# microwaves

## *for students*

MICROWAVE INSTRUMENTS LIMITED . NORTH SHIELDS . NORTHUMBERLAND . TELEPHONE NORTH SHIELDS 70351

# INDEX

**INTRODUCTION**

*advantages of*

# STUDENT SERIES

| | |
|---|---|
| 1 | Wide Range of Microwave components.<br>Specially designed for educational needs. |
| 2 | Kit Covers a complete range of demonstrations and experiments both:—<br>Microwave.<br>Vary from attenuation calibration to a private Microwave link.<br>Optical.<br>Adjustment at 3.2 cm. is far less critical that at optical wave lengths.<br>No need to darken room for optical experiments. |
| 3 | Components either bought separately or as a kit. |
| 4 | Two kits available.<br>(a) Standard kit to cover all experiments (Microwave and Optical).<br>(b) Optical kit to cover Optical experiments. |
| 5 | Kits can be expanded by inexpensive components fabricated in Laboratory Workshop to cover additional experiments. |
| 6 | Complete list of recommended experiments provided. |

MICRO WAVE

EID & ARB INSPECTION. ARB DESIGN APPROVED


**Microwave Instruments Limited**

*The Microwave Specialists of the Hilger and Watts group*

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## STUDENT SERIES — PART ONE

### *Microdesk W16 10*

The Microdesk is the basic unit for the experiments listed in Part II. Self-contained, it incorporates two fixed and stabilised supplies (resonator and heater) and one variable stabilised supply (reflector) to the KS9-20 Klystron. Particular emphasis has been placed on the robustness and reliability needed for Student's work (e.g. paper capacitors rather than electrolytic have been used throughout).

#### BRIEF SPECIFICATION

| | | |
|---|---|---|
| Output power | 15 mW | through flanged W16 waveguide. |
| Frequency | Variable | by knob on front panel within the waveband 8.7 – 9.5 Gc/s. |
| Modulation | Internal | 100 c/s derived from main supply. |
| | External | To the Klystron reflector via a coaxial socket from external variable source. |
| Input | 190v–270v 50 c/s only. | |

Other checkpoints and controls.

| | |
|---|---|
| Klystron current | check by external milliammeter through jack socket |
| Klystron reflector voltage | Controlled by calibrated scale on front panel. |

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### *Demonstration Amplifier W16 15*

This instrument provides:—

(a) External A/F to modulate the Microdesk (W16 10) by means of a variable frequency square wave generator.

(b) Amplification of the detected signal received from a crystal mount (see W16 120) sufficient to drive the internal loud speaker and a signal output for connection to a standard oscilloscope.

#### MAIN FEATURES

Three stage Amplifier.

Outputs (a) Internal loud speaker with own volume control.

(b) Fixed gain output to a coaxial socket for standard oscilloscope.

A/F Modulator (150–1500 c/s).

Inputs (a) Coaxial connection for Crystal mount.

(b) Main connection 190 volts – 270 volts. 50 c/s.

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## *Transistor Amplifier TA3*

The Transistor Amplifier is a highly sensitive audio amplifier and indicator specially designed for use with microwave test benches. It has two inputs which may be used separately or added together for bridge circuits in order to obtain a sharp null when two crystal mounts of opposite polarity are used.

### BRIEF SPECIFICATION

| | SELECTIVE | WIDEBAND |
|---|---|---|
| Sensitivity better than | 2 μv f.s.d. | 20 μV f.s.d. |
| Noise at full gain | 3% | 3% |
| Frequency response | 1 kc/s or 3.2 kc/s<br>± 150 c/s | 150 c/s to<br>10 kc/s. |

### LEAFLET TA3 GIVES FULL DETAILS

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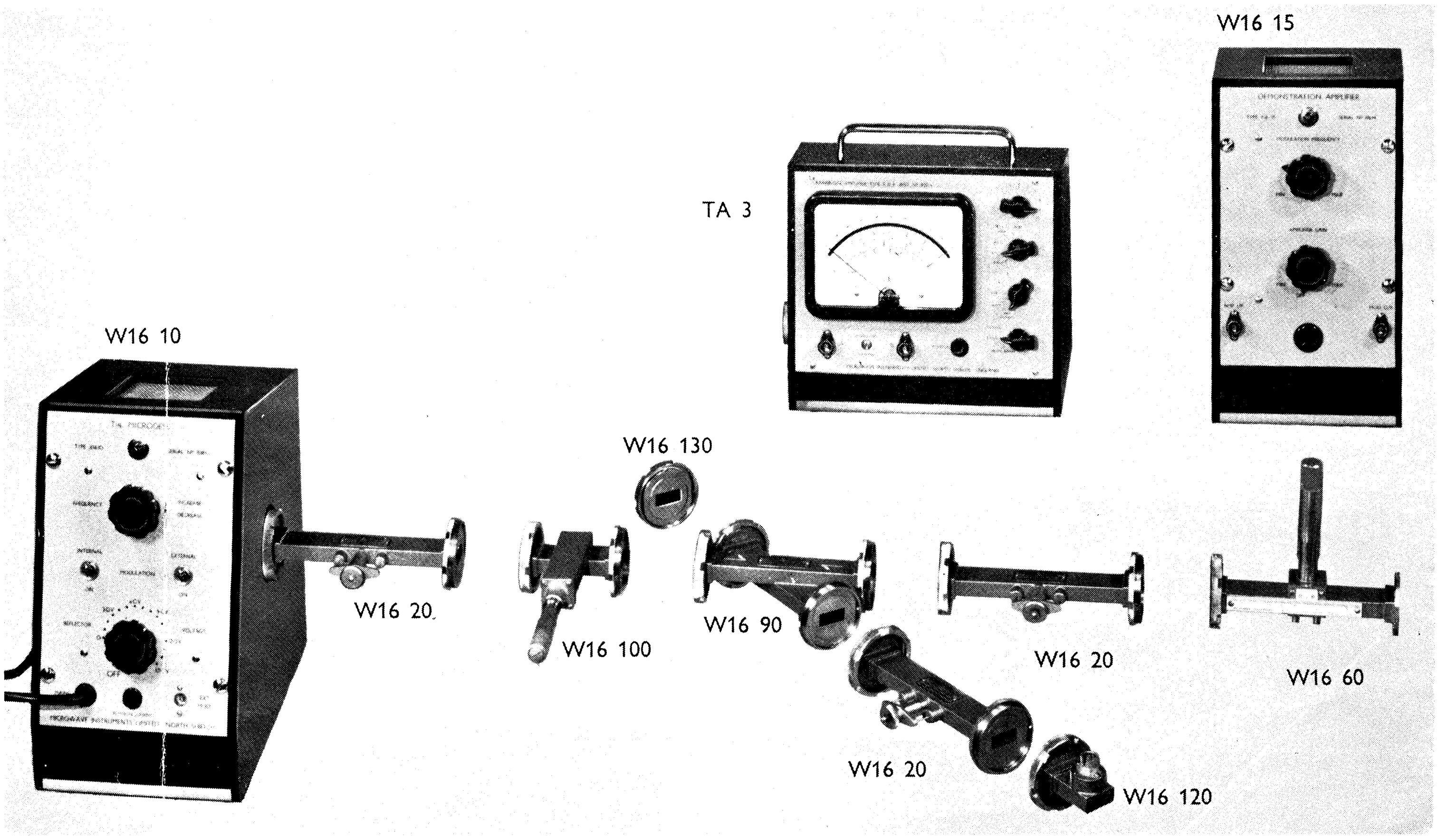
In this photograph waveguide supports have been omitted and the individual items separated for clarity. The arrangement of W16 90 is such that W16 120 will monitor reflected power.
By replacing W16 130 with another W16 120 forward power may also be monitored on a meter which will also serve to register the tuning point of W16 100.



## *Variable Attenuator W16 20*

The variable attenuator is used whenever it is required to adjust the power level in the waveguide; for instance when it is necessary to reduce the incident power to a crystal detector. Used at the output of the Microdesk it both controls the power to the particular experiment and reduces the effect on the Klystron of any reflections along the waveguide. The attenuator consists of a resistive card vane mounted on two rods which pass through the narrow face of the waveguide, suspending the vane with its plane parallel to the narrow face; as the vane is moved in towards the centre line it gives a greater attenuation. The vane ends are tapered to prevent wave reflections. The attenuator has a range of 0—30 dB with a V.S.W.R. better than 0.95, and is fitted with a millimetre scale.

## *Isolator W16 164*

A straight section of waveguide fitted with a ferrite vane is supplied together with a loose magnet in order to demonstrate the directional attenuation due to the presence of the magnetic field and the effect of polarity on direction. Used instead of the attenuator after the Microdesk it isolates the klystron from subsequent mismatches without reducing the forward power. An electromagnet can be used to modulate the microwave flow in the waveguide.

## *Directional Coupler W16 90*

The directional coupler is a 4-port device in which, taking the main waveguide as between Ports 1 and 2, a fixed percentage of the power flowing in the main waveguide appears at either Port 3 or Port 4 depending upon the direction of flow in the main waveguide. With reflection-free flow in the main waveguide the attenuation difference between the outputs 3 and 4 is the Directivity.

Using the device to sample the power flow enables either a bridge circuit to be used or the frequency to be measured by mounting a frequency meter followed by a crystal mount on the appropriate secondary arm. Normally a load terminates the fourth arm; it will be seen that a crystal detector on each output arm will produce a simple reflectometer although normally two directional couplers are employed to avoid direct interaction between the crystal mount reflections.

The W16 90 directional coupler is available with coupling values of 20, 30 or 40 dB which should be specified, when ordering, as a suffix to the catalogue number, e.g. W16 90/30 dB. 20 dB (100:1) is recommended for general use.

## *Frequency Meter W16 100*

In order to find the frequency of the microwave power in a waveguide, some of the power is allowed to enter a cavity through a coupling hole. The cavity length is adjusted by a micrometer actuated plunger until it is an integral number of half wavelengths when it will resonate and absorb power. This condition is indicated by a sharp drop in output from a crystal detector mounted further along the waveguide system. The frequency is then obtained by comparing the micrometer reading with the calibration chart provided. The cavity is designed to have only one mode of resonance and while other measurements are being made, the meter should be tuned off resonance in order to avoid interaction.

| | |
|---|---|
| **Calibration Range** | 8.4 – 10.12 Gc/s. |
| Accuracy | ± 2 parts in $10^4$. |
| Resonance mode | $H_{10}$ absorption. |
| Micrometer discrimination | 1.7–0.7 Mc/s. |
| Q | 3000 approx. |

## *Crystal Mounts:*
## *Positive Output W16 120 — Negative Output W16 122*

The crystal mounts are used in detecting the microwave energy in the waveguide. A crystal diode rectifies the microwave power to give a D.C. output which, with stronger signals, can be shown on a galvanometer or directly on the 100 microamp movement of the TA3.

To obtain appreciably higher sensitivity the klystron is modulated at an audio frequency by a square wave (provided by the Demonstration Amplifier W16 15) when the output from the crystal mount can then be A.C. amplified and presented aurally by the loudspeaker of the W16 15 or visually on the meter of the TA3.

The negative output mount W16 122 is used in a microwave bridge to balance the output either from the positive output mount or from the standing-wave indicator.

## *Standing-Wave Indicator W16 60*

Where there are discontinuities in the waveguide, reflections occur which result in standing waves. The measure of reflection is called the voltage standing wave ratio (V.S.W.R.) which is the ratio of minimum to maximum standing wave voltage.

The V.S.W.R. may be obtained using a standing-wave indicator; this consists of a length of waveguide with a slot cut accurately along the centre of its broad face. A probe with fixed penetration is moved by hand to traverse the slot and is connected via a tuned coaxial line to a crystal detector. Due to the nearly square law characteristic of the crystal the V.S.W.R. is given, in British convention, by the ratio

$$\sqrt{\frac{Imin}{Imax}}$$

This simple standing-wave indicator is quite adequate for student use, having a maximum error of 0.03 V.S.W.R. For more accurate work our Grade I or II instrument should be used.

## *Smith Charts W16 62*

Packs of 25 Smith Charts (circle diagrams) are available to record measurements of V.S.W.R. in phase and amplitude, and to assist in impedance calculations and matching.

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## *Load/Short Circuit W16 40*

This is a dual-purpose component to give either a complete match or total reflection. It consists of a length of waveguide open at one end so that a tapered wedge of iron-loaded resin or a short-circuiting plunger can be inserted. In the former case virtually all the incident power is smoothly absorbed by the load so that there is very little reflection and the waveguide is matched to a V.S.W.R. better than 0.97. On inserting the shorting plunger all the power is reflected, producing a high standing wave. The shorting plunger has a choke section so that the shorting face does not contact the waveguide electrically. The position of the plunger determines the phase of reflection.

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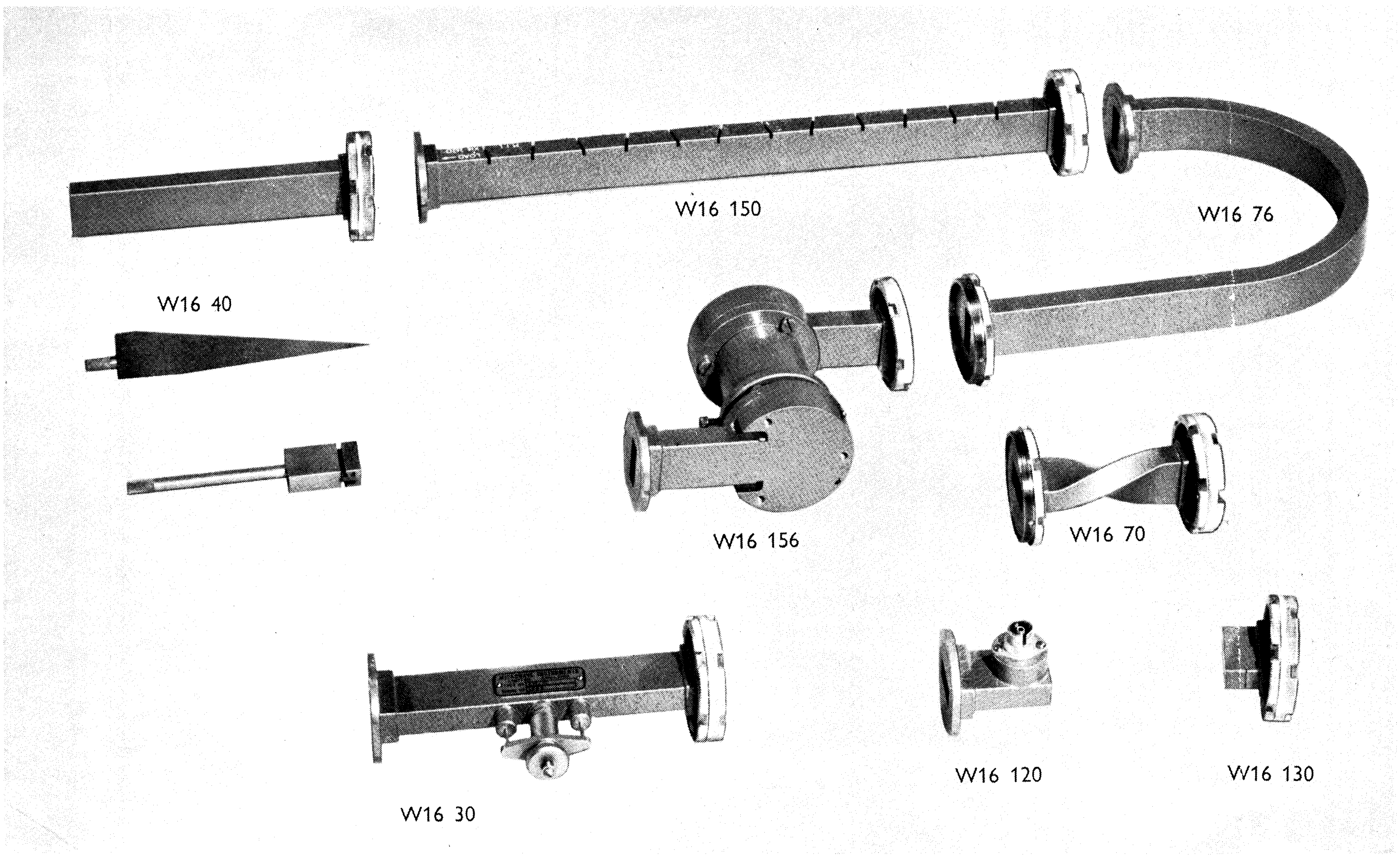
## *Terminating Cap W16 130*

The terminating cap is a second-quality dummy load used, for instance, to terminate the reverse arm of the directional coupler. It consists of a pyramidal cone of lossy material inserted in a short length of waveguide. The V.S.W.R. is better than 0.8 at 9.375 Gc/s.



## *Tuner, Variable WX 820*

A variable reactance is used to create a standing wave of variable amplitude and phase and is normally used to 'tune out' or cancel an existing unwanted standing wave. It consists of a screw probe which has adjustable penetration into the waveguide for amplitude control and is adjustable in position along the centre line for phase variation.

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## *90° Bend: H-Plane W16 50 — E-Plane W16 52*

Bends are often necessary in coupling up waveguides on special installations. These samples also demonstrate the manipulation of waveguide and the relative reflections caused by such. The W16 50 has a centre-line radius of 3″ and V.S.W.R. better than 0.95. The W16 52 centre-line radius is 2¾″ and V.S.W.R. better than 0.96.

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## *90° Twist W16 70*

The plane or polarization of propagation may need to be changed, for example, for a horn output or radiation plotter. This can be done most easily by inserting a 90° twist. The V.S.W.R. is better than 0.95.

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## *180° Phase Shifter W16 30*

The speed of propagation of radio waves differs in different substances. If a dielectric is inserted in the waveguide the effective length of the guide is increased, producing a phase change in the output. Variation of phase is obtained by moving a dielectric vane across the waveguide in a manner similar to that used in the attenuator. The range of phase shift of the W16 30 is 180°, with a V.S.W.R. better than 0.9.

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## *Free Standing Support W16 80 (WX 19)*

The Microdesk itself provides the initial support for a waveguide run; free standing supports are used beyond this, and similarly provide a stable base for detached waveguide items such as receiving aerials in radiation experiments.

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## *Taper Cut-off Unit W16 158*

The taper cut-off is similar in construction to the standing-wave indicator except that, after a section of normal guide size, the broad dimension tapers from 0.9″ to 0.4″. Thus, using the long slot, the probe unit is able to traverse into the region below cut off. As the broad face is reduced relative to the free space wavelength the guide wavelength increases as is seen by the increasing distance between the standing wave nulls. Eventually cut-off is reached, after which attenuation in dB is approximately proportional to distance.

## *Dielectric Chamber W16 142*

Where measurements on dielectrics are required, the dielectric chamber is used to terminate the waveguide. It consists of a short length of waveguide with a brass shorting plate lapped flat and held in place by a standard coupling ring. The dielectric constant of solids which are machined to fit accurately in the chamber are then compared. The size of dielectrics should be slightly under 0.9″ x 0.4″ and up to 0.25″ thick. Using a grade 1 S.W.I. to find the difference in V.S.W.R., the loss angle (power factor) can also be obtained.

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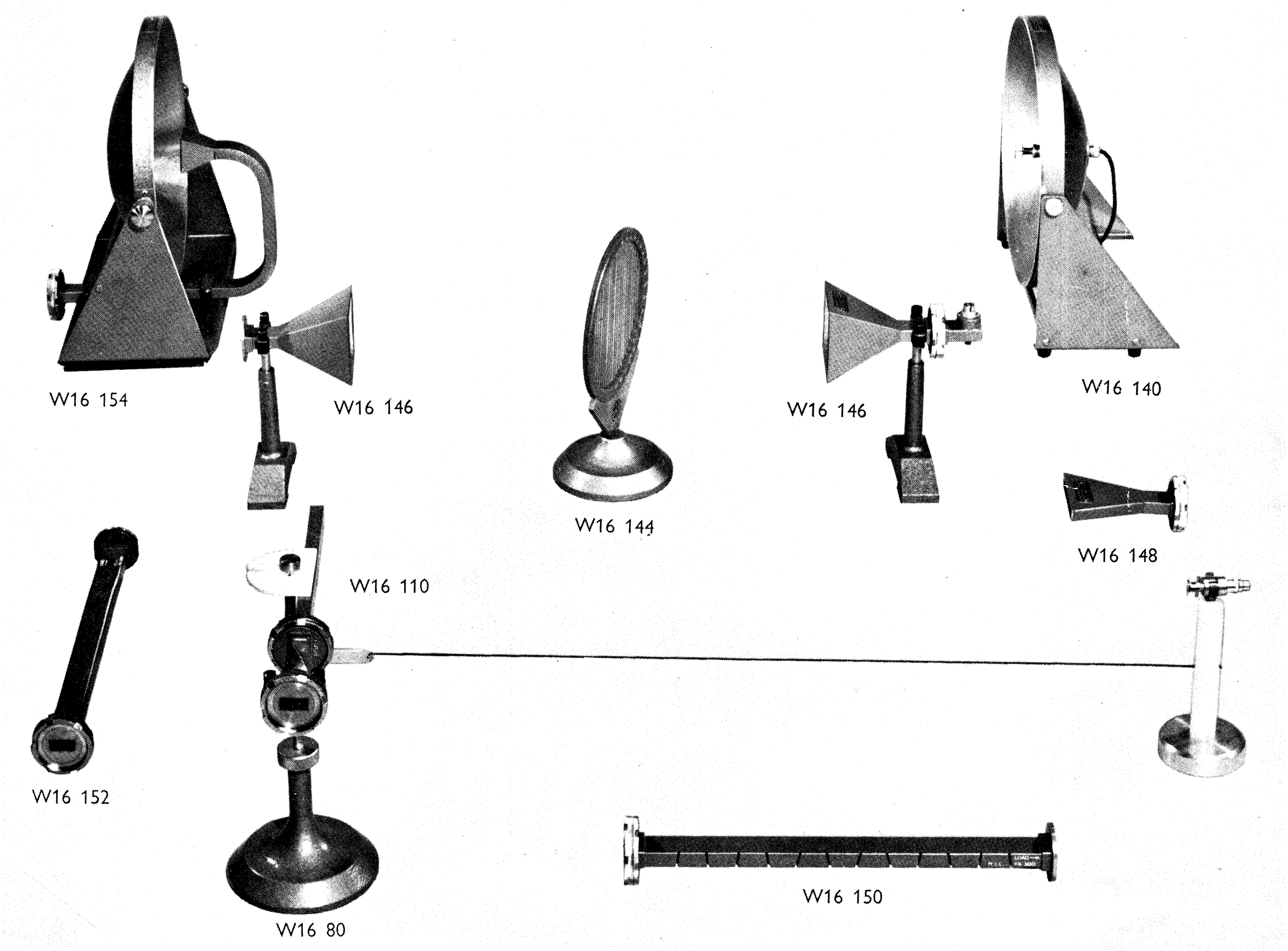
## *Three-way Junctions: H-Plane W16 160 — E-Plane W16 162*

The H- and E-plane Three-way junctions demonstrate the splitting of power into two arms and the standing waves caused by these items in the unmatched condition.



## *Radiation Plotter W16 110*

The radiation plotter shows the interference pattern caused by two adjacent sources and consists of a length of waveguide with two series-resonant slots cut in its broad face. A dipole and crystal detector are mounted on an insulating stand which is connected by a length of cord to a pointer at the centre of a protractor scale mounted on the waveguide. The polar diagram can easily be plotted by moving the detector on an arc controlled by the retaining cord. The slots are normally not exactly half a guide wavelength apart, giving to the polar diagram a squint which varies with frequency. The tapered load from W16 40 should be used to terminate the waveguide of W16 10. The dipole may also be used to plot polar diagrams of other radiating aerials.

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## *Horn 3 x 3 in. (76 x 76 mm) Aperture W16 146*
## *Horn 3 x 0.4 in. (76 x 10.2 mm) Aperture W16 148*

Either of these horns may be connected to waveguide to transmit or receive radiation in free space. The polar diagram of a transmitting horn can be measured with a second horn and crystal mount opposite the transmitter. The 3″ x 3″ Horn W16 146 has a polar diagram which is approximately symmetrical in both planes, while the 3″ x 0.4″ Horn W16 148 is much less directional in the E plane, i.e. parallel to the 0.4″ dimension.

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## *Polarized Screen W16 144*

This screen is used to demonstrate the polarized nature of microwave radiation. It is used in free space, mounted between two aerials placed opposite each other. A scale graduated from 0 to ± 90° is fitted, so that, by rotating the screen, its transmission or reflection can be related to its angle.

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## *Short Linear Arrays*
## *Shunt-inclined W16 150 — Series Resonant W16 152*

The short linear arrays demonstrate the characteristics of shunt-inclined and series-resonant slot radiation. The shunt-inclined array can be mounted directly on the waveguide run; for convenience a 90° twist W16 70 is used with the series-resonant array to direct the radiation parallel to the bench. Matched load W16 40 or terminating cap W16 130 is used to terminate these arrays.

## *Rotating Joint W16 156 — 180° E-Plane Bend W16 76*

The rotating joint (which demonstrates a use of circular waveguide) and the 180° E-plane bend are used together to help measure the polar diagrams of horns and linear arrays. The rotating joint is mounted on a free-standing support W16 80 and coupled to the end of a waveguide run. The 180° E-plane bend has one leg shorter than the other, so that when it is mounted above the rotating joint a linear array or horn can be attached and be free to rotate so that the centre of radiation coincides approximately with the centre of rotation. The rotating joint operates over a frequency range of 8.8 to 9.8 Gc/s with a V.S.W.R. better than 0.95 at 9.375 Gc/s.

## *Paraboloid with Waveguide Horn Feed W16 154*

This paraboloid can be used either as a transmitting or as a receiving aerial. As a transmitting aerial the paraboloid gives an approximately parallel beam with a width of about 8°. When used as a receiver a crystal detector W16 120 is connected to the output flange, and thus in either case the paraboloid can be used to demonstrate basic transmission phenomena.

## *Paraboloid with Dipole and Crystal Detector W16 140*

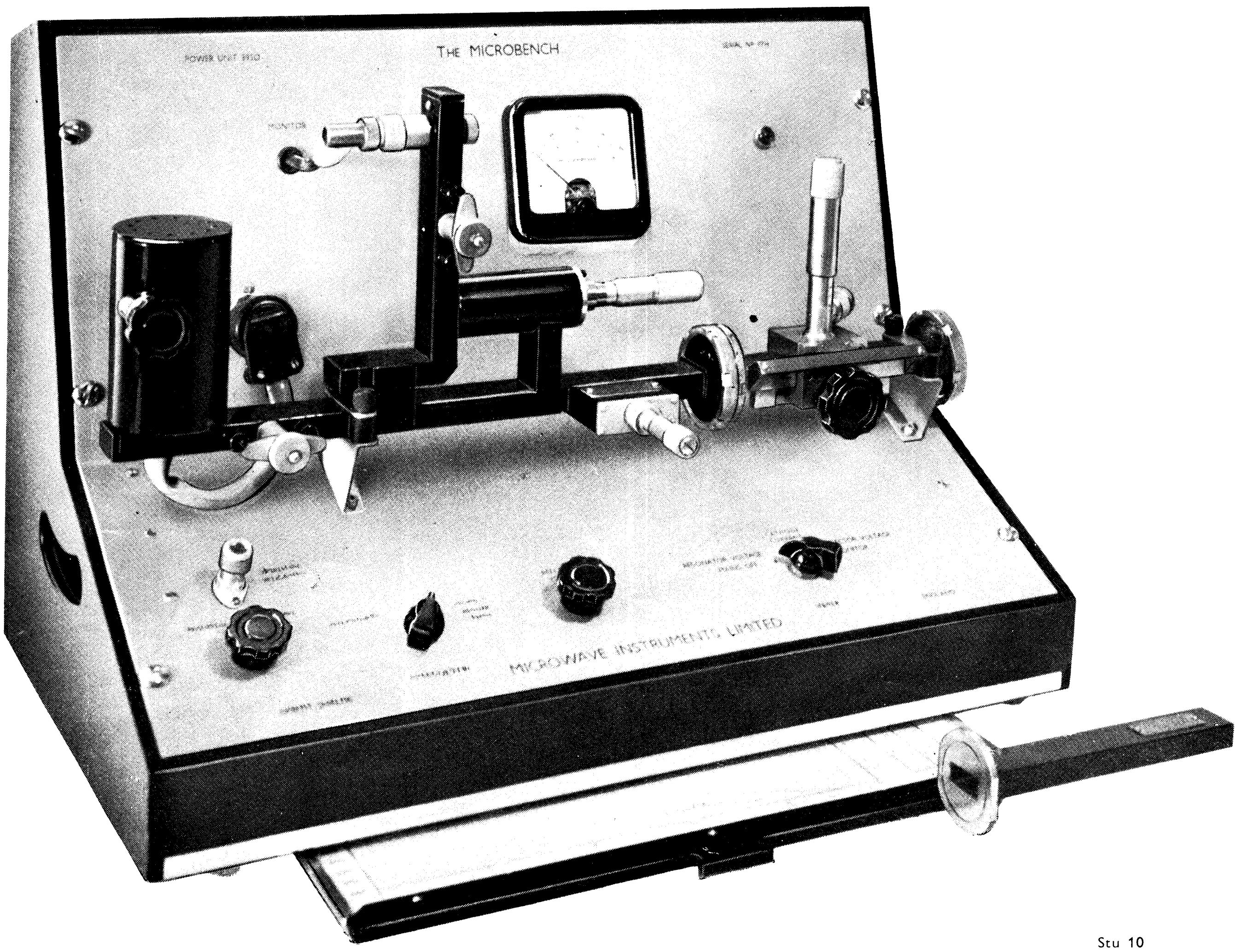
A companion to the W16 154, for receiving purposes only, this unit does not require a separate crystal detector as it has a 3.2 cm dipole and crystal rectifier mounted at the focus of the paraboloid. The two paraboloids make a good demonstration of a microwave link system, the klystron being modulated at any required frequency and the detected output from the receiver fed into the demonstration amplifier W16 15.

## *The Microbench Type WX 3930*

Where microwave experiments of a more precise nature are required the Microbench should be used. This is a more advanced instrument with a much higher, more stable performance, designed specifically for measurement purposes.

The Microbench, in one instrument, replaces many of the Student Series items, chiefly the Microdesk (power unit and klystron), Frequency Meter, Calibrated Attenuator, Standing-Wave Indicator, balance arm and reverse crystal mount for bridge operation and load termination. Internal square wave modulation is also provided.

Used with the TA3 it constitutes a complete test bench for reliable microwave measurements, and with its micrometer-controlled attenuator and Grade II performance standing-wave indicator permits the previously-listed experiments to be carried out more precisely, together with others not previously practical.



## *Waveguide Experiments*

**1. Calibration of the attenuator**
Use TA3 scale at mid-band (9.375 Gc/s, 3.2 cm free space) and compare at extreme frequencies. Use frequency meter W16 100 to measure frequency. Use calibration to check other components, e.g. experiment 3.

**2 Klystron Modes**
Plot power output and frequency of output of the klystron against reflector voltage. Sweep reflector voltage with time base of an oscilloscope and display output on the oscilloscope.

**3 Directional Coupler**
Measure forward attenuation and directivity by substitution of the calibration attentuator. Plot for various values of frequency.

**4 Isolation**
Show effect of magnetic field on a ferrite in a waveguide. Plot forward and reverse attenuation against frequency. With an electromagnet plot attenuation against field and using A.C. on the electro-magnet modulate the microwave power.

**5 Attenuation Bridge**
Use the TA3 as the balance detector. This gives a sensitive method of measuring attenuation, e.g. output variation of a rotating joint against rotation or standing wave indicator (S.W.I.) output against distance.

**6 Percentage dip and Q of a cavity**
Measure and plot at various frequencies by comparing bandwidth for half power response with centre frequency.

**7 Waveguide cut-off**
Use Taper Cut-Off to show effect of the broad waveguide dimension on guide wavelength, plot point of cut-off and attenuation against frequency.

**8 Waveguide wavelength free space wavelength**
Use the standing wave indicator followed by a short circuit for waveguide wavelengths and compare with free space wavelength obtained by the Michelson Interferometer (see experiment 26). Check by using frequency meter.

**9 Reflectometer**
Use directional coupler with two crystal detectors padded by attenuators to make a simple reflectometer.

**10 V.S.W.R.**
Use standing wave indicator to investigate V.S.W.R. of:
  Load termination.
  Terminating Cap.
  Short circuit.
  Three-way Junctions.
  Directional Coupler.
  Horn aerial etc.
Note the phase of each reflection and plot on Smith chart.
Plot V.S.W.R. of variable reactance against insertion. Use to match above items.

**11 Improvement in V.S.W.R.**
Set up various reflections using the Variable Reactance and measure the improvement in V.S.W.R. caused by inserting padding attenuator after the S.W.I.

**12 Crystal Mount**
Plot V.S.W.R. of the mount with frequency using various load resistances (10 ohms, 100 ohms, 1K, 10K). Plot output current and efficiency against input power with the same load resistances. Use the calibrated attenuator to vary the input power and assume the Klystron output is 15 mW.

**13 Calibration of phase shifter**
Use our S.W.I. before and short circuit

after. Calibrate the phase shifter at various frequencies.

### 14 Dielectric measurements

Measure phase of reflection due to different dielectrics in dielectric chamber using the phase shift to give a standard output from S.W.I. with a fixed probe position.

### 15 Polarization

Show polarization of output from waveguide by using two opposing horn aerials. Rotate receiver and note effect.

### 16 Attenuation of free space

Plot attenuation between two horn aerials against separation.

## RADIATION EXPERIMENTS

### 17 Polar diagrams

Plot polar diagrams in attenuation (dB) of various aerials, such as:–

- Open waveguide.
- Radiation plotter.
- Horn 3″ x 3″
- Horn 3″ x 0.4″.
- Shunt inclined linear array.
- Series resonant linear array.
- Paraboloid.

Discuss individual characteristics.

### 18 Microwave Link

Use square wave for 100% amplitude modulation. Use frequency modulation for speech or music modulation; adjust reflector voltage for maximum output and keep modulation amplitude low, say 5v. Insert frequency meter in receiver waveguide and tune to slope of cavity to detect F.M.

Note that duplication of equipment and addition of a directional coupler at each end would make possible simultaneous 2-way operation with one pair of aerials.

### 19 Reflection by ionised gas (Appleton or Heaviside layers)

Use a discharge tube to represent ionised layers.

### 20 Transmission/Loss

Show transmission/loss in various materials, e.g. P.V.C., perspex, ebonite, glass, brick, (wet and dry) etc.

## OPTICAL EXPERIMENTS

Besides the components in the optical kit, a few simple components will be required which can be produced without difficulty in the average laboratory workshops, i.e. mirrors (sheets of aluminium or other metal), half-silvered mirrors (sheets of perspex or cardboard coated with aluminium paint).

### 21 Diffraction at a straight edge

Use one sheet of aluminium interposed between two horns.

### 22 Single slit diffraction

Two sheets of aluminium to form a single slit are placed between two horns. By having strips of metal, 2, 3-slit etc. diffraction can be demonstrated.

### 23 Diffraction grating

This can be made by attaching narrow strips of aluminium to a frame and then placing between two horns.

### 24 Young's slits

Use various slit spacings and frequencies for different fringe spacings.

### 25 Lloyd's mirror

Reflection path from a mirror interferes with directly received signal; as mirror moves along its normal path variations are obtained.

### 26 Michelson Interferometer

A half-silvered mirror splits the incident radiation (by part reflection and part transmission) so that each beam is reflected back to the half-silvered mirror from two mirrors. The reflected beams recombine constructively or destructively depending upon their phases and give a high or low signal at the detector. Moving one mirror moves the interference pattern across the detector giving maxima and minima. For accurate measurements one of the mirrors can be made in the shape of a disc and mounted on the shaft of a micrometer.

**27 Polarization**
Using the Polarized Screen W16 144 show the transmission and reflection effects from a polarized screen.

**28 Refraction**
Use a prism of about 8″ side of paraffin wax or hollow prism of perspex filled with various liquids.

**29 Fibre Optics**
Use a bent candle or polythene rod to convey wave round corner.

**30 Fresnel mirrors**
Reflected rays from two mirrors side by side at a large internal angle (about 170°) produce interference pattern.