I - GENERAL DESCRIPTION

MODEL 63-A U. H. F. Wattmeter is illustrated in Figure 1.
The aluminum cabinet of the wattmeter proper houses a 50-ohm coaxial termination (load or dummy antenna), blower cooled and rated 500 watts, together with a d-c millivoltmeter used as the power indicator. It should be noted that this unit provides a constant impedance termination over a very wide frequency range.

THERMOCOUPLES, plugging into the wattmeter panel, are provided to cover desired portions of the power range 1 to 500 watts. The r-f fittings on panel, thermocouples and cord are Type "N", but transmitters otherwise fitted are readily adapted by changing connectors on one end of the cord. The thermocouples are series-type, i.e., their thermo junctions form a short portion of the center conductor of the coaxial line, are heated by the r-f current therein and generate, in series with the center conductor, d-c millivoltages proportional to r-f power level. They are designed to have a minimum impedance-disturbing effect in a 50-ohm line.

GENERAL THEORY is that of the I^2R method of r-f power measurement. The required constant resistance R is provided by the load over a wide frequency range. The thermocouple d-c output is proportional to I^2 (current squared) and hence to power, but convenience dictates direct calibration in terms of power. It has become customary, of course, to standardize on power measurements, rather than current or voltage, in most high frequency coaxial work because circuit impedance levels have been fixed by the choice of cable characteristic impedance Z_0.

USES are as follows:

1. Power output measurements, on transmitters-during tune up, acceptance test or maintenance test. Transmitting tube tests.

2. As a dummy antenna, non-measuring, without thermocouples in circuit.

3. As a line termination for general use at lower (receiver) power levels.

4. As a non-dissipating, transmitted power wattmeter in certain circuits where conditions are known, and with accuracy depending on knowledge of those impedance conditions.

5. For power loss measurements on connectors, switches, filters and insertion devices generally, in conjunction with the slotted line which is used to determine the ratio of input to output power.

6. As an impedance standard, to which reference may be made in matching antennas and loads to 50-ohm coaxial circuits, in the absence of direct means such as the slotted line.

POWER RATING OF LOAD: Below 700 mc, the load will dissipate 500 watts continuously without difficulty. At higher frequencies, the continuous rating is reduced gradually to 250 watts at 1500 mc, on account of temperature rise in the first few feet of attenuating cable in the load. Somewhat higher power levels may be applied for short time periods, i.e., one minute.

POWER SUPPLY at 115 volts is required for the blower motor only. A series motor is employed, which will operate on d-c or on a-c frequencies of 25 to 60 cycles. Power requirement is about 75 watts.

NO VACUUM TUBES or other devices requiring auxiliary power are used.

SCHEMATIC DIAGRAM is shown in Figure 7.

II - OPERATING INSTRUCTIONS

INSTALLATION: The wattmeter may be located where convenient on the test bench. Attention should be given to instructions below about maximum lengths of r-f cord to transmitter, and about clearance for cooling air. The thermocouples are to be plugged into the r-f input jack on the wattmeter panel as shown in Figure 1. The selection of thermocouples for the expected power output should be made according to the following table:

Thermocouple Type	Color Code	Watts Full Scale at Frequency of 20 mc	100 mc	400 mc	1000 mc
209	Red-Red	6.	6.	6.	5.
220	Red-Yellow	20.	20.	15.	10.
210	Red	65.	55.	40.	27.
211	Yellow	300.	170.	120.	85.
212	Green	900.	550.	400.	250.

Notes: The above values are nominal. Consult calibration curves for exact ranges of individual wattmeters. Thermocouples are identified by type number and serial number stamped on the body, and by color code. Note also calibration constants C on attached metal bands.

When doubt exists as to the probable transmitter output, use higher range thermocouples first. Change to a lower range thermocouple when it is known that the readings will be within range.

PANEL CONTROLS: These are self-explanatory in terms of the panel markings, except possibly the "meter ON-OFF" switch, which is in series with the d-c millivoltmeter. This switch is to be "on" for all normal operation. It is useful in connection with tests for proper operation.

CONNECTIONS TO TRANSMITTER: A five-foot r-f cord (RG-8/U Cable and UG-21/U connectors) is furnished with the instrument for connections between thermocouple and transmitter. The length of cord is not critical with proper coupling in the transmitter, but it is not desirable to use cords longer than five feet or of other than 50-ohm impedance. Above 400 mc, cord lengths down to a practical minimum are advisable simply because of attenuation in the r-f cord. The 63-A measures power at the thermocouple, and for close work, cord losses should be added to the readings. These losses can be calculated with good accuracy from published figures for cable attenuation (because standing-wave ratios are low) and should be added to the readings where appreciable. For instance, from Page 5 of "Index of Army-Navy RF Transmission Lines and Fittings", Navy publication Navships 900102, it will be found that RG-8/U has an attenuation of:

.086 db (2% power loss) per foot at 1000 mc and
.048 db (1.1% power loss) per foot at 400 mc.

With the transmitter off, make connection to its output connector.

BLOWER: If the power to be measured requires the Type 211 or 212 thermocouple, connect the blower line cord of the wattmeter to a 115-volt source, and turn on the blower. The blower should operate at high speed, and air be drawn in through the panel intake. At higher power levels particularly, the air intake and the louvre outlets on top and sides should be in the clear, to permit proper air flow.

In general when using the Type 210 and lower range thermocouples, the blower is unnecessary and may be left off.

MEASUREMENTS: The transmitter may then be turned on, and readings observed on the wattmeter scale. The transmitter should be tuned for maximum output or desired output. After a transmitter has been tuned on some other type of r-f load, adjustments may be necessary, particularly in the coupling to the antenna circuit, in order to obtain maximum power into the 63-A Wattmeter.

The input impedance of the wattmeter, in terms of standing-wave ratio measurements, is shown in Figure 2. With these standing-wave ratios, little difficulty should be encountered in obtaining maximum power transfer on either 50- or 72-ohm transmitter circuits.

CALIBRATION CURVES: To permit ready use of individually calibrated instruments and thermocouples, power values are given in terms of curves and constants as follows:

(a) Most important is the K curve in which frequency characteristics, principally those of the thermocouple, are expressed. Each wattmeter is calibrated with standard thermocouples, and a curve furnished for each thermocouple type ordered.

The instrument has an arbitrary meter scale graduated 0-1 ma, and the K value equals r-f watts per ma (or watts at full scale), as a function of frequency and for a particular thermocouple type.

The transmitter frequency should be known within limits of 1 or 2 percent to get proper results. Figure 3 shows a sample K curve.

(b) For many cases, power calculated from $W = KR$, where $R =$ scale reading in ma, will suffice. However, better accuracy requires secondary corrections for scale non-linearity, and for thermocouple sensitivity.

(c) At all frequencies, the power vs. scale reading relation is approximately linear as assumed in (b) above. The deviation from linearity is most pronounced above 0.8 scale, and usually negligible below 0.6 scale. For any scale reading, apply (to W above) the multiplying scale factor B, from the scale correction curve for the thermocouple type involved. Note that $B = 1.0$ for $R = 0.6$ ma in all cases. Figure 4 shows the scale correction (B) curves.

(d) The new (and lower VSWR) thermocouples are not adjustable to standard sensitivity during calibration. However, the differences between individual thermocouples of a given type are independent of frequency. Banded on each thermocouple will be found a "couple factor" C, by which the uncorrected power value W is to be multiplied. Values of C range from 0.9 to 1.1. It will be noted that C is less for couples of greater sensitivity.

(e) To sum up, the corrected power value:

$$W_c = KRBC$$

in which K is of primary importance and a function of frequency, B and C are numbers between 0.9 and 1.1 and are independent of frequency. B varies around 1.0 with scale reading only, while C is a constant for a given thermocouple.

(f) EXAMPLE: (Using Sample K Curve (Figure 3) for Type 210 Thermocouple)

Frequency 480 mc; K = 38.9
R = scale reading = .72 ma
W (uncorrected) = 38.9 x .72 = 28.0 watts.

To correct this:
For .72 ma reading, B = 1.01, from B curve for Type 210 (Figure 4)
and for an assumed couple factor C = .96, (C values are marked on individual thermocouples).

Then the corrected power:

$$W_c = 28.0 \times 1.01 \times .96 = 27.1 \text{ watts.}$$

(g) It is suggested that the sheets used for recording data be headed to provide for introduction of the correction factors when they logically appear. In the usual case where a series of preliminary tests are necessary to get the transmitter tuned up, etc., only the final test result may need correction for B and C factors. Where uncorrected power values W are noted, the data sheet should, by headings, distinguish these definitely from the corrected values W_c.

III - OPERATING NOTES

(a) RF CONNECTIONS: Keep the transmitter off when changing r-f connections. Otherwise the thermocouple may be part of an unterminated excited line on which high standing wave ratios exist, and be damaged either by excessive current if at a current maximum or by flashover if at a voltage maximum.

See that r-f contacts are good, i.e., that springs have adequate tension, that surfaces are clean, and connectors tightly screwed together. Note that in the 63-A, the r-f connections, including the coupling coil in the transmitter, must complete a low-resistance d-c path for the thermocouple.

(b) CAPACITANCE - COUPLED TRANSMITTERS - TUNING STUB TN-87: This wattmeter depends on a path of low d-c resistance between the transmitter terminals to complete the d-c circuit. Inductively coupled transmitters are thus O.K., since the heavy conductors normally used will not approach the maximum resistance (0.2 ohm for 1% error) permissible within the transmitter. A series capacitance within the transmitter, or the capacitance probe coupling used with cavity-lighthouse tube oscillators, requires auxiliary means of completing the d-c circuit.

It is recommended that a shorted quarter wavelength of coax cable be shunted across the transmitter output terminals, using a tee fitting. The shorted quarter wave cable presents a high r-f impedance across the main output line, and gives the needed d-c short circuit. It must be adjusted in length for the frequency under test. A choice must be made between alternate policies (a) always set the shorted stub at a measured or calculated point of infinite shunt reactance or (b) use a variable-length stub as a shunt-reactance matching adjustment, and tune it for maximum output.

TUNING STUB TN-87 is available for this purpose, as an accessory to the 63-A wattmeter. The tee fitting is built in, and the length is sufficient to provide a full quarter wave down to 220 mc. Information on the use of this stub is given in Figure 11.

THERMOCOUPLES

WORKING STANDARDS: Where several thermocouples of identical type are purchased with the wattmeter, it is desirable to retain one as a standard and use it only for checking the others. Variations in the C factor of the others may be thus recorded and used, if through long use or possible overload any change should occur.

OVERLOADS in terms of off-scale readings should be carefully avoided, although the thermocouples will stand 25 percent overload for short intervals without change in characteristics.

In burned-out units, the elements can be replaced and the unit recalibrated, at the factory, with considerable saving over new units.

STRAY THERMAL EMF's: The d-c millivoltage of the thermocouple is in series with the antenna loop of the transmitter and with the various r-f fittings in this circuit, and a possibility exists that stray thermal and contact emf's may exist. To check this, turn the transmitter off, and throw meter switch OFF. Set the mechanical zero of the meter exactly and turn the meter switch ON. If stray voltages are present with the transmitter off, they will show up as slight deflections from zero. These should not be allowed to exceed .005 ma (1/4 div.). If strays show up, look for trouble in r-f connectors which may not be making a good contact or which may have been heated as the result of arcing at poor contacts. Normally, thermal emf's due to temperature differences between the various points in the d-c loop including the transmitter connectors and output circuit, will cancel out and will be low because of similarity of metals in all of these various contacts.

EXTERNAL D-C METERS of lower range than the 25 millivolt range instrument built into the 63-A, can be used for special purposes, such as to lower the full scale power range of a certain thermocouple. Such meters should be thought of as millivoltmeters, and consideration given to their internal resistance, in which the higher resistances are preferable. Meters above 25 MV full scale should not be used. Figure 10 shows the d-c circuit in detail, and gives resistance values from which r-f calibrations can be figured.

OVERLAPPING RANGES: The 63-A thermocouples are designed generally for 3 to 1 steps between full scale powers, say from the 210 to the 211. There exists in each case a range of power in which adjacent thermocouples in the series can be checked against one another, without having to read extremely low scale values on the less sensitive unit.

USE ON 72-OHM SYSTEMS

The Model 63-A Wattmeter may be used to measure the power output on transmitters designed for 72-ohm loads with satisfactory results. Since the wattmeter correctly reads power delivered to the thermocouples regardless of the source from which this power is obtained, the question of accuracy on 72-ohm equipment is one of whether or not the equipment will deliver to the 63-A Wattmeter, when adjusted therefore, as much power as into its nominal 72-ohm load. Experience shows that well designed transmitters are not too critical to a variation of resistive load impedance over the range 50-100 ohms. The 63-A can be depended upon to present a resistance close to 50 ohms, both at the thermocouple and at the end of 50-ohm extension cables, and it will be found that maximum power is readily delivered by 72-ohm equipment with no changes other than adjustment of antenna circuit coupling.

It is preferable to use 50-ohm cables and connectors between wattmeter and transmitter, in the case of 72-ohm transmitters also. The idea here is that the standing wave ratios existing on the cables are determined by the wattmeter impedance and the Z_0 of the cables, and are independent of the transmitter. With 50-ohm cables, the impedance presented to the transmitter terminals will depend very little on cable length, etc.

If 72-ohm cables must be used, it can be noted that in the worst case (lines 1/4 wave length or odd multiples) the transmitter would be presented with a load impedance of 110 ohms ($= 72^2/47$) and that the load at the transmitter would vary between 47 and 110 ohms as the electrical length of the cable (thermocouple to transmitter) goes through alternate quarter and half-wave conditions. Even this is a reasonable range for the transmitter to match.

COMPARISON OF WATTMETERS AND THERMOCOUPLES

Attention is called to the Standing Wave Product method, described under V - Methods of Calibration, as a means of overcoming the limitations of the substitution method. However, with stable transmitters, the substitution method should give acceptable results in comparing various 63-A Wattmeters, in comparing thermocouples of the same type, or in cross comparisons among the type 210, 211 and 212 thermocouples.

In comparing the type 209 with other types, or in any comparisons between the above mentioned thermocouples and the older types 205, 206 and 207, it is recommended that the S. W. P. method be used.

BLOWER SYSTEM

R-F NOISE: When operated in close proximity to radio receivers, the r-f noise originating at the commutator of the blower motor may be objectionable. A line filter, inserted close to the 115-volt receptacle and grounded to the wattmeter case, will probably cure this trouble. When specified, filters can be furnished within the wattmeter.

One test for proper air flow is to close the air intake with the palm of the hand. If operating properly, this will cause a considerable increase in blower speed, since shutting off the air intake unloads the motor. The screen over the intake should be kept clean, and the inside of the wattmeter blown out occasionally with compressed air. Dirt is not likely to collect inside the terminating resistor in harmful amounts.

IV - THEORY OF OPERATION

DESIGN OF THE LOAD IMPEDANCE

In all attenuating coaxial cables so far made, the attenuation increases with frequency. A length of such attenuating line furnishes a constant input resistance equal to its characteristic impedance, regardless of termination of the line, for frequencies sufficiently high so that the reflections produced by an imperfect termination can be neglected. In general, the constant resistance termination over a wide frequency range is obtained in the 63-A Wattmeter by using the Z_0 of the attenuating line at the higher frequencies, and in order that low frequencies may be handled with a reasonable cable length, the line is terminated in a specially designed coaxial resistor which matches the line and is itself a constant non-reactive resistance over the lower frequency range. As the attenuation of the line increases with frequency, a "transfer of power loss" occurs gradually from the 20 mc condition, in which about 25% of input power is dissipated in the terminating resistor, to the 1000 mc condition, in which 90% of the input power is lost in the initial 25 feet of line. The frequency 200 mc may be stated roughly as the upper limit of effects from the terminating resistor and at higher frequencies the line alone determines input resistance.

In the design of this type of terminated line the foremost problem is to avoid small variations of the input impedance which tend to recur at short frequency intervals because of the electrically long length of the line. The thermocouples to be used with this line are free of such small irregularities and the problem is entirely in the line. It should be pointed out that irregularities in the line input impedance will affect the calibration since the thermocouple is effectively measuring the current into this line input impedance. Impedance irregularities at the thermocouple input caused by the thermocouple itself are of less significance, since they may be considered as reactance in the thermocouple and affect only the impedance presented to the transmitter but not the power calibration.

CHARACTERISTIC IMPEDANCE: The 63-A Wattmeter uses one hundred feet of a synthetic-rubber-dielectric, copper-conductor type of line. The average characteristic impedance of this line is 47 ohms and this of course fixes the load resistance presented to the thermocouple. The calibration of the individual wattmeter is made so as to include the effects of variation of individual lengths of line from the 47-ohm nominal value. The terminating resistors are chosen to match the individual lines within practicable limits and the effect of the termination is included in the low frequency part of the calibration.

V.S.W.R. CURVES: Figure 2 shows the input impedance of a typical wattmeter expressed in terms of voltage standing-wave ratio vs. frequency. This is for a 52-ohm slotted line. The standing-wave ratio with thermocouples in the circuit is also shown for reference. It will be noted that the standing-wave ratio of the line input is around 1.1 over the frequency range, and this ratio is that produced by the 47-ohm characteristic impedance of the line when it terminates the 52-ohm slotted line. The impedance at the thermocouple input shows higher standing-wave ratios, but it should be noted that the values of standing-wave ratio throughout those curves are low enough so that both the line input and the thermocouple input can be considered quite good power absorbing loads for circuits of nominal 50-ohm impedance level.

SMOOTHNESS OF LINE INPUT IMPEDANCE

LOW FREQUENCIES: At frequencies below 100 mc it has not so far proved possible to get in every case, and throughout this frequency range, an exact match between terminating resistor and the Z_o of the attenuating line. The result of this is a cyclical variation, with frequency, of the line input impedance about the Z_o of the line as an average. This results in an accuracy limit of plus or minus 5% at 20 mc from this cause, since the varying impedance mentioned occurs in the load into which the thermocouple works. The impedance variations occur at intervals of 3 to 6 mc between successive maxima, which frequency interval is determined by the velocity constant and the 100-foot length of the attenuating line. The magnitude of these variations reduces to less than 2% (plus or minus) for frequencies above 100 mc.

ABOVE 100 MC, impedance irregularities within 2% (plus or minus) are again found, occuring at short and erratic frequency intervals up to the maximum calibrated frequency, 1500 mc. At these higher frequencies, the cause is not reflection from the termination, but lies in the very complex way in which slight point-to-point variations in dielectric diameter, shield braiding, etc., contribute to the impedance at the line input.

Fortunately these variations are small, and center around a value of Z_o which changes little with frequency. It should be remembered however, that accuracy of the K curves is limited to 2% (plus or minus) by this fact. Methods of calibration have been worked out to draw the K curves through the average of these minor jiggles. Impedance variations which persist over longer frequency intervals of 50 or 100 megacycles are of course shown in the calibration.

THERMOCOUPLE THEORY

Figure 6 shows a cross section typical of the Types 209-210,211 and 212 thermocouples. These have a butt-welded junction of two straight lengths of thermo-sensitive wire. The composite wire thus formed is connected between the center conductor pins. The diameters through the insulator (5) and connector portions are maintained at a 50-ohm diameter ratio. The tapering inner and outer diameters between insulators (5) also have a 50-ohm diameter ratio down to the pin ends. On account of impractical clearances which would result, the 50-ohm diameter ratio is not maintained through the heated wire portion, and the higher diameter ratio here is equivalent to a small lumped inductance.

PRINCIPLE OF OPERATION: In operation the composite wire is heated, the temperature rise being considerable at its center where the welded junction is located and very much less where the wire joins the contact pins, because of the cooling effect of the large diameter pins. A thermoelectric voltage is generated proportional to the temperature difference between the junctions at the center of the wire and those at the pin ends. This generated d-c millivoltage is almost directly proportional to r-f current squared and hence to r-f power transmitted. The scale factor curves previously mentioned show and allow for the small-non-linearity which is present.

By keeping the length of the composite wire to a minimum consistent with required sensitivity, and by adhering as closely as possible to a 50-ohm diameter ratio throughout, the input impedance to the thermocouple and load is kept close to 50 ohms as shown by Figure 2. The principal difference between the Types 209, 210, 211 and 212 thermocouples and the earlier designs (Types 205, 206 and 207 used with the TS-118/AP and 532-B Wattmeter) is in this respect. The earlier thermocouples have a much higher standing-wave ratio, which is included in their power calibration, but still means that the impedance they present to the transmitter departs considerably from 50 ohms.

FREQUENCY CHARACTERISTICS: Since the line input impedance is practically constant throughout the frequency range of the wattmeter, the K curves are essentially the frequency calibration of the thermocouples. Reference to Figure 8, wherein the K curves of the various thermocouples are given together, will show that for each thermocouple the sensitivity increases (K curve falls off) with frequency above the knee of the curve. The knee frequency is inversely proportional to the power range of the thermocouple, and to the sizes of wire used in the composite element.

SKIN EFFECT: Calculations based on accepted skin-effect theory have shown that the measured K curves of the various types of thermocouples in this series agree with calculated ratios of r-f resistance to d-c resistance for the composite element. This agreement is within limits of plus or minus 5 percent, which is as close as could be expected from calculations based on a single resistivity figure for the small wire, whereas in fact the wire is composite and the two metals have considerably different resistivities.

LINEARITY OF THERMOCOUPLES: In Figure 9 is shown the manner in which r-f power and d-c millivoltage generated are related in these thermocouples. For the user, this result is expressed in the alternate form of the scale factor (B) curves, Figure 4, which are more convenient, in that they allow the generally linear relationship to be used and give the correction to be applied when necessary. A scale reading of 0.6 ma is chosen as the point at which B x 1.0 (no correction for linearity). Calibrations of the individual wattmeters are made at this scale reading. Referring to Figure 4, it will also be noticed that the scale correction B is in all cases small for scale readings below 0.6 ma and may often be neglected there. The non-linearity which exists is greater in the higher power thermocouples. It is the same in all thermocouples of a given type.

THERMOCOUPLE CALIBRATION: In the new thermocouple designs (Type 210, etc.), it is not practicable to adjust individual thermocouples to standard sensitivity, as was done with the older thermocouples (Type 205, etc.). The thermocouples are individually calibrated against standards, however, at several frequencies up to 1200 mc. It is found that the thermocouple sensitivity, expressed in the C factor, is independent of frequency in general, since it depends on known factors affecting the temperature reached at the junction, which factors are the same for all frequencies. In some cases, with the Type 209 thermocouple, a slight variation in the C factor appears with frequency, and if so, appropriate values of C are noted for the various test frequencies.

LIFE OF THERMOCOUPLES: The first objective in design of these thermocouples is to realize a low insertion standing-wave ratio. The heated wires operate in air, since no design of evacuated enclosure has yet met the impedance requirements. It is necessary also that the wire sizes be smaller than are usually used outside of evacuated glass envelopes. Therefore, the life expectancy of the thermocouples is not as high as for well-designed thermocouple ammeters used at much lower frequencies. Among the 63-A thermocouples, the life is greater in the higher power ratings because of the larger wire sizes usable, and the life will be shortest with Type 209. Another point is that the life at scale readings of .6 and lower will be greatly in excess of life at full scale.

Since the wattmeter and thermocouples will be most used intermittently rather than continuously, the matter of thermocouple life does not appear to be a serious problem. The general effect of aging is an increase in sensitivity (reduction of K factor) as the surface of the wire oxidizes and the resistance increases. The general life data above are based on K factor changes of less than 5% maximum.

OPENING FOR INSPECTION: Thermocouples may be inspected by removing the knurled locating ring and carefully lifting out the cover. Cover should be lifted without lateral motion. A dark oxide coating on the wire element is normal and occurs in the initial aging given couples before they are calibrated. Small loops or hairpin bends, which will be noticed in the wire elements, are incorporated to allow free expansion (lengthwise) as the element becomes hot.

V - METHODS OF CALIBRATION

STANDARDS OF POWER

At present, there are no universally accepted standards at these frequencies to which other power measuring instruments can be referred. We believe the results indicated by the Model 63-A Wattmeter to be accurate, certainly within plus or minus 5% throughout the frequency range, and where detailed calibrations are made for restricted portions of the frequency range, to within plus or minus 2%. In comparing with other methods of power measurement, certain precautions, not too widely known, are necessary and are outlined below. One of the principle points covered is the question of whether or not the given transmitter actually delivers identical powers to two different wattmeter devices when they are successively connected to the transmitter and where the assumption is made that the transmitter power is the same in each case. (Substitution method.)

CALORIMETERS

Practically all methods of power calibration at these frequencies are calorimetric. On account of high frequencies involved, the conventional thermoammeters are not usable and one must go directly back to the fundamental methods of heat measurement which are capable of accurate power results regardless of whether or not impedances, resistances, or currents and voltages are accurately known.

The general idea, which has been used and which we use, is that of the transfer calorimeter, i.e., a device which gives meter indications of either steady power level dissipated in it or of the heat energy dissipated in it in fixed time intervals. Since the measurements are made directly on power or energy, such a device may be made independent of frequency and may be calibrated by supplying to it easily measured power at d-c, 60 cycles or at other low frequencies.

Calorimeters for this purpose may be further divided into flow calorimeters, either air or liquid cooled at constant velocity, where the temperature rise in the coolant stream is used for the power indication, and the static type in which the heated element is insulated against stray heat losses and measurements are made in terms of the rate of temperature rise or of the final temperatures attained in a calorimeter element of fixed heat capacitance.

OTHER INSTRUMENTS: Other methods of determining high frequency power are the thermistor bridge, the bolometer bridge, and the barretter bridge methods which are quite accurate for the very low power levels which may be directly introduced into their measuring elements but which, however, for the measurement of transmitter power levels, require accurate high power attenuators of types not yet produced except for narrow frequency ranges.

METHODS USED: We have chosen to make power calibrations against static types of calorimeters which operate through the same power range as the wattmeter devices under calibration. The calorimeter element is a special design of resistance which is physically small and, therefore, has a low thermal time constant. Instantaneous values of temperature rise in this calorimeter element are recorded by means of a Leeds & Northrup recording resistance thermometer. This combination not only has passed a variety of tests for accuracy and repeatability, but it also gives power readings within a sufficiently short time, so that the great number of repeat references and cross checks, which are necessary in this work, can reasonably and readily be made.

COMPARISON OF POWER READINGS

For close work it is not satisfactory to rely on substitution comparisons in which two power measuring instruments are successively connected to the same transmitter, and in which the transmitter alone is depended upon to deliver identical powers to the two instruments. Not only must one contend with variations in transmitter output with time and line voltage, but more significantly the differences in input impedance between the two instruments are not allowed for in this method. We are speaking here of two different types of instruments such as when the Model 63-A is compared with the calorimeter just mentioned, and the same thing holds when comparing the 63-A with other types of power instruments. Difficulties with present connector designs and with cable variations are well known and are part of this picture.

TRANSMITTED POWER INDICATOR: In comparing instruments of two different types, a "transmitted power" instrument is needed which need be calibrated only relatively in power. The slotted line, in conjunction with probes accurately calibrated in terms of relative voltage, has proved a very satisfactory solution to this problem. When properly applied, this method will frequently explain the discrepancies of 10% or less which generally exist at present between power figures coming from various sources. It would appear that a good bit of the observed discrepancies are due to the fact that different types of wattmeter do not actually absorb identical power values from the same transmitter. Incidentally, it seems that at these frequencies readings of transmitter plate current and voltage are a poor indication of relative r-f power output.

THE STANDING-WAVE PRODUCT METHOD

The slotted line may, of course, be used to measure the two wattmeter impedances in detail, but this is unnecessary since the slotted line is capable of accurately measuring transmitted power through the relation:

$$P = \frac{E_1 E_2}{Z_0}$$

Where E_1 and E_2 are respectively the highest and lowest voltage on the standing wave pattern, located 1/4 wave apart, and Z_0 is the characteristic impedance of the slotted line. Note that the unknown impedance of the load is not involved here but only the known and constant characteristic impedance of the slotted line.

Where E_1 and E_2 can be accurately measured in absolute terms, absolute values of the power transmitted through the slotted line may be read with corresponding accuracy, since the Z_o of the line is readily determined. In the case of comparing two types of wattmeter, absolute calibration of the probe as a voltmeter is not necessary, but an accurate curve of the relationship between probe meter and relative voltage is necessary. This may be obtained from the known sinusoidal voltage distribution on the slotted line when open or short circuited.

USE OF THE SWP METHOD: To use this method wattmeter A is connected to the slotted line and simultaneous readings of S_1, S_2 and wattmeter scale are taken. The notation S_1 and S_2 is used for scale readings on the probe meter. This is repeated with wattmeter B, for the same setting of the transmitter, usually. Although it is not necessary that the transmitter output remain constant between the two sets of readings, it is necessary that the transmitter be constant during the reading of S_1, S_2 and wattmeter scale for each case, and it is necessary that the voltage calibration of the probes remain constant throughout the time required for both sets of readings. By reference to the probe calibrations, the probe scale readings S may be converted to numbers proportional to voltage, which we can call E_{1a} and E_{2a}, etc. The power values transmitted through the line and read by the respective wattmeters are then connected by the relationship:

$$\frac{P_a}{P_b} = \frac{E_{1a}\ E_{2a}}{E_{1b}\ E_{2b}}$$

and this allows corrections to be made where necessary for the differences in power transmitted to and absorbed by the two wattmeters.

A note of caution should be inserted here about:

(a) HARMONICS: The thermocouples of the 63-A Wattmeter, while operated thermally, are still not flat as to sensitivity versus frequency in the range where the K curve is sloping. The sensitivity is increasing with frequency and therefore, harmonics of considerable amplitude will cause indications higher than the sum of fundamental and harmonic powers. Harmonic amplitude however, must be quite large to cause appreciable error from this source. A rough calculation indicates that 20% of third harmonic voltage is necessary to make the scale reading 2% higher than the true sum of fundamental and harmonic powers.

Harmonics must be particularly watched, however, in using the slotted line for transmitted power readings as outlined above. The reason is that small percentages of harmonics can cause considerable error in E_1 and E_2. To eliminate harmonics, one of the best methods is to use low-pass filters designed around resonant coaxial line elements. These are quite readily made to have flat pass-band characteristics with high attenuation above cutoff. A series of such filters, with cutoff frequencies related in the ratio 1.8 to 1, is used in connection with the calibration of the 63-A Wattmeters. With this choice of cutoff frequency relationship, any desired frequency range can be covered while always maintaining adequate protection against the second harmonic.

(b) RADIATION FROM TRANSMITTERS and transmission (longitudinal) on the outer conductors of coaxial lines. The 63-A will, of course, read only the power delivered to it in the coaxial sense, i.e., the power transmitted within the outer conductor. The wattmeter itself is not at all sensitive to external fields and it is not meant to imply that the instrument in itself can be in error from uncontrolled transmitter radiation. However, it has frequently been found that erratic results in measuring power were due to the fact that the coaxial output line was functioning in two ways, i.e., as a coaxial line, and also the shield was part of an open wire antenna, leading to erratic readings depending on the wattmeter position and surrounding conditions. Obviously the answer is to confine r-f energy emitted from the transmitter to the coaxial dielectric space in the output line. In commercial equipments this is done as a matter of good design practice, and the reference here is to experimental equipment. Coaxial tuned circuits give little trouble, but parallel line circuits, commonly used in the lower part of the 63-A range require care in shielding.

Here again stray radiation can be particularly troublesome when the slotted line is used. On account of the sensitivity of the detecting element in the probe, large errors in values of E_1 and E_2 can be obtained in the presence of stray radiation.

INSTRUCTION BOOK
UHF WATTMETER
MODEL 63-A

LIST OF ILLUSTRATIONS

ADDITIONAL DATA FOR INDIVIDUAL WATTMETER

A. (Bound in book)

1. One copy each, K curves for thermocouple types supplied.
2. List of C factors, for thermocouples supplied

B. (In acetate cover, separate)

1. One copy each, K curves.
2. Figure 4, B curve.