LIST OF R.F. TEST PROCEDURES

This section of the Instruction will include tests of the radio frequency signal parameters listed below. The identifying numbers of those published to date are shown in **bold type.**

RTP1
Level Measurements

Power Level - C.W./F.M. Signals — RTP1.1
Power Level - A.M. Signals — RTP1.2
R.F. Gain — RTP1.3
Field Strength — RTP1.4
Definitions MISSING — RTP1.5

RTP2
Frequency Measurements

Single Carriers — RTP2.1
Multiple Carriers — RTP2.2
Transposers — RTP2.3

RTP3
Swept Frequency Measurements

Amplitude/Frequency Response — RTP3.1
Delay/Frequency Response — RTP3.2
Sideband Analysis — RTP3.3

RTP4
Impedance Measurements

Return Loss — RTP4.1
Time Domain Reflectometry — RTP4.2
LF/MF Impedance Measurements — RTP4.3
HF Impedance Measurements — RTP4.4
VHF/UHF Impedance Measurements — RTP4.5
SHF Impedance Measurements — RTP4.6

MISSING

RTP5
Intermodulation and Spurious Products

Relative Amplitude Measurements — RTP5.1
3-tone Testing (Television) — **RTP5.2**
Vision-to-sound Cross-modulation — RTP5.3
Incidental Phase Modulation — RTP5.4
Cross-modulation in Stereo-multiplex Systems — RTP5.5

MISSING

RTP6
Modulation

A.M. Audio — RTP6.1
A.M. Video — RTP6.2
F.M. — RTP6.3
S.S.B. — RTP6.4

RTP7
Noise

Noise Figure — RTP7.1
Co-channel Interference — RTP7.2
Oscillator Noise — RTP7.3

RTP8
Miscellaneous

Phase Measurements RTP8.1

MISSING

Appendices

RTP-A	Spectrum Analysers
RTP-B	Tracking Generators
RTP-C	Network Analysers
RTP-D	The Smith Chart
RTP-E	BBC Transmission Bands and Systems
RTP-F	Sideband Analysers
RTP-G	Balanced/Unbalanced Systems
RTP-H	Limiters and Compressors
RTP-I	Measurements in the Presence of Pre- and De-emphasis

MISSING

MISSING

TECHNICAL INSTRUCTION P2

R.F. TEST PROCEDURES
(PRELIMINARY ISSUE: FEB.1981)

INTERMODULATION
IN
COLOUR TELEVISION
R.F. SYSTEMS
(R.T.P. 5.2)

Technical Instruction P2 has now become so bulky and its distribution so widespread that it is necessary to review its method of presentation.

This preliminary issue of R.T.P. 5.2 is being made available whilst the review is taking place and will be incorporated in any new system resulting from the review.

R.F. TEST PROCEDURES

LEVEL MEASUREMENTS:
POWER LEVEL - CW/FM SIGNALS

Introduction

The method used to measure R.F. power is determined by the power level present.

For low power measurements, it is possible to totally absorb the power in a calibrated power measuring instrument.

Where the measuring device is unable to absorb the total power, a known proportion of the power is derived for measurement. This is achieved by the inclusion of a calibrated coupler, probe or attenuator in the circuit. Further calibrated attenuators may be included to reduce the sampled power to a level within the range of the instrument.

To minimise errors, the impedance of the measuring device and associated test items must match the characteristic impedance of the transmission system.

At high powers the test load is cooled by liquid flow and the power calculated from the temperature rise and rate of flow of the coolant.

At the highest power levels the transmitter must remain connected to its aerial. The power may be deduced indirectly as above, or from measurement of the field strength at a known distance from the aerial. Where the feeder impedance is known, a special R.F. Voltmeter can be used to measure the voltage across the feeders and hence the power calculated.

N.B. *Safety Regulations must be strictly observed.

Types of Power Meter

Power meters use either a:

1. Thermistor or
2. Thermocouple or
3. Diode

as the power sensing element to convert r.f. power to a measurable d.c. or low frequency signal.

1. Thermistor Sensors

The thermistors used for r.f. power measurement are semiconductors with a negative temperature coefficient. The fundamental premise of the thermistor power sensor is that the r.f. power absorbed by the thermistor has the same heating effect on the thermistor as d.c. power.

The resistance / power characteristic of a thermistor is non-linear. The characteristics also vary from thermistor to thermistor. Therefore, the technique of using a thermistor as a power sensor is to maintain the thermistor at a constant resistance (which matches the impedance of the system) by means of a d.c. or low frequency bias. As r.f. power is dissipated in the thermistor, the resulting temperature rise causes the thermistor resistance to fall with a consequent decrease in bias current required to maintain the resistance at the same value. The decrease in bias current is displayed on a meter to indicate r.f. power.

2. Thermocouple Sensors

A thermocouple measurement system consists of a power sensor which produces a d.c. output voltage proportional to the power dissipated in it, and a measurement circuit, which measures this d.c. voltage and displays it in units of power. The thermocouple sensor is less sensitive to changes in ambient temperature than the thermistor type of power sensor.

The modern thermocouple sensor employs both thin-film and semiconductor technologies. A thin-film resistor, deposited on the surface of a silicon chip, converts the r.f. energy to heat. The resistor forms a low-reflection termination for the transmission line. It is mainly due to this type of construction that the thermocouple type sensor has the most precisely defined impedance of the power sensing methods. As the resistor converts the r.f. energy into heat, the centre of the chip, which is very thin, gets hotter than the outside edge. Thus there is a thermal gradient across the chip which gives rise to a thermo-electric e.m.f. The cold junction is formed by the outside edge of the silicon chip and the resistor. The hot junction is the resistor-silicon connection to the centre of the chip.

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*Safety Regulations for Engineering Staff; BBC Engineering Division Publication

3. Diode Sensors

There are two main types of diode sensors. One is a simple rectifier circuit whereas the other uses a Schottky diode as the basis of a precision measuring system. A variant of the simple type derives a fixed proportion of the power, by means of an integral directional coupler, which drives a diode detector and meter. An example of this type of power meter is the Thruline (Bird) wattmeter which can be used for measuring forward and reverse power flow.

The system of precision power measurement using a diode sensor is similar to that used with a thermocouple sensor, the only difference being the method used to convert r.f. power into d.c. voltage. Diode and thermocouple power sensors can often be used with the same power meter.

By using diode sensors the range of power measurement can be extended down to 100 pW sensitivity at frequencies of up to 18 GHz with low noise and drift.

The modern precision diode sensor uses a low-barrier Schottky diode which is operated in its square law region (V_{out} proportional to P_{in}) and therefore can be used to measure the power of complex waveforms. The advantage of the Schottky diode over the thermocouple power sensor is that detecting diodes are more effective in converting r.f. to d.c. The diode sensor is less sensitive to changes in ambient temperature than the thermistor type of power sensor.

Sources of Error

(a) Variations in the reading caused by reflections on the transmission line due to mismatched loads.
(b) A mismatch between the power meter and its connecting cable.
(c) Discontinuities caused by the insertion of adaptors, connectors, bends or attenuators causing reflections within the feeder.
(d) The presence of harmonic or spurious components at the output of the r.f. amplifier.
(e) Calibration and directivity of directional coupler and/or attenuator.
(f) Induced RF in power meter leads or circuits.
(g) The accuracy of the power meter:
  (1) Zero set
  (2) Noise
  (3) Drift
  (4) Meter tracking errors
  (5) Circuit non-linearities
  (6) Range-change attenuator inaccuracy
  (7) Meter amplifier gain errors
  (8) ±1 count – digital meter
(h) Errors due to overload damage to components or their use outside the intended frequency range.

Bibliography

1. BBC Engineering Division Publication; Safety Regulations for Engineering Staff.
2. Hewlett Packard, Application Note 64-1; Fundamentals of RF and Microwave Power Measurements.
3. T.C.P.D. Technical Note No.36; Directional Couplers: Principle of Operation.
4. Proc.I.E.E. May 1955; Coupled Transmission Lines as Symmetrical Directional Couplers, G.D. Monteath.

Comparison between types of Power Meter

Examples of typical commercial types of meter which are in common use are given in the table below. Limited specifications are given for comparison purposes, *for full specifications see the manufacturers' literature.* See also list of possible sources of error.

Type:	Thermistor	Thermocouple		Diode			
						Absorption	
Model:	Hewlett Packard 432A with 8478B thermistor mount	Hewlett Packard 435A		Hewlett Packard 435A with 8484A Schottky diode sensor	Bird Thruline Model 43	Bird (Termaline) Model 61	Racal-Dana 9100/02/03
		with 8481A sensor	with 8482A sensor				
Claimed Accuracy	† ±0.2% ±0.5 μW	† ±1.2%	† ±1.2%	† ±1.2%	¶ ±5% of FS	¶ ±5% of FS	¶ ±7.5% of FS
Lower Freq. Limit	10 MHz	10 MHz	100 kHz	10 MHz	2 MHz ‡	30 MHz	1 MHz
Upper Freq. Limit	18 GHz	18 GHz	4.2 GHz	18 GHz	1 GHz ‡	1 GHz	1 GHz
Lower Power Limit (as engraved)	0.2 μW	0.3 μW	0.3 μW	0.1 n W	0.02 W ‡	0.5 W	0.01/0.1/1 W *
Upper Power Limit (without att'n)	10 mW	100 mW	100 mW	10 μW	1 kW ‡	80 W	3/30/100 W *
Max. Cont. Input level		300 mW Av	300 mW Av	200 mW Av	-	80 W	3/30/50 W *
SWR	1.35 30 - 100 MHz 1.10 0.1 - 1 GHz 1.35 1 - 12 GHz	1.18 30 - 50 MHz 1.10 50 MHz - 2 GHz 1.18 2 - 12 GHz	1.6 100 - 300 kHz 1.2 300 kHz - 1 MHz 1.1 1 MHz - 2 GHz	1.4 10 - 30 MHz 1.15 30 MHz - 4 GHz 1.2 4 - 10 GHz	1.05	1.2	<1.2

‡ This meter uses a range of wide-band (2:1) couplers. The figures refer to the lower and upper frequency and power limits of the complete range. The unit does not provide a terminating load.

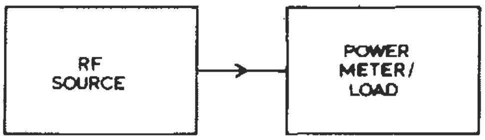
* These figures refer to the power limits of the 9100/9102/9103 range of meters.

† Practical field accuracy ±(2 to 3%)

¶ Practical field accuracy ±10%

MEASUREMENT METHODS

1. Power Level within Meter Range

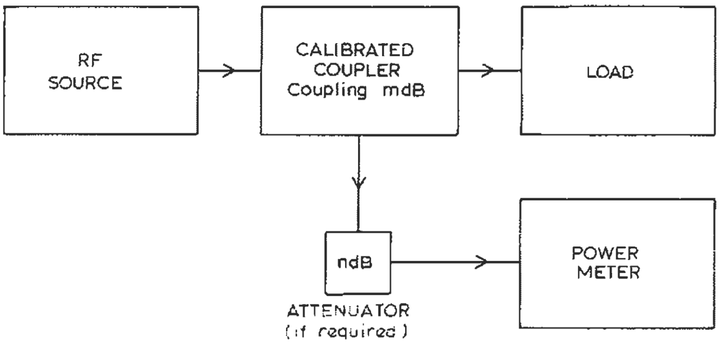


Power Indicated Directly

2. Power Level in excess of Meter Range

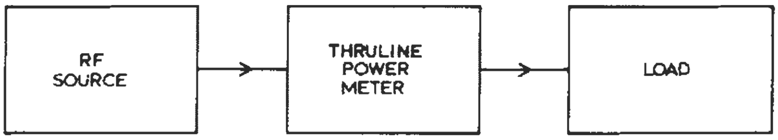
$$\text{Power} = \text{Power Indicated} \times \text{Antilog}\,\frac{n}{10}$$

3. Power Level in excess of Meter Range



$$\text{Power} = \text{Power Indicated} \times \text{Antilog}\,\frac{(n+m)}{10}$$

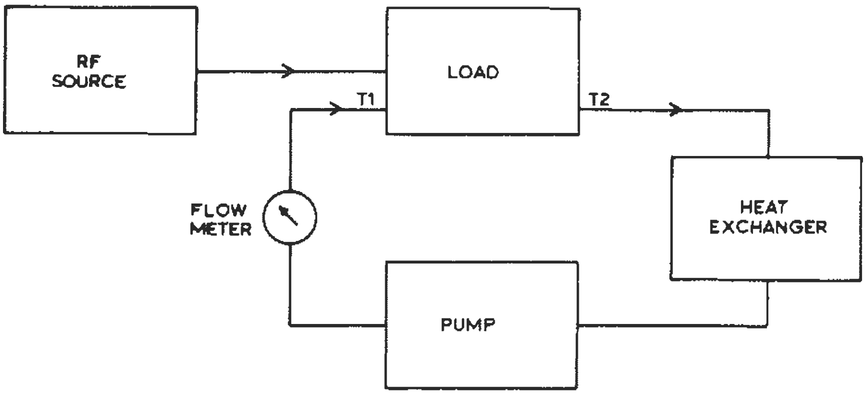
4. Thruline Measurement



Power Indicated Directly

MEASUREMENT METHODS (continued)

5. The Calorimeter



The resistor which forms the test load is cooled by a flow of water or other fluid, surrounding the resistor; the fluid itself can also form part of the test load. The power absorbed by the load is given by:

$P = 4.187\ m\ C_p\ (\Delta T)$

where P = power in watts
m = flow, grams per second
C_p = specific heat of the liquid, calories per gram per °C
ΔT = temperature rise in °C $(T_2 - T_1)$

If pure water is used then the power absorbed by the load is given by:

$P = 0.317\ F\ (\Delta T)$

where P = power in kilowatts
F = flow, in gallons per minute
ΔT = temperature rise in °C $(T_2 - T_1)$

or

$P = 0.069\ F\ (\Delta T)$

where P = power in kilowatts
F = flow of water, litres per minute
ΔT = temperature rise in °C $(T_2 - T_1)$

If a 2:1 mixture of water and glycol is used then the power absorbed by the load is given by:

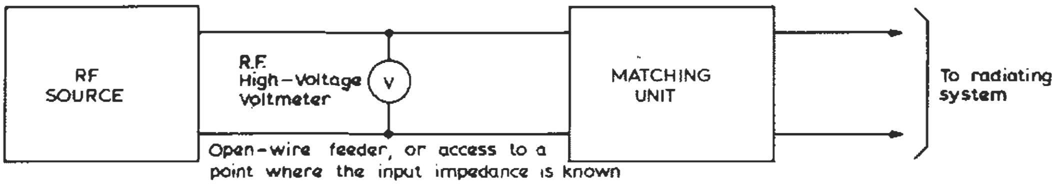
$$P = 0.317 \times 0.95 \times F \times \Delta T$$
$$= 0.3\ F\ \Delta T$$

where P = power in kilowatts
F = flow, gallons per minute
ΔT = temperature rise in °C $(T_2 - T_1)$

MEASUREMENT METHODS (continued)

6. High Power Measurement below 30MHz (Aerial connected)

N.B. *Safety Regulations must be strictly observed before connecting equipment to a feeder or matching system.



$$\text{Power} = \frac{V^2 \text{ r.m.s}}{R_p}$$

where R_p is the value of shunt resistance at the connection point.
It is also given approximately by:

$$\text{Power} = \frac{V^2 \text{ r.m.s.}}{Z_0}$$

where Z_0 is the characteristic impedance of the feeder and the S.W.R. is near unity. The accuracy is about 10%.

At the upper end of the high frequency spectrum a mismatch due to the connection of the voltmeter could be sufficient to cause a significant error.

7. Field Strength Comparison Method

A change of power level is determined by measuring the change in field strength at a fixed location. The transmitting system and the field strength meter are set up and the effect of any subsequent change in transmitter power output is measured by the corresponding change in field strength. It is assumed that the system is linear and that there is no change in propagation characteristics. To determine the power level of a high power transmitter, determine the field strength at a known point using a low power source, the power output of which has been determined. Substitute the high power transmitter, the power output of which is required, and again measure the field strength

$$\frac{P_1}{P_2} = \left[\frac{E_1}{E_2}\right]^2$$

where E_1 is the field strength measured with transmitter power P_1
E_2 is the field strength measured with transmitter power P_2
With care, measurement accuracies within 5% are possible.

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*Safety Regulations for Engineering Staff; BBC Engineering Division Publication

R.F. TEST PROCEDURES

LEVEL MEASUREMENTS: DEFINITIONS

CHARACTERISTIC IMPEDANCE OF A TRANSMISSION LINE – is the impedance that would be presented by a uniform line if it were infinitely long. If any length of the line is terminated in its characteristic impedance, then the energy reaching the termination is absorbed by it and none is reflected back along the line.

COUPLING FACTOR OF A DIRECTIONAL COUPLER – is the ratio, expressed in decibels, of the input power flowing in a matched transmission line to the power from the coupled port.

DIRECTIVITY OF A DIRECTIONAL COUPLER – is the change in coupled power (expressed in decibels) in a matched system when the direction of propagation is reversed.

R.F. POWER DEFINITIONS – Dependent on the class of emission the output power of a radio transmitter is expressed in terms of mean power, carrier power or peak envelope power, as defined below.

MEAN POWER is the power supplied to a test load under specified conditions of modulation, averaged over a time sufficiently long compared with the period of the lowest frequency encountered in the modulation.

CARRIER POWER is the average power supplied to a test load during one r.f. cycle under conditions of no modulation; for each class of emission the condition of no modulation should be specified.

PEAK ENVELOPE POWER is the average power supplied to a test load during one r.f. cycle at the highest crest of the modulation envelope taken under specified conditions of modulation.

RATED OUTPUT OF A TELEVISION TRANSMITTER is defined as being that of the vision transmitter.

OUTPUT POWER OF A VISION TRANSMITTER shall be expressed in terms of **PEAK ENVELOPE POWER**; hence:
for **TRANSMITTERS WITH NEGATIVE MODULATION** the output power is equal to the mean power supplied to the terminal load during one r.f. cycle having an amplitude corresponding to synchronising level.

*These **R.F. POWER DEFINITIONS** are taken from I.E.C. Recommendations* and apply to measurements carried out under specified conditions of modulation (instead of under normal operating conditions) and with the transmitter connected to a test load instead of to an aerial system.*

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*International Electrotechnical Commission, Methods of Measurement for Radio Transmitters.
Publication 244-1, 1968.
Part 1: General Conditions of Measurement of Frequency, Output Power and Power Consumption.
Publication 244-5, 1971.
Part 5: Measurements particular to Transmitters and Transposers for Monochrome and Colour Television.

R.F. TEST PROCEDURES

INTERMODULATION IN COLOUR TELEVISION R.F. SYSTEMS: THREE-TONE TESTING

BACKGROUND

If two r.f. carriers are modulated by television colour video and sound signals respectively to form a single transmission and are then passed through a device with a non-linear transfer characteristic, interaction will occur between them and intermodulation products will result. In normal operation three of these products will be in-band[*] and two of them may be of significant amplitude, these latter two products occur at frequencies of:

$$fv \pm (fs - fc)$$

where fv = vision carrier frequency
fs = sound carrier frequency
fc = colour sub-carrier frequency (r.f.)

The third in-band product is usually of much lower amplitude than the other two and occurs at (2fc − fs).

In System I[†], fs = fv + 6 MHz and fc = fv + 4.43 MHz; therefore the frequency of those in-band modulation products which may have significant amplitude (greater than -52 dB with respect to peak sync power) will be fv ± 1.57 MHz. Intermodulation distortion will appear as patterning in the demodulated signal and will be particularly visible in large coloured areas. As seen on a monitor, the most susceptible colour is saturated red. The sound modulation tends to break up the patterning and make it less visible and thus the subjective visibility of intermodulation distortion is dependent both on picture content and on the accompanying sound modulation.

It is conventional to measure the intermodulation product (fv + 1.57 MHz) as a carrier and to relate it to the vision carrier amplitude at peak synchronising power. To do this the amplitudes of fv, fs and fc must be defined as specified in BS4478: 1969[‡]. The defined test signal amplitudes are:

vision carrier	−8 dB	relative to peak sync power
colour sub-carrier	−17 dB	
sound carrier	−7 dB	

The first two of these signals correspond approximately, in video terms, to the luminance and chrominance amplitudes present in the green bar of the so-called 95 per cent colour bar waveform[¶]. The hue is indeterminate, because subcarrier burst phase is not defined.

The sound carrier amplitude is that which would normally be radiated. The amplitudes of the three signals add up approximately to peak-sync voltage and do not therefore explore the full dynamic range.

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[*] For the purpose of this test procedure 'in-band' is defined as being within the frequency range (fv − 2) to (fv + 6) MHz.

[†] CCIR Recommendations and Reports 1978: Vol.XI, Report 624-1

[†] Specification of Television Standards for 625-line System I Transmissions: published jointly by the BBC and the ITA; 1971

[‡] Methods of Measurement of Intermodulation Products in Electronic Valves and Tubes intended for use in Colour Television Transposers.

[¶] Technical Instruction P8: Waveforms, page 2.5

Viewer reaction to intermodulation distortion has been analysed* and used to derive a relationship between intermodulation distortion and Q-rating (see VTP-F). The resulting scale, shown Fig. 1, gives the subjective impairment with the intermodulation product for a 100 per-cent colour bar signal which has 50Hz hum modulation on the sound carrier.

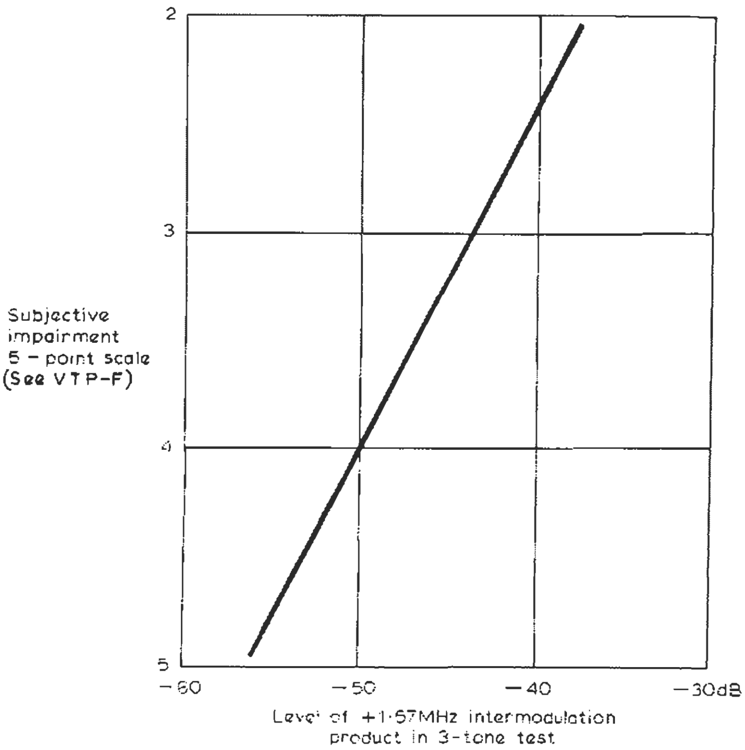

Fig. 1 Suggested Allowable Level of Intermodulation Product for a Given Grading

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* See Research Department Report 1974/35

Comparison of Three-tone Test with Related Methods

There are three ways of measuring intermodulation distortion; they are:

1. Three-tone Method
2. Chrominance Bar Method
3. National I.T.S. (B) Method

1. Three-tone Method.

This is the original method. A generator is required, to produce signals corresponding to the three tones at the correct carrier frequencies and amplitudes, and a spectrum analyser is used to measure the intermodulation produced by the device under test.

Advantages – it is accurate and can be done locally, without the aid of a parent transmitter.

Disadvantages – involves an interruption of programme,. cannot be easily applied to high-level carrier-modulation systems (because they lack a suitable low-level input point) or to systems requiring a base-band input. It cannot always be applied to tandem chains whilst a.g.c. systems are operating. It does not explore the full dynamic range, i.e. it does not cover the full amplitude of the transmitted signal.

2. Chrominance Bar Method.

Uses a video signal with chrominance and luminance levels which correspond, during the active line period, to the vision and colour sub-carrier amplitudes of the three-tone test. Synchronising and blanking pulses are added to the signal, which can then be used either in the line-repetitive mode or inserted into the field-blanking period. The resulting signal is then used to modulate the transmitter. The sound carrier is produced either by the transmitter drive or by the test modulator in use to drive a transposer.

There are three ways of measuring the intermodulation product, these are (a) using a bandpass filter and a noise meter, (b) using a spectrum analyser and (c) using an oscilloscope to measure the beat pattern amplitude of the demodulated signal.

Advantages – does not necessarily involve interruption of programme. Can be used with high-level carrier-modulation systems. Does explore full dynamic range.

Disadvantages – may give poorer resolution than the three tone test when used for performance comparision. (However, it is more representative of what the viewer sees and is hence, arguably a more suitable test).

3. National I.T.S. (B) Method.

Uses the National Insertion Test Signal (B) which is transmitted on lines 20 and 333 in the field-blanking interval (see VTW.4).

The intermodulation product is measured by viewing the demodulated signal on an oscilloscope and measuring the beat pattern amplitude.

Advantages – simple test equipment requirements and no necessity to interrupt programme. Dependent chains do not require attendance during tests. Can be used with high-level carrier-modulation systems. Does explore full dynamic range.

Disadvantages – it does not meet the requirements of BS4478 for luminance level and it is more prone to error than the Chrominance Bar method.

All three methods have their applications; these are:

(a) ***Three-tone*** for precise measurement of the performance of a constituent part of a chain.
(b) ***Chrominance Bar*** for performance measurements on an operational system.
(c) ***National I.T.S. (B)*** for quick checks in the absence of specialised test equipment.

ASSOCIATED INFORMATION
(normally issued with this Test Procedure)

Operating Instructions (P2, Part 2) for:

1.	EP14M/507	U.H.F. TEST EQUIPMENT
2a.	GE4/546	BAR AND SWEEP GENERATOR (part of PA1M/560 or PA1M/561)
	or	
2b.	GE4M/561	TEST GENERATOR
3a.	ME1/509	FIELD INTERVAL NOISE METER (part of ME1M/508 or EP1M/524)
	or	
3b.	ME3M/502	TV WAVEFORM ANALYSER

DEFINITIONS

CHROMINANCE-LUMINANCE INTERMODULATION (also called: Chrominance-Luminance Crosstalk and Chrominance Axis Shift) – refers to the unwanted change in amplitude of the luminance component of a colour television signal which is caused by the associated chrominance component.
– it can be defined as the change in luminance level expressed as a percentage of the picture amplitude which results from the superimposition of a chrominance component of specified amplitude.

QUADRATURE DISTORTION – is harmonic distortion which is caused by any asymmetry of the two sidebands in a vestigial sideband transmission affecting the shape of the modulation envelope. It may be considered as being due to the appearance of a quadrature component of the modulating signal which adds vectorially to the in-phase component; hence the name quadrature distortion.

Because it is an envelope phenomenon, it is present in signals recovered by envelope demodulation, but it can be eliminated by synchronous demodulation which is able to discriminate between the in-phase and quadrature components.

TRANSPOSER – is a device which accepts a transmission at one frequency and (without demodulation) rebroadcasts it at a different frequency.

MEASUREMENT METHODS

A. Three-tone Method

Equipment Required

A generator to produce the three carriers (corresponding to the three tones) at the correct frequencies and amplitudes. The preferred equipment is:
EP14M/507 U.H.F. TEST EQUIPMENT
(If an EP14M/507 is not available, any suitable generator can be used.)

A spectrum analyser; either of the following can be used:
EP14M/507 U.H.F. TEST EQUIPMENT (and associated oscilloscope)
A commercial spectrum analyser; e.g. HEWLETT PACKARD 180 SERIES

Test Procedure

First make sure that the resolution and bandwidth of the test equipment is adequate (see ***OPERATING INSTRUCTIONS****)*

1.1 Connect the test equipment to the test item as shown in Fig. 2.

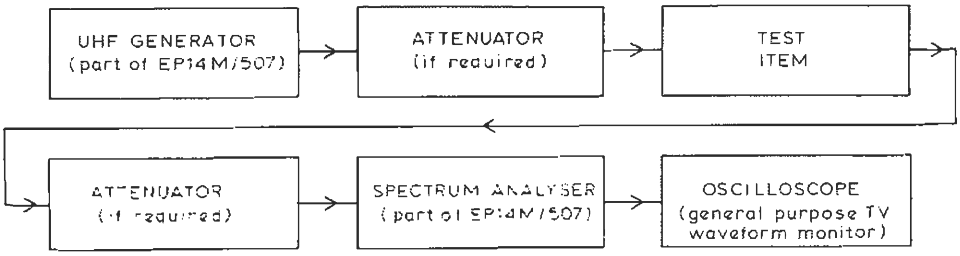

Fig. 2 Connection of Test Equipment to Test Item

1.2 With the system operating normally use a vision carrier signal to calibrate the output of the item under test and obtain a reference level corresponding to peak sync output power (0 dB).

1.3 Check that the u.h.f. generator provides the correct relative levels of the three carrier signals.

BS4478 calls for the levels to be correct at the output of the test item. It is, however, normally sufficient if they are correct at the input, provided that no serious frequency distortion is present.

1.4 Adjust the input attenuator for the correct vision output level from the generator (−8 dB with respect to peak syncs).

MEASUREMENT METHODS (continued)

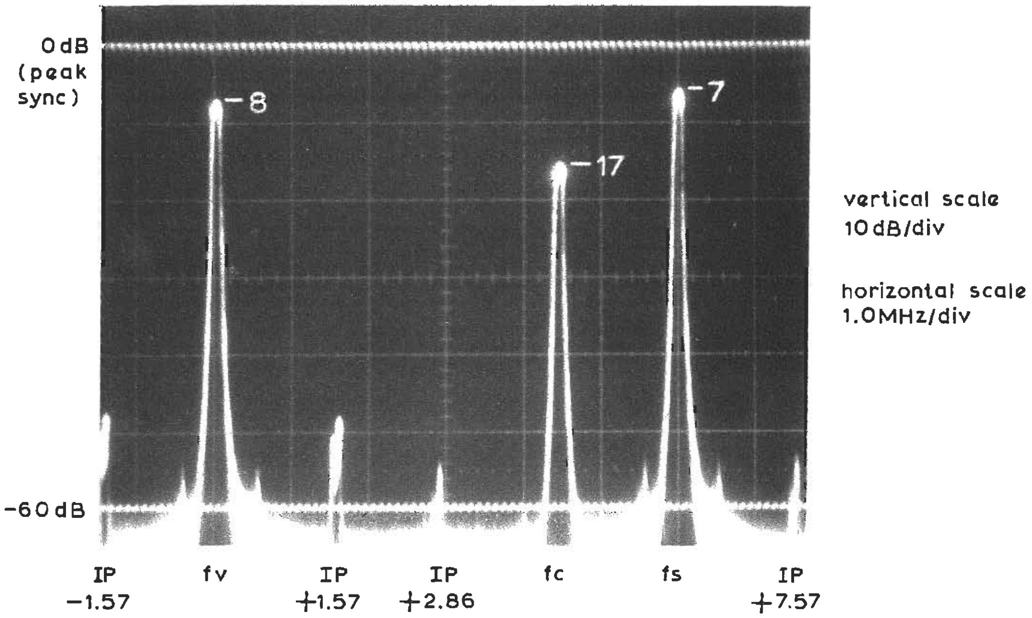

Fig. 3 A typical three-tone display showing an intermodulation product of –48 dB with respect to peak sync power.

Note that although several intermodulation products appear on the display, only those which are spaced 1.57 MHz either side of the vision carrier are both in-band and of significant amplitude.

1.5 Display the spectrum analyser output and measure the amplitude of the intermodulation products (in dB relative to peak sync power); a typical three-tone display is shown in Fig. 3.
Check the amplitude of any intermodulation produced by the test equipment by connecting the spectrum analyser (via the attenuator) to the generator u.h.f. output and adjusting the attenuator for the same display amplitude as before. For the original measurement to be valid any intermodulation produced by the test equipment must be at least 10 dB lower than that produced by the item under test (see Fig. 4).

1.6 Record the measurement method used.
Step 6 is necessary because the three measurement methods used may give slightly different results.

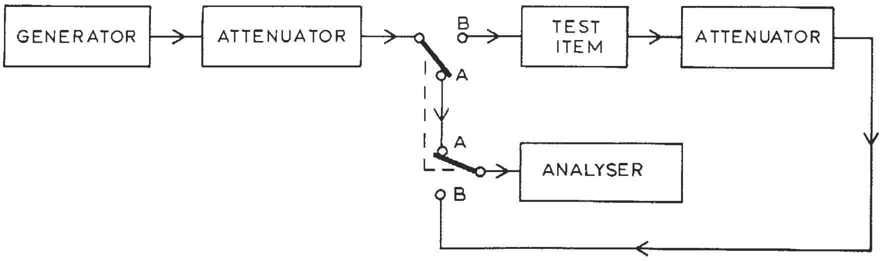

Fig. 4a Connection of Test Equipment to Test Item

MEASUREMENT METHODS (continued)

Correction to intermodulation product levels measured at the output of a test item to take into account intermodulation product levels measured at the input.

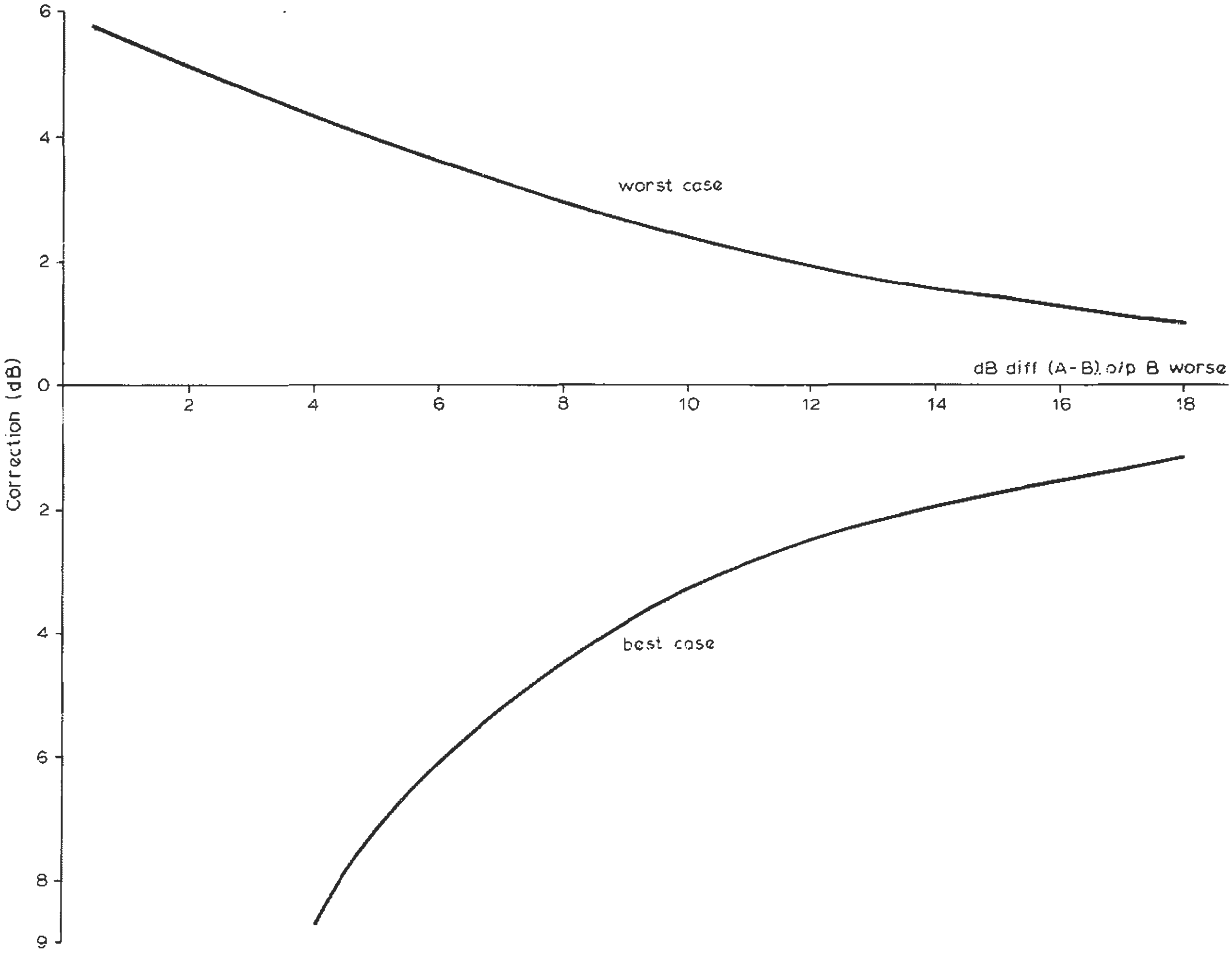

Fig. 4b Graph Showing Correction Necessary

Example: A = −58 dB (intermodulation at input)
B = −50 dB (intermodulation at output)

Difference (A − B) = 8 dB

Worst case +2.8 dB - add this to B
−50 + 2.8 = −47.2 dB due to the test item

Best case −4.5 dB - add this to B
−50 + (−4.5) = −54.5 dB due to the test item

Note: the worst case is the most significant.

MEASUREMENT METHODS (continued)

2. Chrominance Bar Method

Equipment Required

GE4/546	BAR AND SWEEP GENERATOR (part of PA1M/560 or PA1M/561)	
or		
GE4M/561	TEST GENERATOR (with three-tone facility)	
PA1M/560 or	PA1M/561 TEST LINE ERASER/INSERTER	if a field-interval signal only is required.
ME1/509	FIELD INTERVAL NOISE METER	
or		
ME3M/502	TV WAVEFORM ANALYSER	

A Spectrum Analyser	(if the signal is line-repetitive)
A Test Modulator	(if an R.F. Test Signal is required)
General-purpose TV Waveform Monitor	
Demodulator	

The modulator, demodulator and spectrum analyser facilities can be supplied by an EP14M/507 U.H.F. Test Equipment.

Test Procedure

2.1 Set the GE4/546 to **SUBCARRIER** (or the GE4M/561 to **3-TONE**); check that the output consists of syncs and 700 mV peak to peak of subcarrier, superimposed on a luminance bar of 450 mV (see Fig. 5).

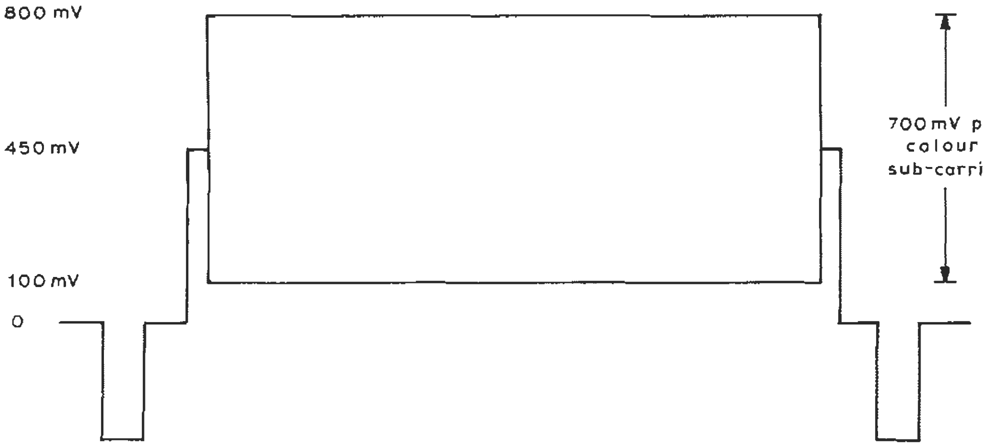

Fig. 5 Chrominance Bar Output of GE4/546

Because of chrominance-to-luminance intermodulation and/or quadrature distortion a demodulated chrominance bar may have its luminance component altered. This is particularly likely if an envelope detector is used. No attempt should be made to compensate for this, beyond checking that the signal is correct at the input to the item under test.

MEASUREMENT METHODS (continued)

2.2 The intermodulation product is measured as the amplitude of the +1.57 MHz component in the demodulated video signal. The product which is 1.57 MHz below the video carrier is removed by the vestigial sideband characteristic of the receiver.

2.3 The various methods of measurement are:

2.3i. If the signal to be measured is inserted in the field-blanking interval, the measurement can be made by using a demodulator and an ME1/509 which is set to the **1.57 MHz** (bandpass) position.
The meter on the ME1/509 measures the equivalent power of the intermodulation component and expresses it relative to picture amplitude. The reading must be corrected (see the ME1/509 **OPERATING INSTRUCTION**) to express it as a power which is relative to peak synchronising power.

Note that the signal is conventionally inserted on lines 21 and 334 of the field blanking interval. Both the PA1/560.561 ERASER/INSERTER and the ME1/509 FIELD INTERVAL NOISE METER or ME3M/502 should be set accordingly.

2.3ii. For a repetitive signal, the measurement can be made using a spectrum analyser in the same way as for a three-tone test (see Method 1). Note that the display will show peak sync level and not −8 dB with respect to peak syncs.

The display is less clear than a three-tone display, because the vision carrier is at full amplitude and because a sideband structure due to synchronising pulses is present. This, typically, limits the measurement to products which are greater than −50 dB.

2.3iii. For a signal which is relatively noise-free at a demodulated measurement point, the intermodulation component can be seen on an oscilloscope as a beat pattern which is superimposed on the subcarrier (see Fig. 6).

$$\text{Intermodulation Product} = 20\,\lg\left[\frac{A}{700}\right] - 17\ \text{dB}$$

$$= 20\,\lg A - 74\ \text{dB}$$

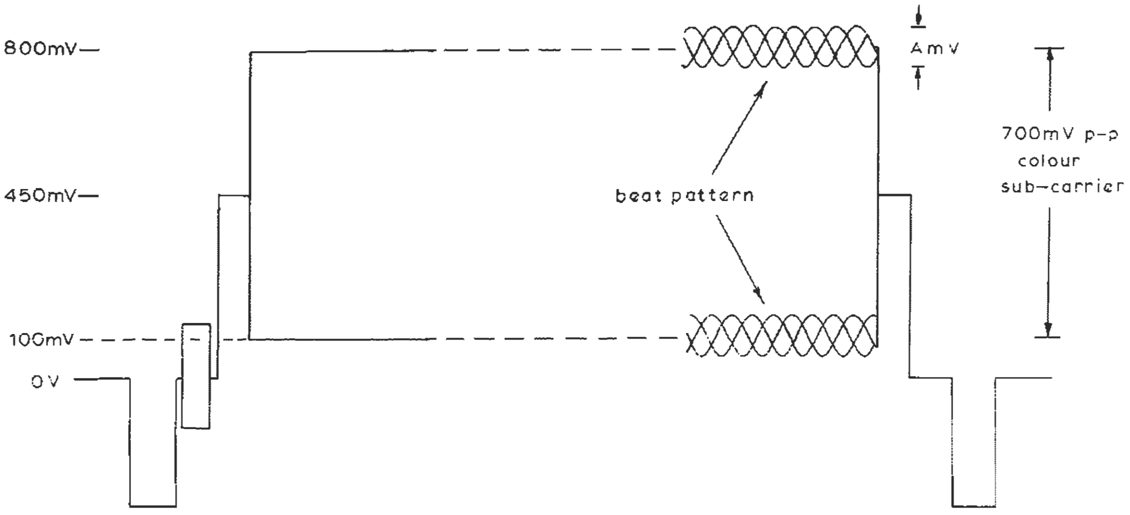

Fig. 6 Showing Intermodulation Product as a Beat Pattern

MEASUREMENT METHODS (continued)

The peak-to-peak amplitude of the beat pattern is measured and expressed in dB's relative to the 700-millivolt picture component of the video signal. −17 dB is then added to the figure obtained, to express it as a power relative to peak synchronising power.

2.4 Record the measurement method used.

Step 4 is necessary because the three measurement methods may give slightly different results.

3. National I.T.S. (Waveform B) Method.

This is similar to the Chrominance Bar method described under 2 but uses instead the chrominance bar which is located on the first half of lines 20 and 333 in the National Insertion Test Signal (B) as shown in Fig. 6. Because the luminance lift of this signal is only 350 mV, instead of the 450 mV provided by Method 2, the test does not meet the requirements of BS4478; however, it does give an indication of performance that is, typically, within 3 dB.

Equipment Required

Grade 1 general-purpose TV waveform monitor
Demodulator

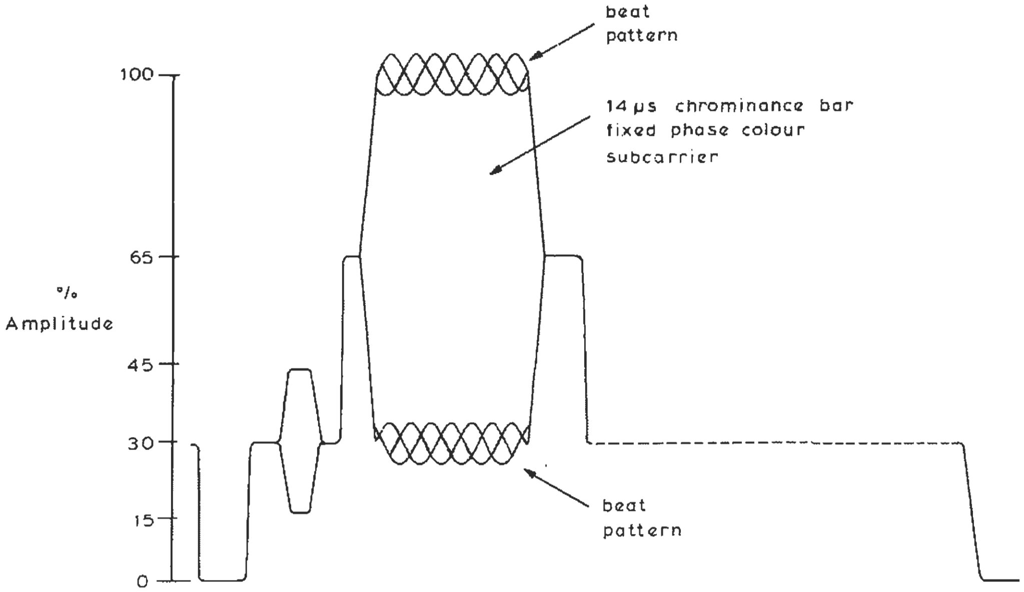

Fig. 7 National Insertion Test Signal (B) (lines 20 and 333) Test Procedure

Test Procedure

3.1 Carry out the Test Procedure as defined in Method 2 (step 2.3iii).

3.2 Record the measurement method used.

Step 2 is necessary because the three measurement methods may give slightly different results.

R.F. TEST PROCEDURES

INTERMODULATION AND SPURIOUS PRODUCTS: VISION-TO-SOUND CROSS-MODULATION

Introduction

In an R.F. system, non-linearity distortions occur when more than one carrier shares a common amplifier. One of these effects is cross-modulation of the sound carrier and is defined as the unwanted amplitude modulation of the sound carrier caused by variations in the level of the vision carrier.
There are two methods of measuring cross-modulation and, since they can produce different results, the method of measurement should be stated.

Measurement of Vision-to-Sound Cross-modulation

1. Steady State Method

Vision-to-Sound Cross-modulation is measured using unmodulated vision and sound carriers. A spectrum analyser is used to measure the change in sound carrier level when the vision carrier is switched off.

Advantages

(a) The method is simple and the results obtained repeatable.

Disadvantages

(a) It is not always possible to switch the vision carrier off and on and measurements can not be made during programme. Also, some systems require the presence of sync pulses to maintain correct operation.
(b) Serious errors can be introduced because this method does not measure cross-modulation at intermediate levels of vision carrier. This is particularly important in systems using pre-correction.
(c) When the vision carrier is switched off and on there may be a change in amplifier gain, due to thermal effects, which can have a time constant of several milliseconds. This is not shown by a dynamic measurement which would give a different result.

2. Dynamic Method

The system is set to deliver normal rated power levels. Modulation is applied to the vision carrier and any corresponding amplitude modulation of the sound carrier is measured.

Advantages

(a) Can be measured without interrupting programme.
(b) Produces a more relevant result than the steady state method.

Disadvantages

(a) When received sound and vision carriers are used as the test signal, any inherent distortion of the test signal will lead to incorrect results. In particular, the vision-to-sound ratio and any cross-modulation of the incoming carriers should be noted.

Bibliography

UHF Test Set Application Notes: Transmitter Group

MEASUREMENT METHODS

1. *Steady State Method*

Equipment Required

2 UHF CW Generators
Attenuators
Combining pad
Spectrum Analyser

Test Procedure

1.1 Connect the test equipment as shown in Fig. 1.

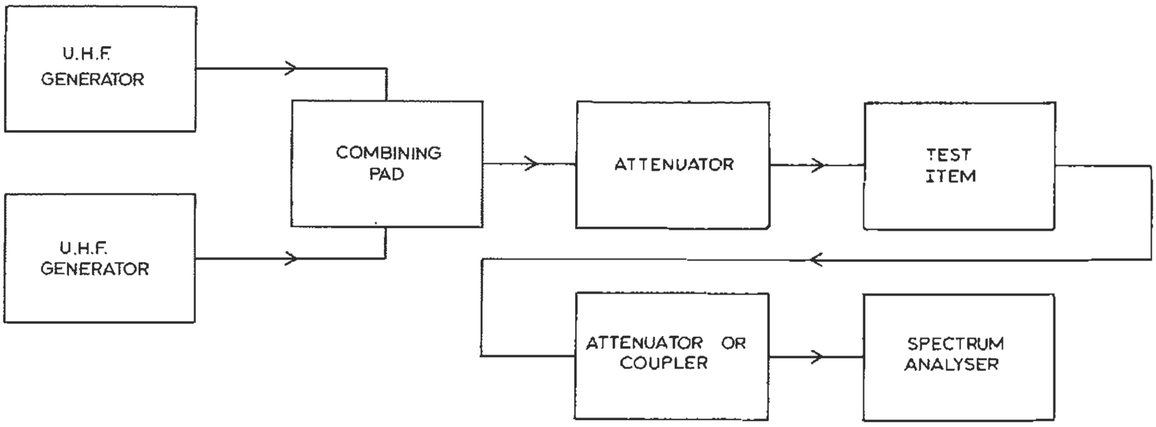

Fig. 1

1.2 The vision and sound carriers should be set to give the rated power levels at the output of the test item. If the signal sources can not be independently varied, it is normally sufficient if the power levels are correct at the input.

1.3 Check that no cross-modulation effects are produced either by interaction between the generators or by non-linear operation of the Spectrum Analyser.

1.4 With the vision carrier switched on, measure the amplitude of the sound carrier.

1.5 Switch off the vision carrier and note the percentage increase in sound carrier level; a decrease should be expressed as a negative percentage.

MEASUREMENT METHODS (continued)

2. *Dynamic Method*

Equipment Required

Video Generator	GE4M/561 etc.
UHF Test Modulator	MD1/502 or MD1/507, EP14M/501, EP14M/507
Spectrum Analyser	Commercial Spectrum Analyser or EP14M/507 (note different procedures)

Test Procedure

2.1 Connect the test equipment as shown in Fig.2.

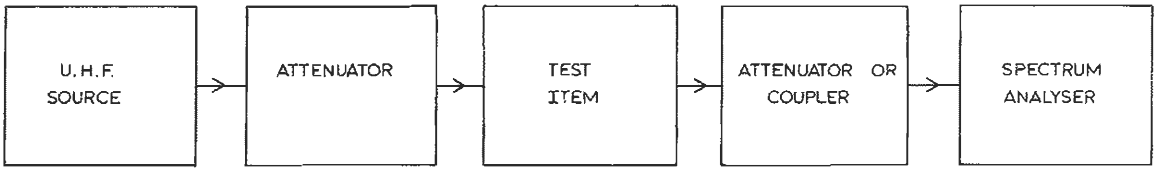

Fig. 2

2.2 Modulate the vision carrier with a composite video waveform* which covers the full video dynamic range, e.g. Sawtooth or 5-step staircase, without chrominance.

2.3 The vision and sound carriers should be set to give the rated power levels at the output of the test item. If the carriers can not be independently varied, set the vision power output to the correct level and note any vision-to-sound ratio error.

2.4 Set the analyser display to Linear Mode+ and display the sound carrier to give a vertical deflection of A divisions, see Fig. 3.

2.5 Set the I.F. bandwidth to at least 100 kHz* and adjust the dispersion, or sweep rate, to give a display similar to those shown in Figs. 3 & 4. These displays are of an amplifier with normal compression. Note that the I.F. bandwidth is insufficient to show full line-sync information.

2.6 Measure the peak-to-peak thickening of the trace, (which is normally absent during the field interval) B divisions, and calculate the vision-to-sound cross-modulation.

$$\text{Cross-modulation} = \frac{B}{A} \times 100\%$$

2.7 If the amplifier includes pre-correction, over-compensation may cause the cross-modulation to appear inverted. B will appear to be negative and this should be noted.

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* If a line repetitive video waveform is used, the analyser I.F. bandwidth *must* be set to at least 300 kHz. If the R.F. Test Set is used with a 100 kHz I.F. bandwidth, then the measured cross-modulation must be multiplied by 1.1.

\+ If the analyser is used in the logarithmic mode (preferably 1 dB or 2 dB per vertical division) then the thickness of the trace is the cross-modulation in decibels.

MEASUREMENT METHODS (continued)

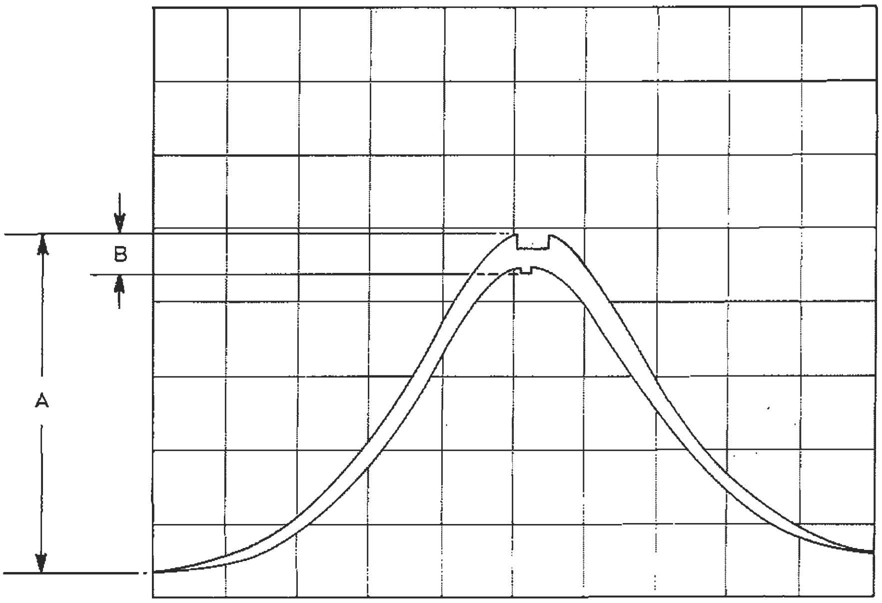

Fig.3 A and B dimensions

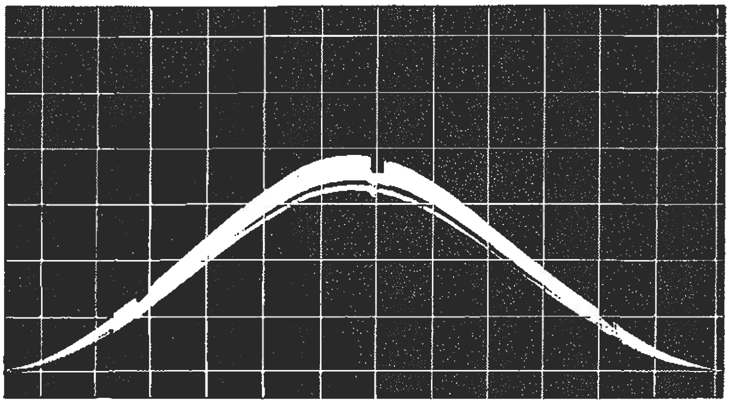

Fig. 4 Typical display showing approximately 15% Vision-to-Sound Cross-modulation

APPENDIX RTP-D

THE SMITH CHART

1. Introduction

The Smith Chart is mainly used for impedance calculations involving transmission lines. It is sometimes referred to as the circle diagram.

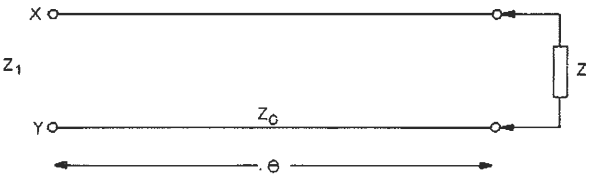

Fig. 1
An Impedance connected to a Lossless Transmission Line

Fig. 1 shows an impedance $Z=R+jX$ connected to a lossless transmission line of characteristic impedance Z_0. The impedance Z_1 at the terminals XY is given by:

$$Z_1 = Z_0 \frac{Z + jZ_0\tan\theta}{Z_0 + jZ\tan\theta} \qquad (1)$$

where θ is the electrical length of the line.
For a lossless line, Z_0 is a pure resistance. If the impedances Z and Z_1 are divided by Z_0 they are said to be normalised. Equation (1) then becomes:

$$z_1 = \frac{z + j\tan\theta}{1 + jz\tan\theta} \qquad (2)$$

$$\text{where } z = Z/Z_0 \text{ and } z_1 = Z_1/Z_0$$

The Smith Chart provides a convenient way of solving Equation (2); it may be regarded as a two-dimensional slide rule. An example of the chart is illustrated in Fig. 2. Any normalised impedance may be plotted on it, for example the point A represents the normalised impedance $0.32+j0.68$.
The circumference of the chart has two scales labelled *wavelengths towards generator* and *wavelengths towards load.* These represent the electrical length θ of the transmission line, expressed in terms of its length in wavelengths. For example, 0.25λ corresponds to $\theta=90°$, although it is represented on the circumference of the chart by a rotation of 180°.
One wavelength in the transmission line is equal to the free-space wavelength only if the line is air-spaced. Otherwise it is shorter, by a factor k called the velocity factor, given in tables of cable data. For a polythene-insulated line, for example, $k=0.67$; if the free-space wavelength is 30 cm the wavelength inside the cable is only 20 cm.
If the point A in Fig. 2 represents the impedance Z of Fig. 1 (when normalised), then the impedance at the terminals XY of Fig. 1 is found by moving the point A in a clockwise direction (i.e. towards the generator) round the centre of the chart. Thus if the length of the line is 0.1λ ($\theta=36°$), then A moves to the point B, which indicates that the impedance Z, (when normalised) is equal to $1.58+j2.06$.
In its most convenient form, the Smith Chart has a transparent overlay which can be rotated. The point A is marked on the overlay, which is then rotated through the required number of wavelengths. The new impedance value can then be read directly.

2. Applications

Some of the many uses of the Smith Chart are described below.

2.1 Effect of a Transmission Line on a Known Impedance

This application was described in Section 1.

2.2 Interpretation of Impedance Measurements

It often happens that an unknown impedance, such as that of an aerial, is measured through a length of transmission line. The unknown impedance can be determined by rotating the measured impedance in an anticlockwise direction, i.e. towards the load.

2.3 Standing-wave Ratio (S.W.R.)

For a given flow of power along a transmission line:

$$\frac{V_{max}^2}{R_{max}} = \frac{V_{min}^2}{R_{min}} \qquad (3)$$

where R_{max} and R_{min} are the resistive impedances at the voltage maxima and minima. It then follows that:

$$\text{S.W.R.} = \frac{V_{max}}{V_{min}} = \left[\frac{R_{max}}{R_{min}}\right]^{1/2} = \left[\frac{r_{max}}{r_{min}}\right]^{1/2} \qquad (4)$$

where r_{max} and r_{min} are the normalised resistances at the voltage maxima and minima. In the example shown in Fig. 2, the points A and B represent complex impedances which, if rotated further, will cross the vertical axis at $4.67 + j0$ and $0.214 + j0$. These values correspond to r_{max} and r_{min} respectively. Since r_{min} is the reciprocal of r_{max}, it follows from Equation (4) that the S.W.R. is equal to 4.67 and that the values at which the circle described by the points A and B cuts the real axis indicate the S.W.R. and its reciprocal.

2.4 Reflection Coefficient

If a transmission line is mismatched, some of the power incident on the termination is reflected and travels back towards the source. The voltage across the termination can be resolved into two components, one corresponding to the incident wave (V_i) and the other corresponding to the reflected wave (V_r). The ratio V_r/V_i is known as the reflection coefficient and denoted by ρ. In general it is complex and is given by:

$$\rho = \frac{z - 1}{z + 1} \qquad (5)$$

where z is the normalised impedance of the termination. The Smith Chart can be used to derive ρ from z, or vice versa, as an alternative to solving Equation (5).

The radial distance of a point from the centre of the Smith Chart is proportional to $|\rho|$. If the point lies at the centre of the chart, the transmission line is matched and $\rho = 0$. On the other hand, if it is situated at the edge of the chart, $|\rho| = 1$ and the line is terminated by a pure reactance. A scale around the circumference of the chart indicates the phase of ρ.

In the example shown in Fig. 2, the distance of the point A from the centre of the chart is 0.64 times the radius, and the radial line through A indicates a phase of 108°. The reflection coefficient at the end of a line terminated by the impedance represented by the point A is therefore $0.64\ \underline{/108^\circ}$. The reverse process is used to determine z from ρ.

A linear scale showing $|\rho|$ on the transparent overlay is a useful addition to the Smith Chart. Alternatively $|\rho|$ may be converted to S.W.R., or vice versa, using one of the following expressions:

$$|\rho| = \frac{S - 1}{S + 1} \quad \text{or} \quad S = \frac{1 + |\rho|}{1 - |\rho|} \qquad (6)$$

where S is the S.W.R. The scale on the real axis of the Smith Chart can then be used to plot the impedance when ρ is given, or to determine ρ for a given impedance.

2.5 Impedance/Admittance Conversion

If the normalised impedances z and z_1 in Equation (2) are replaced by the corresponding normalised admittances, given by $y = 1/z$ and $y_1 = 1/z_1$, the following result is obtained:

$$y_1 = \frac{y + j\tan\theta}{1 + jy\tan\theta} \qquad (7)$$

This equation is of the same form as Equation (2) and the Smith Chart can therefore also be used for normalised admittances.*

If $\theta = 90°$, Equation (2) simplifies to $z_1 = 1/z = y$. Thus the normalised impedance of a load seen through a quarter wavelength of line is equal to its normalised admittance. The admittance of any impedance can be determined by plotting it on a Smith Chart and rotating it through 0.25λ.

2.6 Impedance Matching

The centre of the Smith Chart corresponds to a perfect match. For well-matched impedances an enlargement of the central part of the chart, shown in Fig. 3, gives better accuracy.

One method used for matching is to place a shunt capacitance at a strategic point on the transmission line. This method is illustrated in Fig. 3 where the point A represents the impedance to be matched. It is first converted to normalised admittance by means of a 0.25λ rotation to point B. The next step is to find a point on the line where the normalised conductance is equal to 1.0 and the susceptance is negative, corresponding to parallel inductance. In the example, this is achieved by moving a distance of 0.144λ towards the generator, to the point C. Here the normalised admittance is 1.00 – j0.41 and the addition of a capacitor having a normalised susceptance of j0.41 moves the point to the centre, resulting in a perfect match.

3. The Effect of Attenuation

The transmission line has, so far, been assumed to be lossless. Points revolve around the centre of the chart at constant radius, so that impedance values repeat every half wavelength. Attenuation, however, makes points spiral inwards as the terminals XY of Fig. 1 are approached. If the line were infinitely long the points would spiral to the centre and the impedance at XY would then be equal to Z_0, regardless of the termination.

Attenuation can be taken into account by modifying the standing-wave ratio according to the formula:

$$S_1 = \frac{(S + 1)10^{0.1A} + (S - 1)}{(S + 1)10^{0.1A} - (S - 1)} \qquad (8)$$

where S is the S.W.R. of the termination, S_1 the S.W.R. at the terminals XY of Fig. 1 and A is the total attenuation of the line in dB. Fig. 4 shows the relationship between S and S_1 for attenuations up to 10 dB.

In practice the impedance Z (see Fig. 1) is plotted on the Smith Chart and its S.W.R. (S) is determined by the method described in Section 2.3. The corresponding value of S_1 is then derived from Fig. 4, or Equation (8), and the point is moved radially inwards to the new S.W.R. value. The point is then rotated as before. The opposite procedure applies when impedance measurements are being interpreted because S_1 is now known and it is S which has to be derived from Fig. 4, to enable the point to be moved radially outwards. In all applications, movement towards the load causes the point to spiral outwards, and vice versa.

Bibliography

Smith, P.H., Transmission Line Calculator, Electronics, Vol 12, No. 1 pp 29-31, January 1939.

Hickson, R.A. The Smith Chart, Wireless World, January, February and March 1960. Available as BBC Engineering Division Reprint Article A.110.

Jordan, E.C. and Balmain, K.G., Electromagnetic Waves and Radiating Systems. Prentice Hall 1968 (Section 7.17).

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*The scales of commercially available Smith Charts are usually labelled in terms of normalised resistance and reactance. When used for admittance these scales represent normalised conductance and susceptance. The left-hand half of the chart corresponds to negative susceptance (shunt inductance).

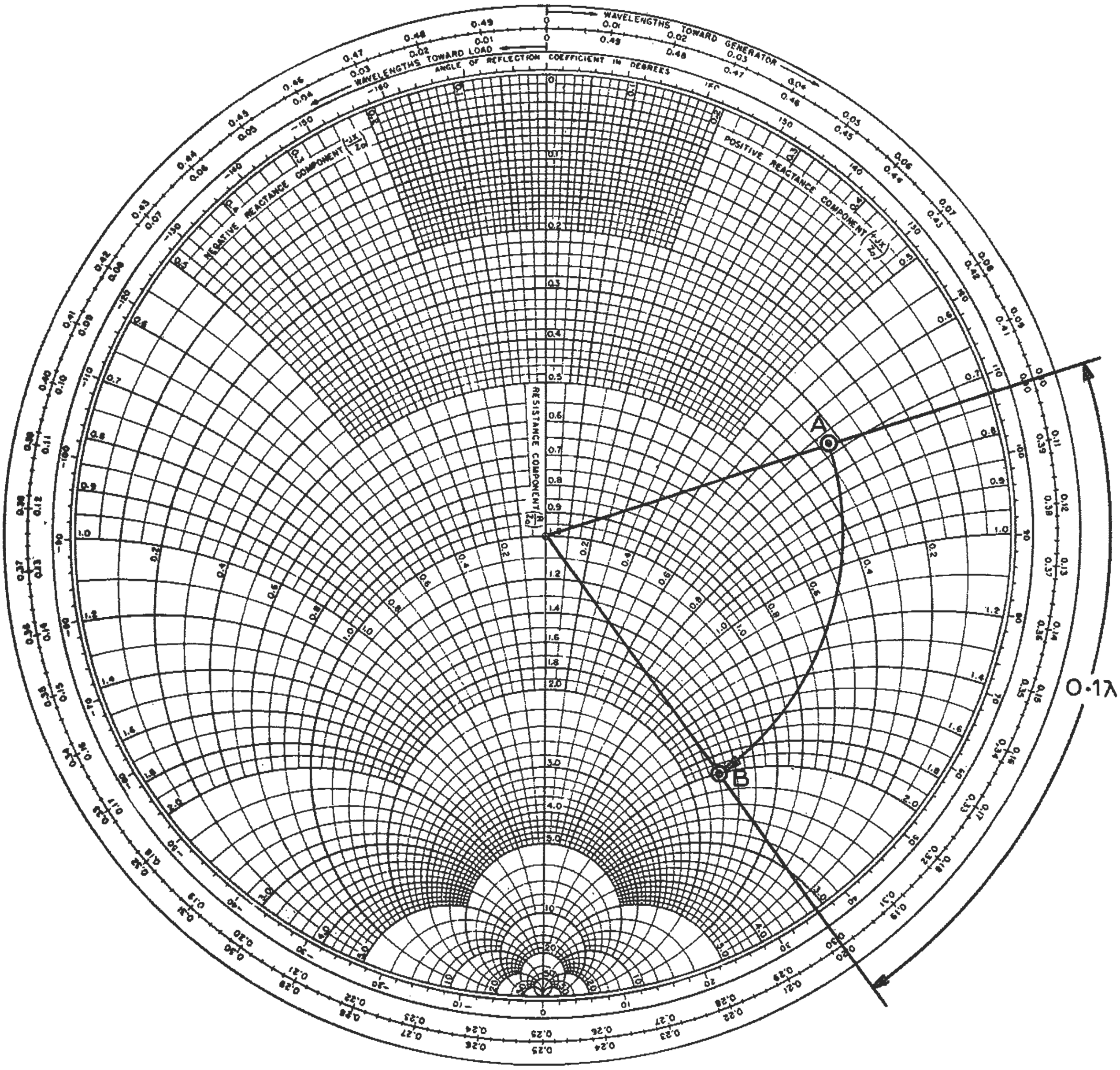

Fig. 2 The Smith Chart

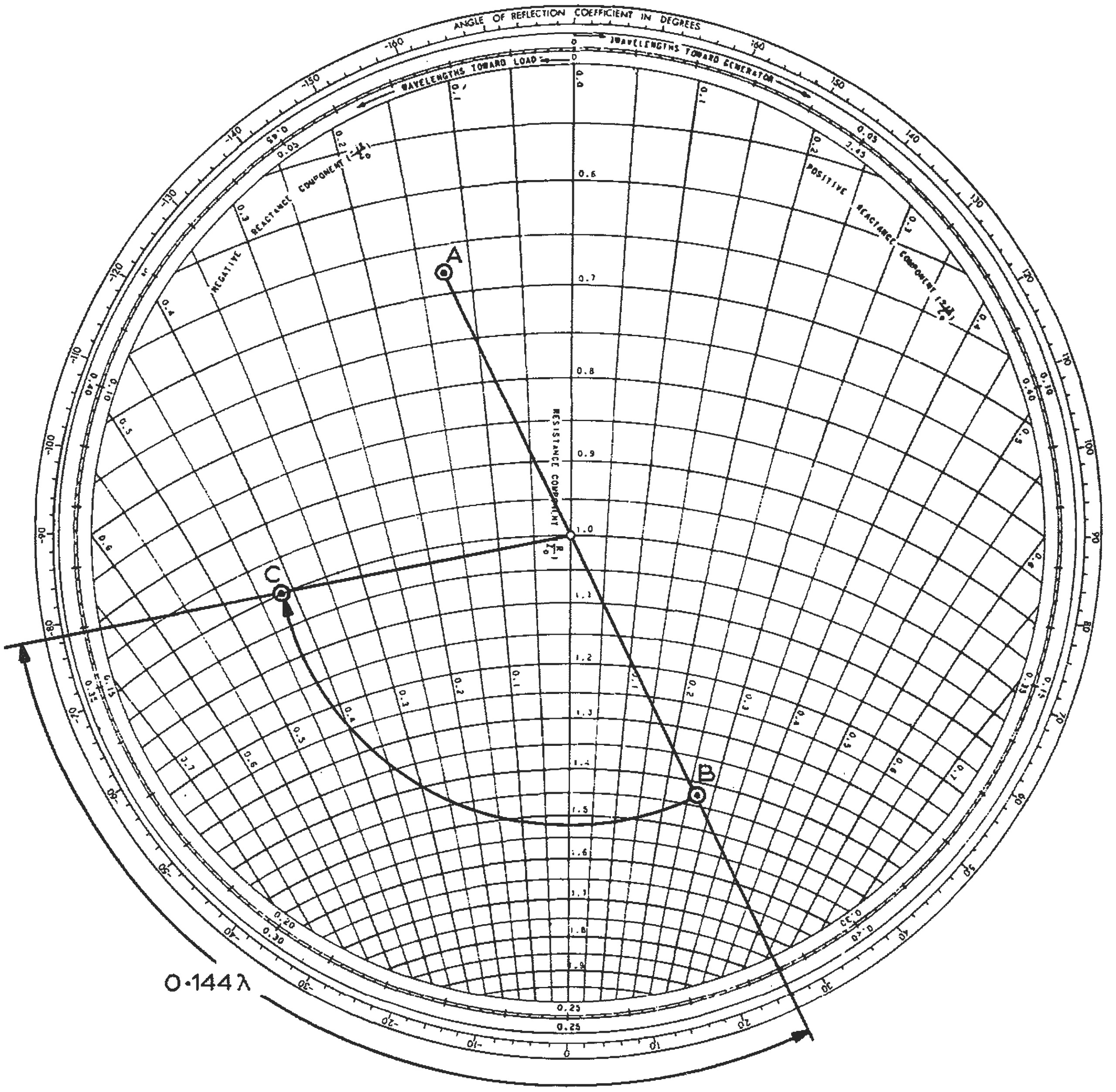

Fig. 3 Impedance Matching with a Smith Chart

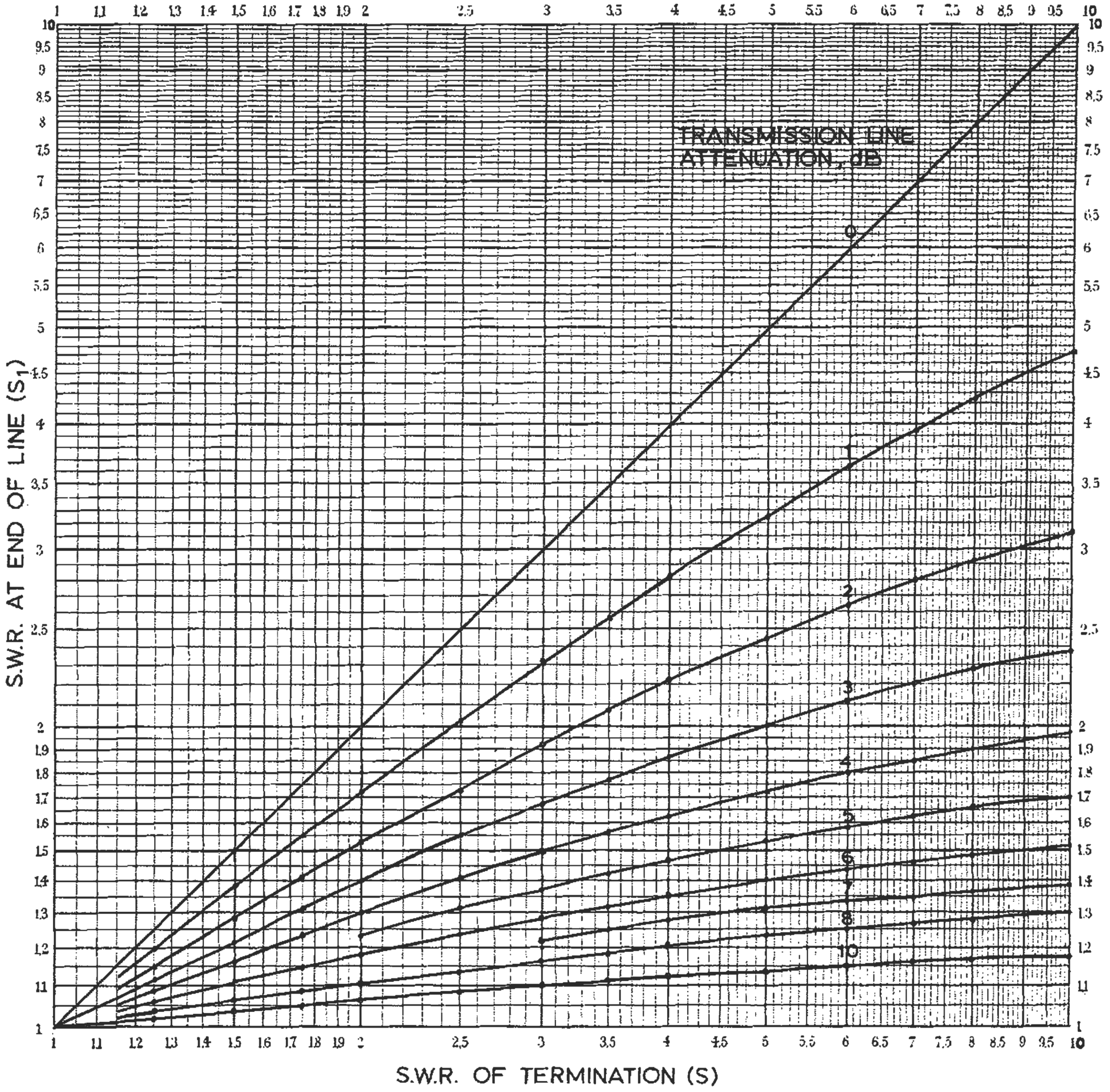

Fig. 4 Effect of Attenuation on S.W.R.