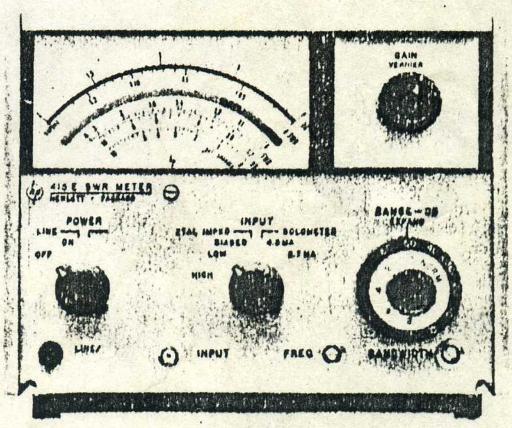
OPERATING AND SERVICE MANUAL

SWR METER
415E



HEWLETT hp PACKARD

SECTION III
OPERATING INSTRUCTIONS

3-1. INTRODUCTION.

3-2. This section contains information and procedures for operation of the Model 415E (from either AC or battery power source) in making swr and attenuation measurements. Also included is information on slotted line techniques, instruction in the use of a Smith Chart for plotting load impedance, and discussion of Model 415E noise performance with various source impedances and noise effect on meter indication.

3-3. FRONT AND REAR PANEL FIXTURES.

3-4. Figures 3-1 and 3-2 identify by number the front and rear panel fixtures of the Model 415E. The descriptions in Table 3-1 are keyed by number (1-12 for front, 13-18 for rear) to the figures. Further information regarding the various settings and uses of the controls, indicators, connections, and adjustments is included in the procedures of this section. Information on battery is found in Paragraph 3-6.

3-5. GENERAL OPERATING AND MEASUREMENT CONSIDERATIONS.

3-6. BATTERY OPERATION.

3-7. The Model 415E may be operated from a battery instead of the 115 or 230 volt AC supply (see Paragraph 2-13). Battery operation requires some slightly different procedures to prolong battery life and to ensure proper results. The rechargeable nickel - cadmium battery is factory installed if ordered as Option 01 (see Paragraph 1-7). The same battery may be ordered and installed later. To obtain this, order hp Stock Number 00415-606, Rechargeable Battery Installation Kit.

3-8. INITIAL BATTERY USE. When the Model 415E is to be battery operated for the first time, perform the following steps:

a. Switch the Model 415E POWER switch to BATTERY/TEST position and note meter pointer indication: A meter pointer indication in the "BAT. CHARGED" area indicates the internally battery properly charged and ready for use; A meter pointer indication to the left of the "BAT. CHARGED" area means that the battery must be charged as described below.

b. Connect the Model 415E to AC power source. Set POWER switch to BATTERY/CHARGE and charge the battery for a minimum of 16 hours or overnight.

c. After at least 16 hours of recharge time, switch POWER switch to BATTERY/TEST position and check battery charge. If the battery charge indication is still unsatisfactory, see Paragraph 5-35.

3-9. OPTIMUM BATTERY USAGE. It is recommended that the Model 415E be operated by the battery for up to 8 hours, followed by 16 hours of recharge. If continuous battery operation is required for more than 8 hours, the recharge time should be double the operating time. Continuous battery operation is possible for up to 36 hours but this must be followed by a prolonged recharge period.

3-10. BATTERY STORAGE. Storage of the battery at or below room temperature is best. Extended storage at high temperatures will reduce the cell charge but not damage the battery if the storage temperature is less than 140°F. It is suggested that the battery be charged after removal from storage and before using the Model 415E for battery operation.

3-11. GROUNDLOOP CURRENTS.

3-12. The 415E SWR Meter audio amplifier has high sensitivity to low level signals. To reduce ground loop currents, the 415E grounds are isolated by a 46.4 ohm resistor. Ground loops occur when instruments are connected to 415E outputs and grounded through power cords or rack mountings. Ground loops can be minimized in the following ways:

a. Connect the 415E to instruments with floating inputs;

b. Connect the 415E to instruments with high input impedance; Connect only the signal wire between instrument and the 415E;

c. Operation at higher signal levels;

d. An Adapter on the power cord to float the instrument ground where not prohibited by safety regulations.

3-13. BANDWIDTH AND FREQUENCY SELECTION.

3-14. Two front panel adjustments are provided to optimize operation of the Model 415E tuned amplifier. The FREQ (frequency) control allows a total variation of 7% of the center tuned frequency. When more than one Model 415E is included in the same measurement setup, the variable tuned frequency is used to set all the instruments to the exact frequency modulating the source. The high sensitivity and narrow bandwidth of the amplifier make the Model 415E valuable as a meter-indicating null detector for audio frequency bridges. The BANDWIDTH adjustment varies the tuned filter bandwidth from 15 to 130 cps. A narrow bandwidth is best for low level signals as this improves the signal to noise ratio. A wide bandwidth would find more use in fast sweep rate measurements.

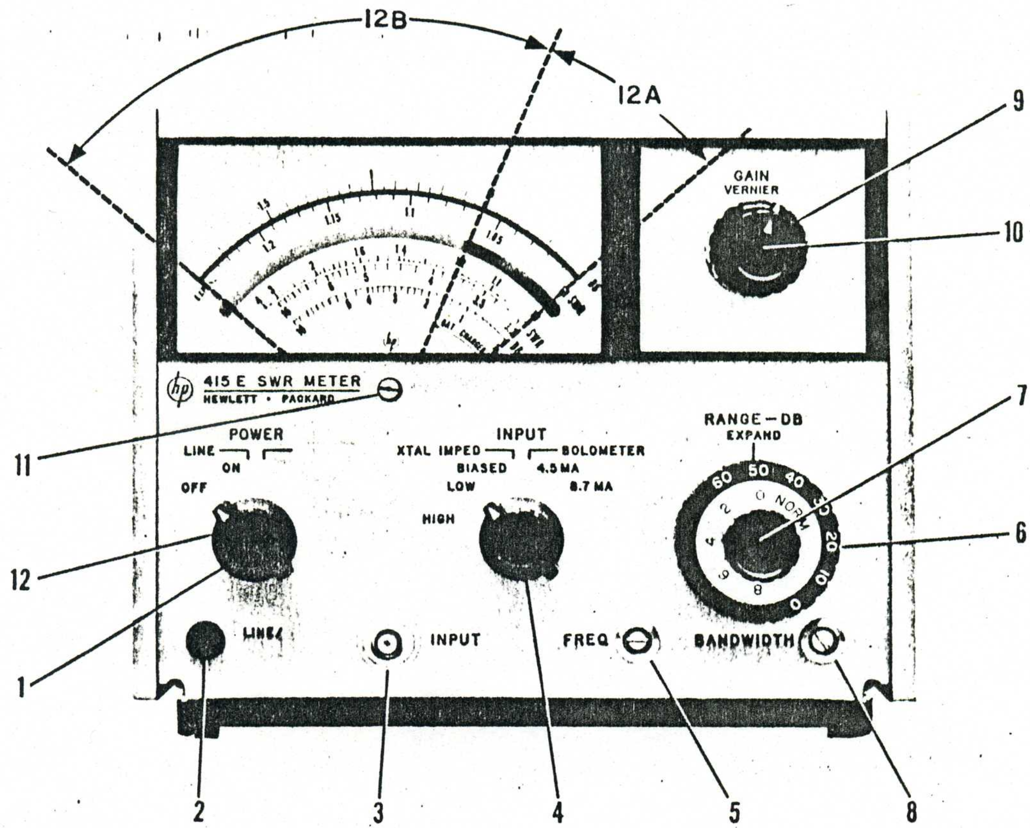


Figure 3-1. Front Panel Operating Controls and Connector

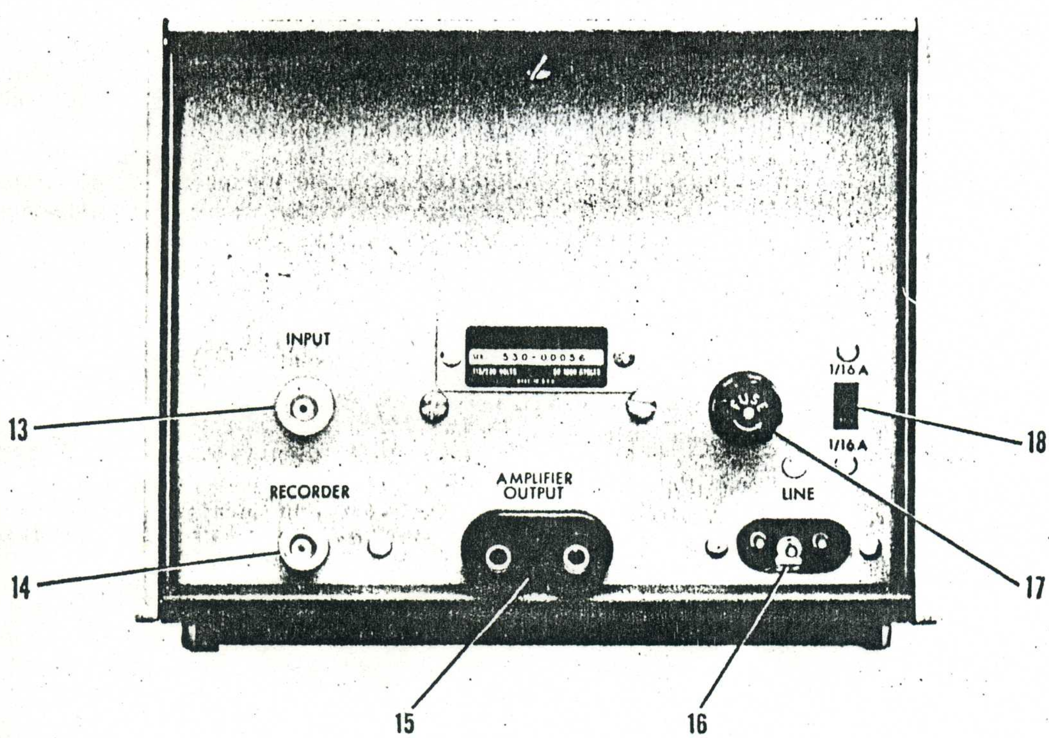


Figure 3-2. Rear Panel Operating Controls and Connectors

Table 3-1. Panel Descriptions

1. Selects desired 415E power source: BATTERY/CHARGE position allows internal battery recharge when power cord is connected to AC line.
2. Indicator lights when power switch is in LINE/ON or BATTERY/CHARGE position.
3. Female BNC INPUT connector.
4. Set input of Model 415E for use with a bolometer or crystal detector mount. See Paragraph 3-53.
5. Adjustment allows center frequency variation by 70 cps.
6. Attenuator adjusts gain in 10 db steps.
7. Allows full scale expansion of any 2.0 db portion of the 10-db scale.
8. Changes bandwidth from 15 to 130 cps.
9. Allows initial meter reference setting with a control range of at least 10-db.
10. Provides fine adjustment of GAIN control meter settings.
11. Mechanical zero adjustment allows exact setting of meter needle to 2.0 db calibration mark.
12. With POWER switch set to BATTERY/TEST, a meter needle indication within the "BATTERY CHARGE" area on the meter face (indicated by 12A) shows that internal battery is charged sufficiently for proper 415E operation; if needle indicator is to left (area 12B) of "BATTERY CHARGED" area, then battery is not charged sufficiently for proper instrument operation (option 01 - ONLY).
13. Additional input connector (wired in parallel with front panel connector); supplied as Option 02 for 415E only upon request.
14. DC output for recorder use (0 to 1 volt into open circuit or 1000 ohms).
15. AC output for use as tuned amplifier output.
16. Three-conductor AC power cord receptacle (NEMA-type).
17. Contains power line fuse.
18. Slide switch to allow 115- or 230-volt AC operation.

3-15. SWR MEASUREMENT EQUIPMENT AND TECHNIQUES.

3-16. EQUIPMENT.

3-17. A typical setup of equipment used in SWR measurements is shown in Figure 3-3. The signal source is usually square-wave modulated at 1000 cps since other modulating waveforms often cause undesirable frequency modulation of the source. Harmonics from the source sometimes cause trouble and can be eliminated with a low-pass filter.

3-18. The detector should be a square-law device (output voltage proportional to RF power input) such as a barretter or a crystal diode operated at low signal levels. The meter of the 415E is calibrated for square-law detectors. Crystal diodes are normally more sensitive than barretters but barretters are square-law over a wider dynamic range. Both types of detector normally maintain accurate square-law response up to at least full scale deflection with the RANGE-DB switch set to 30 position and coarse GAIN at maximum. (1 mv RMS sine wave or 2.2 mv peak-to-peak square wave causes full scale deflection on HIGH XTAL IMPED position. On other positions of INPUT switch, 0.15 mv RMS sine wave or 0.33 mv peak-to-peak square wave causes full scale deflection.) Above this level these detectors should be individually checked for departure from square-law behaviour or manufacturer's data should be consulted.

3-19. A short circuit termination is useful in establishing reference positions along the transmission line and in measuring transmission line wavelengths.

3-20. SLOTTED LINE PROBE PENETRATION.

3-21. A general rule in slotted line measurement is to use minimum probe penetration that still picks up adequate signal to measure. The probe couples to the

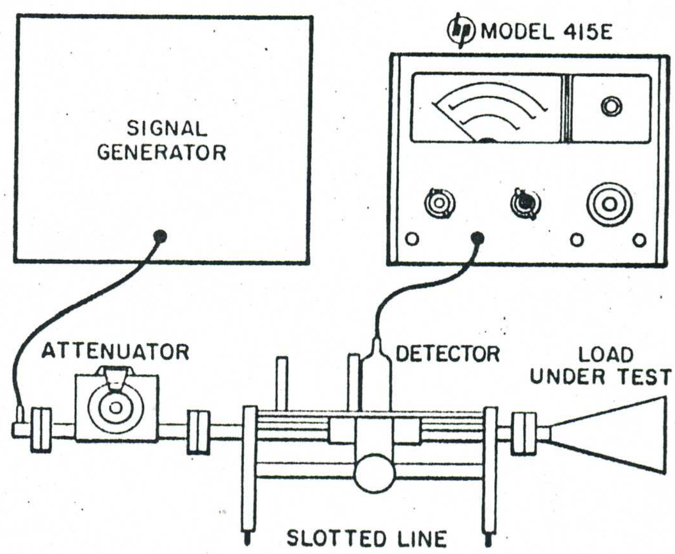
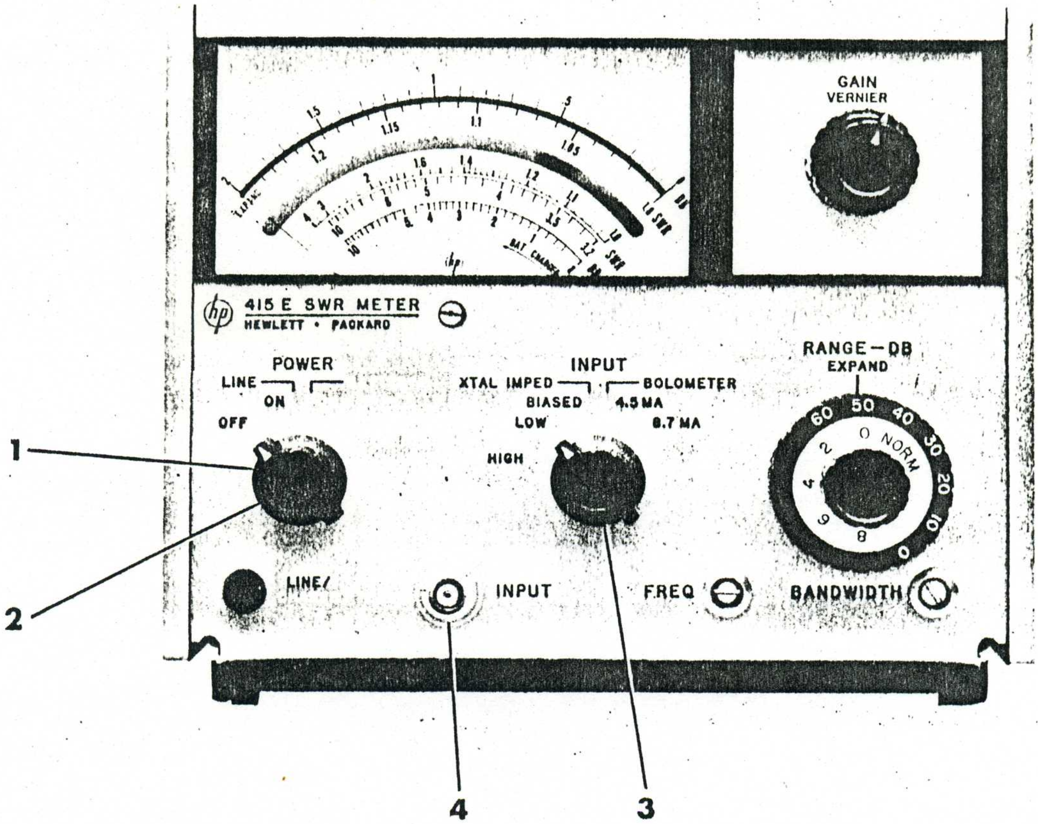


Figure 3-3. Typical SWR Measurement Setup



1. Set POWER switch to OFF. Meter pointer should rest at 2 on the 0-2 DB scale (if not refer to Paragraph 5-10).

2. Set POWER switch to LINE/ON (or BATTERY/ON).

Note

If set to BATTERY/ON refer to Paragraph 3-5 and check battery potential.

3. Set INPUT to desired input impedance. (Note see Paragraph 3-55.)

4. Connect audio source to INPUT (i.e., crystal detector, bolometer, audio oscillator, etc.).

5. Adjust modulation frequency (audio input signal) to approximately 1000 cps.

6. Adjust RANGE-DB, GAIN, and VERNIER controls and the amplitude of the input signal for a convenient meter reference near mid-scale.

7. Adjust FREQ control for maximum meter pointer deflection.

8. Adjust BANDWIDTH control: fully counterclockwise rotation is minimum bandwidth and fully clockwise rotation is maximum bandwidth.

Note

A narrow bandwidth is usually best for low level signals; 30 cps is convenient for most applications; and a wide bandwidth is usually best for fast sweep rate measurements.

Figure 3-4. General Turn-On Procedure

transmission line as a shunt admittance which increases (disturbing the transmission line more) as the probe penetrates farther. To find out whether a given probe penetration is too great or not, measure SWR, then change probe penetration and remeasure SWR. If the second reading is different, the probe is penetrating too far and loading the transmission line significantly.

3-22. PROCEDURE.

3-23. MODERATE SWR. The scales of the 415E are calibrated for reading standing wave ratio directly from the meter. Set the slotted line probe at a voltage maximum and adjust the gain of the 415E with the RANGE-DB, GAIN, and VERNIER controls (EXPAND switch to NORM) for full scale deflection (1.0 on the 1.0 to 4 SWR scale). Now move the probe toward a minimum. If the meter drops below 3.2, rotate the RANGE-DB switch one position clockwise and read on the 3.2 to 10 SWR scale. If the pointer drops below this scale, rotate RANGE-DB switch one more position clockwise and read on the 1.0 to 4 scale and multiply by 10. This pattern continues for still higher SWR readings.

3-24. The DB scales can be used for a standing wave ratio measurement by setting the 415E to full scale at a voltage maximum, then turning the RANGE-DB switch clockwise for an on scale reading at a voltage minimum and noting the difference in DB readings at the maximum and minimum. A DB reading is obtained by adding RANGE-DB switch setting and meter indication.

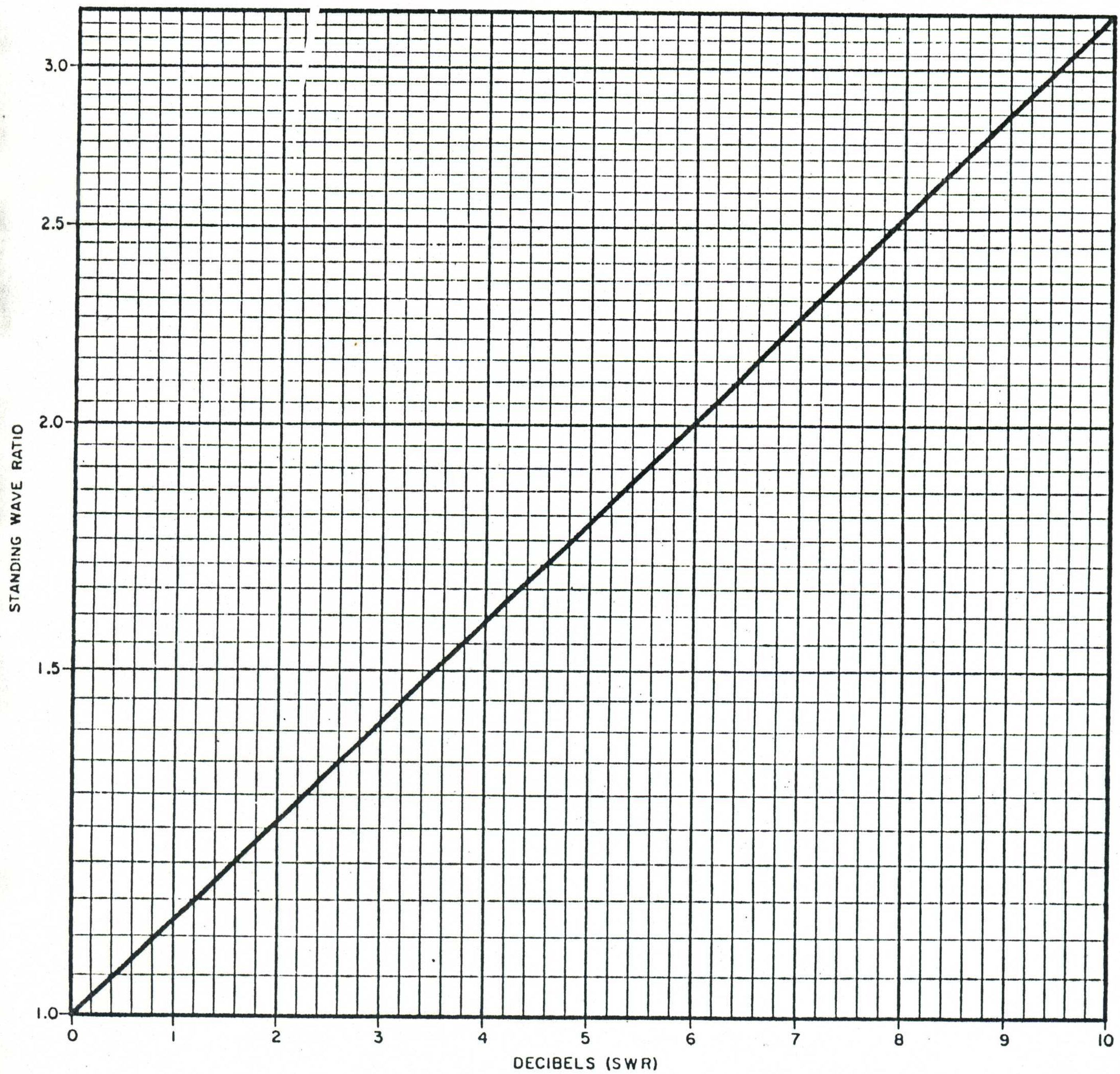


Figure 3-5. Expanded Section of Figure 3-6

3-25. LOW SWR. Standing wave ratio between 1.0 and 1.24 can be read quite accurately on the EXPAND scales of the meter when the EXPAND switch is set to any position other than NORM. que no sea normal.

3-26. MODERATE SWR, HIGH RESOLUTION. The EXPAND and -DB scale can be used together with the EXPAND switch to read any SWR with high resolution in DB. Figure 3-5 and 3-6 are used to convert DB to SWR. The reference level (full scale meter deflection at a voltage maximum) can be used with the EXPAND switch at NORM (since 0 db NORM and 0 db EXPAND correspond) but greater accuracy is obtained by setting the reference level with the EXPAND switch to 0.

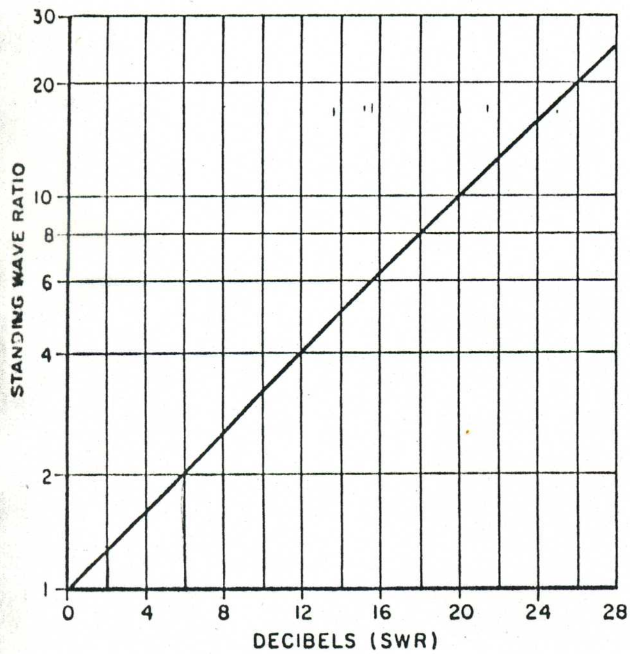


Figure 3-6. Converting Decibels to SWR

3-27. HIGH SWR. High standing wave ratios (greater than 30, or sometimes 10) present problems because of excessive probe penetration (to lift the minimum above the noise level) and departure of detector behaviour from square-law. Both problems are lessened or eliminated by measuring only the standing wave pattern near the voltage minimum, where probe loading effects are least disturbing.

3-28. TWICE-MINIMUM POWER METHOD. The basis for this method (and the TEN-TIMES-MINIMUM POWER METHOD) is the fact that for a high SWR, the standing wave pattern approximates a parabola in the vicinity of a voltage minimum. The slotted line carriage must have a good scale or dial indicator. Measure the distance (ΔX) between positions on the standing wave pattern where the voltage is 3 db above the voltage at the minimum. Also measure the transmission line wavelength λg (standing wave pattern minima are one-half wavelength apart and the sharp minima resulting from short-circuiting the transmission line are easy to locate accurately). Compute the SWR from the following formula:

$$SWR = 1/\pi \left(\lambda g / \Delta X\right).$$

3-29. TEN-TIMES-MINIMUM POWER METHOD. Another convenient "level above minimum method" to use for computing SWR is a level 10 db above minimum. The separation (ΔX) between these positions should be put in the following formula:

$$SWR = 3/\pi \left(\lambda g / \Delta X\right)$$

For standing wave ratios as low as 15 to 1, the accuracy of this method is within 1%.

3-30. SWR MEASUREMENT-SOURCES OF ERROR. Several possibilities have already been mentioned: excessive frequency modulation of source (smears out sharp, deep nulls of high SWR pattern), harmonics of signal frequency from source, departure of detector from square-law behaviour, and excessive probe penetration. Also, reflections in the transmission line between the slotted line and device being measured must be minimized.

3-31. ATTENUATION MEASUREMENT.

3-32. The 415E may be used for high resolution insertion loss measurements simply by inserting the device to be measured between signal source and detector and noting the change in DB indication on the 415E. A typical measurement is shown in Figure 3-7. The continuous coverage of the EXPAND scales allows any attenuation measurement to be made on the EXPAND scales. For accurate results, both the signal source and the detector should be well matched. Impedance match of source and detector can be improved, if necessary, with padding attenuators, isolators, or tuners.

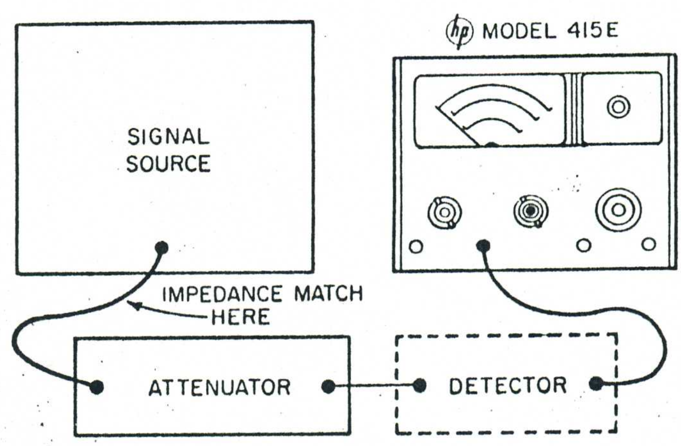


Figure 3-7. Attenuation Measurement Setup

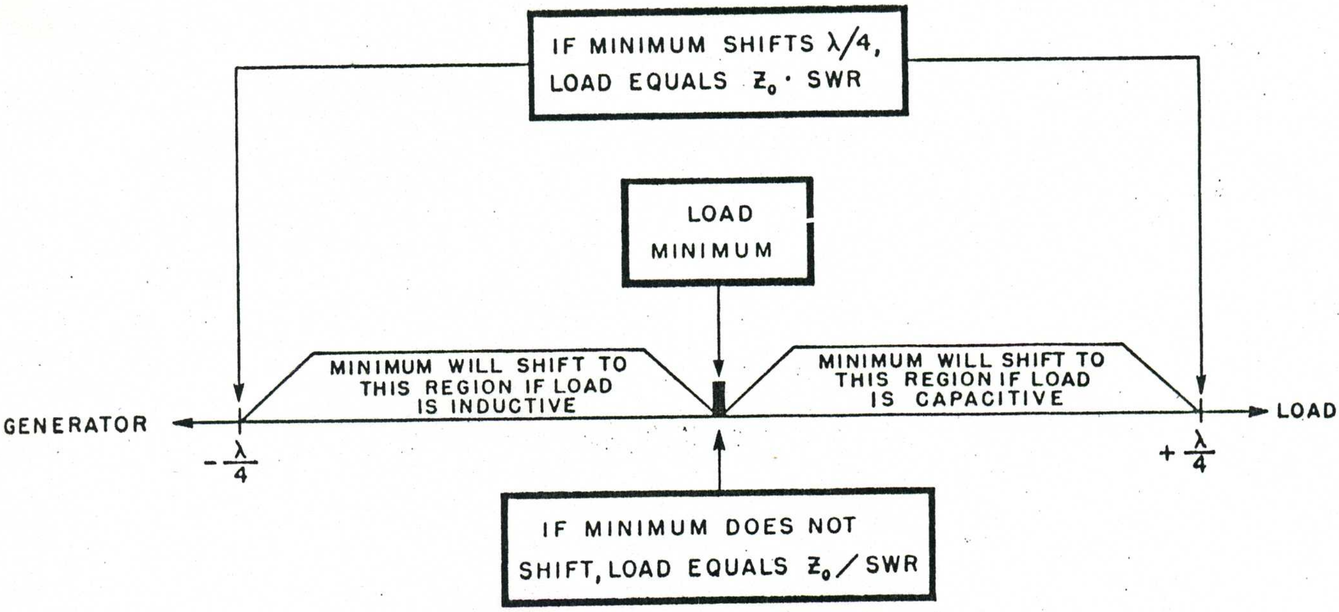


Figure 3-8. Impedance Measurement Rules Summary

3-32. LOAD IMPEDANCE MEASUREMENT.

3-33. GENERAL.

3-34. Slotted line techniques provide information to allow calculation of a load impedance. The following rules apply to the indications given by the voltage minimum when the load is replaced by a short. Figure 3-8 summarizes and graphically presents these impedance measurement rules. When the load is replaced by a short, then:

a. The shift in the minimum is never more than ±1/4 wavelength.

b. If the minimum moves toward the load, the load has a capacitive component.

c. If the minimum moves toward the generator, the load has an inductive component.

d. If the minimum does not move, the load is completely resistive and has a normalized value of 1/swr.

e. If the minimum shifts exactly one-quarter wavelength, the load is completely resistive and has a normalized value equal to the swr.

f. The minimum will always be at a multiple of a half wavelength from the load.

3-35. IMPEDANCE MEASUREMENT PROCEDURE.

3-36. The procedure for performing the actual impedance measurement with a slotted line is as follows:

a. Connect the load under test to the slotted line section and measure the swr (see Paragraph 3-26 or 3-28). Also note the position of the probe carriage at the minimum.

b. Replace the load under test with a short.

c. Locate the minimum with the line shorted.

d. Referring to Figure 3-9 and the following formulas, compute the normalized load impedance:

$$\text{Normalized } Z_L = \frac{1 - j(\text{swr}) \tan X}{(\text{swr}) - j \tan X}$$

$$\text{where } X = \frac{180° \, (\pm \Delta d)}{\lambda_g/2}$$

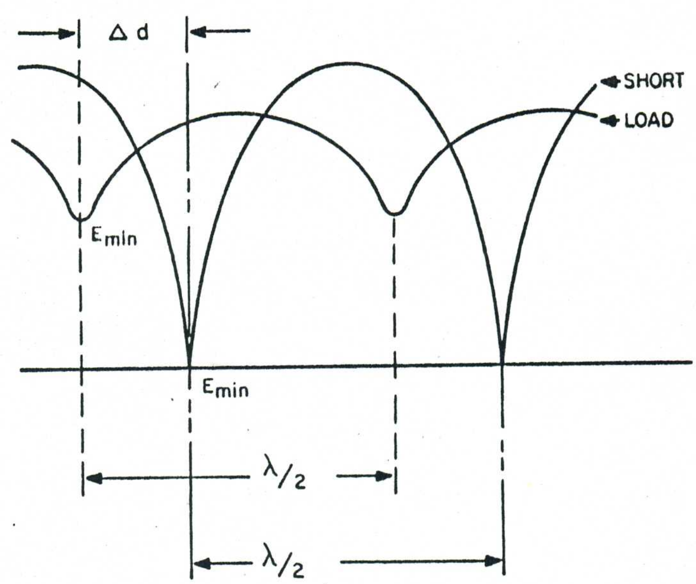


Figure 3-9. Shift of Minimum with Load and Short

and: $\pm \Delta d$ = Shift in centimeters of the minimum point when the short is used. Δd takes a positive sign (+) if the minimum shifts toward the load. Δd takes a negative sign (-) if the minimum shifts toward the generator.

$\lambda g/2$ = one-half guide wavelength, i.e., the distance in centimeters between two adjacent voltage minima.

Note

The above calculations are based on the assumption that no losses occur in the transmission line. It is assumed that the characteristic line impedance, Z_0, is resistive.

3-37. SMITH CHART EXPLANATION.

3-38. When data is obtained from a slotted line system, one of the best aids for determining impedance is the Smith Chart.* A Smith Chart with an example (see Paragraph 3-39) is shown in Figure 3-10. The values of resistance and reactance are based on a normalized value obtained by dividing the actual value by the characteristic impedance, Z_0, of the line. Thus if $Z = 5 + j\,25$ ohms and if $Z_0 = 50$ ohms, then $Z_N = 0.1 + j\,0.5$. On the Smith Chart, the circles which are tangent to the bottom of the chart are for a constant, normalized resistance; lines curving to the right from center are the normalized positive reactance components; lines curving to the left from center are the normalized negative reactance components; the straight line forming the vertical diameter is a line of zero reactance; the lower half of the zero reactance line (marked 1 through 50) also represents the standing wave ratio line.

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

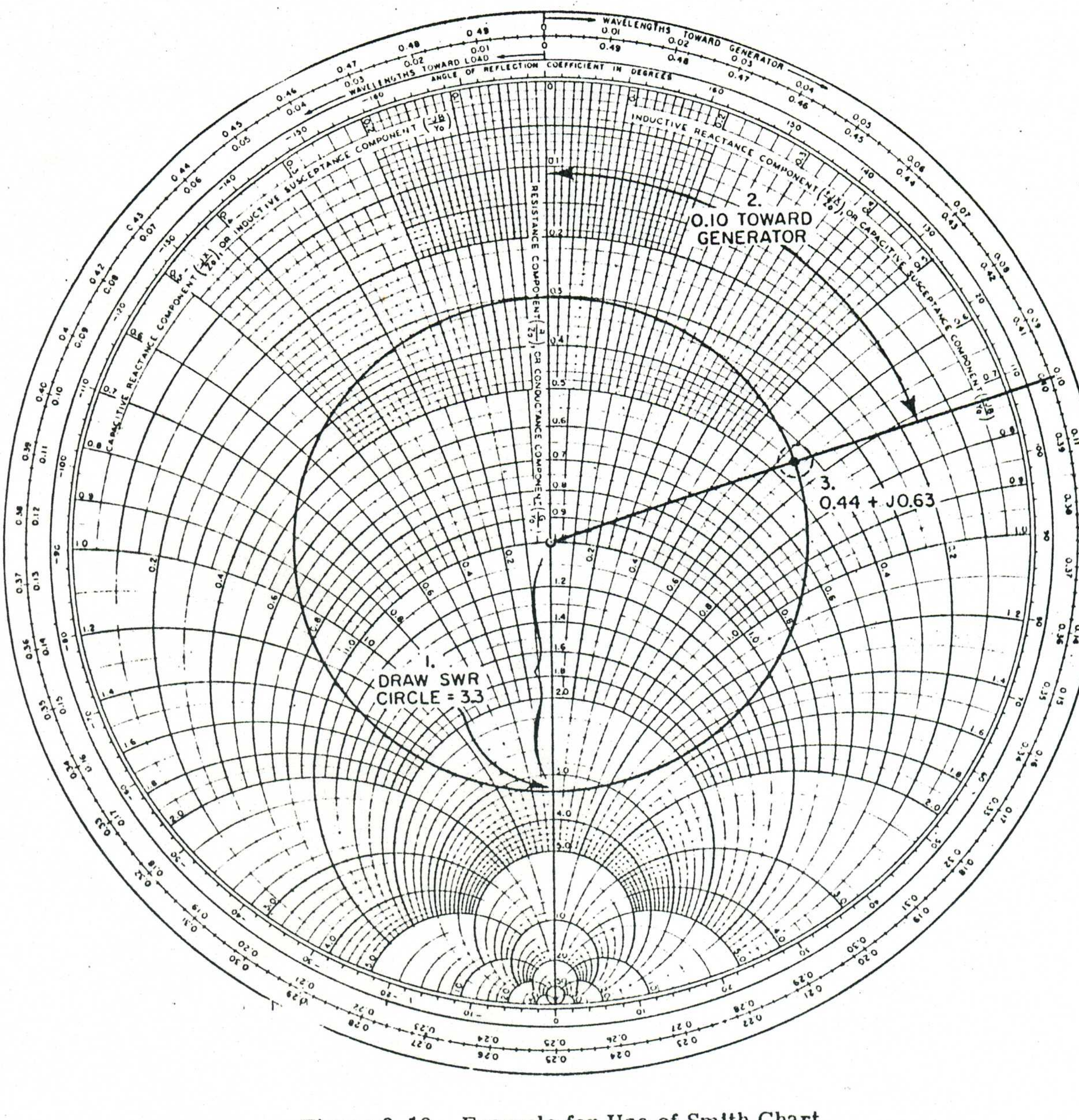


Figure 3-10. Example for Use of Smith Chart

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3-39. SMITH CHART CALCULATIONS

3-40. Use of the Smith Chart for calculating impedance is outlined below. Following the generalized procedure is a numerical example. Other methods are possible for first entering the Smith Chart, but the one suggested here is practical and easy to use.

a. Determine the guide wavelength, λ_g, as explained in Paragraph 3-28.

b. Measure the swr by the method in either Paragraph 3-26 or 3-28.

c. Locate a convenient minimum with the load still in place. Record the probe carriage reading.

d. Replace load by a short, relocate the minimum and record the probe carriage reading. Determine Δ d, the difference between this reading and the one from step c. Note whether the minimum was moved toward the load or toward the generator.

e. Calculate the shift of the minimum, in terms of wavelength:

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

f. Start at center of Smith Chart and draw a circle with a radius equal to the swr.

g. Enter the Smith Chart at the top, move in the direction of probe movement noted in step d and a distance Δλ, computed in step e. Use wavelength scale at the periphery of the Smith Chart.

h. Draw a line from the Δλ point to the center of the chart.

i. Locate the normalized impedance as the intersection of the swr circle and the line drawn in step h.

j. The actual impedance is the product of the normalized impedance from step i and Z_0, the line characteristic impedance.

Note

The convention of entering the chart as stated in step g applies only if the minimum is located first with the load on the line and relocated when the line is shorted. If it is necessary to first establish the shorted minimum point, the direction of Δλ would be opposite to the direction of probe movement required to relocate the minimum with the load concerned.

3-41. The following example will clarify the above procedure. Figure 3-10 shows the important steps involving the Smith Chart. The assumed characteristic impedance is 50 ohms. The distance between adjacent minima is 15 cm, therefore λ_g = 30 cm. The swr is measured as 3.3. A minimum is located at 22 cm. The load is shorted and the minimum shifts to 19 cm, toward the generator.

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

$$\Delta\lambda = \Delta d/\lambda_g = 3 \text{ cm}/30 \text{ cm} = 0.1 \text{ wavelength}$$

3-42. The following numbered steps refer directly to Figure 3-10.

(1) A circle for swr = 3.3 is drawn.

(2) A line is drawn from the 0.1λ point (toward the generator) to the center of the chart.

(3) The normalized impedance at the intersection of the circle and the line is 0.44 + j 0.63.

The impedance of the load (for Z_0 = 50Ω) is then:

$$50\,(0.44 + j\,0.63) = 22 + j\,31.5 \text{ ohms}$$

3-43. SPECIAL APPLICATIONS.

3-44. The Model 415E is equipped with outputs which allow applications other than as a meter indicating device for swr or attenuation.

3-45. RECORDER.

3-46. The rear panel recorder output furnishes an output from 0 to 1 volt DC with internal resistance of 1000 ohms and provides a convenient means of obtaining a permanent record of measured data. For proper operation, the recorder output ground (BNC shell) must be connected to a floating ground. Adapters are commonly available to float the ground of grounded input instruments at the power cord (see Paragraph 3-11).

3-47. AMPLIFIER OUTPUT.

3-48. The rear panel amplifier output furnishes an output from 0 to 0.8 volt RMS into 10K ohms or more. The Model 415E will supply up to 126 db of voltage gain. For proper operation, the ground terminal (black) must be connected to a floating ground (see Paragraph 3-11). With the 415E EXPAND switch set to NORM, a full scale meter reading will result in a 0.3 volt RMS output signal, and a minimum scale reading (10 db) will result in approximately 0.03 volt RMS. With the 415E EXPAND switch set to any position except NORM, a full scale meter reading results in a 0.8 volt RMS output and a minimum scale reading (2 db) results in a 0.5 volt RMS output signal. A zero input signal results in a zero volt output signal.

3-49. The Model 415E is especially useful as a tuned amplifier in a measurement setup using an Oscilloscope and a Sweep Oscillator. Sweep speeds may be increased (over the speeds using a ratio meter in a reflectometer system) and the Model 415E, used as a high gain amplifier, provides the required sensitivity.* The AMPLIFIER OUTPUT (AC) is often more useful for this purpose than the RECORDER OUTPUT (DC) since the DC output is filtered to reduce ripple and its response is too slow to make full use of maximum bandwidth.

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* See hp Application Notes 54, 61, 65, and 66.