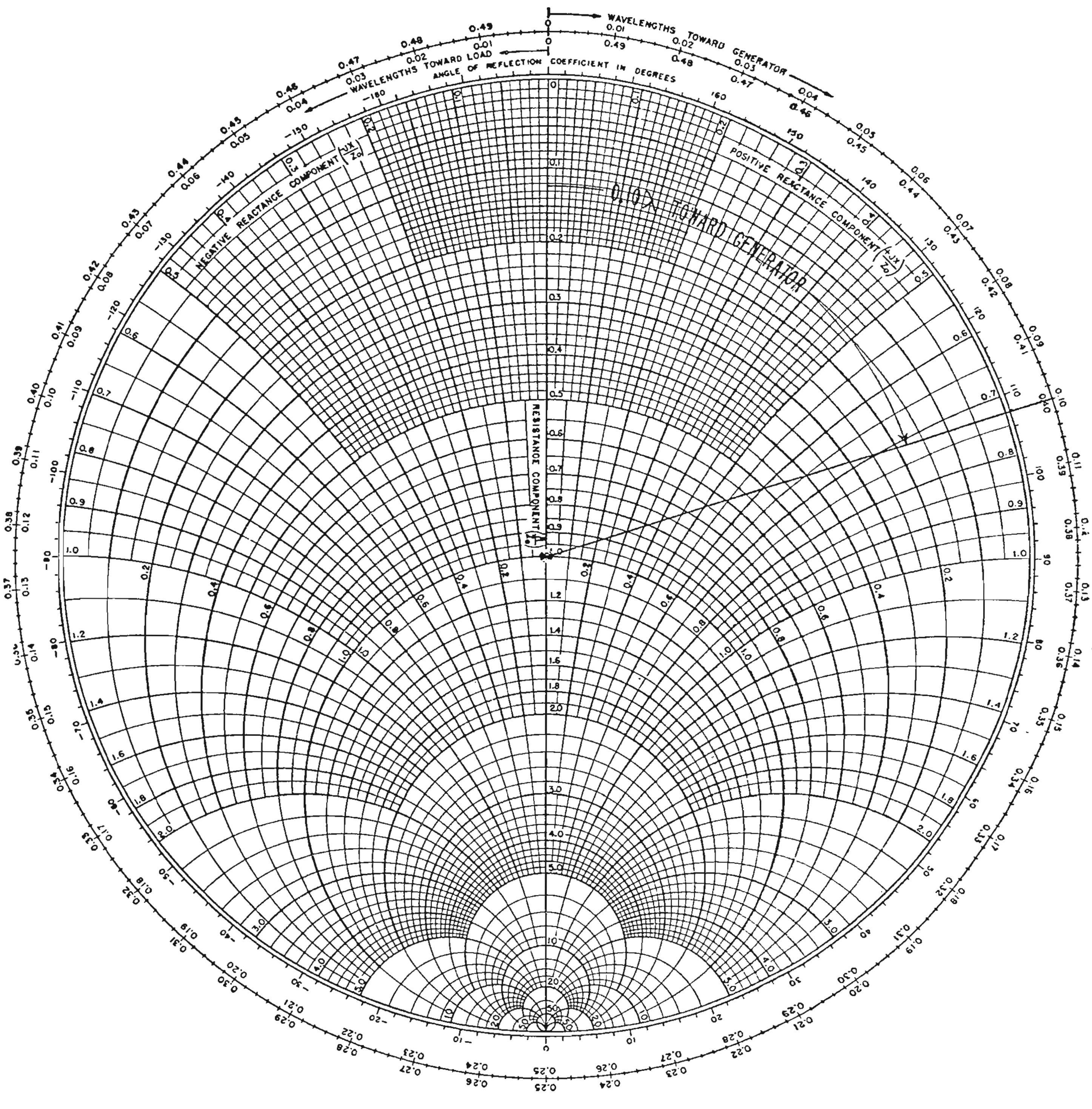


Figure 2-11. Smith Chart with Wavelength Shift Point Constructed as a Radius. $\Delta\lambda = 0.1$

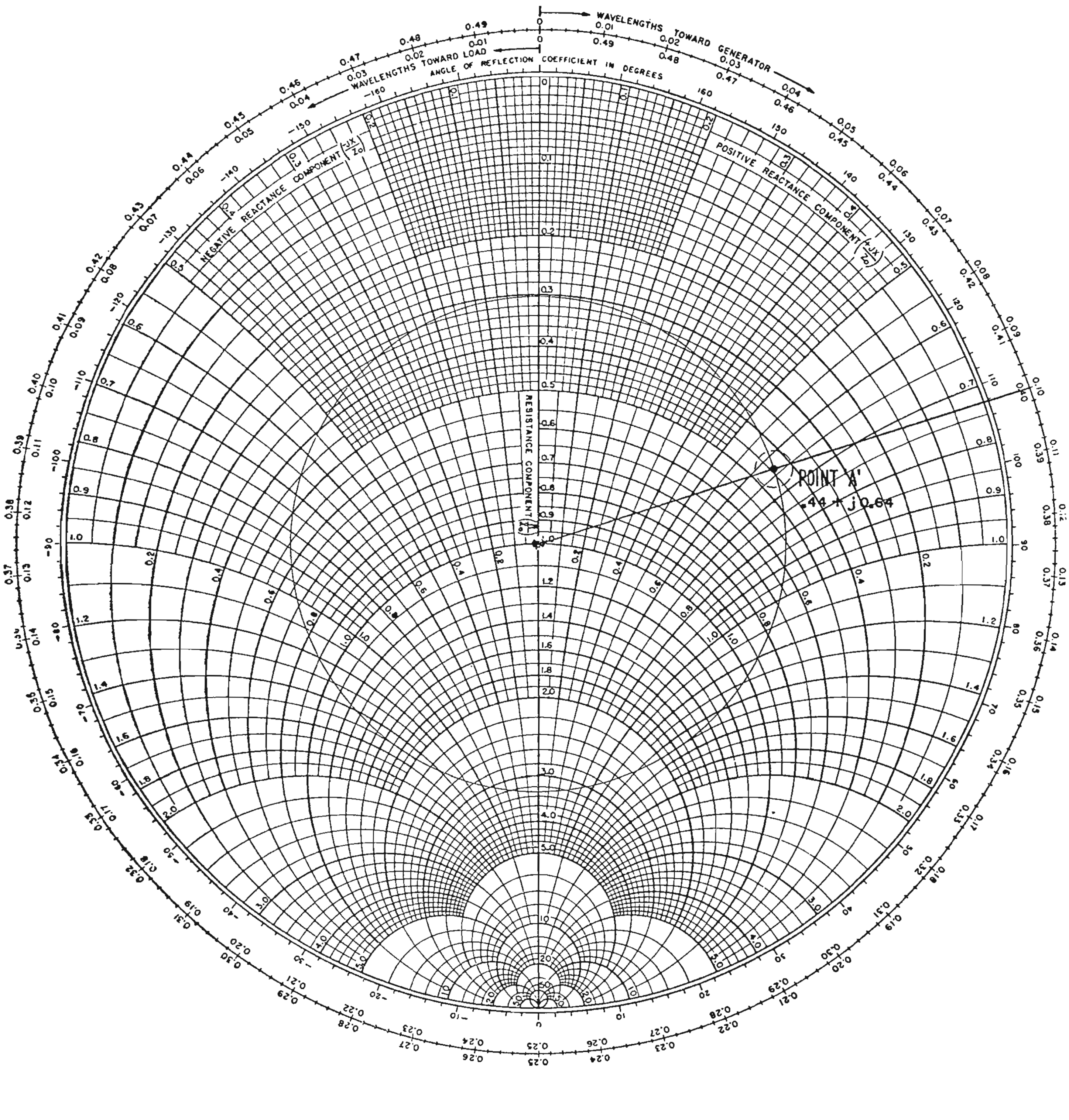


Figure 2-12. Smith Chart Showing Impedance Point, Δ

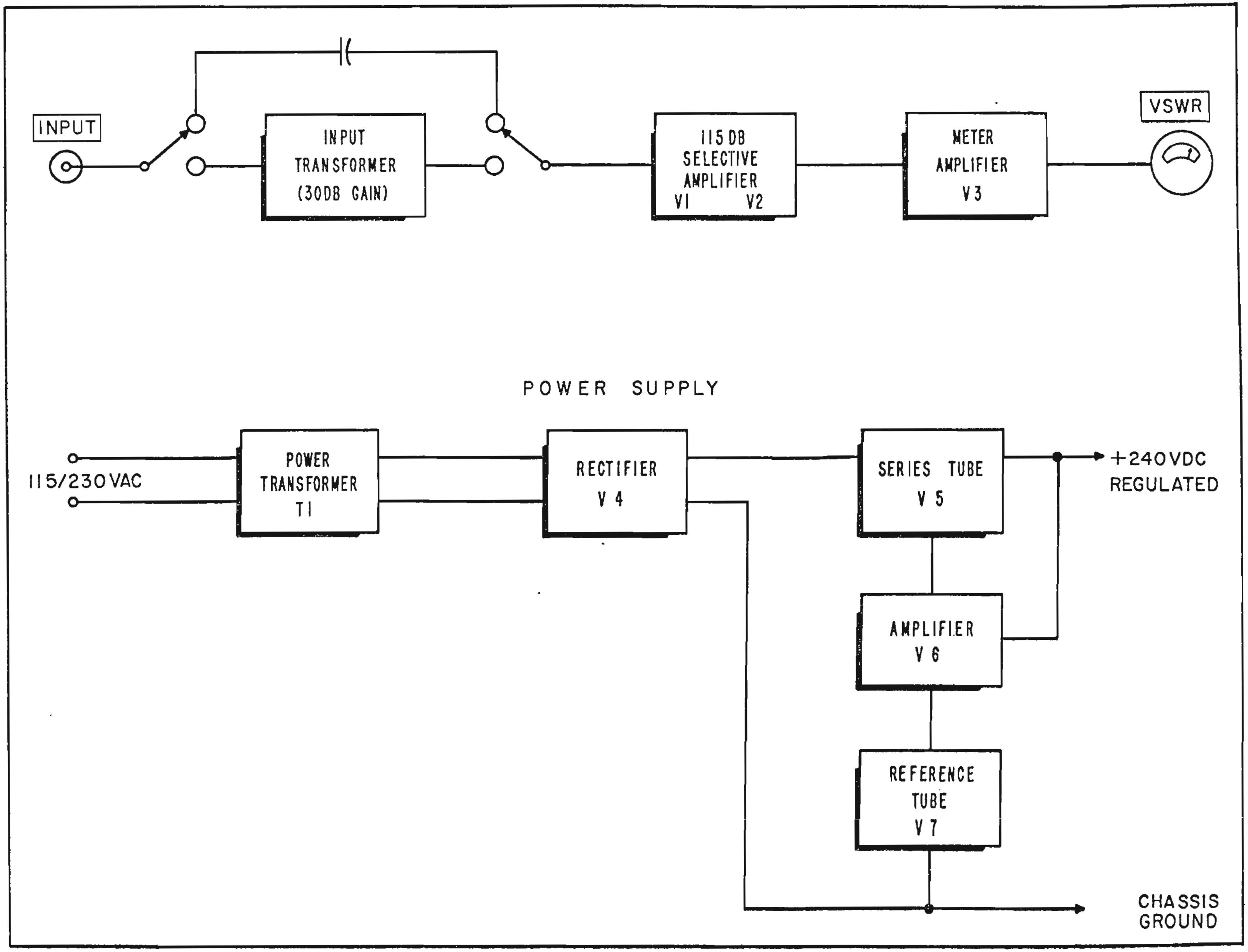


Figure 3-1. Model 415B Block Diagram

SECTION III
THEORY OF OPERATION

3-1 CIRCUIT DESCRIPTION

The Model 415B Standing Wave Indicator consists of a high-gain amplifier, a 1000 cycle resonant circuit, an indicating meter and an electronically regulated power supply. All tubes of the instrument are shown in the block diagram in Figure 3-1. Basically, operation of the instrument is as follows:

a. A four-stage, frequency selective amplifier amplifies the input signal a maximum of 115 decibels for application to the indicating circuit. The sensitivity of the selective amplifier is adjusted by two front panel controls, the SWR-DB RANGE selector and the GAIN control.

b. The 1000-cycle signal from the selective amplifier is fed to a feedback amplifier which in turn operates the vswr meter.

c. All circuits are powered from the electronically regulated +240-volt power supply.

3-2 FREQUENCY SELECTIVE AMPLIFIER

The frequency selective amplifier consists of 31:1 step-up input transformer T2, three resistance coupled hi-mu triode stages and a fourth stage which is plate tuned to 1000 cps. The amplifier without the input transformer provides a total of 115-db gain, while T2 provides an additional 30 db.

The input circuit to the selective amplifier is arranged to match various external signal sources such as a crystal diode, barretter or a relatively high-impedance device (bridge circuit, etc.). When the input circuit is switched to 200KΩ CRYSTAL the input jack connects through the SWR-DB RANGE switch S5 to the grid of the first amplifier tube. In the 200Ω CRYSTAL position the INPUT jack connects to the primary of T2 which provides a reflected load of 200 ohms to any device connected to the INPUT jack.

In the BOLO. position the input jack connects to the primary of the input transformer as above; except that the primary winding is now returned to a current source, R2 and R3, providing d-c operating bias through the transformer winding to any 200 ohm detector element connected to the input jack. The HIGH-LOW toggle switch shunts the current source with R1 so that two different values of bias (4.3 and 8.4 milliamperes) may be used. The bias current is fed also through a jack on the front panel so that an external milliammeter may be used to measure the bias current passing through the detector.

The SWR-DB RANGE switch, S5, consists of a three-section step attenuator which changes the gain of the amplifier in 20-db steps. However, to obtain square law meter calibration, the steps are calibrated 10 db on the front panel. The three sections of the attenuator are located in the grid circuits of the first three amplifier stages, V1A, B and V2A. The third section provides the first attenuation step, the second section the second attenuation step and the first section provides the remaining four attenuation steps. Selected precision resistors are used throughout the range switch. Because of the extremely high gain in this amplifier, the grounding of all parts in the first and second stages is very critical and is specially indicated on the schematic diagram. The heavy lines indicate common negative tie points which in turn are together and connected to chassis only a J1.

The output level from the amplifier is controlled by a two-section potentiometer (GAIN control R22A and B) in the grid circuit of the last amplifier stage. The potentiometers are connected in series, one providing approximately 25 db (12.5 db on the meter scale) of control for coarse adjustments, the other approximately 1.5 db (0.75 db on the meter scale) of control for fine adjustments.

Switch S4a between the second and third amplifier stages, when in the -5 db position, reduces the sensitivity of the amplifier to decrease the vswr meter indication by 5 db so that down-scale meter readings may be made upscale on the next lower range of the VSWR-DB RANGE switch.

To make the amplifier frequency selective, the plate circuit of the last stage is loaded with parallel resonant circuit, Z1, having an effective Q between 20 and 30. The tuned circuit allows a 1000-cps signal to pass unattenuated, while the decreased impedance at off resonant frequencies attenuates these frequencies considerably. The effective bandwidth is approximately 40 cycles at the half-power points.

3-3 METER CIRCUIT

The 1000-cps signal from the selective amplifier is applied to a two-stage feedback amplifier which operates crystal rectifiers CR1, CR2 and the indicating meter M1. To assure linear operation, negative feedback is used around both the amplifier and the rectifier circuit. A 0.46-volt rms signal is required at the first grid of V3 to obtain a full scale meter indication. The signal from the second plate of V3 is fed to crystal diode CR2 which allows current to flow through R37 and the meter during the negative half of the signal cycle. During the positive half cycle the current returns through CR1 and R36.

Front panel selector S4, when set to the EXPAND position, applied a d-c bucking voltage to the meter rectifiers so that a meter reading is forced off-scale, i.e., downward. The amplifier sensitivity must then be increased to obtain an upscale reading; which can then be read on the expanded meter scales.

3-4 POWER SUPPLY

The power supply consists of a power transformer with a single high-voltage winding feeding a full wave rectifier and electronic voltage regulator supplying +240 volts dc to all the circuits of the standing wave indicator. The voltage regulator circuit maintains constant output voltage with wide changes in load current and line voltage.

V5, V6 and V7 constitute the voltage regulator circuit. V7 is a constant-voltage tube which provides the reference bias for V6. V5 operates as a series tube, or variable resistor, controlled by the voltage at the grid of V6. If the regulated B+ at the cathode of V5 tends to increase, the grid voltage for V6 increases causing V6 to draw more current. This lowers the plate voltage of V6 and therefore the grid voltage of V5 and results in greater plate resistance for V5. The greater plate resistance causes a greater voltage drop across V5, compensating for the increased voltage at its cathode and resulting in a substantially constant voltage output.

If the regulated B+ voltage tends to decrease, the reverse of the above action occurs, also tending to maintain the cathode voltage substantially constant. Ripple in the output voltage is coupled to the grid of V6 by capacitor C12. Variations in the dc voltage are coupled to the grid of V6 through the voltage divider R44, R45 and R46. The bias for V6 and the level of the output voltage from V5 are determined by the setting of R45.

The heaters of amplifier tubes V1, V2 and V3 are operated from a positive biased heater winding to reduce hum pickup from the heaters of these tubes. The bias voltage is obtained from a 10 volt point on the voltage divider stick R44, R45, R46 and R48 in the power supply.

SECTION IV
MAINTENANCE

4-1 INTRODUCTION

This section contains instructions for adjustment and repair of the ⓗⓟModel 415B Standing Wave Indicator. The information in this section is as follows:

4-2 Trouble Shooting the 415B
4-3 Replacing Tubes
4-4 Replacing Crystal Diodes
4-5 Range Switch Repairs
4-6 Equipment Required for Test and Adjustment
4-7 Test and Adjustment Procedure (General)
4-8 Set Meter Mechanical Zero
4-9 Adjust Regulated Power Supply
4-10 Check Bolo. Current Jack
4-11 Check Sensitivity
4-12 Check Range Tracking
4-13 Check Noise Level
4-14 Calibrate Expanded Scale
4-15 Check -5 DB Switch

4-2 TROUBLE SHOOTING THE 415B

The Model 415B is basically a high-gain, tuned amplifier with a "relative" indicating voltmeter. The instrument has few critical circuits. The maximum sensitivity may decrease as the tubes weaken with age but the accuracy will not be affected. Only adjustment of the power supply and/or recalibration of the EXPANDED scale is necessary after tube replacement.

The accuracy of the meter calibration is largely determined by crystal diodes CR1 and CR2. The mechanical tracking of the meter movement and the linearity of the amplifier affect meter calibration accuracy to a lesser degree. The amplifier linearity does not normally change.

Any unstable condition can usually be traced to the power supply. The power supply can be quickly checked by measuring the dc output voltage and by noting the noise level indication on the 415B meter. An incorrect regulated voltage and/or a high residual noise level can be corrected by adjustment or by changing tubes. A high residual noise level that cannot be traced to the power supply can usually be corrected by replacing tube V1.

Individual stage gain measurements can be used to analyze an inoperative instrument. Gain can be checked by applying a small voltage (0.01 volt) from an audio oscillator to each stage in turn and measuring the stage output voltage. Set the audio oscillator to the same frequency as filter Z1 (usually 1000 cps). The approximate gain from each stage is as follows:

STAGE	DB GAIN (approx.)
Input Transformer	30
V1a	34
V1b	27.5
V2a	31
V2b	22
V3	***

*** Approximately a 0.46 volt rms signal at the input of V3 will give a full scale meter deflection.

4-3 REPLACING TUBES

The tubes in the Model 415B can be replaced without making any adjustments except for those in the regulated power supply. The EXPANDED scale calibration should be checked after replacement of V3. After changing tubes in the power supply, the output voltage of the power supply should be checked and adjusted. Control R45 should be adjusted to set the dc voltage between the chassis and the cathode of the series regulator tube.

When replacing V1, select a tube that minimizes the noise indication and if possible the microphonics also.

4-4 REPLACING CRYSTAL DIODES

Use diodes with a high front-to-back resistance ratio of several hundred to one or better when replacing diodes CR1 and CR2.

Adjustments are not necessary following replacement of CR1 and CR2 except that the calibration of the EXPANDED scale should be checked.

4-5 RANGE SWITCH REPAIRS

The precision resistors on the SWR-DB RANGE switch are selected and matched for accuracy during manufacture. Attempted replacement of individual resistors is usually not practical. Replacement of the entire switch assembly is recommended as a time-saving measure and guarantee of maintaining the original calibration accuracy.

If replacement of a single resistor is necessary, the resistor must be very carefully selected to maintain attenuator accuracy. Avoid excessive soldering heat or twisting or bending of these resistor leads during installation.

4-6 EQUIPMENT REQUIRED FOR TEST AND ADJUSTMENT

The following test equipment is used for testing and adjusting the Model 415B Standing Wave Indicator during manufacture. Any equivalent test instruments can also be used.

--- An ⓗⓟModel 200CD Wide Range Oscillator.

--- An ⓗⓟModel 400D, 400H, or 400L AC Vacuum Tube Voltmeter.

--- A pair of ⓗⓟModel 350B Attenuators.

--- An ⓗⓟModel 410B Vacuum Tube Voltmeter.

--- An adjustable line voltage source with meter.

--- An 0-10 dc milliammeter with a known internal resistance and connected to a three-circuit phone plug. Connect the positive terminal of the meter to the "ring" of a 1/4 inch diameter "tip-ring-sleeve" phone plug and the negative terminal to the "tip".

--- A BNC connector with a 1 watt composition resistor connected between the center contact and the outer shell. The resistor value plus the resistance of the 0-10 dc milliammeter must equal 200 ohms.

--- A pair of ⓗⓟModel AC-16A banana plug to banana plug shielded cables and an ⓗⓟModel AC-16B banana plug to BNC shielded cable.

4-7 TEST AND ADJUSTMENT PROCEDURE (General)

The procedures that follow are listed in a sequence that is most easily followed when all of the procedures are to be completed. In many cases, only one or two of the procedures will be needed and they can be done without completing all the other tests.

A ten to fifteen minute warm-up and a check of power supply output voltage is always recommended before making any other tests or adjustments.

The specifications for your ⓗⓟModel 415B Standing Wave Indicator are given in the front of this manual. The following test procedure contains extra checks to help you analyze a particular instrument. These extra checks and the data they contain cannot be considered as specifications.

NOTE

The Model 415B is calibrated for use with square law detectors such as crystals and barretters. The output voltage of these detectors varies directly with input power. The 415B compensates for this characteristic by being calibrated to indicate a 1 db change on the meter for a 2 db change in input voltage. Thus, each 10 db step on the 415B range switch represents a twenty db change in input voltage.

DURING ADJUSTMENT THE 415B INPUT SIGNAL IS CONTROLLED BY AN EXTERNAL ATTENUATOR CALIBRATED IN DB. THE INDICATION ON THE 415B WILL CHANGE ONE DECIBEL FOR EACH TWO DECIBELS CHANGE IN THE EXTERNAL ATTENUATOR SETTING.

4-8 SET METER MECHANICAL ZERO

Turn the 415B ON long enough for the meter movement to reach the ambient temperature within the cabinet. Turn the instrument OFF and set the mechanical zero while the meter is still warm.

Rotate the meter mechanical zero adjusting screw clockwise until the meter pointer is traveling to the left toward 1.3 on the EXPANDED VSWR scale and stop at 1.3. If you overshoot, continue rotating the adjustment screw clockwise and again approach from the high side of the scale. The adjustment screw should not be turned counterclockwise during any part of this adjustment.

4-9 ADJUST REGULATED POWER SUPPLY

Connect the 410B VTVM between cathode (pin 3) of series regulator tube V5 and chassis ground. Adjust control R45 for a voltmeter reading of 245 volts dc with the line voltage set to 115 volts. As the line voltage is varied between 103 and 127 volts, the reading on the voltmeter will normally not change by more than ±1%.

4-10 CHECK BOLO. CURRENT JACK

Insert the phone plug from the 0-10 dc milliammeter into the BOLO. CURRENT jack. Attach the BNC connector with resistor to the INPUT. The milliammeter connections and the resistor value are given in paragraph 4-6.

Set the input selector switch to BOLO. The milliammeter will usually indicate 8. 4 ±0. 4 milliamperes with the bias current switch in the HIGH position or 4. 3 ±0. 3 milliamperes with the switch in the LOW position.

If the currents are incorrect, check resistors R1, R2, and R3 as well as the power supply output voltage.

NOTE

Several precautions must be used if you wish accurate results when using the Figure 4-1 test set-up. At least 20 db of attenuation should be inserted in the attenuator set at all times. The maximum attenuation inserted by either attenuator should not be over 80 db. The Model 415B chassis connection through the third wire in the NEMA-type power cord should be disabled by using a three-prong to two-prong polarized adapter. The only ground connection to the 415B must be through the shielded cable from the attenuator set.

4-11 CHECK SENSITIVITY

Connect your test equipment as shown in Figure 4-1. The ac vtvm should be connected to the output of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to CRYSTAL 200 Ω and the meter scale switch to the NORMAL position.

Tune the audio oscillator to the Model 415B filter frequency as indicated by maximum deflection of the 415B meter. Adjust the audio oscillator output to obtain a full scale indication on the 415B. The indication on the ac vtvm should be 0. 1 volt or less.

The basic sensitivity of the Model 415B can be obtained by dividing the meter indication by 1, 000, 000. Each position of the 415B range switch multiplies the sensitivity by 10 or by 1, 000, 000 when you switch directly from the 0 DB to the 60 DB switch position.

If the basic sensitivity is found to be low, try several replacement tubes for V1, V2 and/or V3.

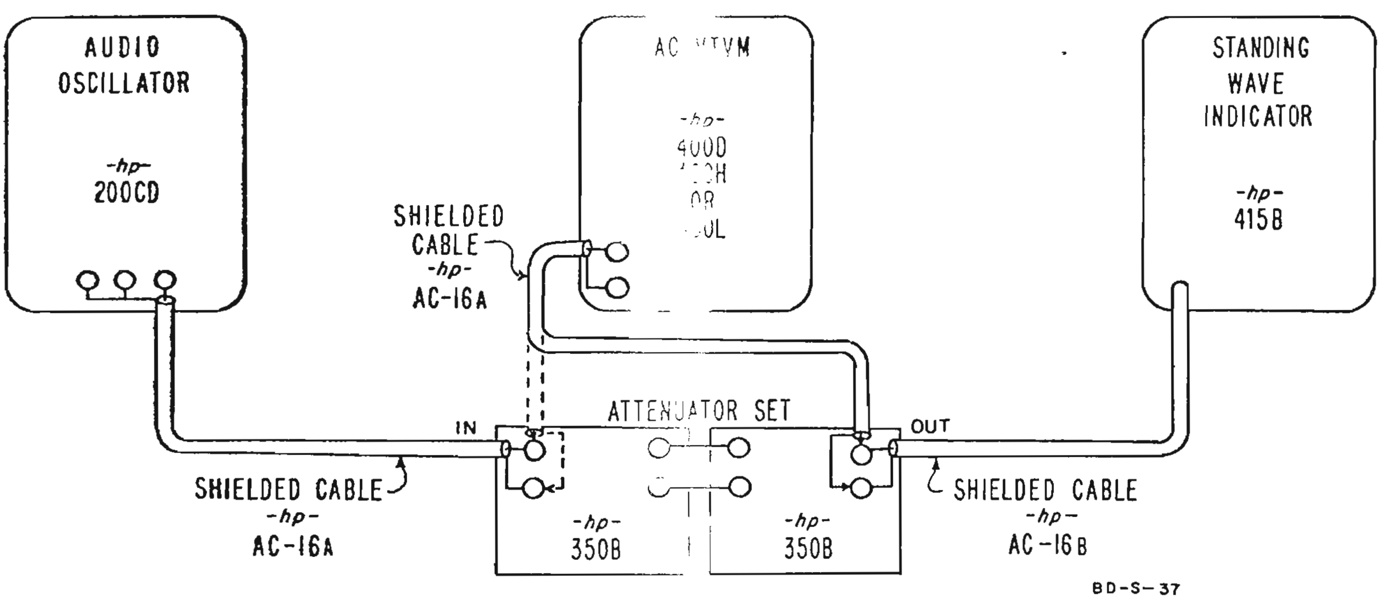


Figure 4-1. Instrument Connections for 415B Test and Adjustment

4-12 CHECK RANGE TRACKING

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the input of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to CRYSTAL 200 Ω and the meter scale switch to NORMAL.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Adjust the audio oscillator output for a full scale indication of "0" on the db scale. Note the indication on the ac vtvm and adjust the output of the audio oscillator to keep this reading constant.

Add 20 db attenuation in the attenuator set and rotate the 415B RANGE switch to 10 DB. The 415B meter should again indicate 0 db ±0.1 db.

Repeat this procedure for each step of the 415B RANGE switch. The 415B meter should indicate within ±0.2 db of the full scale 0 db mark on all six ranges. Adjacent ranges should read within ±0.1 db of each other.

4-13 CHECK NOISE LEVEL

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the output of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to CRYSTAL 200 Ω and the meter scale switch to NORMAL.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Adjust the audio oscillator output to obtain an indication of 0.03 volts on the ac vtvm. Note the indication on any convenient scale of the 415B. This indication will be used as a "reference".

Disconnect the ac vtvm and the audio oscillator. Set both 350B attenuators for 110 db attenuation. This is the only exception to the precaution given in the NOTE for Figure 4-1. Switch the 415B RANGE switch to 60 DB.

The indication on the 415B should be less than (to the left of) the "reference" indication noted above.

4-14 CALIBRATE EXPANDED SCALE

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the input of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to CRYSTAL 200 Ω and the meter scale switch to EXPAND.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Check that the attenuator set is introducing at least 20 db of attenuation and adjust the output of the audio oscillator to provide a full scale indication.

Attenuate the signal 4 db with the attenuator set. The 415B should now indicate 2 DB on the EXPANDED DB scale. If not, repeat the following procedure until a 4 db attenuation drops the meter indication from full scale to exactly the 2 db mark: ---Note the meter deviation from the 2 db mark and adjust R33 to get an equal error on the other side of the 2 db mark. Readjust attenuator set and signal for a full scale deflection, then attenuate signal 4 db. Repeat until no additional adjustment is necessary.

4-15 CHECK -5 DB SWITCH

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the input of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to any convenient position. Set the input switch to CRYSTAL 200 Ω and the meter scale switch to NORMAL.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Check that the attenuator set is introducing at least 20 db of attenuation and adjust the output of the audio oscillator to provide a "full scale" indication.

Attenuate the input signal 10 db on the attenuator set and switch the meter scale switch to the -5 DB position. The 415B indication should remain at the "full scale" point.

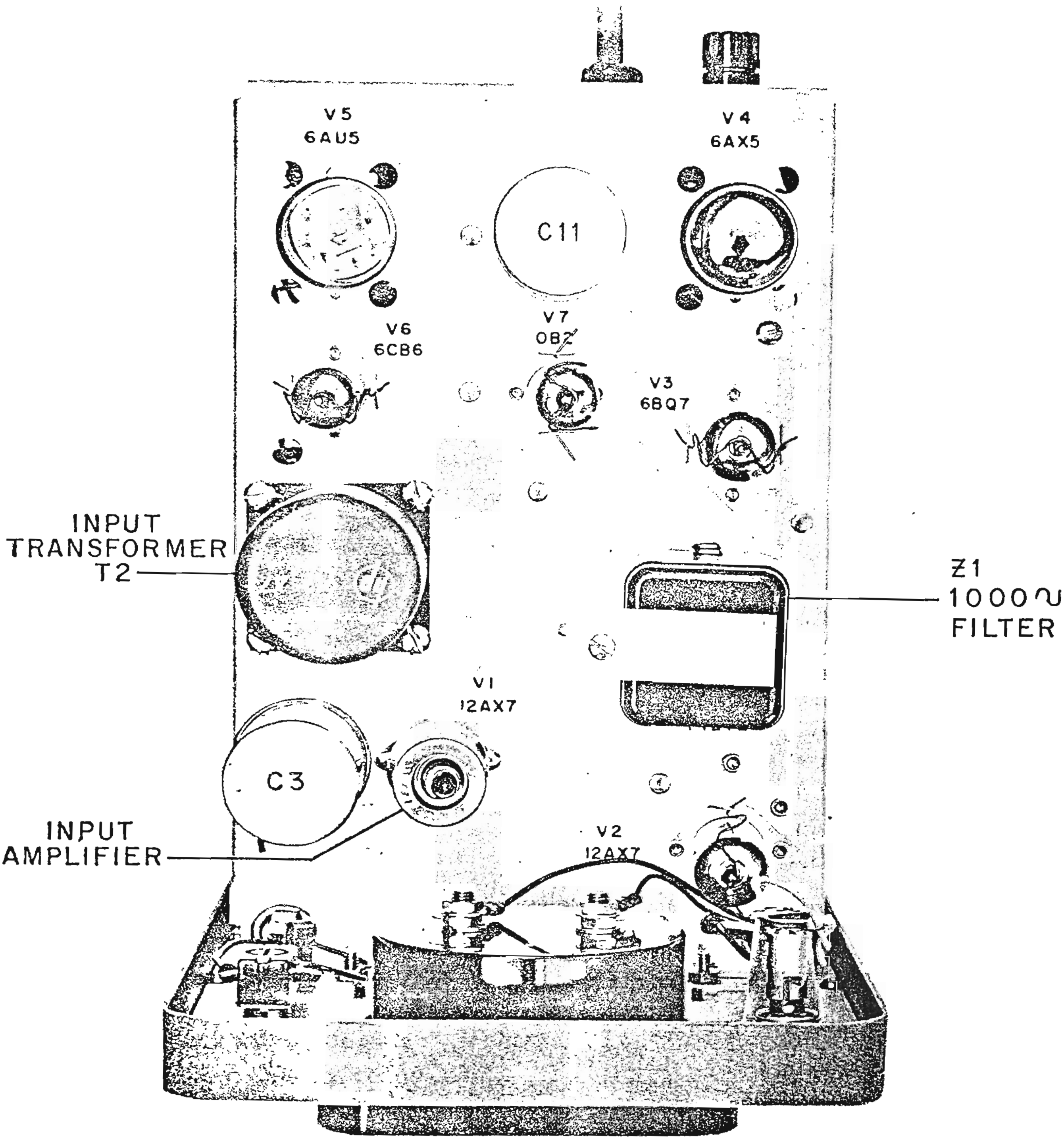


Figure 4-2. Model 415B Top View

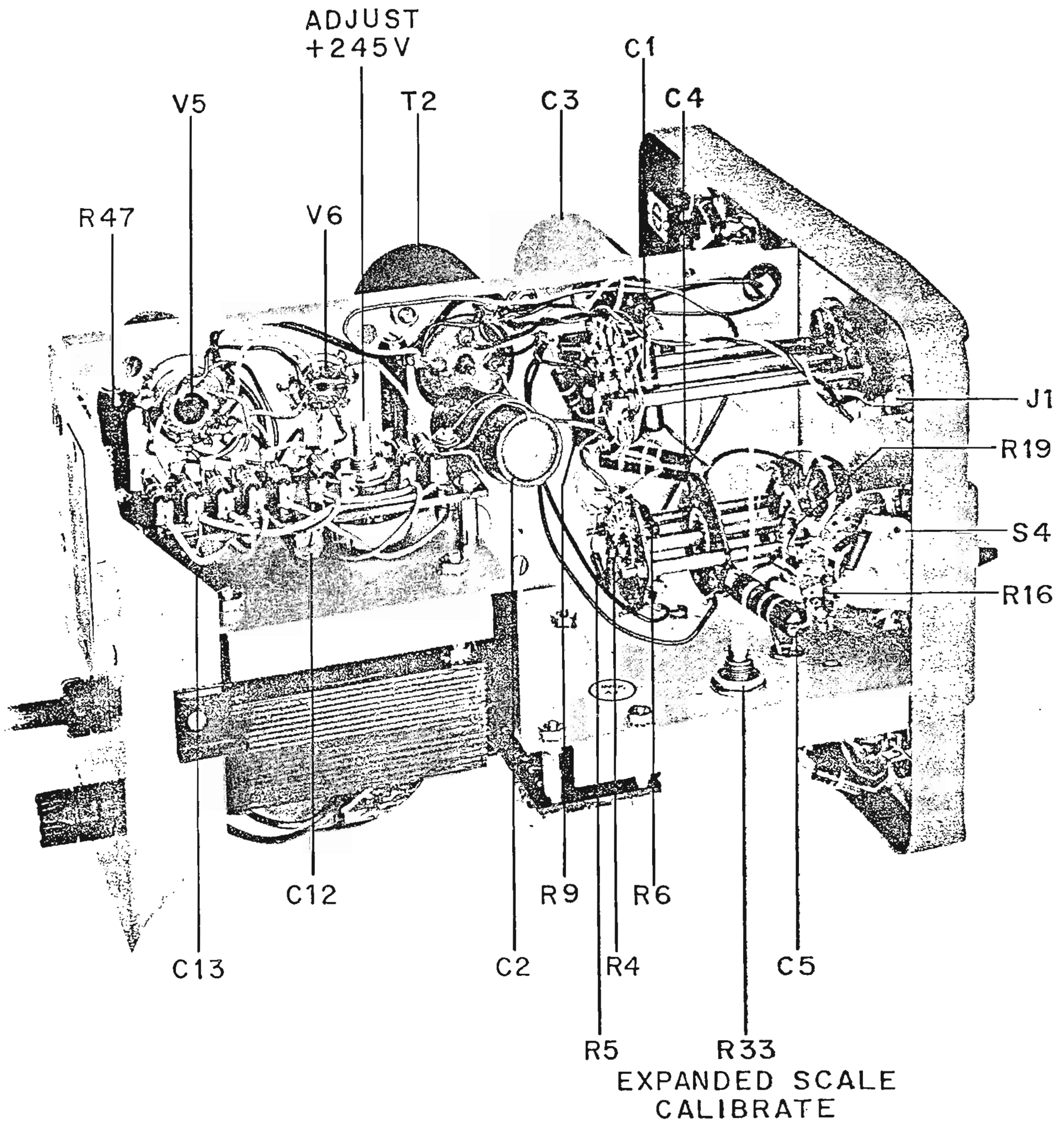


Figure 4-3. Model 415B Bottom View

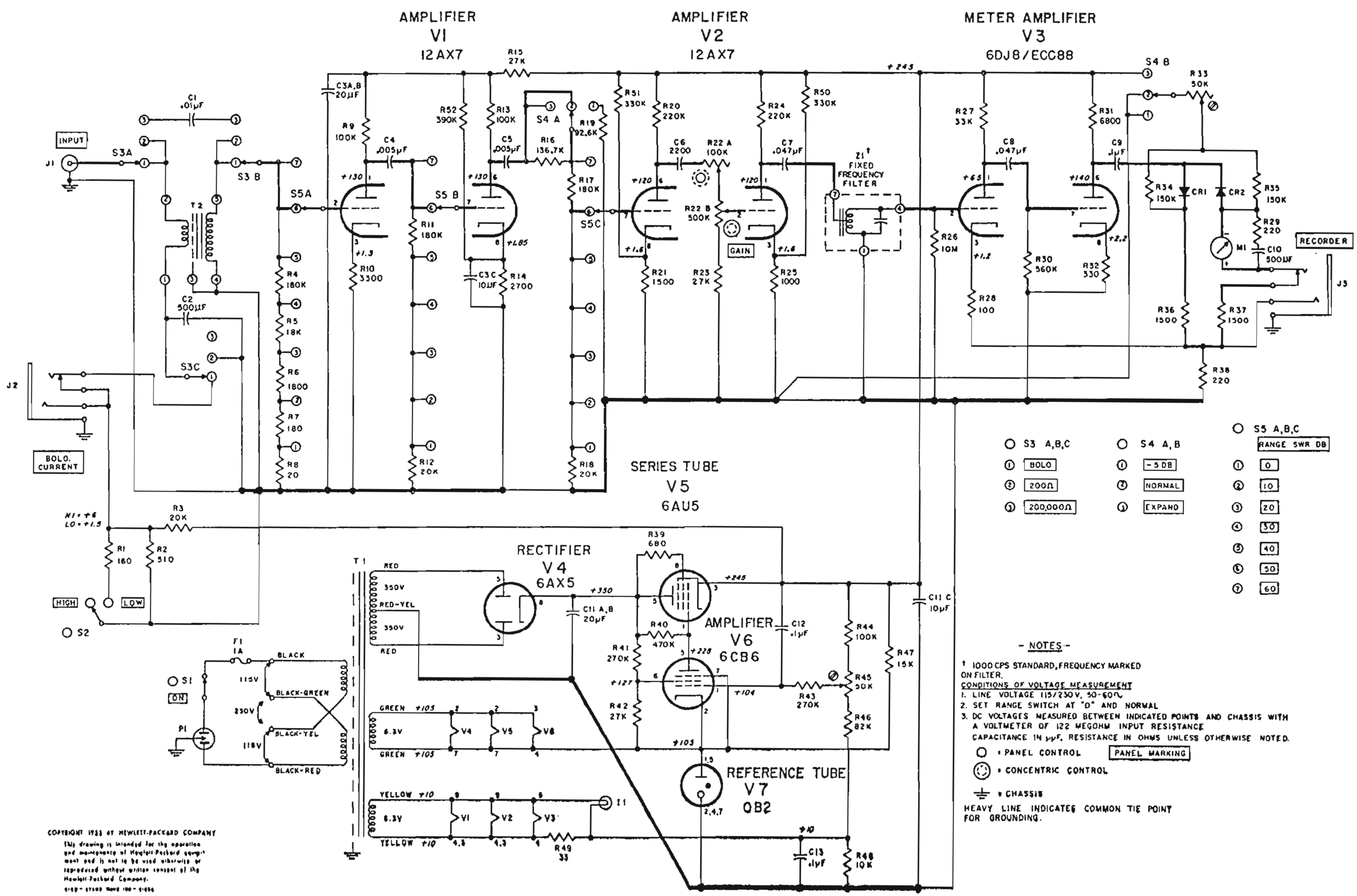


Figure 4-5. Model 415B Standing Wave Indicator

SECTION V
TABLE OF REPLACEABLE PARTS

NOTE

Any changes in the Table of Replaceable Parts will be listed on a Production Change sheet at the front of this manual.

When ordering parts from the factory always include the following information:

Instrument Model Number
Serial Number
hp Stock Number of Part
Description of Part

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION, MFR. * & MFR. DESIGNATION		Ⓗ STOCK NO.	#			
C1	Capacitor: fixed, paper, .01 μf ±10%, 600 vdcw	CC*	16-11	1			
C2	Capacitor: fixed, electrolytic, 500 μf, 15 vdcw	X*	18-5	2			
C3 A, B, C	Capacitor: fixed, electrolytic, 3 sections, 10 μf/sect., 450 vdcw	X*	18-31	2			
C4, 5	Capacitor: fixed, paper, .0047 μf ±10%, 600 vdcw	CC*	16-25	2			
C6	Capacitor: fixed, paper, .0022 μf ±10%, 600 vdcw	CC*	16-22	1			
C7, 8	Capacitor: fixed, paper, .047 μf ±10%, 600 vdcw	CC*	16-15	2			
C9	Capacitor: fixed, paper, 0.1 μf ±10%, 400 vdcw	CC*	16-35	3			
C10	Same as C2						
C11 A, B, C	Same as C3, A, B, C						
C12, 13	Same as C9						
CR1, 2	Rectifier, crystal: germanium diode	BU*	212-G11A	2			
F1	Fuse, cartridge: 1 amp, 115 V	E*	211-18	1			
	Fuse, cartridge: 1/2 amp, 230 V	E*	211-20	1			
I1	Lamp, incandescent: 6-8V, .15 amp, #47	N*	211-47	1			
J1	Connector, receptacle: 52 ohms impedance (cabinet model)	LL*	125-UG-1094/U	1			
	Connector, BNC type: (rack model)	LL*	125-9	1			
J2, 3	Jack, telephone: for 3 conductor plug	KK*	124-10	2			
M1	Meter: dc milliammeter	BF*	112-60	1			
P1	Power cord	Elec. Cords Co.	812-56	1			

* See "List of Manufacturers Code Letters For Replaceable Parts Table".
\# Total quantity used in the instrument.

TABLE OF REPLACEABLE PARTS

CIRCUIT REF.	DESCRIPTION, MFR. * & MFR. DESIGNATION		ⓗⓟ STOCK NO.	#			
R34, 35	Resistor: fixed, composition, 150, 000 ohms ±10%, 1 W	B*	24-150K	2			
R36, 37	Same as R21						
R38	Same as R29						
R39	Resistor: fixed, composition, 680 ohms ±10%, 1 W	B*	24-680	1			
R40	Resistor: fixed, composition, 470, 000 ohms ±10%, 1 W	B*	24-470K	1			
R41	Resistor: fixed, composition, 270, 000 ohms ±10%, 1 W	B*	24-270K	2			
R42	Same as R15						
R43	Same as R41						
R44	Same as R13						
R45	Same as R33						
R46	Resistor: fixed, composition, 82, 000 ohms ±10%, 1 W	B*	24-82K	1			
R47	Resistor: fixed, wirewound, 15, 000 ohms ±10%, 10 W	S*	26-25	1			
R48	Same as R31						
R49	Resistor: fixed, composition, 33 ohms ±10%, 1 W	B*	24-33	1			
R50, 51	Resistor: fixed, composition, 330, 000 ohms ±10%, 1 W	B*	24-330K	2			
R52	Resistor: fixed, composition, 390, 000 ohms ±10%, 1 W	B*	24-390K	1			
S1, 2	Switch, toggle: SPST	D*	310-11	2			

* See "List of Manufacturers Code Letters For Replaceable Parts Table".
# Total quantity used in the instrument.

LIST OF CODE LETTERS USED IN TABLE OF REPLACEABLE PARTS TO DESIGNATE THE MANUFACTURERS

CODE LETTER	MANUFACTURER	ADDRESS
A	Aerovox Corp.	New Bedford, Mass.
B	Allen-Bradley Co.	Milwaukee 4, Wis.
C	Amperite Co.	New York, N. Y.
D	Arrow, Hart & Hegeman	Hartford, Conn.
E	Bussman Manufacturing Co.	St. Louis, Mo.
F	Carborundum Co.	Niagara Falls, N. Y.
G	Centralab	Milwaukee 1, Wis.
H	Cinch-Jones Mfg. Co.	Chicago 24, Ill.
HP	Hewlett-Packard Co.	Palo Alto, Calif.
I	Clarostat Mfg. Co.	Dover, N. H.
J	Cornell Dubilier Elec. Co.	South Plainfield, N. J.
K	Hi-Q Division of Aerovox	Olean, N. Y.
L	Erie Resistor Corp.	Erie 6, Pa.
M	Fed. Telephone & Radio Corp.	Clifton, N. J.
N	General Electric Co.	Schenectady 5, N. Y.
O	General Electric Supply Corp.	San Francisco, Calif.
P	Girard-Hopkins	Oakland, Calif.
Q	Industrial Products Co.	Danbury, Conn.
R	International Resistance Co.	Philadelphia 8, Pa.
S	Lectrohm Inc.	Chicago 20, Ill.
T	Littlefuse Inc.	Des Plaines, Ill.
U	Maguire Industries Inc.	Greenwich, Conn.
V	Micamold Radio Corp.	Brooklyn 37, N. Y.
W	Oak Manufacturing Co.	Chicago 10, Ill.
X	P. R. Mallory Co., Inc.	Indianapolis, Ind.
Y	Radio Corp. of America	Harrison, N. J.
Z	Sangamo Electric Co.	Marion, Ill.
AA	Sarkes Tarzian	Bloomington, Ind.
BB	Signal Indicator Co.	Brooklyn 37, N. Y.
CC	Sprague Electric Co.	North Adams, Mass.
DD	Stackpole Carbon Co.	St. Marys, Pa.
EE	Sylvania Electric Products Co.	Warren, Pa.
FF	Western Electric Co.	New York 5, N. Y.
GG	Wilkor Products, Inc.	Cleveland, Ohio
HH	Amphenol	Chicago 50, Ill.
II	Dial Light Co. of America	Brooklyn 37, N. Y.
JJ	Leecraft Manufacturing Co.	New York, N. Y.
KK	Switchcraft, Inc.	Chicago 22, Ill.
LL	Gremar Manufacturing Co.	Wakefield, Mass.
MM	Carad Corp.	Redwood City, Calif.
NN	Electra Manufacturing Co.	Kansas City, Mo.
OO	Acro Manufacturing Co.	Columbus 16, Ohio
PP	Alliance Manufacturing Co.	Alliance, Ohio
QQ	Arco Electronics, Inc.	New York 13, N. Y.
RR	Astron Corp.	East Newark, N. J.
SS	Axel Brothers Inc.	Long Island City, N. Y.
TT	Belden Manufacturing Co.	Chicago 44, Ill.
UU	Bird Electronics Corp.	Cleveland 14, Ohio
VV	Barber Colman Co.	Rockford, Ill.
WW	Bud Radio Inc.	Cleveland 3, Ohio
XX	Allen D. Cardwell Mfg. Co.	Plainville, Conn.
YY	Cinema Engineering Co.	Burbank, Calif.
ZZ	Any brand tube meeting RETMA standards.	
AB	Corning Glass Works	Corning, N. Y.
AC	Dale Products, Inc.	Columbus, Neb.
AD	The Drake Mfg. Co.	Chicago 22, Ill.
AE	Elco Corp.	Philadelphia 24, Pa.
AF	Hugh H. Eby Co.	Philadelphia 44, Pa.
AG	Thomas A. Edison, Inc.	West Orange, N. J.
AH	Fansteel Metallurgical Corp.	North Chicago, Ill.
AI	General Ceramics & Steatite Corp.	Keasbey, N. J.
AJ	The Gudeman Co.	Sunnyvale, Calif.
AK	Hammerlund Mfg. Co., Inc.	New York 1, N. Y.
AL	Industrial Condenser Corp.	Chicago 18, Ill.
AM	Insuline Corp. of America	Manchester, N. H.
AN	Jennings Radio Mfg. Corp.	San Jose, Calif.
AO	E. F. Johnson Co.	Waseca, Minn.
AP	Lenz Electric Mfg. Co.	Chicago 47, Ill.
AQ	Micro-Switch	Freeport, Ill.
AR	Mechanical Industries Prod. Co.	Akron 8, Ohio
AS	Model Eng. & Mfg., Inc.	Huntington, Ind.
AT	The Muter Co.	Chicago 5, Ill.
AU	Ohmite Mfg. Co.	Skokie, Ill.
AV	Resistance Products Co.	Harrisburg, Pa.
AW	Radio Condenser Co.	Camden 3, N. J.
AX	Shallcross Manufacturing Co.	Collingdale, Pa.
AY	Solar Manufacturing Co.	Los Angeles 58, Calif.
AZ	Sealectro Corp.	New Rochelle, N. Y.
BA	Spencer Thermostat	Attleboro, Mass.
BC	Stevens Manufacturing Co.	Mansfield, Ohio
BD	Torrington Manufacturing Co.	Van Nuys, Calif.
BE	Vector Electronic Co.	Los Angeles 65, Calif.
BF	Weston Electrical Inst. Corp.	Newark 5, N. J.
BG	Advance Electric & Relay Co.	Burbank, Calif.
BH	E. I. DuPont	San Francisco, Calif.
BI	Electronics Tube Corp.	Philadelphia 18, Pa.
BJ	Aircraft Radio Corp.	Boonton, N. J.
BK	Allied Control Co., Inc.	New York 21, N. Y.
BL	Augat Brothers, Inc.	Attleboro, Mass.
BM	Carter Radio Division	Chicago, Ill.
BN	CBS Hytron Radio & Electric	Danvers, Mass.
BO	Chicago Telephone Supply	Elkhart, Ind.
BP	Henry L. Crowley Co., Inc.	West Orange, N. J.
BQ	Curtiss-Wright Corp.	Carlstadt, N. J.
BR	Allen B. DuMont Labs	Clifton, N. J.
BS	Excel Transformer Co.	Oakland, Calif.
BT	General Radio Co.	Cambridge 39, Mass.
BU	Hughes Aircraft Co.	Culver City, Calif.
BV	International Rectifier Corp.	El Segundo, Calif.
BW	James Knights Co.	Sandwich, Ill.
BX	Mueller Electric Co.	Cleveland, Ohio
BY	Precision Thermometer & Inst. Co.	Philadelphia 30, Pa.
BZ	Radio Essentials Inc.	Mt. Vernon, N. Y.
CA	Raytheon Manufacturing Co.	Newton, Mass.
CB	Tung-Sol Lamp Works, Inc.	Newark 4, N. J.
CD	Varian Associates	Palo Alto, Calif.
CE	Victory Engineering Corp.	Union, N. J.
CF	Weckesser Co.	Chicago 30, Ill.
CG	Wilco Corporation	Indianapolis, Ind.
CH	Winchester Electronics, Inc.	Santa Monica, Calif.
CI	Malco Tool & Die	Los Angeles 42, Calif.
CJ	Oxford Electric Corp.	Chicago 15, Ill.
CK	Camloc-Fastener Corp.	Paramus, N. J.
CL	George K. Garrett	Philadelphia 34, Pa.
CM	Union Switch & Signal	Swissvale, Pa.
CN	Radio Receptor	New York 11, N. Y.
CO	Automatic & Precision Mfg. Co.	Yonkers, N. Y.
CP	Bassick Co.	Bridgeport 2, Conn.
CQ	Birnbach Radio Co.	New York 13, N. Y.
CR	Fischer Specialties	Cincinnati 6, Ohio
CS	Telefunken (c/o MVM, Inc.)	New York, N. Y.
CT	Potter-Brumfield Co.	Princeton, Ind.
CU	Cannon Electric Co.	Los Angeles, Calif.
CV	Dynac, Inc.	Palo Alto, Calif.
CW	Good-All Electric Mfg. Co.	Ogallala, Nebr.