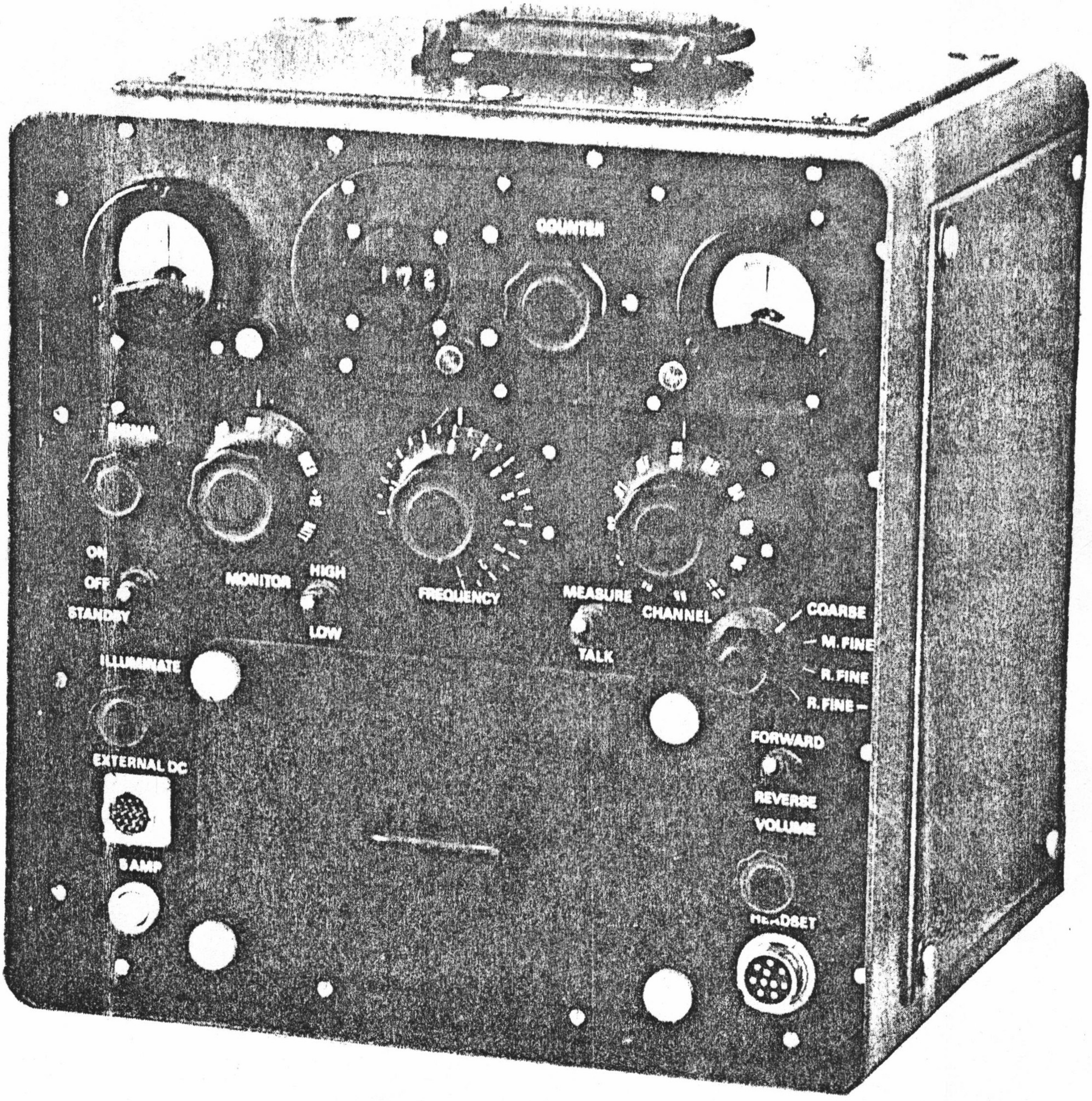

THE TELLUROMETER MODEL MRA 4

CHAPTER 1

GENERAL DESCRIPTION

Section 1. INTRODUCTION

1. Scope

This manual covers the theory of operation, the application and limitations, and the instructions for use of the TELLUROMETER Model MRA4. A scheme of simple fault finding and an overall circuit diagram are included.

2. Description

The TELLUROMETER surveying instrument, Model MRA4, is a compact, portable, self-contained, transistorized, tripod mounting instrument utilizing the transmission of microwaves for the accurate measurement of distance.

Two identical instruments are required for distance measuring purposes, one at each end of the line to be measured. In operation, one instrument is designated as the Master and the other as the Remote. These roles are completely reversible as required.

In this instrument the antenna system and the power unit are integral features. The unit can be operated with a 12-volt or 24-volt external battery or alternatively a 12-volt internal, re-chargeable nickel cadmium battery can be provided as an optional extra.

The measuring frequencies (see Paragraph 46) are controlled by quartz crystals whose frequencies are accurately set by reference to some standard. As the crystals are ovened at a constant temperature of 85°C, no frequency/temperature calibration is necessary.

The instrument is housed in a self-sealing rainproof case with easily removable covers. Only the antenna cover has to be removed before operating the instrument.

Repair by replacement of assemblies is easily accomplished. When the three covers are unscrewed from the main case, the printed wiring assemblies can be removed. The sub-units and printed wiring assemblies can be tested independantly of the instrument and suitable monitor points are provided to facilitate the location of faults.

For taking meteorological readings, a surveyor's aneroid barometer (reading to the second decimal place in inches of mercury) and a whirling psychrometer are required. Psychrometers of the mechanically aspirated type are preferable for accurate work, particularly at low temperatures.

To enable the instrument to be accurately beamed in both the horizontal and vertical directions a tilting head is provided. The tilting head is graduated in degrees and fits into the standard WILD T2 tribrach with optical plummet.

It is also provided with a gun sight attachment for optical beaming. This attachment is necessitated by the narrow beamwidth of the instrument (less than 2°).

Section 2. RANGE AND ACCURACY

3. Range

The instruments are capable of measuring distances of up to 50 kilometres. The maximum range is limited by the intervisibility of the two stations and the meteorological conditions.

The minimum length of line that can be measured is approximately 50 metres.

4. Accuracy

Under favourable conditions and subject to zero error calibration, the overall measuring accuracy is ± 3 mm ± 3 parts per million of the length to be measured.

To ensure accurate results, it is necessary to take readings on a number of successive carrier frequencies in order to average out the possible effects of ground reflections which can cause the indicated readings to differ from the true readings (see Paragraph 10). On most lines, however, these effects will not be present due to the narrow beamwidth of the antenna. If a slight reduction in accuracy can be tolerated, it is possible to take readings at one frequency only. This saves considerable time in taking measurements but may necessitate a slightly different zero correction being applied.

For all measurements, particularly over long ranges, it is necessary to take accurate readings of atmospheric pressure, temperature and humidity, in order to correct for the refractive index of the atmosphere.

To obtain the optimum accuracy it is advisable for a given pair of instruments to be individually calibrated for zero error (see Paragraph 26).

Section 3. PERFORMANCE AND EQUIPMENT DATA

5. Performance Data

Range	50 metres to 50 kilometres
Accuracy	± 3 mm ± 3 parts per million
Resolution	1 millimetre
Temperature Range (operational)	-65°F to +105°F
Temperature Range (storage)	-80°F to +155°F
Input Voltage	11 volts to 14 volts d.c. 22 " " 28 " " "
Current Consumption (operational)	3 amperes with lamps off
Current Consumption (warm-up)	4 amperes with lamps off
Power transmitted	30 milliwatts
Carrier frequency	34.5 to 35.1 Gc/s
Modulation frequency	Between 5.9 and 7.5 Mc/s 70 kc/s and 75 Mc/s
Beamwidth	2°

6. Equipment Data

The TELLUROMETER model MRA4 as supplied consists of the following items:-

1 Instrument MRA4

1 Headset

CHAPTER 2

PRINCIPLES OF OPERATION

Section 1. DESCRIPTION OF THE MEASURING TECHNIQUE

8. General Principle

A continuous radio wave, having a frequency that lies in the band 34.5 to 35.1 Gc/s is radiated from the Master antenna. This wave is frequency-modulated by what are referred to as "channel frequencies", which are of the order of either 7.5 Mc/s or, on the "fine" channel, 75 Mc/s. The modulated wave is received at the Remote instrument and is, in effect, re-radiated to the Master. There the phase of the received modulation is compared with that of the transmitted modulation.

The phase difference is a measure of the transit time of the radio wave over the path. If the velocity of the wave is assumed to be known, the instrument can be considered to measure directly the distance between the Master and Remote stations.

With a channel frequency of 7.492377 Mc/s (M_1), one complete phase rotation represents a change of 40 metres in the length of the double path, i.e. a change of 20 metres in the distance between the two stations. These figures are dependant on the velocity of the wave, which in turn is dependant on the atmospheric refractive index. The above frequency is selected as giving a readout directly in metres, when the refractive index is 1.000325 which is an average value.

In order to have a decimal readout, a second channel M_2 is provided. The difference frequency M_2 minus M_1 is 2 x 7.492377 = 14.984754 Mc/s, as M_2 is negative. With this frequency (14.984754) one complete rotation represents a change of 10 metres in the distance between the stations.

This difference frequency, then, indicates only the final digit (and the first and second decimal digits) of the distance in metres. The preceding digits are resolved by providing four further frequencies. The channel frequencies are:-

M_1 Channel	7.492377 Mc/s
M_2 Channel	7.492377 "

M_3	Channel	5.993902 Mc/s
M_4	"	7.342530 "
M_5	"	7.477393 "
M_6	"	7.490879 "

The Remote frequencies differ from these by 1.498 kc/s.

The differences between the M_1 Channel reading and the M_2, M_3, M_4, M_5 and M_6 readings, respectively, give phase readings relative to the difference frequency of the modulations.

M_6 minus M_1	1.498 kc/s	100,000 metres
M_5 " M_1	14.985 kc/s	10,000 "
M_4 " M_1	149.848 kc/s	1,000 "
M_3 " M_1	1.498475 Mc/s	100 "
M_2 " M_1	14.984754 Mc/s	10 "

An additional channel called the "fine" channel has been added to achieve millimetric accuracy. The difference frequency F+ minus F- is 2 x 74.92377 Mc/s = 149.84754 Mc/s; with this frequency, one complete rotation represents a change of 1 metre in the distance between the stations.

The phase is measured with an accuracy of one part in a thousand, giving a resolution of 1 millimetre.

Section 2. ELIMINATION OF ERRORS

9. Instrument Errors

Small instrument errors are eliminated by the use of the "Forward and Reverse" function on the fine readings. This equivalent to the taking of "circle left" and "circle right" on a theodolite.

10. Ground Reflections

An error can result from the reflection of the microwave beam from the ground or other objects. Ground reflection effects cause the reading to deviate from the true reading by an amount that is a function of the excess length of the indirect ray and the relative amplitude strength of the direct and deflected rays. This error can be either positive or negative and depends on the carrier frequency. It will swing about the true value as the carrier frequency is changed. Although errors introduced by most ground reflections are negligibly small due to the narrow beamwidth of the instruments (less than 2°), it is recommended practice to take a series of readings through the carrier tuning range.

The manner in which the error changes with carrier frequency is termed "swing".

In the STANDBY position all low voltage circuits are energized.

In the ON position all instrument circuits are energized.

If the switch is switched directly from OFF to ON there is a delay of approximately 20 seconds before the klystron switches on.

d. Monitor Switch

When the "Measure-Talk" switch is set to "Talk" the monitor switch selects the following monitoring functions:-

Use of the MONITOR Switch

Switch Position	Function Monitored	Normal Reading on MONITOR Meter
BATT	Input voltage	Over 10
+ 12	+12-volt d.c. supply	Over 10
OVEN	Oven Heater current	10,5 or 0
RF	Mixer crystal current	Over 4
SIG	Sample of AGC voltage	* 00 to 10
AFC	Output of AFC amplifier	* 10 to 0 to 10

* Used to tune the instrument

e. Monitor Meter (left-hand side)

The readings on the "Monitor" meter are used to tune the instrument and to monitor the signal levels and voltages.

f. Null Meter (right-hand side)

On the Master instrument this meter displays the phase detector output and is used as a null meter to determine the distance measured.

On the Remote instrument this meter is used to indicate the operation of the 1.5 kc/s frequency lock. A steady reading of between + and - 10 should be obtained with both instruments switched to "Measure".

g. Frequency Control

The carrier frequency is adjusted by rotation of the "Frequency" control. The dial is marked with reference numbers 1 to 12 and covers a frequency range of 34.5 Gc/s to 35.1 Gc/s.

h. Counter Control

When a distance measurement is being taken the "Counter" control knob is rotated to obtain a null reading on the "Monitor" meter. The 3-digit number displayed in the "Counter" window is used to compute the distance being measured.

i. Forward-Reverse Switch

This switch is normally set to the "Forward" position. It is set to the "Reverse" position at the Remote station only, on instructions from the Master.

j. Channel Switch

The 12-position channel selector switch selects one of twelve modulation or channel frequencies. The positions M1 to M6 apply to operation as Master instrument. The positions R1 to R6 are used in Remote operation.

For these "coarse" channels the secondary channel switch should be switched to "Coarse".

For Master operation on the "fine" pattern the main and secondary channel switches are both switched to "M.FINE".

For Remote operation on the "fine" pattern the main channel switch is switched to "R.F." and the secondary channel switch to "R.FINE+" or "R.FINE-", as required.

k. Low-High Switch

The "Low-High" switch is used to select the correct polarity of AFC voltage to control the klystron.

(i) When the Remote station "Frequency" control is numerically higher than that of the Master station, set the switch to "High".

(ii) When the Remote station "Frequency" control is numerically lower than that of the Master station, set the switch to "Low".

l. Measure-Talk Switch

When making a distance determination, set the "Measure-Talk" switch to "Measure". When voice communication is required, set the switch to "Talk".

NOTE: At either station voice communication can be received with the switch in the "Measure" position, but the switch must be set to "Talk" in order to transmit voice communication.

m. Volume Control

Clockwise rotation of the "Volume" control increases the audio level in the headset.

n. Headset Receptacle

The "Headset" receptacle connects the headset to the instrument.

o. Signal Control

The "Signal" control is used to facilitate accurate pointing of the instruments.

With a pair of instruments tuned in to each other and switched to "Talk" and with the monitor switch set to "SIG", the "Signal" control can be turned anti-clockwise to reduce the reading on the "Monitor" meter to 5. In this way a pair of instruments can be accurately pointed by aligning them for a maximum meter deflection. The "Signal" control should afterwards be turned fully clockwise.

Section 3. INITIAL ADJUSTMENT OF THE INSTRUMENTS

17. General

Although the equipment is adjusted in the factory, certain pre-operational checks may be necessary. It is advisable, therefore, to check the instruments according to the following instructions, before they are operated in the field.

18. Pre-operational Checking

If the instruments do not pass these checks, refer to the fault finding procedure in Paragraph 45.

a. Remove the instruments from their transit cases and mount them side by side. Do not point them directly at each other.

b. Remove the antenna covers from the instruments.

c. Plug in the headsets.

d. Connect separate 12-volt batteries to each instrument by means of the cables provided. It is important to ensure that correct polarity is maintained at the battery terminal connections. Incorrect polarity will result in a blown fuse.

e. Switch both instruments to "Standby" and set the "Measure-Talk" switch to "Talk". Check the operation of the "Illumination" control.

f. Set the "Monitor" switch of one instrument to "Batt". Ensure that the left-hand meter reads over 10. A reading of 10 or less indicates a discharged battery.

g. Set the "Monitor" switch to +12. Ensure that the meter reads over 10.

h. Set the "Monitor" switch to "Oven". Observe the meter and ensure that the oven cycles. After an initial period the meter reading should drop from approximately 10 to 5 and should then cycle between 5 and zero.

i. Switch the instrument from "Standby" to "On" and wait 30 seconds.

j. Set the "Monitor" switch to "R.F." Turn the "Frequency" control from

1 to 12 slowly. Ensure that the meter reading remains over 4 throughout the entire range.

k. Repeat steps "f" to "j" with the second instrument.

l. Set the "Channel" selector on one instrument (Master) to M1, and the second selector switch to "Coarse". Set the "Frequency" control to the bottom stop below 1. Ensure that the "Signal" control is turned fully clockwise.

m. Set the "Channel" selector switch on the other instrument (Remote) to R1 and the secondary selector switch to "Coarse". Set the "Low-High" switch to "High" and the "Frequency" control to 4. Ensure that the "Signal" control is turned fully clockwise.

n. Set both "Monitor" switches to "Sig", and turn the "Frequency" control of the Master instrument clockwise until an increase in reading is obtained on the left-hand meter. A decrease in the noise in the headset will also be obtained at this point. When the instruments are in close proximity more than one tuning point may be obtained. The first one will be the correct one, however, and will give the highest meter reading. Turn the "Signal" control of both instruments anti-clockwise and ensure that the left-hand meter reading can be reduced to 5 on each instrument. After this check, ensure that both "Signal" controls are left in the fully clockwise position.

o. Switch both "Monitor" switches to "AFC" and by means of very small adjustments to the "Frequency" control set the left-hand meter reading to zero on the Master instrument. The direction of movement of the frequency control required to produce a given direction of change in the meter reading will depend on the position of the "Low-High" switch on the Remote instrument.

The left-hand meter on the Remote Instrument should read between + and -5.

p. Ensure that two-way communication is possible between the instruments.

q. After both instruments have been switched on for at least 15 minutes, set both "Measure-Talk" switches to "Measure".

r. Ensure that a steady audio tone (1.5 kc/s) is heard in both headsets. Adjust the volume controls and ensure that an adequate level is present.

Rotate the counter control of the Master instrument. Ensure that the right-hand meter swings from approximately -10 through zero to +10. The zero will be extremely unstable under these conditions and is not indicative of conditions in the field.

The right-hand meter on the Remote instrument should remain fixed at a reading of between + and -10.

s. Switch the Remote "Channel" selector switch to R_2 and repeat step "r". Switch both Master and Remote instruments to M_3, M_4, M_5, and M_6 and R_3, R_4, R_5, R_6 respectively and repeat step "r".

t. Switch the main "Channel" selector switch of the Master instrument to "M.F." and the secondary "Channel" selector switch to "M.FINE". Switch the main "Channel" selector switch of the Remote instrument to "R.F." and the secondary "Channel" selector switch to "R.FINE+". Repeat step "r".

u. Switch the secondary "Channel" selector switch of the Remote instrument to "R.FINE-" and repeat step "r".

v. Repeat steps "l" to "u" with the other instrument used as the Master.

When both instruments have passed these checks they are ready for field use.

Section 4. DETAILED OPERATING INSTRUCTIONS

19. General

Before going to the field, determine the following data:-

a. The location of stations to be used and the lines to be measured.

b. Time at which initial contact will be established, and procedure to be followed in the event of failure to establish contact.

c. Which of the two stations is initially to act as Master.

d. Initial Remote "Frequency" control setting. (A setting of 4 is normally used with the Remote "Low-High" switch switched to "High"). If some difficulty is expected in pointing the instruments and establishing contact it is advisable to tune the instruments to each other and establish the exact "Frequency" control setting for both instruments before going to the field.

e. Ensure that a set of meteorological equipment, a tripod and battery are available for each instrument.

f. Ensure that the approximate direction of the other station is known. If not, some difficulty may be experienced in establishing contact as the beamwidth of the instruments is extremely narrow (less than 2°). A compass or other aid may be required.

In cases where the direction is not easy to establish, the instrument can be pointed at a known object by means of the sight fitted to the tilting head. It can then be rotated through a pre-computed horizontal and vertical angle to ensure that it is beamed onto the other station. The tilting head is graduated in degrees for this purpose.

20. Pattern of Operation

The following general pattern of operation should be observed for all measurements:-

a. When on station, set up the tripod (or beacon adaptor) and tribrach and ensure that the tribrach is level and vertically over the point. Place the tilting head in the tribrach and fasten the clamp. Place the instrument on the tilting head and fasten the two clamps by means of the knurled knobs on either side.

Point the instrument in the approximate direction of the other station by means of the sight on the tilting head (see Paragraph 19f).

b. Remove the antenna cover from the instrument and connect the headset.

c. Connect the battery to the instrument by means of the cable provided. It is important to ensure that correct polarity is maintained at the battery terminal connections. Incorrect polarity will result in a blown fuse. If the internal battery is being used, insert the jumper plug into the "External D.C." socket. Switch the instrument to "Standby".

d. Switch the "Measure-Talk" switch to "Talk", and set the "Monitor" switch to "Batt". Ensure that the left-hand meter reads over 10. A reading of 10 or less indicates a discharged battery.

e. Set the "Monitor" switch to +12. Ensure that the meter reads over 10.

f. Set the "Monitor" switch to "Oven". Observe the meter and ensure that the oven cycles. After an initial period the meter reading should drop from approximately 10 to 5 and should then cycle between 5 and zero.

g. Switch the instrument from "Standby" to "On" and wait 30 seconds.

h. Set the "Monitor" switch to "R.F." Turn the "Frequency" control from 1 to 12 slowly. Ensure that the meter reading remains over 4 throughout the entire range.

i. Re-check the level of the tribrach and ensure that it is still vertically over the point. The weight of the instrument may have moved it, particularly if the legs of the tripod are not pressed firmly into the ground.

j. Steps "a" to "i" apply to both Master and Remote stations. From hereon the sequence at each station is as follows:-

21. Tuning In

MASTER	REMOTE
a. Set the main "Channel" selector switch to M1 and the secondary "Channel" selector switch to "Coarse". Set the monitor switch to "Sig" and ensure that the "Signal" control is turned fully clockwise.	a. Set the main "Channel" selector switch to R1 and the secondary "Channel" selector switch to "Coarse". Set the monitor switch to "Sig" and ensure that the "Signal" control is turned fully clockwise.
b. Set the "Low-High" switch to "Low" (see Paragraph 24) and the "Frequency" control to the bottom stop below 1.	b. Set the "Low-High" switch to "High" and the "Frequency" control to 4.

MASTER

c. Turn the "Frequency" control slowly clockwise until the left-hand meter reading increases. At the tuning point there will be a decrease in noise in the headset. More than one tuning point is possible, particularly at short range. The first one is the correct one, however, and will be indicated by the largest meter deflection. Adjust the "Frequency" control for a maximum deflection of this meter.
(With the Remote "Frequency" control set to 4 and the Remote "Low-High" switch set to "High", the Master should tune at a "Frequency" control setting of between 2 and 4 approximately.)
Establish two-way communication with the Remote.
Adjust the "Volume" control for a comfortable level.

d. If the position of the other station is visible, point the instrument accurately by means of the sight fitted to the tilting head. Lock the movement of the tilting head. If the location of the other station is not certain, turn the "Signal" control anti-clock wise until the left-hand meter reading is reduced to 5.
Adjust the direction in which the instrument is pointing, both vertically and horizontally, to obtain a maximum meter deflection.

REMOTE

c. Wait for the Master instrument to tune in. The left-hand meter reading should then increase accompanied by a decrease in noise in the headset. Two-way communication should now be possible. Adjust the "Volume" control for a comfortable level.

d. Wait for the Master instrument to beam accurately onto the Remote.

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MASTER

d. Continued.

Lock the movement of the tilting head and turn the "Signal" control fully clockwise. It is important to ensure that the instruments have been switched from "Standby" to "On" for at least two or three minutes before performing this operation, otherwise they may drift off tune. Instruct the Remote operator to adjust the direction of pointing of his instrument.
At ranges of less than 200 metres adjustment by means of the "Signal" control is not sufficiently accurate and the instrument should be pointed by means of the sight on the tilting head only (See Paragraph 25.f).

e. Wait for the Remote instrument to beam accurately onto the Master.

REMOTE

e. After receiving instructions from the Master instrument, adjust the direction of pointing of the Remote.
If the position of the other station is visible, point the instrument accurately by means of the sight fitted to the tilting head. Lock the movement of the tilting head.
If the location of the other station is not certain, turn the "Signal" control anti-clockwise until the left-hand meter reading is reduced to 5.
Adjust the direction in which

MASTER	REMOTE
	the instrument is pointing, both vertically and horizontally, to obtain a maximum meter deflection. Lock the movement of the tilting head and turn the "Signal" control fully clockwise. At ranges of less than 200 metres adjustment by means of the "Signal" control is not sufficiently accurate and the instrument should be pointed by means of the sight on the tilting head only. (See Paragraph 25 f.) Inform the Master operator when the adjustment is complete.
f. Switch the "Monitor" switch to "AFC" and by means of very small adjustments to the "Frequency" control, set the left-hand meter reading to zero. The direction of movement of the "Frequency" control required to produce a meter deflection in the required direction will depend on the position of the Remote "Low-High" switch.	f. Switch the "Monitor" switch to "AFC" and allow the Master operator sufficient time to adjust the "Frequency" control. The left-hand meter should read between + and - 5.

22. Initial "Coarse Readings

Ensure that both instruments have been switched to "Standby" or "On" for at least 15 minutes before attempting to take readings.

	MASTER	REMOTE
a.	Instruct the Remote operator to switch the "Measure-Talk" switch to "Measure", also switch the Master instrument to "Measure". A 1.5 kc/s measuring tone should be heard in the headset. Speech can be received with the "Measure-Talk" switch set to "Measure", but two-way communication is only possible with both switches set to "Talk".	When instructed by the Master operator, set the "Measure-Talk" switch to "Measure". A 1.5 kc/s measuring tone should be heard in the headset. Speech can be received with the "Measure-Talk" switch set to "Measure". but two-way communication is only possible with both switches set to "Talk". Switch the "Forward-Reverse" switch to "Forward".
b.	Rotate the "Counter" control to obtain a reading of zero on the right-hand meter. Two nulls exist for each rotation of the counter and only one is correct. In approaching the correct null the meter swings in the same direction as the "Counter" control is turned. While taking the reading it is important that the left-hand meter also reads zero (within ± 2 divisions). Slight adjustments to the "Frequency" control will ensure this. Record the reading displayed in the "Counter" window.	Ensure that the right-hand meter reading is between + and -10.
c.	Switch momentarily to M_3 and then back to M_2. This action interrupts the 1.5 kc/s tone in the Remote headset.	When the 1.5 kc/s tone in the headset is interrupted, switch to R_2.
d.	Check the presence of the 1.5 kc/s tone in the headset. Rotate the "Counter" control to obtain the correct null and record the reading as in "b".	Check the presence of the 1.5 kc/s tone in the headset. Ensure that the right-hand meter reading is between + and -10.

MASTER

e. Switch to M_3.

f. Proceed as above for M_3, M_4, M_5 and M_6.

g. Switch the "Measure-Talk" switch to "Talk" and instruct the Remote operator to do the same.

REMOTE

e. When the 1.5 kc/s tone in the headset is interrupted, switch to R_3.

f. Proceed as above for R_3, R_4, R_5 and R_6.

g. When instructed by the Master operator, switch the "Measure-Talk" switch to "Talk".

23. Fine Readings

MASTER

a. Instruct the Remote operator to take meteorological readings. Take initial meteorological readings (pressure and dry-bulb and wet-bulb temperatures) and record them and those obtained from the Remote in the appropriate places on the field record pad.

b. Instruct the Remote operator that "fine" readings will now be taken. Switch the main "Channel" selector switch to "MF" and the secondary "Channel" selector switch to "M.FINE".
Switch to "Measure"

c. Check the presence of the 1.5 kc/s measuring tone and rotate the "Counter" control to obtain the correct null.
Record the reading as before.
Remember to ensure that the left-hand meter reading is zero (within $\pm$ 2 divisions) while taking this reading.

d. Switch momentarily from "MF" to M_3 and back to "MF" to interrupt the 1.5 kc/s tone in the Remote headset.

REMOTE

a. When so instructed, take meteorological readings (pressure and dry-bulb and wet-bulb temperatures) and relay them to the Master operator.

b. When instructed that "fine" readings will be taken switch the main "Channel" selector switch to "R.F" and the secondary "Channel" selector switch to "R.FINE+".
Switch to "Measure".

c. Check the presence of the 1.5 kc/s measuring tone and ensure that the right-hand meter reading is between + and -10.

d. When the 1.5 kc/s tone in the headset is interrupted, switch to "R.FINE-".

MASTER	REMOTE
e. Take the reading as in "c" above	e. Check the presence of the 1.5 kc/s measuring tone and ensure that the right-hand meter reading is between + and -10.
f. Switch momentarily from "MF" to M3. and back to "MF".	f. When the 1.5 kc/s tone in the headset is interruptedm switch the "Forward-Reverse" switch to "Reserve".
g. Take the reading as in "e" above.	g. Check the presence of the 1.5 kc/s measuring tone and ensure that the right-hand meter reading is between + and -10.
h. Switch momentarily from "MF" to M3 and back to "MF".	h. When the 1.5 kc/s tone in the headset is interrupted, switch the secondary "Channel" selector switch to "R,FINE"+.
i. Take the reading as in "e" above.	i. Check the presence of the 1.5 kc/s measuring tone and ensure that the right-hand meter reading is between + and -10.
j. Record the "Frequency" control setting of the Remote, in this case 4. "Fine" readings are now complete on this setting. Switch the "Measure-Talk" switch to "Talk" and instruct the Remote operator to do the same.	j. "Fine" readings are now complete on this "Frequency" control setting. When instructed by the Master operator switch the "Measure-Talk" switch to "Talk".
k. Instruct the Remote operator to increase his "Frequency" control setting to 6. (See Paragraph 25 h). After allowing sufficient time for this to be done, tune the Master instrument to the Remote as described in Paragraph 21 c).	k. When instructed by the Master operator, increase the "Frequency" control setting to 6. Wait for the Master instrument to tune in as described in Paragraph 21 c. Switch the "Forward-Reverse" switch to "Forward" and the secondary "Channel" selector switch to "R.FINE+".

MASTER	REMOTE
l. Instruct the Remote operator to switch the "Measure-Talk switch to "Measure" and switch the Master instrument to "Measure".	l. When instructed by the Master operator, switch the "Measure-Talk" switch to "Measure".
m. Repeat a set of "fine" readings as in "c" to "j" above.	m. Repeat a set of "fine" readings as in "c" to "j" above.
n. "Fine" readings should be repeated, as above, with Remote "Frequency" control settings of 8, 10 and 12. This completes the full set of "fine" readings.	n. "Fine readings should be repeated as above with Remote "Frequency" control settings of 8, 10 and 12. This completes the full set of "fine" readings.
o. Instruct the Remote operator to take meteorological readings. Take final meteorological readings as in Paragraph 23 a. Instruct the Remote operator that the roles of Master and Remote will now be reversed.	o. When instructed by the Master operator, take final meteorological readings as in Paragraph 23 a.

24. Instrument Roles Reversed

A complete set of readings can now be taken with the roles of Master and Remote completely reversed. The following exceptions apply:-

The "Low-High" switch of the Master instrument should be set to "High" and the "Frequency" control set initially to 4. Subsequent readings can be taken at Master "Frequency" control settings of 6, 8, 10 and 12. It is the setting of the Master instrument which is recorded. With all these readings it should be the function of the Remote instrument, with its "Low-High" switch set to "Low", to tune to the Master. In other words each individual instrument should have its "Low-High" switch set to the same position, regardless of whether it is being used as a Master or a Remote.

Another complete set of readings can be taken both ways with the "Low-High" switches reversed. This is normally unnecessary, however, and may necessitate a slightly different zero correction being used. (See Paragraph 25 e).

When all readings are complete make a final check to ensure that the instruments are still vertically over the point. Switch the "On-Off-Standby" switch to "Off" and pack away the instruments.

25. Special Precautions to ensure Maximum Accuracy

In order to achieve the high degree of accuracy of which the MRA4 is capable, it is essential that certain precautions are taken.

a. When rotating the "Counter" control of the Master instrument to obtain a null on the meter, ensure that the correct null is always used. In each revolution of the "Counter" two nulls exist, only one of which is used to take data. In approaching the correct null the meter needle swings in the same direction as the "Counter" control is turned. In approaching the wrong null, differing from the first by a reading of 500 on the "Counter" dial, the meter reading swings in the opposite direction from the "Counter" control.

b. When taking these readings, ensure that the left-hand meter reading of the Master instrument is between + and -2. This can be set by means of small adjustments to the Master "Frequency" control.

c. Constant checks should be made to ensure that the tribrachs remain level and vertically over the point. If the legs of the tripod are not pushed sufficiently hard into the ground, or if the ground is soft, this setting may alter during the measurement.

d. Ensure that the tribrachs in use have accurately set levels and optical plumbs (See Paragraph 13).
Ensure that all meteorological equipment has been accurately calibrated. Mechanically aspirated psychrometers are preferable, particularly at low temperatures.

e. In order to obtain the maximum accuracy of which the instruments are capable, all measurements with a given pair of instruments should be done with one instrument selected to be switched to "High" and the other to "Low", regardless of whether they are used as Master or Remote. The zero error calibration should also be done under these conditions (See Paragraph 26). If the "Low-High" switches are reversed it may be necessary to apply a slightly different zero correction.

f. Due to the narrow beamwidth of the instruments, it is most important to ensure that they are accurately pointed. If the antennae are pointed more than $\frac{1}{2}^{o}$ away from the correct direction, errors can occur. The tilting heads are fitted with a sight which can be used when inter-visibility between the two stations is good. Alternatively, the instruments can be pointed by means of the "Signal" control as described in Paragraph 21 d. At ranges of less than 200 metres the instruments should be pointed by means of the sight only as adjustment by means of the "Signal" control is not sufficiently accurate.
It is important to ensure that the sight on the tilting head is accurately aligned with the antenna. This can be checked by measuring on a line of at least 1 kilometre. The instruments are pointed by means of the "Signal" control and the sight is checked to ensure that it is also pointing within $\frac{1}{2}^{o}$ of the far station. This check should be made fairly regularly as slight structural damage can easily upset the alignment of the antenna.
It is advisable to always use the same tilting head with a particular instrument. In this way slight errors, which may be present in the alignment of the centres, can be avoided by incorporating them into the zero correction.

g. The "Coarse" difference readings as recorded on the field record pad (Fig. 1) should be examined. Check that the second digit of each difference reading agrees with the first digit of the difference reading recorded immediately on its left. If there is a difference exceeding $\pm$ 3 between the corresponding digits of any two patterns, the "Coarse" readings should be repeated with a different "Frequency" control setting. A difference of $\pm$ 5 between the corresponding digits of any two patterns will result in an ambiguous result for the final distance.

h. "Fine" readings are normally taken at "Frequency" control settings of 4, 6, 8, 10 and 12. These settings apply to the instrument which has its "Low-High" switch set to "High". Although these settings normally give enough "fine" readings, In cases where a large spread in the readings is obtained, more settings of the "Frequency" control can be used. In cases where a slight reduction in accuracy can be tolerated, only one "Frequency" control setting need be used. In this case it is important to ensure that the particular pair of instruments has been calibrated for zero correction for this particular setting as this zero correction may be slightly different.

i. Due to the fact that the electrical and mechanical centres of the instrument do not coincide, a zero correction has to be subtracted from the measured distance to obtain the true distance. The correction is printed on the front panel of the instrument and is only provisional. This correction is applied only once to each measurement and not at each end of the line. To achieve maximum accuracy a given pair of instruments should be individually calibrated for zero correction. (See Paragraph 26). If more than one pair of instruments is being used for measurements, each combination should be accurately calibrated for zero correction.
Although it is not anticipated that the zero correction will vary with time for any given pair of instruments, it is advisable for this to be checked from time to time, especially if any repairs have been made to the microwave section, or any structural damage has occurred.

26. Method of determining the Zero Correction

The zero correction for a given pair of instruments can be determined by taking measurements on a number of lines whose length is accurately known. At least 4 or 5 good lines varying in length from about 100 to 300 metres should be measured to obtain an accurate correction. The mean of the differences between the true distances and the measured distances is the zero correction.

It is quite possible to calibrate a pair of instruments for zero correction without having accurately taped baselines available. Approximately four points should be selected on a straight line an arbitrary distance apart and the distances between each pair of points, and also the overall distance measured, viz.:-

$$\cdot \longleftarrow (S_1 = d_1 + Z) \longrightarrow \cdot \longleftarrow (S_2 = d_2 + Z) \longrightarrow \cdot$$

$$\text{overall} \quad S_3 = (d_1 + d_2) + Z$$

thus $Z = S_1 + S_2 - S_3$ where S_1, S_2, S_3 are the observed readings

Z = zero error

d_1, d_2 = unknown distances

A number of different combinations should be used to obtain the most accurate result. The zero correction for a given pair of instruments may depend on the position of the "Low-High" switches. To overcome this the pair should be calibrated with the switch of one particular instrument set to "High" and the other to "Low" regardless of whether they are used as Master or Remote.

If it is intended to take readings at one "Frequency" control setting only, the pair should be calibrated at this setting.

Section 5. OPERATION UNDER NORMAL CONDITIONS

27. Operation over Land

Although, in principle, any line over which it is possible to transmit and receive signals can be measured by the TELLUROMETER system, circumstances may be such that a choice of sites for the instruments can be made. This applies particularly to surveying in country where beacons either do not exist or need not be used. As operation at sites with suitable properties may improve accuracy and ease of measurement, some attention should be paid to their selection.

Two factors influence the choice of a line for good working: reception of signals, and ground reflection.

In the first place, the line should be free from obstructions. Furthermore, the cone of the radio beam (2° wide) should not be obstructed for the first hundred feet. This point can be assured by raising the instrument about 6 feet, if the ground is level, or selecting a site that falls gradually from the station for at least 100 feet.

28. Operation over Water

Certain conditions of water surface, such as a very choppy sea, can cause scattering of the indirect ray in a similar manner to rough ground, but, in general, the conditions are similar to flat, bare ground.

An additional effect is a regular or irregular change in the length of the indirect ray, caused by a vertical rise and fall of the surface produced by swell. This rise and fall results in a changing of the relative phase of the direct and indirect rays in the same way as does a change of carrier frequency. Thus, if the carrier frequency were kept constant, the readings would nevertheless swing about a mean value; in principle, it would be sufficient to average this swing instead of obtaining a swing by frequency diversity. In practice, however, an operator cannot be certain that a full swing has been developed, and the method of frequency diversity must be carried out.

Since swell can introduce errors even though frequency diversity is employed, sites at which the ground obscures the water surface from the instruments are to be preferred. There will then be no reflection from the water.

29. Meteorological Effects

The final limiting factor in obtaining maximum accuracy at medium and long range is the effect of meteorological conditions, the procedure set out in this Manual for normal meteorological corrections being adequate for most purposes. This procedure assumes that the meteorological conditions are constant or vary uniformly along the line. If neither condition exists, an error in measurement can result, the error at times being quite appreciable.

Because there is often no way of determining the meteorological conditions along the line, the best procedure is to carry out measurements during periods of certain weather conditions.

Fine, dry, sunny weather, which induces vertical air currents, is ideal. A fair breeze, blowing along the line, is to be preferred to any other type of wind. Night measurements thus tend to be less accurate than day measurements.

In damp climates, measurements on cooler days will be more accurate than those on warmer days, when the vapour pressure may be higher. In coastal areas, anomalies may be experienced, owing to variations in vapour pressure along the line; however, in general, vapour pressure is constant over large areas and changes slowly with time.

If meteorological variations along the path are suspected, observations could be made at mid-path or elsewhere as a check. However, these observations will be representative only on shallow lines, where the ray path is always near the ground. When the ray path is much elevated, surface observations at mid-path will not be representative, and no gain will result from this procedure.

CHAPTER 4

COMPUTATIONS

Section 1. REDUCTION OF READINGS

40. General

This section describes the method to be adopted by the Master operator to record the instrument readings on the field record sheet (See Fig. 1). It also describes the subsequent reduction of readings to a measure of linear distance, and the method of correcting for refractive index from recorded meteorological readings.

41. Recording

a. Fill in the station data at the top of the field record sheet. These data include the instrument serial number, operator's name, station identity, date and time.

b. Record the height of the instrument above the point. This can be measured to any convenient place on the instrument, provided the same place is used for both Master and Remote.

c. All recording of "Frequency" control settings must be taken from the instrument which has its "Low-High" switch set to "High". The switch should remain in this position while the instrument is used as both Master and Remote. Record the serial number of this instrument.

d. Record the zero correction. The zero correction printed on the front panel of the instrument is only provisional and for maximum accuracy a given pair of instruments should be individually calibrated. (See Paragraph 26).

e. Record the "coarse" readings under $M_1, M_2, M_3, M_4, M_5, M_6$, in the table. Also record the "Frequency" control setting at which these readings were taken.

f. Record the "fine" readings in the table and the "Frequency" control settings at which they were taken.

g. Record two sets of meteorological readings both before and after the "fine" readings are taken. Also record those obtained by the Remote, and the time at which they were taken, in the table.

h. Record the weather conditions and any other conditions relating to the site.

i. When the roles of Master and Remote are reversed, a separate field record sheet should be completed by the other operator.

42. <u>Obtaining the Distance</u>

a. Underneath the readings obtained for M_2, M_3, M_4, M_5 and M_6, fill in the M_1 reading. Subtract the reading obtained for M_1 from M_2, M_3, M_4, M_5, and M_6 and fill in the results in the squares marked "diff". These are the "coarse" difference readings. If the M_1 reading is greater than the reading from which it is to be subtracted add 1000 to the top figure.

b. Subtract the "R.Fine-" from the "R.Fine+" readings and fill in the results in the squares marked "diff". This must be done at each "Frequency" control setting for both "Forward" and "Reverse" readings. Take the mean of "Forward" and "Reverse" readings for each "Frequency" control setting and fill in the results in the right-hand column marked "Mean". These are the "fine" difference readings. Take the mean of the "fine" difference readings and fill in the result in the space opposite "Mean of fine readings".
In cases where a particularly large spread in "fine" readings is obtained, a different procedure is adopted to obtain the mean. (See Paragraph 43).

c. Fill in the M_6, M_5, M_4, M_3 and M_2 difference readings in the squares on the right-hand side of the field record sheet, only the first two digits of each reading need be used. Also fill in all three digits of the figure obtained for the mean of the "fine" readings. The second digit of each figure should agree with the first digit of the figure immediately below it. If the digits differ by more than $\pm$ 3 the "coarse" readings should be repeated at a different "Frequency" control setting.

d. To obtain the uncorrected distance, first write down the 3 digits of the mean of the "fine" readings, each one directly below the square in which it appears. Correct the M_2 difference figure by not more than $\pm$ 3 digits so that the last digit agrees with the first digit of the figure directly below it. Write down the first digit of the corrected M_2 difference figure directly below the square in which it appears. Correct the M_3, M_4, M_5 and M_6 difference figures in the same way and write down the first digit of each. The sample field record sheet (Fig.1) is a good example. The mean "fine" reading 945 is written down first. The M_2 difference reading 80 is corrected so that the last digit agrees with the first digit of the mean "fine" readings. As a correction of more than $\pm$ 3 is not allowed this corrected figure becomes 79 and not 89 as might be at first supposed. The figure 7 is then recorded next to 945. The first digits of the corrected M_3, M_4, M_5, and M_6 readings are recorded in the same way. The final result is the uncorrected distance in millimetres and should be recorded opposite the word "Distance" at the bottom of the field record sheet.

e. Add the zero correction (this correction is negative) which is applicable to the pair of instruments being used and fill in the result opposite "Distance + zero correction". This correction is only added once and not at each end of the line.

f. From the recorded meteorological data subtract the wet-bulb temperature from the dry-bulb temperature for each reading and fill in the result in the column marked "diff".

Determine the R.I. (refractive index) correction in parts per million of the distance measured by referring to the nomogram (Figs.3 & 4).

In cases where a nomogram is used that gives the value of N = $(n - 1)10^6$ (where n = refractive index) subtract 325 from this value of N if it is greater than 325. The result is the R.I. correction in parts per million and is negative. If the value of N obtained is less than 325 subtract this value from 325. The result is the R.I. correction in parts per million and is positive.

Multiply the R.I. correction (p.p.m.) by the uncorrected distance in kilometres to obtain the R.I. correction in millimetres. Add or subtract this correction, as the case may be, to the distance + zero correction to obtain the final corrected distance in millimetres. Refer to the sample field record sheet (Fig.1) for an example.

Alternatively, the value of refractive index (n) can be calculated from the formula given in Fig. 3. The distance plus zero correction is then multiplied by $\frac{1.000325}{n}$ to obtain the final corrected distance.

g. When the roles of Master and Remote have been reversed, compare the two figures obtained for the final corrected distance and take the mean.

43. Interpretation of Error Swings

When measuring over long distances a large spread in "fine" readings is often obtained. If this is due to random noise and fluctuations in meteorological conditions, such as rising air currents, the right-hand meter will fluctuate continuously and it will be difficult to obtain a null reading. Under such conditions the readings obtained at different "Frequency" control settings will not necessarily be repeatable and it is advisable to take more readings before taking the mean. The same effect may be observed, even on very short lines, when taking readings over moving water. In this case the errors are due to reflections off the water and once again the best results will be obtained by taking more readings to obtain the mean.

Occasionally a line may be measured which produces a large spread in "fine" readings, but the readings are steady and repeatable. This effect is due to ground reflections and to obtain an accurate result it is best to plot a graph of reading against "Frequency" control setting. If the graph displays a cyclic variation take the mean of a whole number of cycles only. If the readings appear to be random, take the arithmetic mean as before.

An excessively large spread in "fine" readings will be obtained if the instruments are not pointed accurately at each other. In such cases it is advisable to check the alignment of the sight fitted to the tilting head (See Paragraph 25 f).

CHAPTER 5

FAULT FINDING PROCEDURE

44. General

Only minor repairs should be attempted in the field. Major repairs, such as those requiring the re-alignment of tuned circuits, should be carried out only at maintenance depots and by qualified technicians equipped with suitable apparatus.

45. Operating Faults

a. Wrong monitor reading BATT:-

Probable Cause	Possible Remedy
Dead battery	Recharge or replace battery
Wrong polarity of input voltage.	Change to correct polarity and replace 5 amp fuse.
24-volt battery connected 12-volt cable	Connect correct cable and replace 5 amp fuse.
Defective power supply	Replace power supply

b. Wrong monitor reading +12:-

Probable Cause	Possible Remedy
Power supply output disconnected	Plug in output connector
Defective power supply	Replace power supply

c. Wrong monitor reading Oven:-

Probable Cause	Possible Remedy
Power supply cable disconnected.	Connect cable

Probable Cause	Possible Remedy
Oven connector not plugged in.	Plug in connector.
Defective oven	Replace oven.

d. Wrong monitor reading RF:-

Probable Cause	Possible Remedy
Mixer cable disconnected	Connect cable.
IF input cable disconnected	Connect cable.
Defective mixer crystal	Replace crystal
Defective klystron	Replace klystron
Defective power supply unit	Replace power supply unit.

e. Wrong monitor reading Sig:-

Probable Cause	Possible Remedy
No received signal	Tune the instruments.
IF unit disconnected	Plug in IF connector
IF unit defective	Replace IF unit
"Signal" control turned anti-clockwise	Turn control clockwise.

f. Wrong monitor reading AFC:-

Probable Cause	Possible Remedy
IF connector not plugged in	Plug in IF connector
IF unit defective	Replace IF unit

g. AFC does not lock in:

Probable Cause	Possible Remedy
"High-Low" switch in wrong position	Set switch in correct position.
Defective I.F.unit	Replace I.F. unit

h. No voice communications from headset:

Probable Cause	Possible Remedy
Headset not connected	Connect headset
Defective headset	Replace headset
Defective 70 kc/s detector board	Replace 70 kc/s detector board

i. No tone in headset:

Probable Cause	Possible Remedy
Either or both "Measure"Talk" switches set to "Talk".	Set both switches to "Measure"
"Channel" switch set to wrong position	Set switch to correct position
Defective crystal oscillator	Replace crystal oscillator
Defective modulator board	Replace modulator board

46. To ensure maximum accuracy it is advisable for the Master crystal frequencies to be checked twice per annum. This should be carried out by a qualified technician in accordance with the table below:-

Position	Crystal	Frequency (Mc/s)	Tolerance (p.p.m.)
M_1	Y_1	7.492377	± 1
M_2	Y_1	7.492377	± 1
M_3	Y_2	5.993902	± 1
M_4	Y_3	7.342530	± 1
M_5	Y_4	7.477393	± 1
M_6	Y_5	7.490879	± 1

MRA 4 TELLUROMETER FIELD SHEET

MASTER		REMOTE
STATION ALPHA	TO	STATION BRAVO
INSTRUMENT NO. 1001		INSTRUMENT NO. 1002
OPERATOR [illegible]		OPERATOR [illegible]
DATE 23/2/67 TIME 14.40		HEIGHT OF INSTRUMENT 3'11"
FREQUENCY CONTROL SETTINGS TAKEN FROM		INSTRUMENT NO. 1002 (HIGH)
		ZERO CORRECTION −131 m.m.

COARSE READINGS.

FREQUENCY CONTROL SETTING 4

M1	M2	M3	M4	M5	M6
524	325	003	074	780	551
	624	524	524	524	524
Diff.	801	479	550	256	027

FINE READINGS

FREQUENCY CONTROL SETTING		FOR.	REV.	MEAN
4	RF +	895	395	
	RF −	952	451	
	Diff.	943	944	943·5
6	RF +	895	395	
	RF −	951	452	
	Diff.	944	943	943·5
8	RF +	897	398	
	RF −	950	449	
	Diff.	947	949	948
10	RF +	898	397	
	RF −	949	450	
	Diff.	949	947	948
12	RF +	895	395	
	RF −	952	451	
	Diff.	943	944	943·5

MEAN OF FINE READINGS 945

M6 Diff.	0	2						
M5 Diff.		2	5					
M4 Diff.			5	5				
M3 Diff.				4	7			
M2 Diff.					8	0		
MEAN FINE						9	4	5

DISTANCE 0 2 5 4 7 9 4 5 m.m.

METEOROLOGICAL READINGS

		TIME	DRY BULB	WET BULB	DIFF.	PRESS.	R.I. CORRECT.	CONDITIONS.
INITIAL	MASTER	14.45	62°F	59°F	3°	30·0 ins.	−17	S.E. Wind approx 10 knots.
	REMOTE	14.45	61°F	58°F	3°	30·0 ins.	−15	
FINAL	MASTER	14.50	63°F	60°F	3°	30·0 ins.	−19	
	REMOTE	14.50	62°F	59°F	3°	30·0 ins.	−17	

MEAN R.I. CORRECTION (p.p.m) −17

MEAN R.I. CORRECTION (m.m) −43

DISTANCE 2547945 m.m.

DISTANCE + ZERO CORRECTION 2547814 m.m.

DISTANCE + ZERO CORRECTION + R.I. CORRECTION 2547771 m.m.

FIGURE 1.

REFRACTIVE INDEX OF RADIO WAVES

(EXTENDED RANGE)

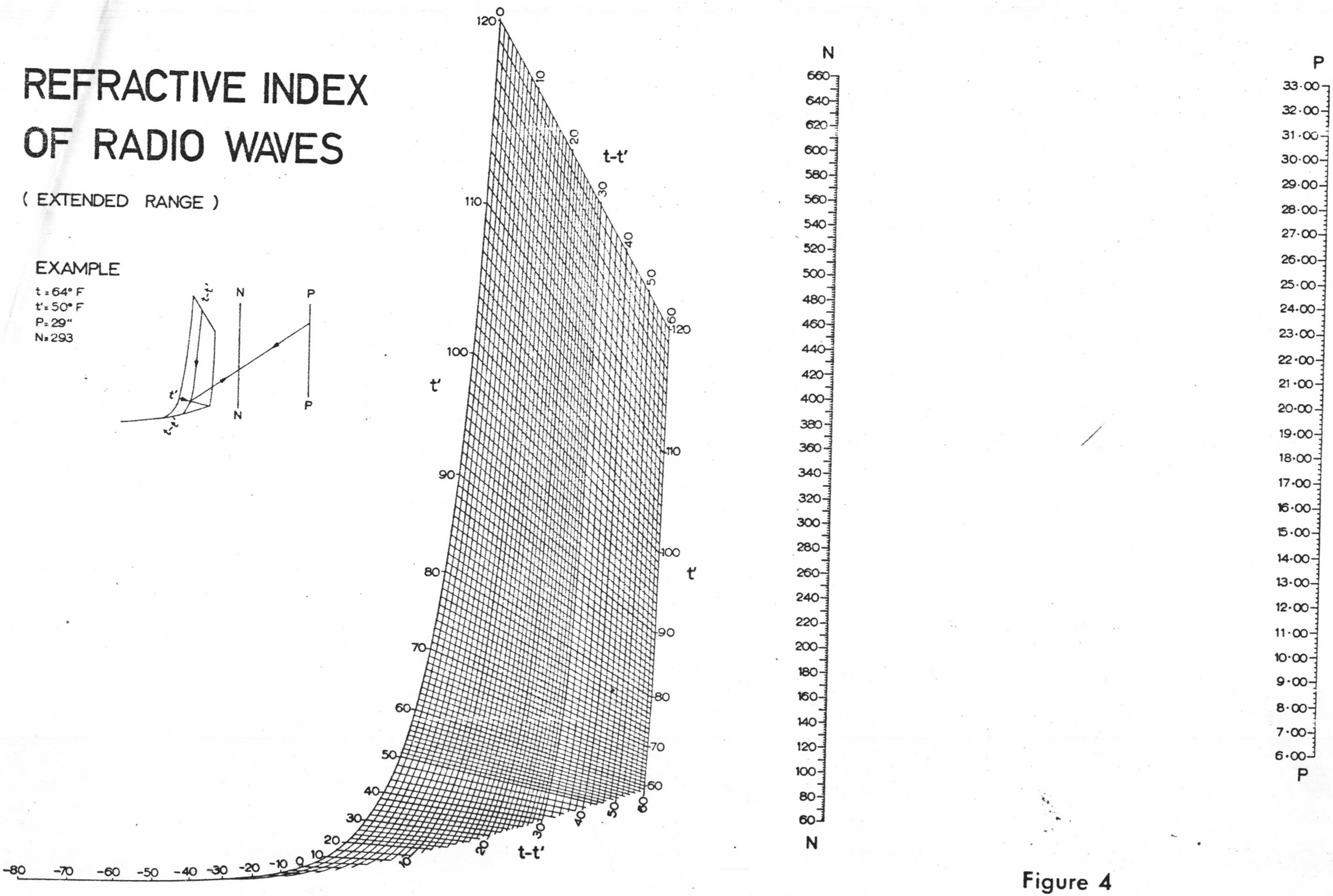

Figure 4