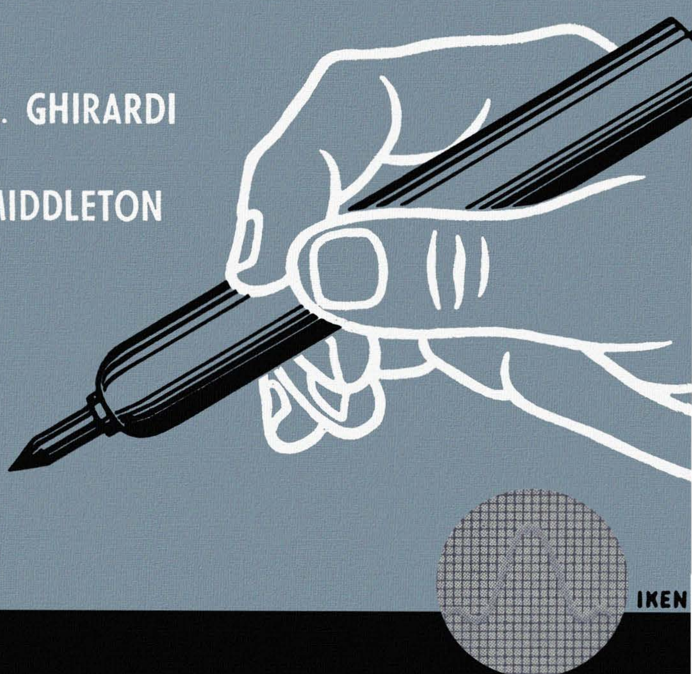
how to use

TEST PROBES



by ALFRED A. GHIRARDI

AND

ROBERT G. MIDDLETON

Including

- HIGH-VOLTAGE PROBES
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PREFACE

The ever-increasing application of volt-ohm-milliammeters (vom), vacuum-tube voltmeters (vtvm) and oscilloscopes in troubleshooting and adjusting the circuits of all forms of complex electronic equipment has greatly increased the diversity of voltages, frequencies and test-circuit characteristics with which they are called upon to operate. As a result, their operating demands often exceed the inherent capabilities of these fundamental test instruments.

Suitably designed auxiliary devices, arranged in convenient "probe" form, which add new ranges and new functions to these conventional instruments are now widely employed for extending their fields of application into circuits of very high voltage, high frequency, or high impedance. Such probes provide practical and inexpensive extensions of the inherent capabilities of the instrument, since they may be quickly connected externally to its input circuit.

The use of a variety of special-purpose instrument probes has now become a practical necessity, especially in tv receiver servicing. Consequently, it is important for every service technician to understand thoroughly the function and basic theory of operation underlying all types of probes and also the correct methods of using them to obtain the maximum amount of service they are capable of giving. It is also important to be able to quickly decide which type of probe is best suited for a particular application, so as to avoid incorrect usage which may result in misleading test instrument indications, and consequent incorrect conclusions regarding the observed results of the tests.

It is the purpose of this book to present the required information in a simple and thorough manner that will make this subject easily understandable and helpful to both practicing technicians and beginners alike, so that they will know how to use test instrument probes correctly.

The authors wish to thank Milton S. Snitzer, managing editor of John F. Rider, Publisher, Inc., who technically reviewed and edited the manuscript for this volume.

New York City
August, 1954

A.A.G.
R.G.M.

CONTENTS

Chapter 1

RESISTIVE HIGH-VOLTAGE D-C PROBES

1-1. Function of the Resistive High-Voltage D-C Probe

Most conventional volt-ohm-milliammeters (vom) and vacuum-tube voltmeters (vtvm) have d-c voltage measuring ranges which do not exceed 6,000 volts —in fact, many do not exceed 2,000 volts. Such ranges are sufficient for measurement of the low and medium voltages generally encountered in electronic and industrial electric equipment. However, it is frequently necessary to measure the much higher d-c voltages present in some of the circuits in industrial electrical equipment, electromedical apparatus, radio and tv transmitters, and the horizontal output and high-voltage picture tube circuits of television receivers (see Fig. 1-1A). For example, the typical actual second-anode d-c operating voltages for black-and-white tv picture tubes of various sizes, and for the color picture tubes announced thus far, are as follows:

The normal d-c voltage measuring range of a conventional high-resistance vom, and of a vtvm, can be effectively extended to make high-voltage measurements possible through the use of a simple external multiplier resistor of proper value, arranged in a suitable insulated probe body, and connected in series with the input circuit of the instrument. A typical resistive high-voltage probe is illustrated in Fig. 1-1B. While such probes are primarily intended for use with high-resistance vom's and with vtvm's, they also have some special applications in connection with oscilloscopes (see Sec. 1-9).

The multiplier resistance employed is ordinarily chosen to provide a convenient decimal scale-multiplication factor such as 100-to-1, or 1,000-to-1, so that the d-c scale of the vom or vtvm is direct-reading with the addition of one or more zeros when the probe is used.

1-2. Calculating the Multiplier-Resistance Values Required for use with a VOM

The value of multiplier resistance required to extend the d-c voltage range (usually the *highest* d-c voltage range of the instrument is extended) of a vom to a desired value may be easily calculated if the sensitivity of the instrument is known, or if the input resistance of the instrument when the range switch is set for that particular d-c voltage range value, is known. The following practical example will illustrate this:

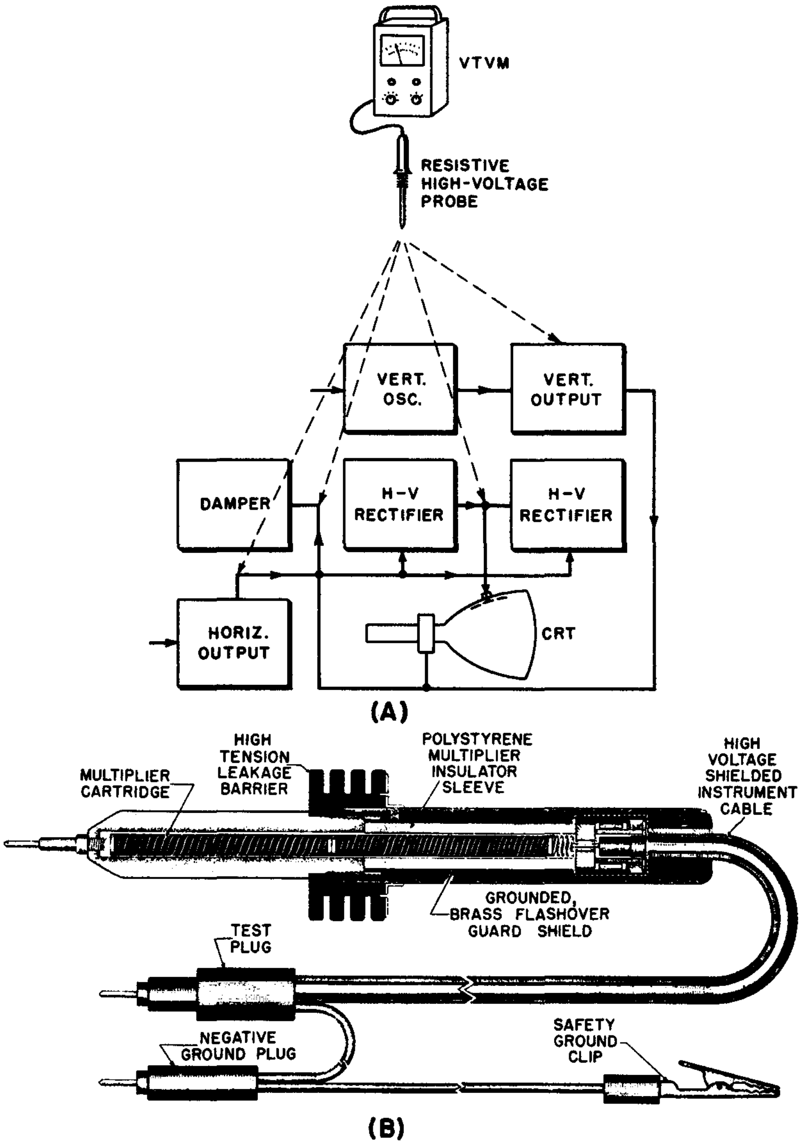


Fig. 1-1. (A) Tv high-voltage circuits where a resistive high-voltage probe must be used with a vom, or a vtvm, for d-c voltage measurement. (B) Cross section of a high-voltage d-c probe, and its heavy-duty connecting cable, for use with a sensitive vom or a vtvm. The insulating probe housing is specially shaped and constructed to minimize electrical leakage and corona. The full handle length contains a grounded internal flashover guard shield. A ribbed external leakage and arc-back barrier is also provided. The long spiral-film type multiplier resistor in removable cartridge form extends almost the full length of the probe. Either the pin-plug type termination shown here, or a standard screw-on mike type (panel) connector for use with most vtvm's may be provided at the meter end of the connecting cable. This probe will provide voltage ranges to 60,000 volts dc when used with standard vtvm's or high-sensitivity (20,000 ohms-per-volt) vom's. *(B) Courtesy: Precision Apparatus Co., Inc.*

TABLE 1-1

TYPICAL ACTUAL SECOND-ANODE VOLTAGES FOR PICTURE TUBES OF VARIOUS SIZES

Pix Tube Size	*Voltage (dc)*	*Pix Tube Size*	*Voltage (dc)*
10″	8,000- 9,000v	19″	12,000-14,000v
12″	6,000-11,000v	20″	10,000-16,000v
14″	11,000-12,000v	21″	14,000-16,000v
15″	12,000-13,000v	22″	14,000-18,000v
16″	9,000-14,000v	CBS Colortron	20,000v
17″	12,000-16,000v	RCA Tri-Color Kinescope	20,000v

Let us assume that a service-type vom whose sensitivity is 20,000 ohms-per-volt and whose maximum d-c voltage range is 6,000 volts is to have this range extended to 30,000 volts, so that all required high-voltage measurements in monochrome and in color tv receiver servicing may be made with it. This is to be accomplished by means of an external multiplier resistor, R, connected in series with it, with the range switch set at the 6,000-volt range position, as shown in Fig. 1-2A.

The input resistance, R_M, of the instrument is equal to the full-scale voltage of the range multiplied by the instrument sensitivity in ohms-per-volt. In this particular case, $R_M = 6{,}000 \times 20{,}000 = 120{,}000{,}000$ ohms, or 120 megohms.

The voltage distribution in the probe-plus-meter circuit will be as shown in Fig. 1-2B. Observe that when the test circuit voltage is 30,000 volts, the meter is to read full scale, so the voltage being applied to input terminals of the meter must be 6,000 volts. This leaves $30{,}000 - 6{,}000 = 24{,}000$ volts to appear as a voltage drop developed across the multiplier resistor R. Since this is a simple series circuit, the voltage drops are proportional to the resistance, so

$$\frac{R}{R_M} = \frac{24{,}000}{6{,}000} \text{ or } \frac{R}{R_M} = 4$$

Therefore, $R = 4 \times 120 = 480$ megohms .This is the required multiplier resistor value for these particular conditions. When this resistor is used, each reading taken on the 6,000-volt d-c scale must be multiplied by the factor 5 ($30{,}000 \div 6{,}000$), to obtain the true voltage.

When selecting and applying resistive high-voltage probes to vom's, it must be remembered that because the input resistance value of a vom is entirely different for each setting of the d-c voltage range switch, the calculated value of the multiplier resistance required to obtain a particular multiplying factor with a specific instrument is the correct one *for only the particular range-switch setting that was considered in the calculation.*

Table 1-2 is presented here as an aid in the rapid determination of the correct multiplier resistance required to extend the normal specified d-c voltage range of conventional 20,000, 25,000, or 100,000 ohms-per-volt vom's to the higher ranges frequently required in the testing of some high-voltage circuits in electrical and electronic equipment. For added utility, the manufacturer's name

TABLE 1-2

HIGH-VOLTAGE (D-C) MULTIPLIER RESISTANCE SELECTION CHART FOR VOM's

For Meter Having a Sensitivity of: (Ohms-per-Volt)	*To Give D-C Voltage Range of:*	*With Instrument D-C Range Switch Set at: (A)*	*Use Multiplier Resistance Value of: (Megohms)*	*Multiply Scale Readings By:*	*Commercial VOM's Which Have This Sensitivity and Maximum Range (A)* Manufacturer	Model No.
20,000	10,000v	1,000v	180	10	General Elect.	YMW-1
	25,000	1,000	480	25	Simpson	250, 277
	30,000	1,000	580	30	Triplett	2405-A
	50,000	1,000	980	50	Weston	772, 779, 785
20,000	10,000v	1,500v	170	6.7	Precision	850
	15,000	1,500	270	10	Roller-Smith	500
	30,000	1,500	570	20		
	50,000	1,500	970	33		
20,000	10,000v	2,500v	150	4	Triplett	625-NA
	25,000	2,500	450	10		
	50,000	2,500	950	20		
20,000	10,000v	5,000	100	2	Clough-Brengle	220
	25,000	5,000	400	5	Electronic Inst.	555
	30,000	5,000	500	6	General Elect.	UM-2
	50,000	5,000	900	10	Hickok	435, 534, 538
					Precision	852
					Radio City	461, 462
					Simpson	260, 445, 1005
					Supreme	567, 584
20,000	10,000v	6,000v	80	1.7	Precision	85, 654, 854, 856, 858, 954, 10-54
	30,000	6,000	480	5		
	60,000	6,000	1,080	10	Radio City	488-A
					Triplett	630
25,000	10,000v	1,000v	225	10	—	—
	50,000	1,000	1,225	50		
100,000	4,000v	1,600v	240	2.5	Simpson	269
	15,000	1,600	1,340	9.4		
	25,000	1,600	2,340	15.6		
Simpson Rotoranger Model 221	30,000v	300v	594	100	Simpson	Rotoranger Model 221
	50,000	5,000	900	10		

Compiled from information supplied by Precise Development Corp.

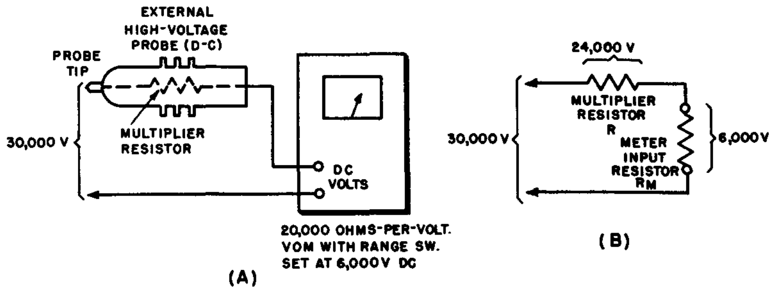


Fig. 1-2. (A) Connection of multiplier resistor in series with vom input circuit. (B) Voltage distribution in the series probe-plus-meter circuit, for the particular conditions specified in the text problem.

and model numbers of popular commercial vom's which fall into each sensitivity-and-range category are also listed. For instrument and range combinations other than those listed in this table, the calculation procedure explained earlier in this section may be used.

1-3. Resistive Loading Effect of Probe-and-VOM Combination

The current drawn from the test circuit by the resistive high-voltage probe and vom combination is a matter of importance when this combination is used for measuring the voltage in high-voltage circuits whose voltage regulation is poor. For example, the voltage regulation of the typical picture-tube high-voltage supplies employed in tv receivers is relatively poor. As a result, the output voltage tends to decrease appreciably (see Fig. 1-3) if the current demand is increased very much percentage-wise above that of the picture tube in normal operation. Consequently, for accurate measurement of the high voltage at the second anode of a picture tube by means of a resistive high-voltage probe and vom combination, it is necessary to make the measurement in such a manner that the current load on the high-voltage power supply of the receiver will not be appreciably greater than the normal beam current of the picture tube. The beam current of most picture tubes of the 17- to 21-inch size group may be considered as being approximately 300 microamperes, for normal brightness.

Let us assume that a conventional 20,000 ohms-per-volt vom having a 6,000-volt d-c range is used in combination with an external 480-megohm resistive high-voltage d-c probe to extend this range to 30,000 volts (see Table 1-2), and that this combination is to be employed to check the second-anode voltage of a 21-inch picture tube. This voltage to be checked will be approximately 14,000 to 16,000 volts (see Table 1-1). If the actual second-anode potential is 16,000 volts, the probe-plus-vom combination (whose total resistance is $20{,}000 \times 6{,}000$ ohms $+ 480$ meg $= 600$ meg) will cause a current drain of approximately 27 microamperes. Obviously, this nominal additional current drain added to the beam current (approximately 300 μa) of the tube for normal brightness will not appreciably alter the actual second-anode voltage. Accordingly, the measurement may be made by merely applying the measuring circuit to the second-anode terminal and chassis-ground of the receiver.

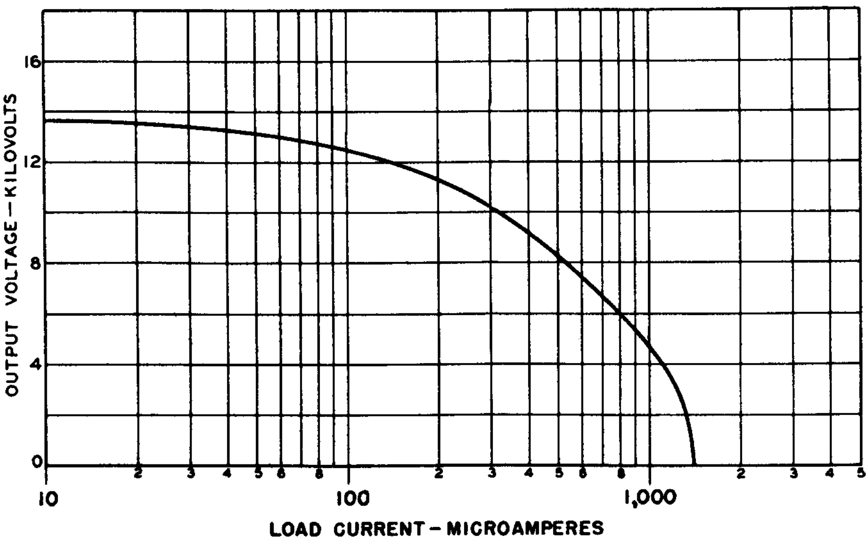


Fig. 1-3. Measured steady-load voltage regulation characteristic of high-voltage supply for the 16AP4 picture tube. *Courtesy: RCA*

To investigate the current loading effects further, let us next consider the conditions if a 1,000 ohms-per-volt meter having a top d-c voltage range of 3,000 volts is used for this measurement. A 27-megohm multiplier resistor would be required to extend the range to 30,000 volts, and the current drain imposed by the measuring-instrument circuit would not be 533 μa. Since the beam current of the picture tube is considered to be 300 μa, it is plain that in this case the appreciable test-instrument current drain would load down the high-voltage power supply very seriously, resulting in a large regulation error if the measurement were made in the conventional manner. More accurate measurement could be accomplished by *removing* the second-anode lead from the picture tube during measurement (or turning down the brightness control to minimum), so that the current drain of the instrument would be *substituted* for (instead of being added to) the normal beam current of the picture tube. Of course, greater accuracy is obtained by using a 20,000 ohms-per-volt vom for this purpose, so that the measuring circuit has relatively high resistance.

1-4. Selection of Multiplier-Resistance Values for use with VTVM's

A series multiplier resistor arranged to form an external probe may also be used to extend the d-c voltage measuring range of a vtvm so that the instrument may be used for the measurement of high voltages. However, the behavior of such a multiplier used with a vtvm is different in one respect from that when used with a non-electronic vom.

The circuit arrangement in Fig. 1-4 shows an external multiplier resistor arranged in d-c probe form connected in series with the conventional type of d-c input circuit employed in vtvm's. In order to permit the vtvm to make d-c voltage measurements accurately over a variety of easily selected voltage ranges, a voltage-divider circuit is usually arranged across the input terminals to the instrument, as shown, and a range switch permits a definite proportion of the applied input voltage to be tapped off and applied to the measuring tube and indicating meter. The tube draws no current from the input circuit. Since the full voltage-divider resistance is always in the input circuit and is constant in value regardless of the setting of the range switch, when this input circuit arrangement is employed, an external multiplier resistor will multiply each range of the vtvm by the same factor (for example 100) and hence the same multiplier resistor can be used when any range of the vtvm is employed. By selecting a suitable value of the multiplier resistance for the high-voltage probe, the normal voltage range *for each position* of the vtvm range switch can be multiplied by a desired amount. A decimal (10, 100, 1,000, etc.) multiplying factor is usually chosen for operating convenience because high-voltage measurements can then always be made on the upper portion of the scale, which provides higher accuracy of indication. In most cases, the multiplier resistance value is selected to provide the desired high-voltage measuring range when the vtvm range-selector switch is set at the highest d-c voltage range of the vtvm.

The multiplier resistance required to extend the voltage range of a vtvm is calculated in the same general manner as for a vom (see Sec. 1-2). For example, suppose it is required to extend the 500-volt d-c range of a vtvm having 11 megohms input resistance, to 50,000 volts (100 to 1 voltage multiplication). When the test input voltage is 50,000 volts, the voltage applied to the normal

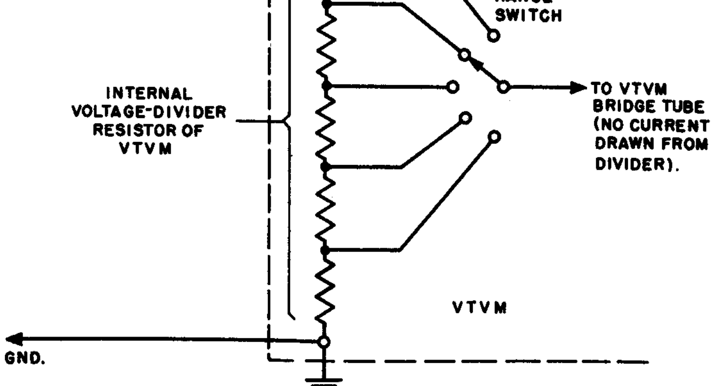


Fig. 1-4. The measuring tube of a vtvm draws no current, and hence the meter in the vtvm really indicates the voltage drop at any selected point along the internal voltage-divider resistor, instead of measuring the current through the instrument, as does a vom. For convenience, the value of the external multiplier resistor in the the resistive high-voltage probe can be selected to multiply each of the vtvm voltage ranges by a convenient decimal factor, such as 100.

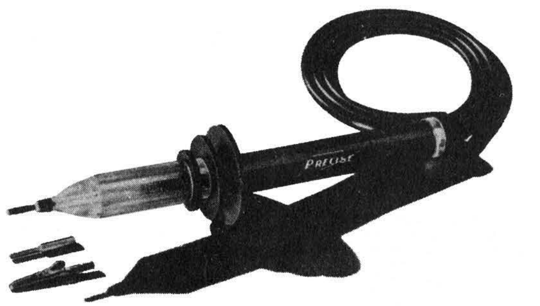


Fig. 1-5. External appearance of a high-voltage d-c probe for use with a vom or a vtvm, provided with an interchangeable conventional tip for probing, and an alligator clip for permanent connection to the circuit. The multiplier resistor cartridge is held between a double-spring suspension system inside of the clear plastic portion at the left. This probe is rated at 30,000 volts maximum. *Courtesy*: *Precise Development Corp.*

vtvm d-c input terminals and 11-megohm input resistance must be 500 volts. A voltage drop of 50,000 – 500 = 49,500 volts must therefore be developed across the multiplier resistor. The value of the latter must be, therefore,

$$R = \frac{49{,}500}{500} \times 11 = 1{,}089 \text{ meg.}$$

(Actually, a 1,090-meg multiplier is used to take into account the 1-meg isolating probe usually used with the vtvm. The h-v probe is substituted for the isolating probe, whose purpose is described in Chapter 2.) If it is desired to measure, say, 19,000 volts with this high-voltage probe and vtvm, the range switch should be set to the 500-volt range. The indication will be 190 volts on the 500-volt scale. The meter reading is then multiplied by the probe multiplying factor of 100, to give 19,000 volts.

It is evident that the high-voltage multiplier resistance value which must be used with a particular vtvm in order to multiply its d-c voltage range by a specific factor, must be selected especially for that particular vtvm. Also, it must not be assumed that two different model vtvm's made by the same manufacturer necessarily have the same input resistance and so may use the same multiplier-resistance value. They may be designed with different internal resistances, making different values of multiplier resistance necessary for a given multiplying factor.

Table 1-3 is presented here as an aid in the rapid determination of the correct multiplier resistance required to extend the normal specified d-c voltage range of a number of popular service-type vtvm's to the higher ranges required in the testing of some high-voltage circuits in electronic equipment. The type of connector required at the end of the probe cable in order to match the type of input terminal employed on the particular vtvm is also specified in each case.

1-5. Physical Design and Construction of Resistive High-Voltage Probes

The multiplier resistors, available in all of the values listed in Tables 1-2 and 1-3 to meet the requirements of most 20,000 ohms-per-volt vom's and most vtvm's, are generally of the high-voltage cartridge type having a spiral film-type resistance element printed on a ceramic core (see Fig. 1-1). They generally are removable so that different values may be used when necessary.

The probe body, which acts as the housing for the multiplier resistor, is made of insulating material having high dielectric strength and low leakage.

Safety, operational simplicity, and rugged construction are the prime considerations in its design. It is provided with several safety flanges to minimize surface leakage and corona, to protect the hand of the operator from coming in contact with the high voltage, and also to protect him from arcing or corona. An insulating handle is provided at the end.

Some high-voltage probes, see Fig. 1-5, are provided with interchangeable tips to increase their versatility in making contact to the circuits under test. One is the conventional type for probing, the other is an alligator clip for connecting the probe permanently to the circuit during test.

A shielded cable is usually employed. The high-voltage probes for use with practically all vom's require a pin-plug type of end connector on the cable to match the input circuit connectors on the meter. Those for use with vtvm's may require any one of three different types of end connectors (see right-hand column of Table 1-3) to match those used on the meter.

An internal shield, grounded to the cable shield, is usually provided for the full handle length to protect the operator from possible flashover and to ground any electrostatic charges that might accumulate on the probe body. The resistor is not shielded.

1-6. Operating an Instrument with a High-Voltage Probe—Safety Precautions

The resistive high-voltage probe is employed by removing the original d-c test lead from the vom or vtvm and substituting the inner conductor of the probe cable for it. The gnd terminal of the vom or vtvm should be connected to the shield of the probe cable and to the chassis or the B-minus line of the equipment under test. Remember that the *shielding in a high-voltage probe and its cable must always be grounded* as directed above, otherwise the entire test

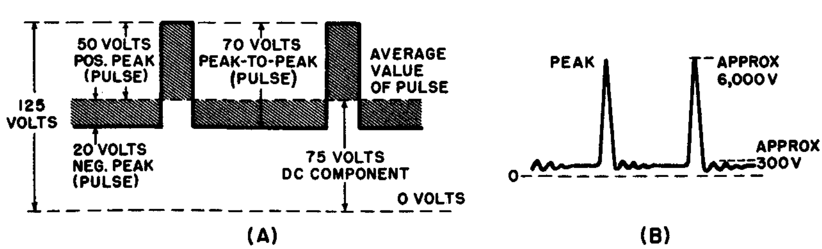


Fig. 1-6. (A) Pulse voltage with a d-c component present. In this particular example, the peak-to-peak value of the pulse voltage is of the same order as the d-c voltage. When this pulsating d-c voltage is applied to the input terminals of a d-c voltmeter, the instrument will indicate 75 volts. In this case, the a-c voltage component is sufficiently low so that the instrument will not be damaged. If the value of the d-c component were only 10 volts, for example, the a-c component would then cross the zero axis, and the wave would not then be referred to as pulsating d-c, but as a-c with a d-c component. The distinction is somewhat academic but can lead to confusion if the definitions are not kept clearly in mind. The pulses present in some tv receiver circuits have peak values very much greater than the d-c component present, as shown at (B). For example, the d-c voltage at the plate of the horizontal-output tube may be of the order of 300 volts, but the pulse voltage which accompanies it may be of the order of 6,000 volts peak-to-peak.

TABLE 1-3

HIGH-VOLTAGE (D-C) MULTIPLIER RESISTANCE SELECTION CHART FOR VTVM's

Mfgr.	*Model No.*	*To Give D-C Voltage Range of:*	*With VTVM D-C Range-Switch Set at:*	*Use Multiplier Resistance Value of: (Megohms)*	*Multiply Scale Readings By:*	*Type of End Connector Required:*
Electronic Design	100	10,000v	1,000v	100	10	†
	"	30,000	1,000	320	30	†
Electronic Instrument Co., Inc.	210	10,000v	1,000v	225	10	†
	"	50,000	1,000	1,225	50	†
	221	10,000	1,000	240	10	†
	"	30,000	1,000	740	30	†
	"	50,000	1,000	1,240	50	†
Electronic Mfg. Co.	100-110	15,000v	600v	265	25	*
	"	30,000	600	540	50	*
Heath Co.	V2, V2, V2A, V4	10,000v	1,000v	100	10	†
		30,000	1,000	320	30	†
Hickok	125	10,000v	1,000v	81	10	**
	"	25,000	1,000	216	25	**
	"	50,000	1,000	441	50	**
	203	12,000	1,200	82.4	10	*
	"	30,000	1,200	218.2	25	*
	209	12,000	1,200	82.4	10	*
	"	30,000	1,200	218.2	25	*
Jackson	645	10,000v	1,000v	109	10	*
	"	30,000	1,000	350	30	*
Precise	907	10,000v	1,000v	240	10	*
	"	30,000	1,000	740	30	*
	909	10,000	1,000	240	10	*
	"	30,000	1,000	740	30	*
Precision	EV-10A	30,000v	6,000v	533.3	5	**
	"	60,000	6,000	1,200	10	**
	EV-20	12,000	1,200	121.3	10	*
	"	30,000	1,200	321.3	25	*
RCA	WV-65A	10,000v	1,000v	100	10	*
	"	30,000	1,000	320	30	*
	WV-75A	10,000	1,000	100	10	*
	"	30,000	1,000	320	30	*
	WV-95A	10,000	1,000	100	10	*
	"	30,000	1,000	320	30	*
	"	50,000	1,000	540	50	*
	162-A	12,500	125	1,090	100	*
	162-B	12,500	125	1,090	100	*
	162-C	10,000	500	210	20	†
	165-A	10,000	1,000	100	10	†
	"	30,000	1,000	320	30	†
	170-A	10,000	100	991	100	†
	195-A	10,000	1,000	91	10	*
	"	30,000	1,000	291	30	*
	"	50,000	1,000	491	50	*

Radio City	345	30,000v	1,000v	740	30	†
	662-A	30,000	6,000	641.3	5	†
	664	10,000	1,000	100	10	†
	"	30,000	1,000	320	30	†
	665-A	30,000	6,000	641.3	5	**
	668	30,000	6,000	641.3	5	**
Reiner	451	10,000v	1,000v	100	10	†
	"	50,000	1,000	540	50	†
	661	30,000	300	1,090	100	†
Simpson	266	25,000v	5,000v	800	5	**
	"	50,000	5,000	1,800	10	**
Supreme	562	10,000v	1,000v	135.9	10	**
	"	30,000	1,000	437.9	30	**
	574	10,000	2,500	120	4	**
	"	25,000	2,500	360	10	**
	"	50,000	2,500	760	20	**
Sylvania	134-Z, 221	10,000v	1,000v	153	10	**
	"	30,000	1,000	493	30	**
Triplett	2541	10,000v	100v	1,090	10	**
	"	30,000	300v	1,090	10	**

Compiled from information supplied by Precise Development Corp.
End-Connector Type Code:
* = Amphenol MC-1F (or equivalent) screw-on type mike (panel) connector.
† = Amphenol MC-1F connector plus Amphenol MC-1P phone jack
** = Pin plug.

system will be "hot" and the operator may receive a severe and possibly dangerous shock. (When testing the circuits of transformerless tv receivers, an isolation transformer should be connected between the receiver and the a-c power line to prevent the possibility of placing a short across the power line if the meter case and chassis should accidentally become grounded). The range switch of the meter should be set to the proper position (in most cases, this is the one for the highest d-c voltage range of the meter). Multiply all voltage indications obtained on this range by the multiplying factor of the probe.

It is advisable to form the habit of keeping your unoccupied hand in your pocket whenever you are making high-voltage measurements. The other hand should hold the handle end of the probe only, keeping it as far away from the safety flanges as possible. It is also advisable to make the connection to the circuit with the power off, then apply power and read the voltage value.

1-7. Use of High-Voltage D-C Probe as a Low-Pass Filter in the Measurement of D-C Voltage with High-Voltage A-C Pulses Present

It is frequently necessary to employ a vom or a vtvm to measure d-c voltages of the order of several hundred volts in the presence of very high voltage short-duration pulses of the order of several thousand volts, without damaging the vom or vtvm (see Fig. 1-6). For example, this condition exists at the plate of a horizontal output tube in a tv receiver where the d-c voltage may be only 300

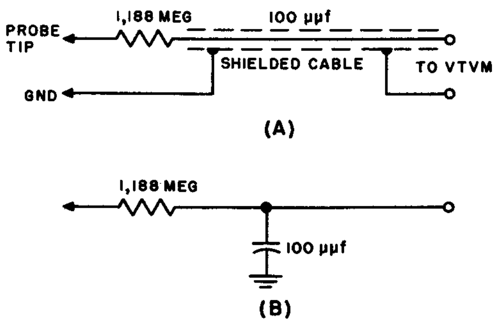


Fig. 1-7. (A) A high-voltage resistive probe with the capacitance of its shielded cable is seen to have the characteristics of a low-pass filter (B). This property of the probe is useful in measuring d-c plate voltage values in the presence of high-voltage short-duration a-c pulses at the plate of the horizontal-output tube of a tv receiver, without damage to the vom or vtvm.

or 400 volts but it is accompanied by sharp, short-duration pulses of approximately 4,000 to 6,000 volts peak-to-peak.

While each high-voltage pulse does not affect the pointer deflection of the d-c voltmeter directly, it may send a large pulse current through its multiplier-resistor network. This current can cause serious damage by overheating or burning out the voltage-divider resistors.

However, it is quite practical to measure the d-c voltage at the plate of a horizontal-output tube without damage to the voltmeter if a high-voltage d-c probe is used. In this case, the high-voltage probe is not used primarily to attenuate the measured voltage but to serve together with the input capacitance of the shielded cable and voltmeter, as a filter which keeps large short-duration pulse currents from flowing. However, the d-c voltage will also be attenuated, so a low-voltage meter range should be used. A 100-to-1 resistive high-voltage probe is convenient; the range switch of the voltmeter must then be set to a low-voltage range, such as 3 or 4 volts full scale. When the range switch is set to the 3-volt range, a 100-to-1 high-voltage d-c probe will provide an effective full-scale range of 300 volts dc, but more important it provides the required circuit filtering so that the vtvm is not damaged by the high-voltage pulses.

Consider how much the 6,000-volt *pulse* voltage is attenuated at the meter terminals. Assume that a vtvm having an input resistance of 12 megohms is used. The 100-to-1 multiplier resistor will have a value of 1,188 megohms. Accordingly, 1/100 of the applied d-c voltage appears at the vtvm input terminals. However, the attenuation factor for the unwanted pulse voltage is very much greater. Suppose that the total input capacitance of the shielded cable plus the vtvm input capacitance is 100 $\mu\mu$f, see Fig. 1-7A. The equivalent circuit is shown in Fig. 1-7B. At the fundamental frequency (15,750 cps) of the horizontal-output pulses, this capacitance has a reactance of about 0.1 megohm, which causes a pulse attenuation of about 12,000 to 1. In other words, only about ½ volt ac (pulse) appears across the vtvm input terminals.

1-8. Use of 100-to-1 Resistive High-Voltage Probe to Increase the Input Resistance of a VTVM for Measurement of Low Voltages in High-Resistance Circuits

The vertical blocking oscillator in a tv receiver often has a high grid impedance, with a resistance component of 10 megohms, or more. Under such circumstances, the application of a vtvm to measure the grid bias seriously disturbs the circuit operation, as the circuit resistance is reduced to approximately one-half by application of the instrument.

To avoid this type of trouble, the operator may make use of a 100-to-1 resistive high-voltage probe. The multiplier resistor in such a probe has a value in the order of 1,000 megohms, which is sufficiently high so that it does not disturb the grid circuit of the vertical blocking oscillator. If the vtvm is operated on the 1-volt range, the full-scale indication becomes 100 volts, and a grid bias of −75 volts represents three-quarters full-scale deflection.

1-9. Objections to use of a Resistive High-Voltage Probe with a Scope to Display Waveforms of High A-C Voltages

A resistive high-voltage probe may be used with a vtvm to accurately and safely measure the value of the high second-anode voltage at the tv picture tube, or the high voltage at the plate of the horizontal output tube, or at the plate of the damper tube. Technicians sometimes fall into the error of trying to go a step further by using the same type of probe with an oscilloscope that has provision for a-c input only, in an attempt to display and measure the peak-to-peak value of the sweep voltage, the ripple present in the high voltage applied to the picture tube second anode, etc. When this is attempted, practically the full high voltage being applied to the probe input circuit can also be present at its output circuit and this may cause breakdown of the input blocking capacitor within the oscilloscope (see Fig. 1-8A). The blocking capacitor in the scope is usually rated at only 600 volts.

It is sometimes recommended in servicing literature that a check of these voltages can be made with a high-voltage probe and a-c type scope if a 1-meg resistor is connected in shunt with the scope input terminals as shown in Fig. 1-8B. Although scope capacitor puncture is avoided by this method, there are other serious drawbacks to its use. These are: (1) since the actual attenuation factor of the probe when used with the a-c scope is unknown, the peak-to-peak voltage of the ripple cannot be measured; (2) the mutliplier resistor in this type of probe is unshielded, so it is quite susceptible to hand-capacitance effects and to variable capacitance effects to surrounding metallic objects. Also, whenever

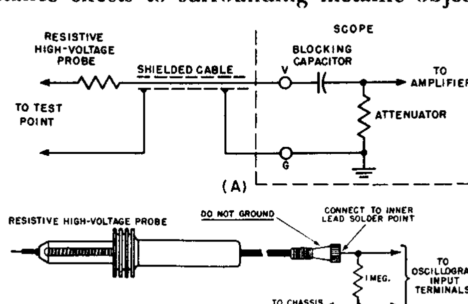


Fig. 1-8. (A) Technicians sometimes make the error of attempting to use a resistive high-voltage probe with an a-c type oscilloscope to observe the ripple in the high-voltage supply. This leads to possible breakdown of the blocking capacitor in the scope input circuit. Use of the alternative circuit arrangement (B), which is often suggested, is also open to several objections which are discussed in the accompanying text.

such a probe is used in the vicinity of stray fields, spurious voltages induced in the resistor by them cause spurious displays that interfere with the main display; (3) the d-c probe is uncompensated, and always introduces some degree of distortion into the desired waveform. Because these actions make it impossible to obtain accurate display of the peak-to-peak voltages on the screen, they cannot be measured accurately.

Such a high-voltage d-c probe cannot be used in such tests with a d-c scope, since the high d-c voltage which is present (with respect to the relatively small a-c ripple voltage) deflects the scope beam off screen whenever the vertical gain control is advanced sufficiently to obtain a sizeable pattern.

A resistive type high-voltage probe designed for use with a vtvm should, therefore, be used only with a vtvm. When high a-c voltages are to be investigated with a scope, the technician should employ a suitable high-voltage capacitance-divider a-c type probe (see Chapter 2). Such probes largely avoid waveform distortion and stray-field pickup, and have a known attenuation factor.

Chapter 2

CAPACITANCE-DIVIDER HIGH-VOLTAGE A-C PROBES

2-1. Need for an A-C Voltage Divider in the Use of Scopes for High-Voltage Circuit Testing

Troubles in the various high-voltage circuits of tv receivers can usually be located very quickly by means of suitable signal-tracing techniques employing the proper instruments. D-c voltage measurements in the high-voltage circuits present no particular problem, for they can be made with a vom or a vtvm in combination with a suitable resistive high-voltage multiplier probe, as explained in Chapter 1. However, it is frequently necessary to employ an oscilloscope to measure the peak-to-peak values, or to observe the waveforms, of the high-voltage pulses present at several points in these circuits—especially in the 15,750 cps horizontal sweep circuits. Whenever oscilloscopes are employed in high-voltage circuits, it should be remembered that they are rated by their manufacturers as to the maximum allowable voltage which may safely be applied to their input terminals, and the majority of these ratings for service-type scopes are of the order of only 600 volts.

Excessive input voltage applied to a scope can do harm in several ways. It may actually puncture the blocking capacitor, and char or burn out attenuator resistors. It may arc through terminal-insulating washers and carbonize terminal strips. Or, it may overload the scope amplifier and distort the displayed waveform without doing actual physical damage to the scope. In fact, although rated at around 600 volts maximum input, many service-type scopes become overloaded and begin to distort the reproduced waveform when much lower voltages are applied to the vertical input terminals.

It is evident that some of the a-c voltages encountered in a tv receiver chassis are sufficiently high to damage the scope input circuit if applied directly to the vertical input terminals of the scope for either voltage measurement or waveform observation. The sweep voltage at the plate of the horizontal-output tube, which may be as high as 6,000 volts peak-to-peak, which is the key voltage to be checked in most horizontal sweep circuit troubleshooting, is a case in point. The voltages at the plate of the damper tube, at the plate of the high-voltage rectifier tube, and in the high-voltage filter circuits, are similar examples (see Fig. 2-1).

To protect a scope against damage when such high a-c voltages must be checked, it is necessary to employ a suitable *voltage divider* which will make it

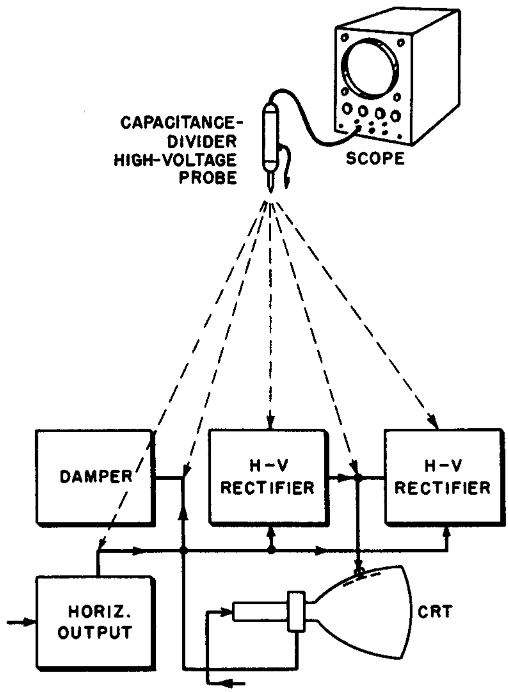


Fig. 2-1. Tv receiver high-voltage 15,750 cps horizontal sweep circuit in which a capacitance-divider type high-voltage probe must be used with a scope for a-c voltage measurement or waveform observation.

possible to apply only a fraction of the actual test circuit voltage to the oscilloscope input terminals *and still preserve the waveshape that is to be observed.* Furthermore, if actual measurement of the voltage is required, the voltage divider must attenuate the test circuit voltage by a definite known factor so that the peak-to-peak (or other) value can be read from the calibrated scope screen.

One possible method of protecting a scope against damage when such high a-c voltages must be checked was discussed earlier, in Sec. 1-9. It utilizes a conventional resistive type high-voltage (d-c) probe, that is connected in series with the vertical-amplifier d-c input of the oscilloscope (in oscilloscopes which provide such a connection). The multiplier resistor in the probe and the internal resistance of the scope functions as a voltage-dividing network. This combination can be designed to provide a voltage-reduction ratio of 1,000 to 1 if desired, depending upon the internal resistance of the scope and the multiplier resistance used. With this stepdown ratio, a 20,000-volt signal input for example, will provide a 20-volt signal to the scope input. If the scope being used has provision for a-c input only, a d-c path may be provided by shunting a 1-megohm resistor across the input terminals as shown in Fig. 1-8B.

The a-c voltage division obtained with this arrangement is not as accurate as the d-c voltage division because the capacitance between the probe body and ground varies with every change of position in which the probe is held. Because the capacitance shunts the multiplier resistance, the divider ratio for a-c is variable. Unfortunately, these variations are particularly noticeable at the 15,750-cycle horizontal-deflection frequency range in which most of the measurements and tests where this arrangement might be used are made. Consequently, this arrangement is unsatisfactory for tests where it is necessary to measure the amplitude of the voltage waveform.

Another objectionable condition is that crosstalk fields in and around the high-voltage section of a tv receiver enter the unshielded portion of the probe and produce undesired currents in the internal series resistor. These currents combine with the desired currents, thereby causing distortion of the observed waveform. Consequently this arrangement is not satisfactory for tests in which it is necessary to carefully check the *waveform* of the voltage under observation. This arrangement is generally satisfactory only for those high-voltage signal-tracing applications where the only scope indication required is one that shows either the presence or the absence, and the *general* shape of, the a-c voltage wave.

A resistive type voltage-divider is satisfactory for use in d-c and low-frequency a-c circuits. For higher frequencies, such as the horizontal deflection frequency in a tv receiver, a *capacitive* form of voltage divider provides much more satisfactory operating characteristics.

2-2. The Capacitive Type of Voltage Divider

In the capacitive type of voltage divider, the high voltage is applied to two capacitors connected in series, as illustrated in Fig. 2-2A. A division of the applied voltage takes place, with a portion appearing across each capacitor. Consequently, this arrangement may be used as a voltage divider between high-

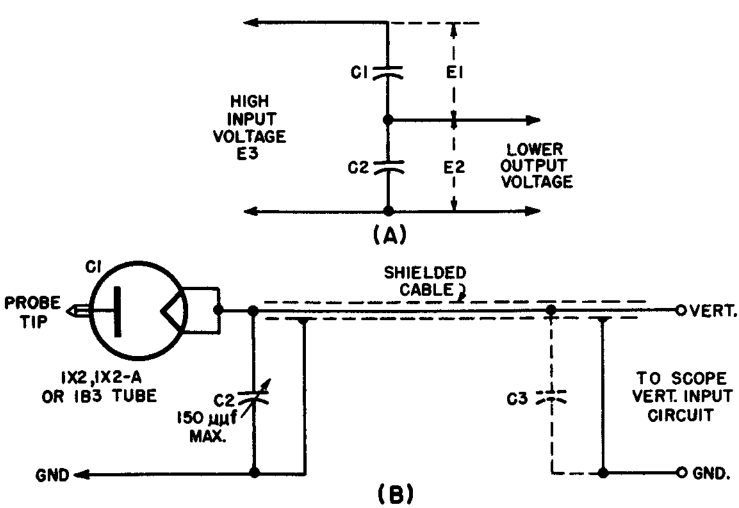


Fig. 2-2. (A) Basic circuit arrangement of a capacitive-type voltage divider. (B) A practical capacitance-divider type high-voltage probe for attenuating high test voltages to the lower values that lie within the safe input voltage rating of the scope. Trimmer capacitor C2 is adjusted to provide the correct desired voltage-stepdown ratio when the probe and its cable are connected to the input circuit of a given scope.

voltage test circuits and the scope input terminals to reduce the test signal voltages to suitable lower values that can be safely handled by the input circuit of the scope. This enables a scope to be used for a-c high-voltage testing which would otherwise damage the input circuit of the instrument. The voltage divider is usually made up in convenient probe form, with a shielded cable for connection to the scope input terminals.

The voltages which appear across the individual capacitors are in inverse ratio to the capacitances (and their reactances). Thus, the following relationship exists in the circuit of Fig. 2-2:

$$\frac{E_1}{E_2} = \frac{C_2}{C_1}$$

also, $E_1 = E_3 - E_2$. Substituting the value for E_1 in the foregoing equation gives,

$$\frac{E_3 - E_2}{E_2} = \frac{C_2}{C_1}, \text{ from which } \frac{E_3}{E_2} - 1 = \frac{C_2}{C_1}$$

Since $\frac{E_3}{E_2}$ is the required voltage-stepdown ratio, r,

we have

$$r - 1 = \frac{C_2}{C_1}, \text{ or } C_2 = C_1 \ (r-1)$$

This last equation enables the value of C_2 to be easily calculated when the voltage-stepdown ratio and the C_1 value that will be used have been decided upon.

For large voltage stepdown, capacitance C_1 is much less than capacitance C_2. Any proportion of voltage division may be affected by proper choice of the two capacitances to provide the desired voltage ratio in accordance with the above equations.

2-3. Practical Capacitance-Divider High-Voltage Probe Design

The essential elements of a practical high-voltage capacitance-divider probe are illustrated in Fig. 2-2B. The input impedance (which varies with the frequency) is made as high as possible to minimize loading of the high-voltage receiver circuits under test, so that the measured peak-to-peak voltage values will be correct. Since the probe is to be used exclusively for high-voltage circuit testing, high-voltage insulation must be provided in its construction. Commercial probes are shielded to minimize hand-capacitance effects and stray-field pickup that would alter the scope trace.

In order to safely withstand the highest voltages encountered in tv receiver test work, the first capacitor, C_1, employed in the network usually consists of a high-voltage rectifier tube, such as a 1 x 2, 1 x 2—A, or a 1B3, connected not as a rectifier but as an inexpensive small high-voltage capacitor. The plate-to-filament capacitance of these tubes ranges between approximately 0.9 to 1.5 *uuf*, and their breakdown voltage is upwards of 15,000 volts. The tube should not be gassy, or it will not withstand the high potentials encountered.

Capacitor C_2, which is mounted within the probe head, is of the variable trimmer type so that the ratio C_2/C_1 can be adjusted to the correct value to produce the desired voltage-attenuation ratio (usually 100-to-1) at any time. In a 100-to-1 ratio probe, the trimmer capacitor need withstand only about 1/100 of the voltage applied to the probe tip. Since the highest voltage encountered in the applications where such probes are used in tv receiver work is less than 20,000 volts, the trimmer capacitor need not have a voltage rating higher than about 200 volts.

In Fig. 2-2B, C_3 represents the combined capacitance of the shielded cable plus the input capacitance of the scope. Since C_3 parallels C_2, the voltage-division ratio and probe calibration will be affected by any change in either the cable capacitance or the scope input-circuit capacitance. Consequently, since the probe trimmer C_2 is adjusted to provide the correct voltage-stepdown ratio with a given shielded cable and scope capacitance, the calibrating capacitor C_2 must be readjusted whenever the probe is used with a different cable or scope.

Service technicians who do not need to use a capacitance-divider type high-voltage probe sufficiently often to warrant the expense of purchasing the ready-made variety may construct the simple home-made 100-to-1 probe, illustrated in Fig. 2-3. This consists of two lengths of RG-59/U coaxial cable. All of the outer braid is removed from the shorter length of coax, and approximately 3½ inches of outer braid is removed from the longer length. The two pieces of coax are placed so that they overlap 3 inches, and are taped together. Plastic electrical tape should be used for this purpose. A 100-$\mu\mu$f, 500-volt capacitor is connected between the inner and outer conductors of the long piece of coax. If a variable trimmer type capacitor is used, it may be adjusted to obtain a stepdown ratio of exactly 100-to-1, so that the calibration factor of the scope will be changed by a decimal value (add two zeros) when the probe is employed. Also, the step-down ratio may be "touched up" whenever it becomes necessary.

2-4. Choice of the Voltage-Stepdown Ratio, and Maximum Voltage Rating

Since it is preferable for convenience in estimating the signal voltage from the height of the trace produced on the scope screen, the voltage-divider probe

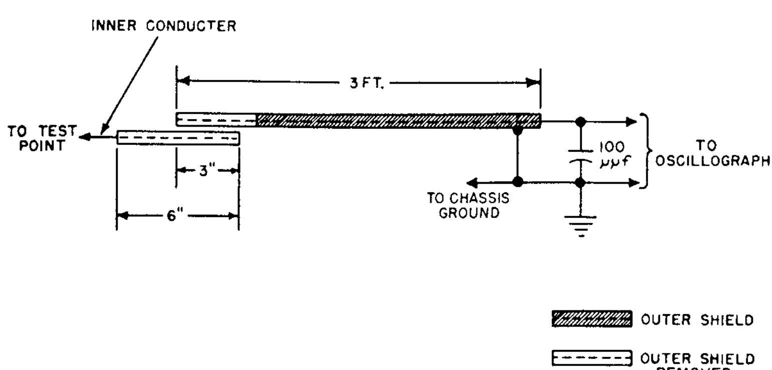


Fig. 2-3. Simple shop-constructed capacitance-divider type high-voltage probe made of coaxial cable. The voltage stepdown ratio is approximately 100-to-1. *Courtesy: DuMont Service News*

is usually designed to provide decimal attenuation; i.e., the stepdown ratio is usually made either 10-to-1, or 100-to-1, the latter being the most commonly used since the greater attenuation is more often required when high-voltage circuits are to be tested. If a 1,000-volt wave is applied to the input terminals of a 100-to-1 voltage divider, only 10 volts will be applied to the input terminals of the scope. If the scope screen has been calibrated for peak-to-peak sensitivity of 1 volt per square, the 1,000-volt wave will produce 10 squares of deflection on the screen. By using such a decimal voltage-divider, it is not necessary for the operator to recalibrate the scope every time the attenuator is employed with it. He merely adds one zero or two zeros, as the case may be, to the original scope calibrating factor.

When circuits in which high voltages of lower levels exist are being checked (as for example when checking the waveform across the horizontal-deflection coils of a tv receiver), it is often more desirable to use a divider probe having a ratio of only 10-to-1 so that sufficient voltage is applied to the scope input terminals to produce adequate deflection for accurate waveform study or peak-to-peak voltage measurement, without overloading the scope amplifier.

The design of the probe must be such that it is able to safely withstand the maximum circuit voltage to which it will be subjected at any time. A rating of at least 30kv is required for picture-tube second anode voltage checks in monochrome and color tv receivers.

2-5. Adjusting the Trimmer Capacitor for Correct Voltage-Stepdown Ratio

If the high-voltage capacitance-divider probe is used when the peak-to-peak voltage values of waveforms are to be measured by the scope, the probe should be adjusted accurately for 100-to-1 (or 10-to-1) stepdown voltage. A simple method of doing this, for a scope that contains a 100-to-1 input attenuator is given below.

Most tv service scopes are provided with a decimal step attenuator. To check the calibration of a 100-to-1 probe, first apply the scope input terminals alone across a low-impedance circuit, such as the cathode circuit of a tv receiver damper tube, using direct leads to the scope. Set the scope step attenuator to the lowest-sensitivity (*X1*) position, and adjust the vernier attenuator for any convenient number of squares of deflection on the screen. Then connect the probe between this same signal point and the scope input and advance the step attenuator to the *X100* position (100 times as sensitive). If the attenuation factor of the probe is correct, the waveform will then occupy the same number of squares on the scope screen as before. If it does not occupy the same number of squares, the probe trimmer may be suitably adjusted by means of an insulated screwdriver until it does. It is then in correct adjustment to produce 100-to-1 voltage attenuation *when it is used with that paricular shielded cable and that particular scope input circuit.*

Some service scopes are in use which do not have a compensated input system. It should be observed that the input capacitance of such a scope will vary as the scope attenuator is varied, and hence the calibration factor of the probe will also be changed somewhat. Further, it is very likely that waveform distortion will be encountered at the lower settings of such an attenuator, due to frequency discrimination and phase shift in the attenuator itself.

2-6. Test Circuit Loading Effects of Capacitance-Divider Type High-Voltage Probes

Because the input capacitance of a 100-to-1 high-voltage capacitance-divider probe is usually less than 2 $\mu\mu f$, as compared with an input capacitance of approximately 8 $\mu\mu f$ for a typical to-to-1 high-voltage capacitance-divider probe, the 100-to-1 probe has a much higher input impedance than the latter, hence imposes much less loading on the circuit to which it is applied.

The reduced likelihood of circuit loading imposed by a high-voltage 100-to-1 capacitance-divider probe is an advantage in many tests. However, this probe cannot be used in low-level circuits because it may be impossible to obtain usable vertical deflection on the scope when the voltage is attenuated to only 1/100 of its original value by the probe.

Most typical service scopes have a vertical-deflection sensitivity of approximately 0.02 volt rms per inch at full gain, corresponding to a sensitivity of 0.057 volt peak-to-peak per inch. Under these conditions, the 100-to-1 probe will provide 1 inch of deflection for an input signal of 5.7 volts peak-to-peak. If the signal voltage is less than this, the 10-to-1 probe will probably have to be used in order to obtain usable deflection on the scope.

The input impedance of the capacitance-divider type of high-voltage probe is relatively high, but becomes less as the frequency increases. The variation of the input impedance of the type of probe shown in Fig. 2-2B in the horizontal sweep frequency range is shown in Fig. 2-4. The value of the input impedance is determined by the plate-filament capacitance of the tube used in the voltage divider.

At lower frequencies, such as 60 cps, the input impedance of the probe becomes extremely high. However, the probe cannot be used in circuits of such

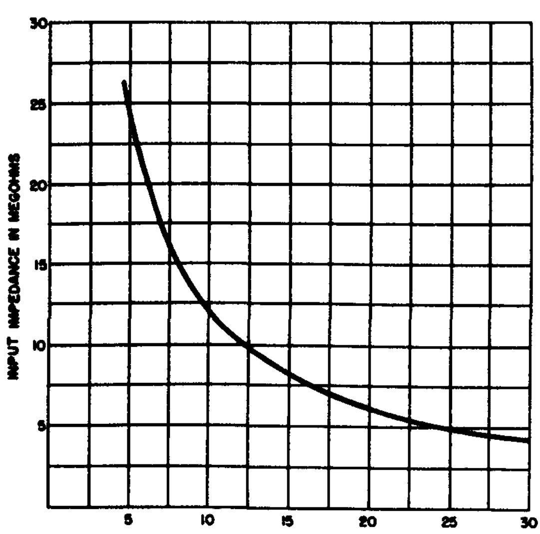


Fig. 2-4. The input impedance of a typical capacitance-divider type high-voltage probe decreases as the frequency increases.

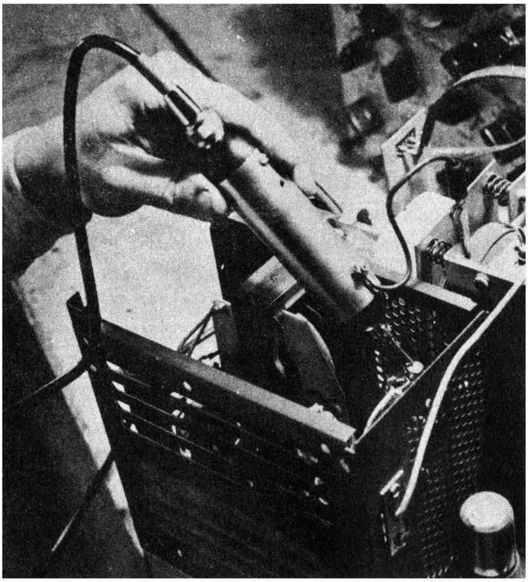


Fig. 2-5. Close-up of a 100-to-1 capacitance-divider type high-voltage probe being applied to the plate terminal of the horizontal-output tube of a tv receiver in order to check the 6,000-volt peak-to-peak voltage and examine its waveform at that point, without impairing the waveshape or incurring danger to the input circuit of the scope. This particular probe is useful to 10,000 p-p volts. Observe the grounding lead from the probe shield clipped to the receiver chassis. *Courtesy: Scala Radio Co.*

low frequency such as a vertical sweep circuit, because it is uncompensated. Therefore the very small series capacitance of the tube used in it, in conjunction with the input resistance of the scope, distorts the waveform of the voltage under test. Spikes (high-frequency components) in the waveform are passed satisfactorily, but the low-frequency sawtooth component is distorted.

2-7. Capacitance-Divider Type High-Voltage Probe Applications and Practical Operating Hints

(1) *Troubleshooting Horizontal-Sweep Circuits.* The capacitance-divider type high-voltage probe is an uncompensated type of probe, and although it does have some other uses, it is intended primarily for use in troubleshooting the horizontal sweep circuits of tv receivers, where the frequency is 15,750 cps, and the capacitive component of the scope input impedance dominates the attenuation factor of the arrangement. It can be applied, for example, at the plate of the horizontal-output tube, as shown in Fig. 2-1 and Fig. 2-5, or at the plate of the damper tube, to examine the operating waveforms and to measure their peak-to-peak voltages, without impairing the waveshape or incurring danger of damage to the scope. The shape of the wave helps the technician identify certain defects in the flyback transformer, and the p-p voltage shows the condition of the drive circuit.

When used in such applications, the scope should first be calibrated for a known sensitivity in peak-to-peak volts of deflection per square on the ruled graph screen. The probe is then connected to the scope, and the calibration factor is multiplied by 100. For example, if the scope has been calibrated for a sensitivity of 10 peak-to-peak volts per square, the 100-to-1 high-voltage probe converts this calibrating factor to 1,000 peak-to-peak volts per square, and a 6,000 peak-to-peak volt waveform will occupy six squares on the scope screen.

The operator should note that the peak-to-peak voltages of such waveforms are usually specified in the service notes for the tv receiver with a tolerance of about 20 percent, which means that the receiver operation is to be judged faulty if a wave that is normally 6,000 p-p volts should measure more than 7,200 p-p volts, or less than 4,800 p-p volts. It must also be observed in this regard that variations in power-line voltage are reflected through the receiver circuits as variations in measured peak-to-peak voltage values. Receiver manufacturers specify waveform voltages upon the basis of a design-center a-c line voltage of 117 rms volts.

(2) *Troubleshooting 60-Cycle Vertical-Sweep Circuits.* Capacitance-divider type high-voltage probes should not be used in the 60-cycle vertical-sweep circuits of a tv receiver, because at 60 cycles the capacitance of the probe is working into an effectively constant resistance. The reactance of the probe input capacitance is not constant, but decreases with increase of frequency (see Fig. 2-4). In consequence, each harmonic component of the waveform undergoes a different attenuation, so waveform distortion results due to the resulting frequency discrimination and phase shift. Because of such distortion, use of this probe in circuits of such low frequency must be restricted to those applications where the technician needs to determine the presence or absence of a waveform without concern about its shape (see also No. 4 below).

(3) *Checking for Ripple Voltage in the High-Voltage Supply.* The alert technician may be interested in additional applications of the capacitance-divider high-voltage probe, such as the one illustrated in Fig. 2-6. This test displays the ripple voltage on the output of the high-voltage supply, as shown in Fig. 2-7. When the ripple is excessive, the beam current in the picture tube is modulated by the ripple, and alternate light and dark gray vertical bars appear on the left-hand side of the raster. The scope is swept at 15,750 cycles per second (or a submultiple) to display the ripple voltage. A probe having a voltage rating of at least 20,000 volts is required for making this test in black-and-white receivers

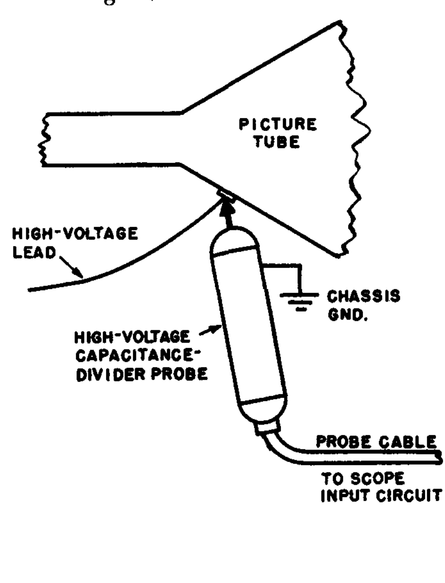


Fig. 2-6. High-voltage ripple and 60-cycle regulation buzz can be displayed on the scope screen with the use of a capacitance-divider type high-voltage probe applied to the crt second-anode terminal. (See also Fig. 2-7 and Fig. 2-9.)

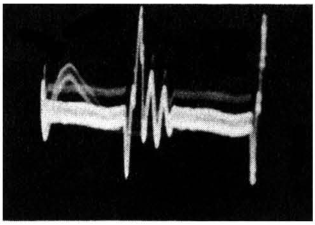


Fig. 2-7. Typical ripple voltage on the output voltage of the high-voltage supply at the second-anode of the picture tube.

(see Table 1-1 in Chapter 1). The color tube in color tv receivers is operated at higher voltages, and a probe with a voltage rating of at least 30,000 volts may be required for such receivers.

Occasionally the technician makes the error of attempting to use a resistive-type high-voltage probe with a scope to observe the ripple on the high-voltage supply. This leads to trouble, because after a short time the blocking capacitor in the scope input circuit charges up to puncture voltage, and ruptures. Only a capacitance-divider type high-voltage probe should be used for such tests.

(4) *Checking for 60-Cycle Buzz Pulse.* When the scope is swept at 60 cps, the same test may be used to check for the presence of 60-cycle buzz pulse in the output from the high-voltage power supply. The buzz pulse is developed by modulation of the beam current in the picture tube by the vertical sync pulse at the grid of the picture tube. The appearance of such a buzz pulse is shown in Fig. 2-8.

In case the d-c voltage at the second anode of the picture tube exceeds the voltage rating of the probe, a series blocking capacitor C should be used, as shown in Fig. 2-9. In this case, the attenuation factor of the probe is altered. It must be remembered that the operating characteristics of a high-voltage capacitance-divider probe are such that ripple voltage is displayed on the scope with its actual waveshape, whereas a buzz pulse of lower frequency is displayed distorted to a greater or lesser extent. However, the distortion encountered when displaying such 60-cycle waveforms is of little concern to the technician, because he is usually interested only in determining whether or not the buzz pulse is present.

In case it should be desired to obtain the true shape of such 60-cycle pulses, it becomes necessary to use a high-voltage type of compensated R-C low-capacitance probe. Such probes are somewhat bulky and their applications are somewhat limited; hence they are not often used in service work.

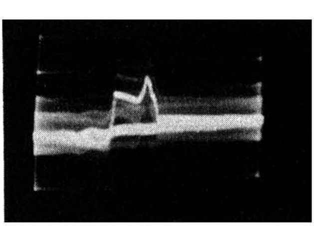


Fig. 2-8. 60-cycle buzz pulse at the second anode of the picture tube, displayed by a capacitance-divider high-voltage probe and scope (sine-wave sweep). The low-frequency characteristics of the probe are such as to distort the pulse waveshape, but since the technician needs chiefly to determine only the presence or absence of the pulse, the distortion is not important in this application.

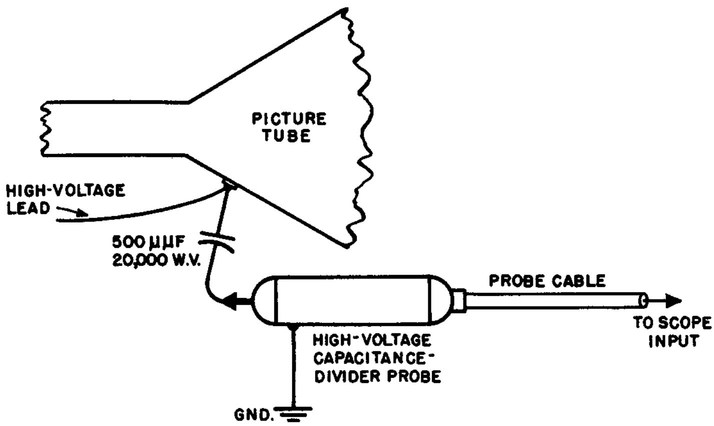


Fig. 2-9. When testing at the second anode of the picture tube for ripple, or for tunable buzz pulses, it is good practice to place a d-c blocking capacitor, C, in series with the voltage-divider probe, as shown here, for protection in the event that the d-c voltage at this point exceeds the voltage rating of the probe.

Another method which is used to obtain good waveform with 60-cycle pulses is to increase the capacitance of both of the capacitors in the probe, in order to minimize the effect of the input resistance of the scope. However, the increased input capacitance causes such a probe to load the circuit under test more heavily, and the probe is accordingly less useful for tests in other circuits where the operating frequency may be higher.

(5) *Video Amplifier Tests.* When tracing low-frequency square waves through a video amplifier, a capacitance-divider type probe should not be used because excessive wave distortion will result. The only satisfactory method of investigating the operation of a video amplifier at low frequencies is by means of a properly compensated R-C low-capacitance probe. Of course, the scope used must have adequate low-frequency response for this use.

Chapter 3

TEST-CABLE SHIELDING AND TEST-CIRCUIT LOADING FUNDAMENTALS

3-1. Probe and/or Test Leads Become Part of the Test Circuit

The internal input circuit of commonly used test instruments, such as vom's, vtvm's, and scopes, are customarily brought out to two or more externally mounted terminals located in a convenient position on the case. Consequently, in order to apply the instrument to selected points in a circuit under test, it is necessary to extend the instrument circuit from these input terminals to the circuit under test by means of a pair of suitable test leads, or by a cable. Various ways of doing this are illustrated in Fig. 3-1. If the particular test conditions make it necessary to use a probe of some kind with the instrument, the probe is attached to the test end of the cable so that its tip may be applied directly to the point of test.

Thus, the function of the pair of test leads (or the test cable) is basically to serve as the electrical link between the test instrument and the circuit under test. In doing so, *it becomes an integral part of the instrument input-circuit system.* If a probe is employed, *its electrical components and internal wiring also become part of this circuit.* This is a vital point to be recognized *and kept constantly in mind* because, as will presently be explained, the high-frequency operating characteristics of the test leads or cable may introduce undesirable effects on the operation of the circuit under test; or the cable and/or probe may allow spurious voltages to be induced in them by extraneous fields, and these spurious voltages enter the input circuit to the instrument. The instrument indication may be adversely affected in either case, so a true indication of the conditions existing at the test points will not be obtained, and misleading conclusions will result.

3-2. Inherent Series Inductance, Shunt Capacitance, and Resonance Effects in Test Leads

Two arrangements of an open-wire line used for the test leads of an instrument are illustrated in Fig. 3-1. Two independent separated wires are shown in Fig. 3-1B; a 2-wire parallel-cord arrangement is illustrated in Fig. 3-1C. There is more than meets the eye here because, from an electrical viewpoint, an open-

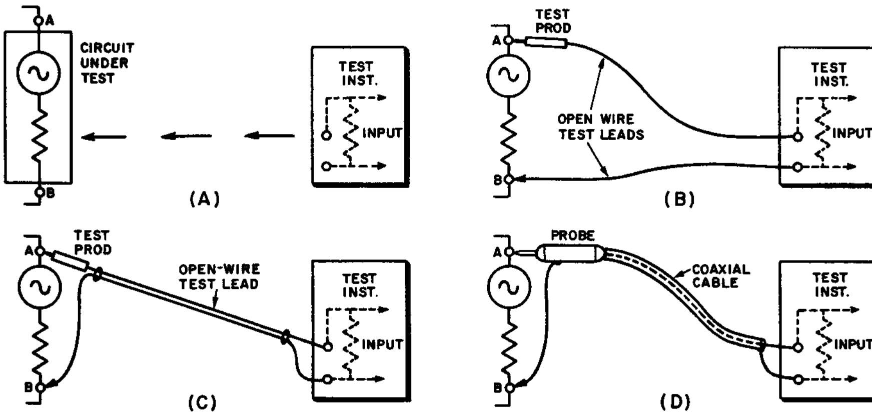


Fig. 3-1. (A) The input circuit of any test instrument must be extended from the instrument input terminals to the test points in the circuit under test. Direct test leads, or a probe and cable, may be employed to accomplish this. (B) Direct test leads employing an open-wire line consisting of two independent separated wires. (C) Direct test leads employing open-wire line consisting of a 2-wire parallel-cord arrangement. (D) If a probe of some kind must be used with the instrument, it is inserted in this extension circuit (usually at the test-point end). In either case, the probe and/or test leads, or cable, become an integral part of the test instrument input system.

wire transmission line is far more than just two wires. The current that flows through each wire produces a magnetic field around it, and simultaneously, the potential difference existing between the wires establishes an electrostatic field at right angles to this. These fields are illustrated in Fig. 3-2A. As a result, each elemental (or small) length of wire in the line has inductance, *L,* as shown in Fig. 3-2B; each elemental (or small) length of line has capacitance, *C,* between the two wires, and also between each wire and any nearby conductor such as a metal chassis, etc. Also, each elemental length has series resistance, *R,* and shunt leakage, *G,* (which can be kept comparatively small in practice, even at high frequencies, by the proper use of modern low-loss insulating materials such as polyethylene). In the separate-wire arrangement in Fig. 3-1B, the distributed capacitance between the wires themselves, and between the wires and other nearby conductors, varies with each shift in position of leads with respect to each other or to the other objects, since this changes the distance between them.

For convenience, these distributed constants may be considered as being lumped at one point along the line as shown in Fig. 3-2C. To them are added the effective L_I, R_I and C_I of the input circuit of the instrument itself. The sum total of these are presented to the circuit under test. The total *L* of this input circuit becomes very important at high frequencies where even a short length of lead, having small inductance, develops appreciable inductive reactance that decreases the signal energy transfer through it. The total distributed or "stray" circuit capacitance (which includes that caused by the proximity of the wires to a metal chassis, to the human body, etc.) also becomes very important, since it results in considerable shunting at the higher frequencies because the reactance of this capacitance decreases as the frequency increases. Also, because

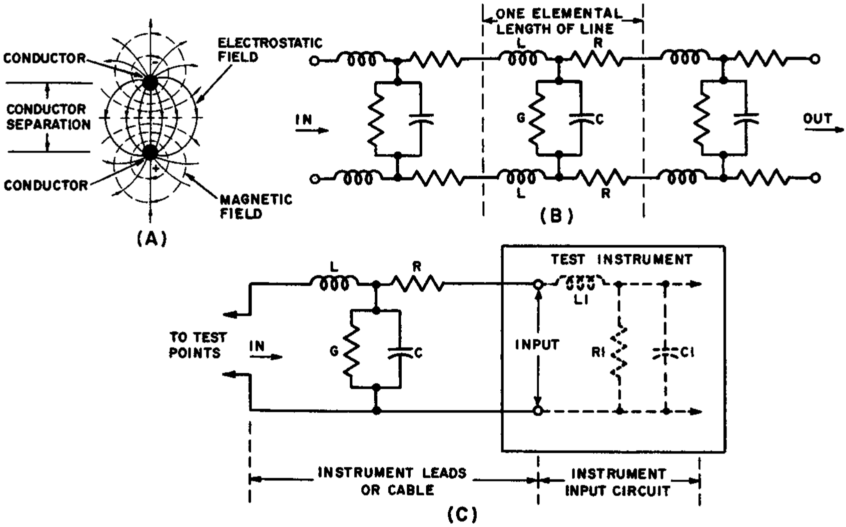


Fig. 3-2. (A) View of the instantaneous magnetic and electrostatic fields about each wire at one point along an open-wire transmission line. (B) As a result of the existence of these fields each elemental length of the line contains series inductance and resistance, and shunt capacitance and leakage. The distributed constants in an open-wire line are shown here. (C) Equivalent circuit, assuming lumped constants.

of this inductance and capacitance, the input circuit can operate in many circumstances as a resonant stub or circuit.

These circumstances can often lead to serious consequences when a vtvm or a scope is applied to certain types of circuits under test. An example of this is illustrated in Fig. 3-3 in which a meter is being employed with open-wire test leads to check the plate voltage in a tv i-f amplifier stage. Under these conditions, the test leads act as an open stub whose detuning influence may cause the stage to break into violent oscillation. This causes the value of the plate voltage to change, resulting in a misleading meter indication and consequent incorrect conclusions regarding the condition of the stage.

3-3. Action of Stray Fields Upon Probes and Open-Wire Test Leads

The use of unshielded open-wire test leads and probes may be responsible for other obscure effects which introduce inaccuracies in measurements made in high-frequency circuits. For example, a test lead, or the internal wiring or components of an unshielded probe, may often act as an antenna in picking up signal energy from one circuit and re-radiating it to another circuit in the device being tested. In this way, normally shielded and isolated sections of an electronic device may become cross-coupled to each other by the application of the test instrument—sometimes to such an extent that regeneration or oscillation occurs.

Another objectionable condition is often encountered when open-wire test leads are used with a vtvm or an oscilloscope. The open-wire leads have spurious voltages induced in them by strong stray magnetic and electrostatic fields which may exist about the equipment under test, or by the power-frequency fields surrounding the wiring system of the test bench and nearby wall. For example, strong stray fields commonly arise from the horizontal and the vertical deflection circuits of tv receivers under test. Stray fields from the vertical sweep system are especially bothersome since the vertical deflection circuits carry power-line frequency (60 cycle) currents. The 15.75-kc fields from horizontal-deflection circuits are also troublesome. The situation is illustrated in Fig. 3-4. When the circuit under test has a high impedance, the spurious interference voltages induced in open-wire test leads used with a scope are likely to result in a corresponding visible interfering pattern on the scope screen. This seriously interferes with the pattern it is desired to check, measure, or study.

Some probes used in tv service work are either unshielded, or only partially shielded, in construction. Such probes often cause incorrect instrument indications when they are used in the vicinity of flyback circuits, etc., in a tv receiver chassis, because the strong stray fields present around such circuits induce spurious voltages in the unshielded components and internal wiring of the probe and these may be sufficiently strong enough to affect the vtvm or scope indication. A simple method for testing a probe to determine whether its shielding is adequate to prevent this is illustrated later in Fig. 7-20.

3-4. Minimizing the Effects of Strong Fields by Means of Shielding

Effective reduction or elimination of spurious-voltage induction by strong fields can be accomplished by employing a suitable shielded construction for those probes which are susceptible to this trouble, and the use of suitable

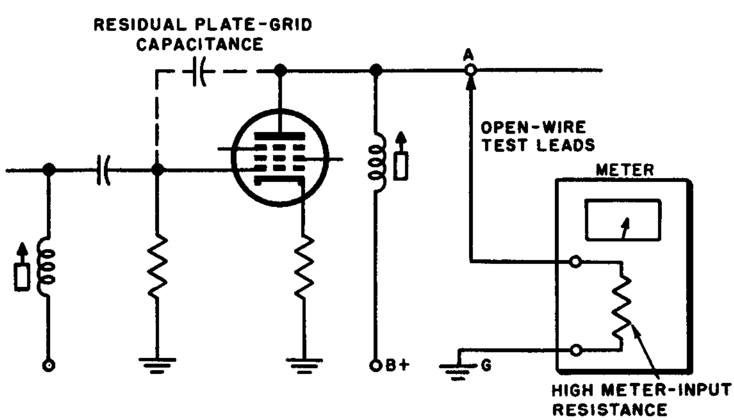


Fig. 3-3. The pair of open-wire test leads work into the high input resistance of the vtvm. Accordingly, the tv i-f amplifier circuit under test "sees" the open-wire test lead as a tuned open stub; this stub has a resonant frequency which changes with each shift in the position of the two wires comprising the test leads, or of the operator. The amplifier plate circuit may become detuned by the stub, and if the detuning is such as to make the plate circuit resonate in the vicinity of the grid circuit frequency, and if there is sufficient tuned-plate tuned-grid feedback present, the stage "takes off" and oscillates violently. As a result of the oscillation, the grid of the tube draws current, which develops a large negative bias on the grid. The negative bias on the grid changes the amplifier operation from Class A to Class C, and changes the average plate current through the tube. This change in average plate current results in a different value of plate resistance, which in turn causes the distribution of d-c voltage drops in the circuit to change. Under these conditions, the technician measures an incorrect value of the plate voltage, and draws false conclusions regarding the conditions of the stage.

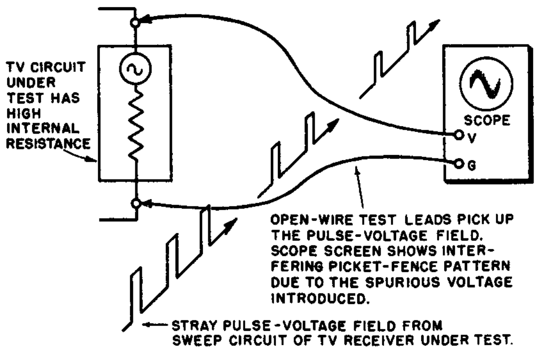


Fig. 3-4. When open-wire test leads are used with a scope, spurious voltages may be induced in the exposed leads, or in an unshielded probe, by strong stray fields present about the equipment under test. If the circuit under test has a high impedance, a corresponding visible interference pattern is likely to appear on the scope screen.

shielded cable (such as flexible *coaxial* cable), for the test leads between the probe and the instrument, as shown in Fig. 3-1D. The type of coaxial cable commonly employed is illustrated in Fig. 3-5A. The inner stranded-wire conductor is used for the "hot" test prod or probe connection, as shown in Fig. 3-1C. The surrounding one or two layers of copper braiding, which is concentric or "coaxial" with the inner conductor, serves as the other conductor of the line and also acts as an electrostatic shield to prevent stray outside fields from inducing spurious voltages in the cable. The instantaneous magnetic and electrostatic fields that exist at a point along a coaxial cable due to the current flowing through it are illustrated in Fig. 3-5B. Observe that the coaxial construction confines them entirely within the cable, so there is no external radiation of any of the radio-frequency energy from within the cable.

The wire, *W*, which serves to connect the outer conductor to the circuit under test should be short. Its contact with the circuit under test should be made as close as possible to the point where the test prod or test probe makes contact with that circuit, because this wire, as well as the corresponding one at the instrument-end of the test cable, is unshielded and so could act as a radiator or could have spurious voltages induced in it by stray fields. If the test cable is viewed as an extension of the measuring-instrument circuit, the logic of effectively shielding the test cable right up to the actual points of contact with the circuit under test, and also up to the instrument input terminals, becomes obvious. This wire also has inductance and capacitance, which can be minimized by keeping it as short as possible. In addition, the use of a fitting that maintains the shielding at the input terminals of the instrument is highly desirable.

3-5. Increased Capacitive Effect in Coaxial Shielded Cable

The use of a shielded input cable represents an important advance over open test leads, because the stray fields about the test bench and equipment under test are rejected by the shield construction. However, the use of a coaxial test cable is not a cure-all for the troubles encountered in sampling the voltage of a circuit under test for application to the indicating instrument, and it introduces some special problems of its own.

The one important disadvantage to its use is the fact that due to the close proximity of the two conductors in the cable, to their increased effective surface area, and to the higher dielectric constant of the insulating material between them as compared with that of air, the distributed capacitance of a coaxial cable is considerably greater than that of a pair of open-wire test leads of the same length. Consequently, the undesirable effects of distributed capacitance in the test lead are intensified when shielded cable is used. However, the capacitance of the shielded cable is fixed and remains unchanged irrespective of the position or movement of the cable while tests are being made. This is a definite advantage over the variable-capacitance effects encountered during manipulation of the open-wire test leads shown in Fig. 3-1B, and to some extent for those shown in part C of the same figure.

The distributed capacitance of a coaxial cable is a function of the material used for the insulation, and a function of the cable dimensions. (Note: Typical values are 20 to 30 $\mu\mu f$ per foot of cable length.) Obviously the only way to reduce the capacitance by a change in cable dimensions is to increase the ratio of the diameter of the outer conductor (shield) to that of the inner conductor. But beyond a certain point, this results in a cable that is too bulky, weighty, and inflexible and uses a prohibitive amount of comparatively expensive dielectric (which also has r-f losses).

3-6. Shielded Test Cable may not always appear Capacitive to the Circuit under Test

It is sometimes assumed that because a shielded input cable to a test instrument usually appears capacitive to the circuit under test, that such must always be the case. The shielded input cable will cease to appear capacitive, and will eventually start to appear inductive as the frequency of the test signal increases. The point at which it begins to act like a coil instead of a capacitor depends

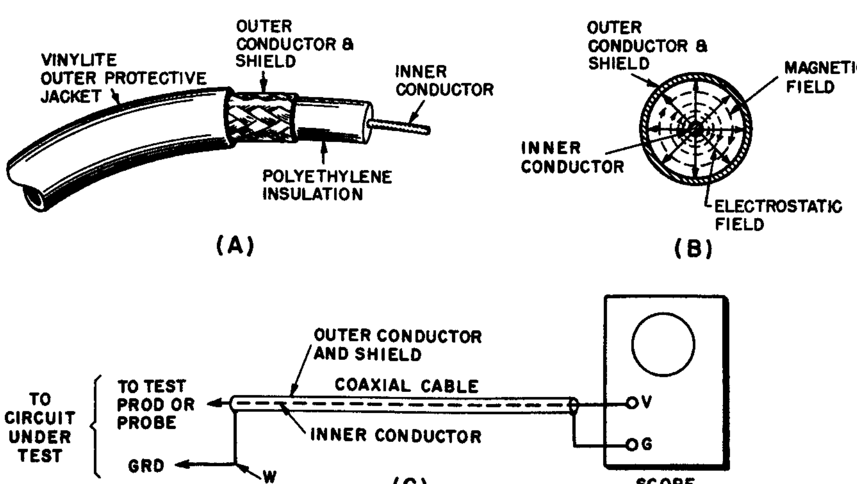


Fig. 3-5. (A) Type of r-f flexible coaxial cable widely employed for test leads. (B) The instantaneous magnetic and electrostatic fields that exist at one point along a coaxial cable due to the current flowing through it at that instant. (C) Method of connecting a coaxial cable to serve as the test leads between a test instrument and a test prod or probe.

upon the length of the cable with respect to the wavelength of the signal under test.

The instrument almost always places a load at the output end of the cable which is *higher* than the characteristic impedance of the cable (typically 50 to 75 ohms). Under this circumstance, the input terminals of the cable will at first appear as a capacitor at lower frequencies, becoming inductive at higher frequencies. At lengths which are an *odd* number of quarter wavelengths at the operating frequency, the cable becomes series-resonant; at lengths which are an *even* number of quarter wavelengths, the cable becomes parallel-resonant. On the other hand, in cases where the instrument places a load at the output end of the cable which is *lower* than the characteristic impedance of the cable, the input terminals of the cable will at first appear inductive at lower frequencies, becoming capacitive at higher frequencies. At lengths which are an *odd* number of quarter wavelengths at the operating frequency, the cable becomes parallel-resonant; at lengths which are an *even* number of quarter wavelengths, the cable becomes series-resonant.

As the frequency of the test signal is progressively raised through multiples of the resonant frequency of the shielded cable, the input reactance changes from capacitive to inductive and goes through various resonances. The first resonance occurs when the cable length is one-quarter wavelength at the operating frequency. For a 4-foot cable, this occurs at about 40 mc, and for a 3-foot cable at about 55 mc.

3-7. Loading Effects Imposed on the Tested Circuit by Test Cable Plus Instrument

Circuit loading caused by test instruments is a problem which the electronics technician must always keep in mind. Several specialized aspects of this subject, as encountered in the two types of probes discussed in Chapters 1 and 2, are explained in Sec. 1-3 and Sec. 2-6. Other reference has frequently been made to "test circuit loading" and its effects on the p-p value and the waveform of the voltage under test. Additional important aspects of this subject must now be considered.

Circuit loading may be classified as *resistive* loading or *capacitive* loading. *Resonance* effects, produced by the application of the testing circuit, may also be considered in conjunction with circuit loading.

(1) *Resistive Loading Effect.* Because the input circuit of a vom, a vtvm, or a scope (d-c input) has a definite resistance value, its connection to a circuit under test places a resistive load on that circuit. However, the actual degree of the effect of this load upon the circuit operation may vary from negligible resistive shunting to a detrimental reduction of the voltage under test. The latter is more frequently the case if the circuit under test is a low-voltage high-impedance circuit (such as a grid-bias or avc circuit, etc.). Resistive loading can be minimized by the use of modern high-resistance type measuring instruments, and in some applications, by the method explained in Sec. 1-8.

(2) *Capacitive Loading Effect.* Where high-frequency circuits are concerned, the effects of the application of the over-all *input* capacitance of the vtvm or scope across the circuit under test is usually of far greater importance as regards possible disturbance of the circuit operation than is the resistive

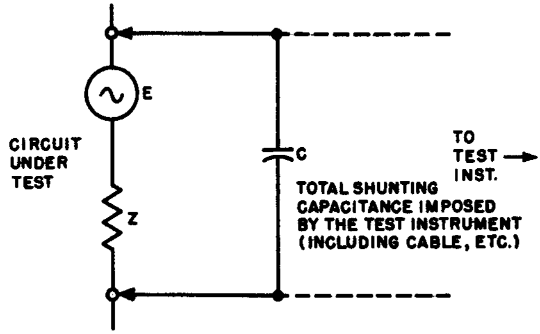


Fig. 3-6. Any typical circuit under test can be represented accurately by a voltage source E and impedance Z. The test instrument and cable applied to it shunt it with capacitance C, which loads it capacitively.

loading imposed. For a setup consisting of the measuring instrument, the test cable, and test prods or a direct-type probe, the *total* or over-all input capacitance is equal to the sum of the paralleled capacitances of these individual devices. For example, if the capacitance of a direct-type probe together with its associated coaxial cable is 60 $\mu\mu$f, and the input capacitance (vertical input circuit) of a scope with which it is to be used is 30 $\mu\mu$f, the over-all input capacitance being applied to the circuit under test is 90 $\mu\mu$f.

Unfortunately, the capacitive loading which a test instrument (including its cable) imposes on a circuit under test is not always considered from the proper, correct or complete viewpoint. The value of the shunting capacitance, *C*, itself does not determine completely the degree of the loading; consequently, it is not sufficient to merely specify the over-all input capacitance which the measuring circuit applies to the circuit under test. This capacitance value means nothing unless it is considered with respect to the internal impedance of the circuit under test, as shown in Fig. 3-6. Any tube, transformer, or coupling capacitor, can be properly represented as a source of voltage, *E*, in series with an impedance, *Z*, which has a value equal to the internal impedance of the circuit under test. It is the value of the *reactance* of *C as compared with the value of Z* which determines whether or not the loading is appreciable. If Z is small, compared with the reactance of *C*, *C* does not load the circuit appreciably; if *Z* is large compared with it, *C* may appreciably alter the operation of the circuit and the voltage and waveform appearing at the test points. In some cases, it may kill the circuit action entirely.

The question to be asked, then, is this: Is the reactance of the over-all capacitance, *C* of the measuring circuit large, or is it small, with respect to the internal impedance of the circuit under test? And it must be remembered that the reactance of *C* is not a constant quantity, but decreases as the circuit frequency increases.

The consideration is often expressed in another manner: A given value of shunting capacitance loads a high-impedance circuit more heavily than it loads a low-impedance circuit. For example, the primary of a horizontal-deflection transformer is a fairly low-impedance circuit, but the primary of a ratio-detector transformer is a high-impedance circuit. Thus, although we can satisfactorily use a direct simple coaxial input cable when measuring the peak-to-peak a-c voltages of a horizontal-output transformer, we shall be disappointed if we try to use the

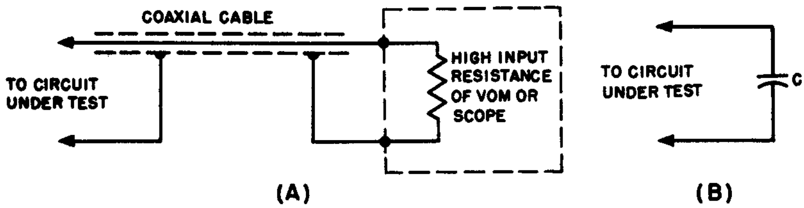


Fig. 3-7. (A) The shielded coaxial cable works into the high input resistance of the vtvm or scope. For all practical purposes, the coaxial cable can be properly regarded as an open stub. Therefore, the cable has a resonant frequency, at which its input terminals "look like" a low resistance (usually 75 ohms). At frequencies below resonance, the cable "looks like" a combination of capacitance and resistance. (B) At low frequencies, the cable "looks like" a capacitor C. The value of C is considerably greater than for a pair of open test leads of the same length, and this is the price that is paid for immunity to stray fields. Naturally, this capacitance can cause the same types of detuning effects in resonant circuits or in low-capacitance circuits to which the cable may be connected, as has already been noted for open-wire test leads (see Sec. 3-2 and Fig. 3-3). The application of this overall capacitance to the test circuit is not harmful in some tests, but in others it may alter the operation of the test circuit sufficiently so that the voltage wave indicate is not the true one as regards either peak value or waveform.

cable alone when measuring the peak-to-peak a-c voltages of a ratio-detector transformer because it will severely load the latter and cause the waveform and p-p value of the voltage to change.

Because the shunting effect of the over-all input capacitance increases with an increase in frequency, appreciable attenuation of the higher frequency components in the test voltage may result, thereby altering its waveform if it happens to be a complex wave or pulse that has considerable high-frequency content.

(3) *Resonance Effects.* Another important effect which the over-all input capacitance of the vtvm or scope may have on the circuit under test is illustrated in Fig. 3-7. As mentioned previously, the input cables used with test instruments become series-resonant at some frequencies, and anti-resonant (parallel-resonant) at others. This causes abnormal increase or decrease of output voltage to the instrument to occur if an input voltage having an r-f component of these frequencies is fed to the cable. In severe cases, the series-resonance action may increase the output to several times the voltage of the input, while at others, the anti-resonance action may reduce the output to practically zero. Such erratic frequency response characteristics can be very troublesome when measurements are being made, if the cable resonances occur at the frequencies of the input test voltage to the cable. Consequently, as we shall learn presently, steps are usually taken to filter out all r-f variations in the output voltage of rectifying and demodulator probes so that resonance effects in the cables used with them are minimized.

The Ferranti effect causes a probe used with an input cable to a test instrument to appear to have increased sensitivity at some frequencies and decreased sensitivity at other frequencies as a result of standing waves which occur on the cable. Standing waves always occur on improperly terminated cables or lines when the operating frequency corresponds to a wavelength for which the cable may be regarded as "long." A cable is electrically long when its input impedance differs appreciably from its characteristic impedance. This situation produces some harmful effects when the cable happens to be an odd or even multiple of one-quarter of the operating wavelength (quarter-wave stub). An eighth-wave stub may also be troublesome, although it is less pronounced in its effects than a quarter-wave section.

3-8. Why Loading Effects of the Measuring Circuit Must Often be Minimized

It is obvious that the actual degree of the effect of the over-all input capacitance of the vtvm or scope may vary from negligible shunting in some circuits under test, to complete upset of the normal operation in others, the latter resulting in susceptibility to the very approach of a test prod to the circuit. To summarize:

(*1*) Use of unshielded input test leads, under some testing conditions, may result in appreciable pickup of spurious pulse voltages and hum voltages that may alter the a-c readings obtained on a vtvm, or obscure and alter the waveform display on a scope, thus leading to incorrect and misleading indications.

(*2*) It is not always satisfactory to use simply a shielded input cable, because the capacitance of the shielded cable plus the input capacitance of the vtvm or scope may result in an overall input capacitance sufficiently large to cause excessive loading of the circuit under test, with consequent alteration of the waveform or the p-p value of the voltage under test. This is especially true in high-frequency, high-impedance circuits.

In some types of a-f measurements, the likelihood of spurious-voltage pickup is so slight that it may be preferable to use an unshielded lead instead of the shielded cable usually supplied with the vtvm—especially when the circuits under test may be adversely affected by the higher capacitance of the shielded cable. The input impedance is greatly increased by using the unshielded lead. For example, the input impedance of the a-c voltage circuit of a particular service-type vtvm, when using the shielded cable supplied, is equivalent to a 2.7-meg resistor shunted by a capacitance of 194 $\mu\mu$f. If an unshielded lead is used instead, the input impedance is equivalent to a 2.7-meg resistor shunted by a capacitance of only 40 $\mu\mu$f. (The shielded lead in this case has a capacitance of 154 $\mu\mu$f.)

(*3*) Since the maximum working-frequency range of a direct-cable and instrument combination varies inversely with the impedance of the test-voltage source, it is impractical to specify one maximum frequency limit for a particular instrument- and cable-combination. In general, all *low-frequency* voltages (including those having complex waveforms) developed across either low-impedance or high-impedance circuits can be displayed or measured with sufficient accuracy if this type of cable is used. Accurate measurement or waveform display of high-frequency voltages (or of complex waves or pulses having considerable high-frequency content) is limited to the lower impedance circuits if only a direct-type cable is used, because the capacitive loading acts to reduce these voltages.

As a general rule of thumb, the over-all input impedance of the test instrument should be at least 10 times that of the circuit under test if the effects of resistive and capacitive circuit loading are to be avoided.

Capacitive loading of the video, sync, and sweep circuits of tv receivers reduces the signal voltage and also distorts the waveform.

(4) Where high-frequency tuned circuits are concerned, the detuning effect caused by application of the over-all input capacitance of the vtvm or scope, or by resonance within the instrument input cable, are the most important factors. The effect of such actions in horizontal, vertical and r-f oscillators is generally to reduce the operating frequency, output voltage, and normal response of the circuits. It is possible to use an isolating resistor to kill the resonant-stub action of the instrument cable.

(5) The stray-field rejection benefits of a shielded input cable used with a d-c vtvm or a scope may be retained, and at the same time the circuit-loading effects caused by the appreciable over-all input capacitance which results may be effectively reduced whenever it is necessary to do so, by means of a suitable circuit-isolation probe. Two types of isolation probes are described in Chapters 4 and 5. Another method, which employs a cathode-follower attachment, is also described later (Sec. 5-11).

3-9. Monitoring-Scope Test for Determining Degree of Circuit-Loading Caused by Test Instrument

The question often arises during peak-to-peak voltage measurement with a vtvm or a scope, or during waveform analyses with a scope, whether application of the instrument to the circuit under test is causing appreciable circuit loading to take place. To quickly and definitely answer this question, the "monitoring-scope" test can be used. One scope, or vtvm, is used to make the desired measurement or check in the circuit. A separate scope is used simultaneously to monitor the operation of that circuit to determine whether substantial circuit loading is taking place.

The first instrument is used with a suitable probe, to test the peak-to-peak voltage, or the operating waveforms, of the circuit at the proper check points. The monitoring scope is left connected at the output of the circuit under test, during the probing procedures. Any decrease in the pattern height or shape of the indication on the monitoring scope when the first instrument is applied at some point in the circuit, indicates that corresponding circuit loading is taking place. To cite a practical example, consider a situation in which the sync circuits of a tv receiver are being checked for trouble. The monitoring scope is left connected at the output of the sync circuit (input of the phase detector), while the checking scope is used to check waveforms and peak-to-peak voltages progressively through the sync circuit. Each time the checking scope is applied, the pattern on the monitoring scope is observed to make certain that the output voltage has the same value and shape as before the probe was applied. In case substantial loading is revealed, a suitable low-capacitance probe (see Chapter 5) must be used with the checking scope.

Chapter 4

RESISTIVE CIRCUIT-ISOLATION PROBE (THE "D-C PROBE")

4-1. Functions and Action of Isolation Resistor in VTVM D-C Probe

The simplest and perhaps most widely used d-c circuit-isolation arrangement is that provided by the 1-megohm resistor which is included in the d-c probe of practically all service-type vtvm's, as illustrated in Fig. 4-1, for use on the d-c voltage ranges. This isolating resistor has two important functions: (1) it greatly reduces the effective over-all input capacitance presented to the circuit under test by the d-c probe; (2) it comprises part of a resistance-capacitance input filter circuit which filters out any strong high-frequency a-c components that may be present in the d-c voltage that is to be measured, thus preventing them from reaching the metering circuit, so that d-c voltages can be measured in the presence of high-frequency a-c.

(*1*) *Action as a Circuit-Isolation Resistor.* The input voltage-divider resistance network, shielded input cable, and test prod of a vtvm have a combined over-all capacitance which may total approximately 60 to 120 $\mu\mu$f or more. If so isolation resistor were used, this capacitance would be applied directly across the circuit whose d-c voltage was being checked, as shown in Fig. 4-2A. Such a large value of shunting capacitance will cause severe capacitive loading and disturbance of the normal circuit operation of many of the r-f circuits whose d-c voltages need to be checked with the vtvm, resulting in erroneous and misleading d-c voltage readings. An example is provided by an attempt to measure the signal-developed d-c bias voltage at the control-grid of a high-frequency oscillator. It is not practical to dispense with the shielded cable in an effort to reduce the capacitance, since excessive spurious voltages would often be induced in an unshielded cable by the strong stray fields existing around the equipment under test. The problem is solved by inserting a suitable isolating resistor R (see Fig. 4-2B), having a value of approximately 1 megohm, in series with the input circuit, between the shielded cable and the test point in the receiver. The most satisfactory arrangement is to mount it within the d-c probe head, as shown in Fig. 4-1.

As indicated in Fig. 4-2B, the effect of introducing the large-value isolation resistance at this particular point in the circuit is to place it in series with the reactance of the over-all input capacitance C. When a resistor is connected in

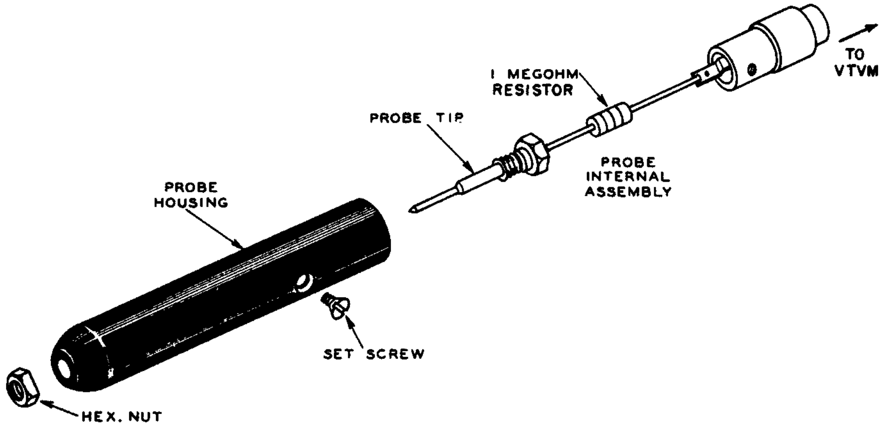


Fig. 4-1. Exploded view of typical vtvm d-c probe containing a 1-megohm series-connected isolating resistor. The particular probe illustrated here is designed to be slipped on to a standard direct-probe and cable whenever d-c voltages are to be measured. *Courtesy: RCA*

series with a capacitor, the series combination has an impedance larger than the reactance of the capacitor alone, for any given frequency. Therefore, the addition of this isolation resistor greatly increases the impedance of the input circuit as seen from the probe tip. This is equivalent to saying that the input capacitance has been reduced in effect, to a value C_I, whose reactance is equivalent to this impedance at the particular frequency being considered. Reduction of the effective input capacitance at the probe tip to a value of only 1 or 2 $\mu\mu$f is common, as shown in Fig. 4-2C. Of course, the probe assembly has a certain amount of stray capacitance from its input to its output circuit, and from its input to ground, which is included in this effective input capacitance. Obviously, these two stray capacitances should be kept as small as possible by proper physical design of the probe.

Another viewpoint regarding the effect of the isolating resistor is that its resistance value is sufficiently high (usually about 1 megohm) to provide protection against the shunting effect of the low impedance presented by the cable at high frequencies. The isolating resistor stands between the high-frequency voltages in the circuit under test, and the low impedance presented by the input end of the cable, which may drop to as low as 75 ohms at high tv frequencies.

Its practical effect is to provide negligible *capacitive* circuit-loading and resonance effects for most vtvm d-c voltage measurements made in radio-frequency circuits, so that little or no detuning, or other disturbance, of such circuits under test is caused by connection of the d-c probe of the vtvm to a load-sensitive point in the circuit. Addition of this 1-meg resistor in series with the usual 10- or 25-meg input network resistance of most vtvm's, see Fig. 4-2B, results in a total d-c input resistance of 11 or 26 megohms, respectively, which is great enough to prevent serious *resistive* loading of most tested d-c circuits, including d-c grid bias circuits.

(2) *Action as a High-Frequency Filter.* It is quickly seen that the combination of the series isolating resistor with the over-all shunt input capacitance, *C*, (Fig. 4-2B), also forms a low-pass resistance-capacitance filter, which causes the components to act as a voltage divider for a-c potentials. When the frequency is fairly low, the capacitive reactance is fairly high, so that the isolating resistor does not drop very much applied a-c voltage. When the frequency is higher, the capacitive reactance becomes fairly low, so that the isolating resistor drops practically all of any applied a-c voltage, causing it to become impossible to maintain an appreciable proportion of this voltage across the cable input. This provides sufficient high-frequency attenuation to keep any strong high-frequency components (such as rf) that may be present in the d-c voltage under test from entering the metering circuit. Here they might drive the metering-tube bias beyond cutoff and cause rectification, which would result in a change in the meter reading.

4-2. Effect of Isolation Resistor on D-C Voltage Calibration of the VTVM

It will be observed in Fig. 4-2B that the isolating resistor is in series with the resistors that form the voltage-dividing network across the vtvm input. The resistance of the latter is 10 megohms in many commercial vtvm's. Consequently, a portion (about 10 percent in this case) of the applied d-c voltage that is to be measured will appear as a voltage drop across the isolating resistor, and the re-

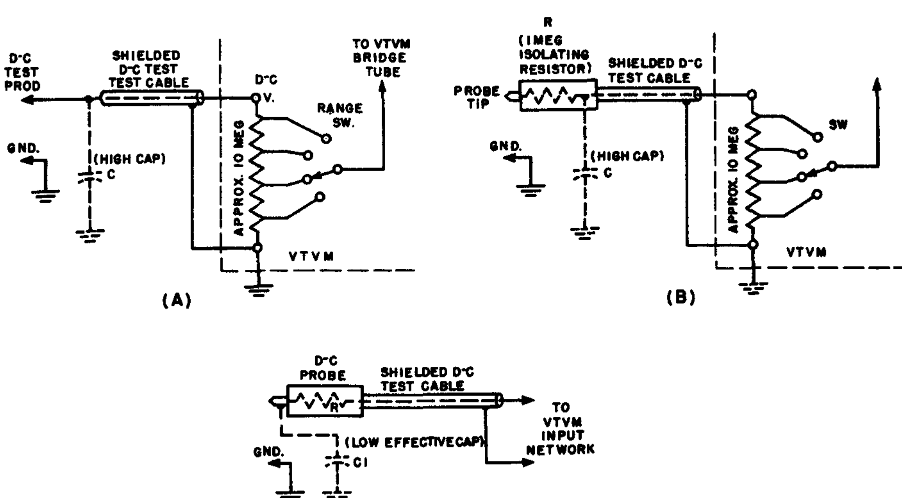


Fig. 4-2. The isolation resistor used with the d-c voltage function of a vtvm usually consists of a carbon resistor having a value of approximately 1 megohm connected in series with the "hot" lead of the input cable at the probe. Its effect is to greatly decrease the effective input capacitance and capacitive loading imposed upon the circuit under test. This resistor also forms part of a R-C filter which keeps possible strong a-c components present in the d-c voltage under test from entering the meter.

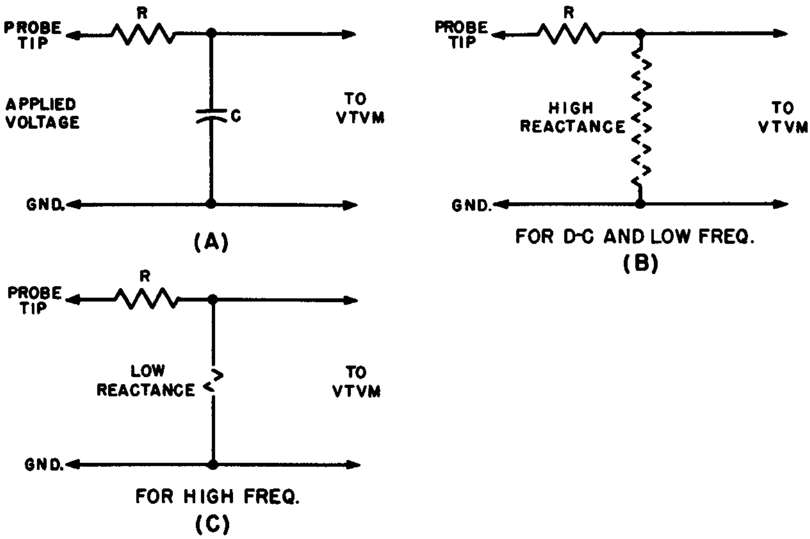


Fig. 4-3. Resistive-isolation probe circuit action which illustrates why the high frequencies are disciiminated against when an attempt is made to employ a resistive isolation probe to minimize the loading effect of the cable capacitance upon the circuit under test during high-frequency a-c voltage measurements made with a vtvm.

mainder (about 90 percent) will be applied to the vtvm. This reduces the meter deflection produced for a given input test voltage.

This matter is of no concern to the user of a vtvm if the isolating probe was supplied by the manufacturer as standard equipment with the meter, for in that case the d-c calibration of the meter already takes into consideration the total resistance of the input voltage divider of the meter plus the isolating resistor. However, if the user wishes to add an isolating resistor to the d-c test prod of a vtvm which does not already employ one, or if he decides to increase the value of the isolation resistor already in a probe in order to obtain improved isolation through the use of a higher resistance, he must remember that the addition of the resistor will cause the d-c voltage scale indication to read low. The amount of correction that must be applied can be calculated on a percentage basis by proper consideration of the voltage division in the series-resistor circuit (see Fig. 4-2B).

4-3. Why Use of a Circuit-Isolation Resistor is not practicable for High-Frequency A-C Voltage Measurements

It is quite essential that the user of a vtvm or a scope remember that the isolation resistor is used only when d-c (or low-frequency a-c) voltage measurements are to be made. The beginner sometimes is inclined to overlook this important limitation, and attempts to use an isolating resistor with a vtvm (or a scope) in the measurement of high-frequency a-c voltages, in order to reduce capacitive-loading effects. Such attempts can only result in erroneous readings. First of all, the fact that the a-c scales of the vtvm have been calibrated on the basis that no series isolating resistor is in the circuit when a-c measurements are being made, should be a sufficient reason not to introduce an isolating resistor into this circuit. Also, let us redraw the combination of isolating resistor, *R*, and over-all input-circuit capacitance, *C*, as in Fig. 4-3A, so that its low-pass filter characteristics may be emphasized.

For input voltage of zero frequency (dc), and low frequencies, the reactance of capacitor *C* is so high that the proper proportion of the applied voltage appears across this capacitance and is applied to the vtvm. Consequently, since d-c voltage, and low-frequency a-c voltage, is passed with little alteration by this filter (except for the drop across *R* which is taken care of in the meter calibration), fairly accurate measurements of voltages of these frequencies may be made.

As the frequency of voltage to be measured is increased, the reactance of *C* diminishes, and it can reach quite low values at radio frequencies. Under these conditions, the combination operates as a voltage divider, and *the voltage step-down ratio increases with the frequency.* Consequently, the a-c voltage actually made available to the vtvm input terminals becomes increasingly less than that applied to the probe for measurement, and the ratio of the two varies with the frequency. As a result of this action, at high frequencies the a-c voltage level in the cable (and applied to the vtvm) may diminish to an insignificant value. It is obvious that accurate measurement of high-frequency a-c voltage is impossible under these conditions.

The fact that a resistive isolating probe discriminates against the higher frequencies is demonstrated experimentally by Fig. 4-4, which shows that the higher frequency components of a square wave are attenuated in passing through such a probe. When it is desired to minimize the capacitive-loading effect of the cable capacitance upon the circuit under test during a-c voltage measurements made with a vtvm, it is accordingly necessary to utilize other means than an isolating resistor.

In some cases, a resistive isolation probe is capacitance compensated to avoid this frequency distortion when measuring a-c voltages at frequencies within the range of vtvm a-c voltage response.

4-4. Substitution, and D-C/A-C Switching, Arrangements for VTVM D-C Probes

The modern trend in high-speed signal tracing and voltage-checking with the vtvm is toward the use of a single test cable for as many meter functions as possible in order to eliminate much of the complication and loss of time expe-

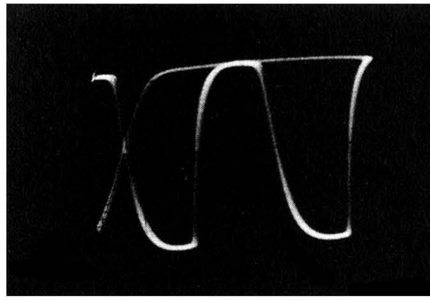


Fig. 4-4. The frequency discrimination resulting from the use of a resistive isolation probe in high-frequency a-c voltage measurements is shown here. A low-frequency square wave a-c voltage was applied to a resistive isolating probe and shielded test cable connected to the scope input. The severe rounding of the corners of the reproduced wave indicates discrimination against the high-frequency components of the square wave by the probe and cable.

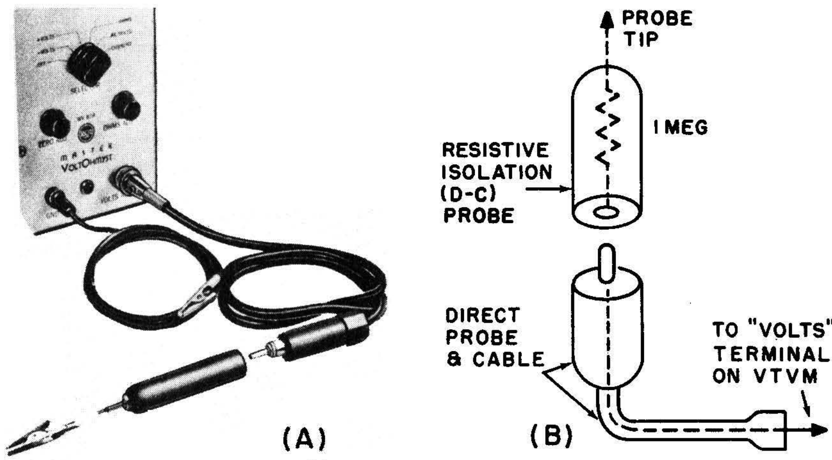


Fig. 4-5. (A) Separable-probe arrangement used for vtvm resistive isolation (d-c) probe. Provides d-c and a-c voltage test facilities with one test cable. (B) Circuit arrangement of separable probe and test cable. (A) *Courtesy: RCA*

rienced with a meter having numerous leads which invariably become tangled. This poses a problem in connection with use of the resistive-isolation probe for all d-c voltage measurements made with the vtvm. The resistor must not be in the voltage-measuring circuit when a-c voltage measurements are being made. However, most service-type vtvm's provide only a single "Volts" terminal for both d-c and a-c voltage measurements. The d-c or the a-c voltage measuring function must be selected by the selector switch on the instrument.

This problem is solved in two ways, in practice. One arrangement is illustrated in Fig. 4-5A. When a-c voltage measurements are to be made, a direct cable and probe, shown at the lower right, is used. When d-c voltage measurements are to be made, a separable probe head containing the 1-megohm isolating resistor (shown to the left of the direct cable and probe) is slipped on to the direct probe, thereby connecting it in series with the "hot" lead of the cable, as shown in Fig. 4-5B.

Another electrically equivalent arrangement is illustrated in Fig. 4-6. The 560,000-ohm resistor for this vtvm is contained within the probe, and it may be switched into the circuit when d-c voltages are to be measured and out of the circuit when low-frequency a-c voltages are to be measured (see Fig. 4-6B). The simple slide switch is conveniently located on the probe housing for rapid manipulation. A modification of this method is also in use where the switch is arranged to short-circuit the isolating resistor. This switch may take the form of a small sleeve on the probe which may be screwed in tight to short-circuit the resistor or unscrewed to remove the short.

4-5. Use of Resistive-Isolation (D-C) Probe with a VOM

A resistive isolating probe cannot usually be used successfully with a vom because the relatively large current drain of the instrument causes excessive voltage drop across the isolating resistor. Furthermore, an isolating resistor which is chosen to provide direct readings on one range, will read incorrectly on the next higher range, because the input resistance of a vom is not constant as is that of a vtvm. The input resistance on any one range is equal to the full-scale value of the range times the ohms-per-volt rating of the instrument. For example, a 100,000 ohms-per-volt vom has an input resistance of 1 megohm on the 10-volt range, and an input resistance of 10 megohms on the 100-volt range.

Consider the input resistance of a 20,000 ohms-per-volt vom on the 3-volt range with respect to the resistance of the isolating probe. While the instrument has an input resistance of only 60,000 *ohms* for this range, the probe has a resistance of approximately 1 *megohm*. Hence, much more of the voltage to be measured is lost in the probe than is made available to the vom.

It might be supposed that the use of a 100,000 ohms-per-volt vom would make the use of a resistive isolating probe more practical, but even in this case, the input resistance of the meter on the 3-volt range is 300,000 ohms, as compared with the 1-megohm resistance of the usual isolating probe. The value of the isolating resistor can be reduced to about 300,000 ohms, thus obtaining an appreciable degree of isolation, at the expense of half the sensitivity of the meter (see Sec. 4-2).

4-6. Erroneous Use of Resistive-Isolation (D-C) Probe in Low-Voltage D-C Circuits Containing High-Voltage Pulses

Another error in probe selection concerns the common mistake of attempting to measure the d-c voltage at the plate of the horizontal-output tube of a tv receiver with a vtvm and its conventional d-c (isolating) probe containing a 1-meg resistor. This practice may lead to burn-out of the isolating probe, and often to damage of the vtvm input circuit also (punctured bypass capacitors, and overheated multiplier resistors). The reason for this damage is that in this particular type of circuit, although the d-c voltage may be of the order of 300 or 400 volts, there is an accompanying pulse voltage of the order of 4,000 to

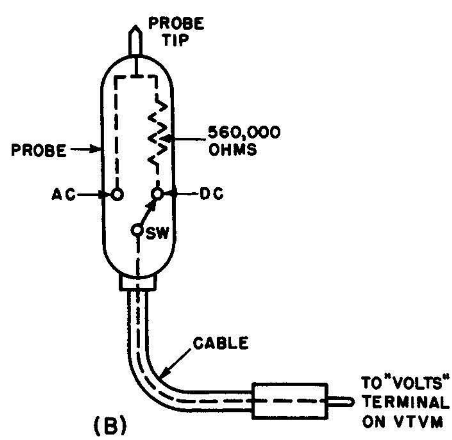


Fig. 4-6. Slide-switch arrangement used on vtvm resistive isolation (d-c) probe to provide d-c and a-c voltage test facilities using one test cable. (B) Switching circuit. (A) *Courtesy: Hickok Elect. Instr. Co.*

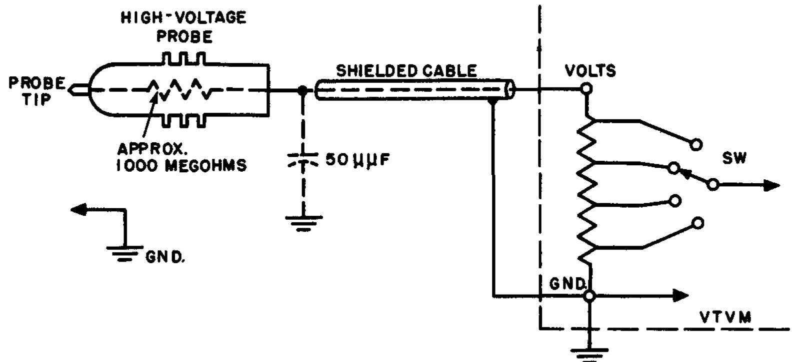


Fig. 4-7. Equivalent circuit of a high-voltage d-c probe, with shielded input cable, working into the input resistance network of a vtvm. The shielded cable and vtvm may have an overall input capacitance of say 50 $\mu\mu$f, which has a reactance of 0.2 megohm at 15,750 cps. A 100-to-1 high-voltage probe makes it possible to measure d-c plate-voltage values in the 15,750 cps horizontal-output circuits, without damage to the vtvm from the accomapnying high-voltage pulses. The attenuation of the pulses in this case is in the order of 1,000 to 0.2 or 5,000 to 1.

6,000 peak-to-peak volts. The proper probe to use is a high-voltage d-c probe (which has a much higher resistance of the order of several hundred megohms) as is explained in Sec. 1-7. This higher resistance provides the necessary low-pass filter action required to attenuate the high-voltage a-c pulses so that they do not reach the meter.

4-7. Erroneous use of Resistive-Isolation (D-C) Probe in High-Impedance Circuits

Another type of error in probe application occurs in the attempt of the technician to measure the d-c bias voltage at the grid of a vertical blocking oscillator with a vtvm and its conventional d-c (isolating) probe containing a 1-meg resistor. If the impedance of the grid circuit is very high, as is often the case, the voltage reading is falsely subnormal due to circuit loading caused by the

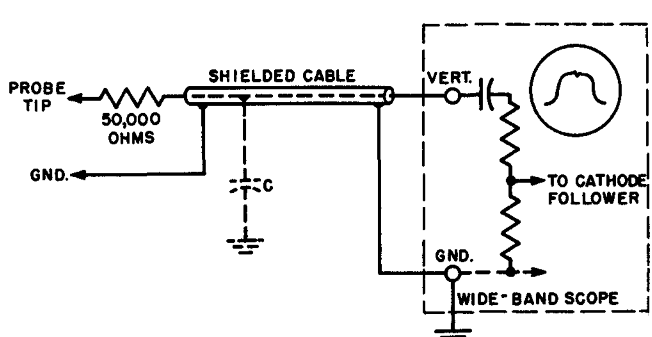


Fig. 4-8. Use of an isolating resistor with scope to produce sharp markers in visual alignment work.

insufficient impedance of the probe input circuit. Here again, the proper procedure is to use a 100-to-1 high-voltage d-c probe with the vtvm, as illustrated in Fig. 4-7. This will permit the bias to be read on the 3-volt scale (as a 300-volt scale) with an input resistance of more than 1,000 megohms.

4-8. Use of Isolation Resistor with Scope to Sharpen Marker Pips during Visual Alignment

An isolation resistor is very helpful in visual circuit-alignment work with a scope because it operates in combination with the overall capacitance, *C*, of the shielded cable and scope input circuit to filter out the high-frequency beat components, thereby sharpening broad marker pips which would otherwise mask important portions of the response traces. The marker is sharpened without producing reactive distortion of the resonance curve, or displacement of the marker. A value of 50,000 ohms connected in the "hot" input lead of the scope, as shown in Fig. 4-8, is recommended for use with the average length of shielded cable. The effect of using such a probe to sharpen the marker display is illustrated in Fig. 4-9.

This isolation-resistor arrangement is not suitable for use in waveform checking in sync and sweep circuits of tv receivers, because the waveforms in these

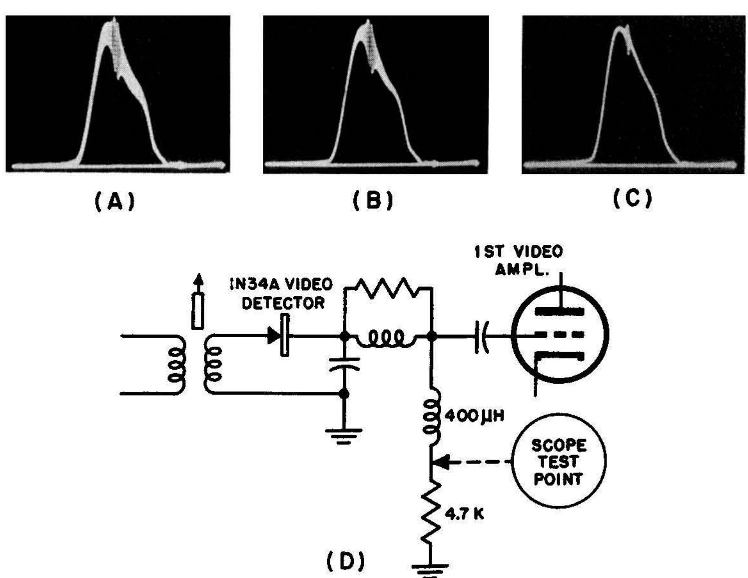


Fig. 4-9. Example of isolating-resistor use with scope in visual alignment work. Unless a suitable probe is used at the output of the picture detector when displaying a visual-response curve and marker indication, the marker may be unsatisfactory, or the curve may be distorted, or both. For example, if a 10-to-1 low-capacitance probe is used (see Chap. 5), its wide frequency response results in display of the higher beat frequencies, and a broad fuzzy marker indication is developed, as shown in (A). When a direct probe is used, fewer of the higher beat frequencies are reproduced, but a satisfactory sharp marker is still not developed, as shown at (B). When a resistive isolating probe is used, the marker indication is quite sharp and satisfactory, as shown in (C).

circuits will usually appear badly distorted when it is used. The reason for this is that troubleshooting in sync and sweep circuits requires wide frequency response instead of the comparatively narrow frequency response that is sufficient for visual alignment. The filtering action of the isolation resistor in combination with overall capacitance, *C*, (Fig. 4-8) results in high-frequency discrimination (see Sec. 4-3) with resulting narrowing of the frequency response. Consequently, a compensated high-impedance probe is required in this type of work, instead of a simple isolation resistor.

4-9. Use of Isolation Resistor with Scope in Front-End Signal Tracing

To determine whether the antenna signal is proceeding through the r-f stage to the mixer grid, it is usually possible to sweep the antenna terminals and check the "looker" point on the mixer grid lead with a scope. In some cases this looker point provides ample isolation from the capacitance of the scope cable, but in other cases an isolating resistor of about 50,000 ohms should be used at the end of the scope cable. This will avoid loading of the mixer grid circuit and detuning of the grid coil. In case of doubt, always include an isolating resistor in the test setup.

If the r-f stage is operating properly, a response curve will be obtained when a sweep-frequency signal is applied to the antenna terminals of the front end. A response curve of larger amplitude usually results when the local oscillator is disabled, because the local oscillator biases the mixer to a relatively insensitive operating point.

Chapter 5

COMPENSATED R-C (LOW-CAPACITANCE), AND CATHODE FOLLOWER, CIRCUIT-ISOLATION PROBES

5-1. Function of Low-Capacitance Circuit-Isolation Probes

The internal vertical-input circuit of an oscilloscope contains a certain amount of resistance shunted by capacitance. Typical normal values for five different popular makes of tv servicing scopes are:

Scope A	2.0 meg	shunted	by	approx.	$22\mu\mu f$
B	1.5	"	"	"	"	$20\mu\mu f$
C	1.0	"	"	"	"	$30\mu\mu f$
D	0.5	"	"	"	"	$26\mu\mu f$
E	0.1	"	"	"	"	$15\mu\mu f$

Thus, typical input resistances are of the order of 0.1 to 2 megohms, and typical shunt capacitances are of the order of 15 to 30 $\mu\mu f$. To this input capacitance is added the approximately 30 to 50 $\mu\mu f$ (or more) combined capacitance of the direct probe and the shielded coaxial input cable that is customarily used to minimize stray capacitance effects and spurious-voltage induction by stray fields (see Sec. 3-3 to Sec. 3-5). Consequently, whenever the test prod of a typical service-type scope, used with its conventional direct probe and test cable, is placed at some point in a circuit in order to measure the p-p voltage or check the waveform present there (see Fig. 5-1), the circuit under test is automatically being shunted by about 0.1 to 2 megohms of resistance $R2$, and 45 to 80 $\mu\mu f$ (or more) of capacitance, $C2$, depending upon the particular make and model of scope employed.

Addition of this shunting resistance and capacitance to some circuits undergoing test produces virtually no noticeable effect on their operation and on the voltage and waveform present at the test point. However, in many other cases this amount of added capacitance may be sufficient to detune resonant circuits, or to capacitively load others enough to seriously distort the waveforms under observation or alter the p-p voltage values, particularly if the circuit under examination has high impedance or contains components of relatively high frequency (such as high video frequencies). For example, the input impedance presented to a video-frequency signal of say 1 mc by a service scope and direct

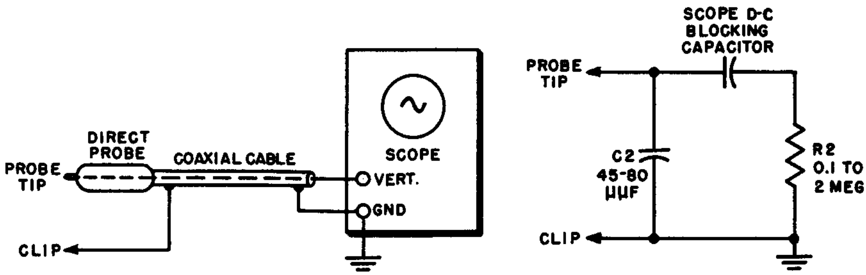


Fig. 5-1. (A) Whenever the vertical input terminals of a typical service-type scope are connected to a circuit through its direct-probe and cable in order to make a waveform or p-p voltage check, that circuit is being shunted, as shown in the equivalent circuit (B), by about 0.1 to 2 megohms of resistance and 45 to 80 $\mu\mu$f (or more) of capacitance, depending upon the particular make and model of scope used. This amount of shunting capacitance is often sufficient to detune resonant circuits or to seriously distort the waveforms under observation, particularly if the circuit under examination has high impedance or contains components of high video frequencies.

cable whose over-all input capacitance is 70 $\mu\mu$f is approximately 2,000 ohms at this frequency. Typical of the latter group of circuits are the following in tv receivers: (1) the sync circuits; (2) the horizontal-deflection coil circuits; (3) the horizontal-oscillator circuits; (4) the composite video circuits; etc. In fact, this difficulty is experienced generally whenever it is required to scope-trace audio, video, sync, or sweep waveforms through high-impedance circuits at moderate voltages.

To prevent the overall input resistance and capacitance of the scope from causing enough circuit loading to produce these disturbing effects in such circuits, it is necessary to employ some means for sufficiently decreasing the normal input capacitance (increasing the input impedance). This may be accomplished in a simple and convenient manner by means of a compensated R-C type of circuit-isolation probe commonly known as a "low capacitance" or "high-impedance" probe because of its function.

5-2. Circuitry and Operation of Typical 10-to-1 Low-Capacitance Probes

The simplest type of conventional frequency-compensated R-C divider low-capacitance probe for use with scopes is illustrated in Fig. 5-2A. A small semi-variable tubular or ceramic trimmer-type capacitor, *C1,* shunted by high resistance *R1,* is connected in series with the "hot" lead of the shielded test cable to the scope, thereby placing the parallel combination in series with the overall 0.1 to 2-megohm input resistance *R2,* and the 45-to-80-$\mu\mu$f input capacitance, *C2,* of the scope.

The complete equivalent circuit is illustrated in Fig. 5-2B. It is seen that a resistance-capacitance (R-C) divider circuit results. The d-c blocking capacitor of the scope is shown, but since it has a large capacitance and therefore a very low reactance, it may be neglected in all high-frequency a-c test signal combinations.

Since the resultant capacitance of two capacitors in series is less than that of the smaller capacitor, the *effective* input capacitance at the probe may be made almost any desired fraction of the overall scope input capacitance *C2* by suitable choice of the value of the series capacitor *C1* in the probe. The use of the series resistor *R1* also reduces the effective input capacitance of the scope as explained previously in Chapter 4 (Sec. 4-1).

Furthermore, since the two capacitors and the two resistors in series form a voltage divider for applied a-c voltages (see Sec. 2-2), and the a-c voltages which appear across the individual capacitors are in inverse ratio to the capacitances, and directly proportional to the resistances, it follows that the increase in the overall scope input impedance and the reduction of the overall scope input capacitance by a certain ratio is accompanied by a loss of a-c signal voltage (in the same ratio) entering the scope. This loss is usually referred to as the *attenuation* of the probe.

The series capacitor and resistor are usually chosen and adjusted to have a value which makes the attenuation ratio a convenient figure—usually 10-to-1, or 100-to-1. The 10-to-1 probe is the most widely used in tv service work (see Sec. 5-5). Since the a-c voltage-stepdown ratio is then a decimal fraction, use of the probes with a calibrated scope does not destroy the rms or the p-p voltage calibrating factor (or deflection-sensitivity rating) of the scope. A zero, or two zeros, as the case may be, is merely added to the initial calibrating factor of the scope. Thus, if the vertical deflection sensitivity of a particular scope is 0.02 volt rms (0.057 volt p-p) per inch when it is used with its direct probe and cable,

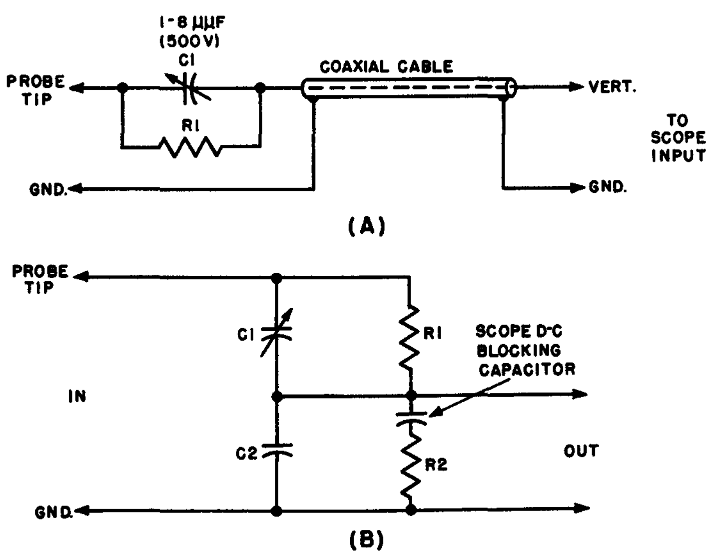


Fig. 5-2. (A) A simple type of low-capacitance probe which causes a-c signal attenuation only. The probe capacitance C1 and resistance R1, and the overall scope (plus cable) input capacitance C2 and resistance R2, form the resistance-capacitance divider circuits shown in (B). The scope d-c blocking capacitor is neglected in this consideration, because its reactance is practically zero at radio frequencies.

it becomes 0.2 volt rms (0.57 volt p-p) per inch when it is used with a 10-to-1 low-capacitance probe.

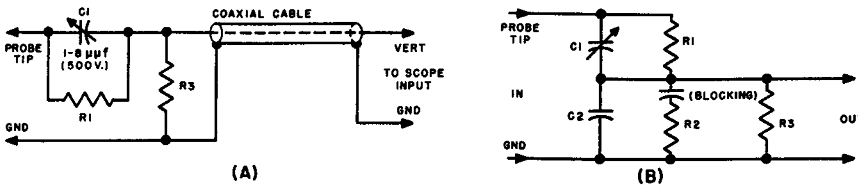
It is evident that it is desirable that the attenuation factor of the probe be maintained practically constant for low frequencies as well as high frequencies. Consequently, the probe must be frequency-compensated for the entire frequency range over which it will be used in practice. No waveform distortion occurs in the probe if its time constant ($R1 \times C1$) is made equal to that ($R2 \times C2$) of the overall scope input circuit. (The method of adjusting the series capacitor of the probe to make these time constants equal is explained in Sec. 5-8.) When the two time constants are equalized, the probe divides input voltages of all frequencies in the same proportion. An exception to this rule occurs where the voltage input delivered to the scope is increased (or decreased) by resonance (or anti-resonance) effects occurring in the shielded input cable, such as when the frequency of the a-c voltage under test is sufficiently high so that the length of the probe cable is a substantial fraction of the operating wavelength. However, this limitation does not impair the usefulness of the probe for most service applications, because most service-type scopes do not respond to frequencies within the resonance-frequency range of the input cables supplied with most conventional low-capacitance probes.

In a 10-to-1 low-capacitance probe of the type illustrated in Fig. 5-2, the capacitance of $C1$ is made approximately one-ninth that of $C2$, and resistance $R1$ is made 9 times that of $R2$ in order to provide the 10-to-1 factor. A ± 1 percent, 1-watt carbon resistor is ordinarily employed for $R1$.

The practical effect of employing this type of 10-to-1 low-capacitance probe with a scope and input cable whose normal over-all input resistance and capacitance are, say, 1 megohm shunted by 75 $\mu\mu$f of capacitance, is to present an input circuit of 10 megohms shunted by a capacitance of only about 7.5 $\mu\mu$f to the circuit under test.

Since the probe arrangement in Fig. 5-2A presents an open circuit with respect to d-c voltage (because of the series blocking capacitor which is usually present in the scope input circuit), it provides a-c signal attenuation only. Consequently, it has advantages in such uses as checking the waveform at the grid of a vertical blocking oscillator tube in a tv receiver. A high d-c bias, as well as the a-c waveform that is to be checked, exist here and the grid circuit has a high resistance. The operation of the vertical blocking oscillator depends upon the maintenance of this d-c bias, and since the grid resistance is quite large, very little input resistance can be tolerated in the scope input circuit. Therefore, it is usually found necessary in such tests to use the type of low-capacitance probe which presents practically an open circuit with respect to d-c voltage. Then, the correct bias is maintained in the high-resistance grid circuit, while the low-capacitance probe reduces the effective overall input capacitance of the scope to a value low enough so that the a-c waveform is not distorted by capacitive loading of the circuit under test. This type of low-capacitance probe is usually used where there is no high d-c voltage component present at the circuit point under test.

Another version of the low-capacitance probe which is preferred for some test conditions because it provides both d-c and a-c voltage attenuation is shown



RESISTANCE VALUES FOR A 10-TO-1 PROBE

RESISTANCE VALUE	RATING
R1 = 0.9 R2	±1%, 1 WATT
R3 = 0.11 R2	±5%, 1/2 WATT

WHERE R2 IS THE INPUT RESISTANCE OF THE OSCILLOSCOPE

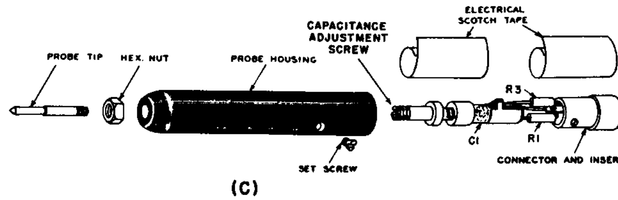


Fig. 5-3. (A) The addition of shunt resistor R3 to the simple low-capacitance probe circuit of Fig. 5-2 serves to attenuate any d-c voltage components which may be present at the circuit point to which the probe is touched, and which would stress the blocking capacitor in the scope input circuit. Thus, this low-capacitance probe provides both d-c and a-c signal attenuation, and also stabilizes the input impedance of the scope as the vertical attenuation of the scope is varied. The resistance-capacitance divider circuit formed is shown in (B). (C) An exploded view of this type of probe, showing the arrangement of the components and wiring. Required adjustment of the value of series capacitor C1 is provided by the adjusting screw which is usually reached by unscrewing the probe tip. *(C) Courtesy: RCA*

in Fig. 5-3A. It is similar to the type previously described, except that it contains a shunt resistor, *R3*, added in the probe circuit, as shown. The resistance-capacitance divider circuit which is now formed is shown in Fig. 5-3B. Observe that since resistor *R3* parallels *R2* and the blocking capacitor, it provides a path for d-c current flow around them. Resistors *R1* and *R3* form a resistive voltage divider that attenuates any d-c component which may be present at the test point. This attenuation reduces the d-c voltage that is applied to the blocking capacitor usually present in the scope input circuit, thus protecting this capacitor against excessive voltage stress that would otherwise result when testing circuits that contain a-c waveforms with a relatively high d-c voltage component. The shunt resistor also serves to stabilize the input impedance of the scope, as the vertical attenuator of the scope is varied.

One disadvantage of this circuit arrangement is that the input resistance of this probe, which is lower than that of the one in Fig. 5-2, may cause too much resistive loading of critical high-impedance circuits in which d-c is present, such as the load-sensitive grid-bias circuit of the vertical blocking oscillator previously mentioned. Consequently, it is not ordinarily used in such circuits unless a high-quality blocking capacitor is connected in series with the probe tip to block the flow of d-c. This blocking capacitor is already built into some commercial probes of this type, care being taken to keep its stray capacitances very low. Its capacitance must be large enough (approximately 0.05 to 0.5 μf, high-quality low-leakage paper type capacitor used) so that it will not cause low-frequency discrimination.

No waveform distortion occurs in the probe when the various resistances and capacitances are such that the following relationship exists:

$$R1 \times C1 = \left(\frac{R2 \times R3}{R2 + R3}\right) \times C2$$

It will be noted that the expression enclosed within the parenthesis here is the combined resistance of resistors $R2$ and $R3$ in parallel. Since $C1$ is made equal to 1/9 of $C2$ for a 10-to-1 probe, we have

$$R1 = 9 \left(\frac{R2 \times R3}{R2 + R3}\right)$$

If $R1$ is made equal to $0.9R2$, then a value of $R3$ equal to $0.11R2$ must be employed. With these values in use, the input characteristics are such that the *resistance* presented to a circuit under test is the same as when no probe is used, but the effective input capacitance is reduced.

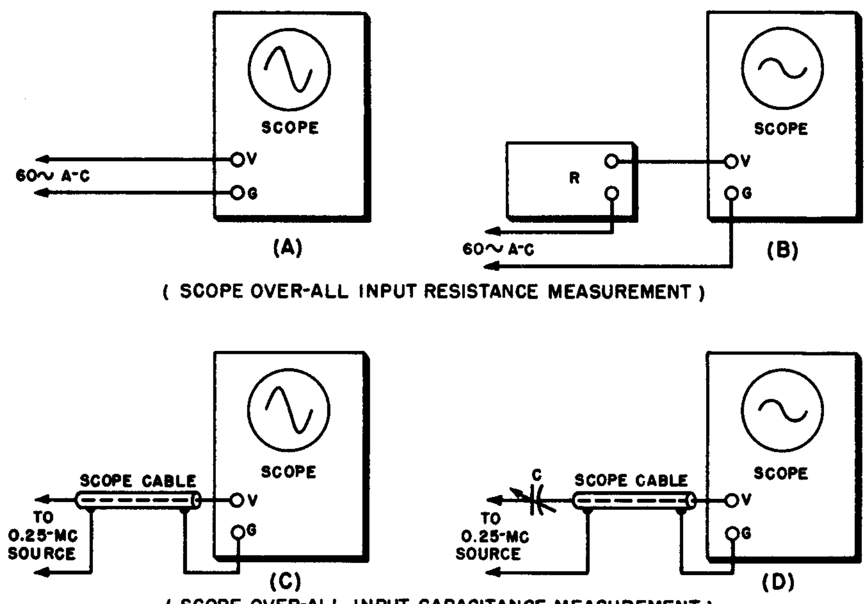


Fig. 5-4. (A) To measure the input resistance of a scope, first connect the vertical-input terminals to any convenient low-frequency a-c voltage source, such as a 60-cycle source. Note the amount of deflection which is obtained on the scope screen. (B) Next connect a potentiometer, or a decade resistance box R, in series with the source voltage, and adjust the value of the resistance to reduce the deflection to one-half. The value of this resistance is then equal to the value of the input resistance of the scope. (C) To measure the overall input capacitance of the scope, first connect the vertical-input terminals through the direct-probe and cable to a source of a-c voltage which has a frequency of approximately 0.25 mc. Note the amount of deflection which is obtained on the scope screen. (D) Next, connect an adjustable series capacitor, C, (or different fixed capacitors of known values) between the scope cable and the source of 0.25-mc a-c voltage, and adjust this capacitance value to reduce the deflection to one-half. The value of this capacitance is then equal to the value of the overall input capacitance of the scope and cable.

(A) (B)

Fig. 5-5. (A) External appearance of a low-capacitance type scope probe provided with its own shielded cable and terminals. (B) A separable type of low-capacitance probe designed to be slipped on to the standard direct probe (with cable) employed for several models of this manufacturer's scopes. *(A) Courtesy: Hickok Elect. Inst. Co. (B) Courtesy: RCA*

It is evident that the overall input resistance *R2*, and capacitance *C2* of a scope should be known if a low-capacitance probe is to be designed especially for it. The value of the input resistance is especially important, because the probe resistors employed usually are of the fixed type. Since the probe capacitor is the adjustable type, some leeway is allowable in the size of the adjustable capacitor that is needed.

In some cases, the input resistance and capacitance of the scope are unknown. To measure them, proceed as shown in Fig. 5-4. The determination is quite simple, provided a supply of resistors and capacitors of known and proper values is at hand.

The low-capacitance probe must be well designed to reduce to a minimum all stray capacitance between the probe tip and all components and circuit wiring on the scope side of series capacitor *C1*, otherwise the required low value of probe input capacitance will not be realized. An exploded view of this type of probe is illustrated in Fig. 5-3C to show the typical construction.

Many of the manufacturers of service-type oscilloscopes provide a low-capacitance probe with their instruments, or make them available separately. Some are provided with their own shielded cable and terminals, as shown in Fig. 5-5A. Another arrangement, illustrated in Fig. 5-5B, employs the separable type of construction. The low-capacitance probe shown in the foreground here is designed to be slipped onto the standard direct probe with the cable (at the left) that has been designed specifically for use with the oscilloscope. The ground cable with its alligator clip appears at the right.

5-3. Scope-Attenuator Factors Affecting Overall Frequency Response When Low-Capacitance Probe is Used

There is more than meets the eye in the operation of a low-capacitance probe in conjunction with the input circuit of a scope, even when the scope employs the conventional frequency-compensated step attenuator in its input circuit, especially where the high-frequency response of the combination is concerned. Practical experience in the use of low-capacitance probes with scopes soon teaches the technician that hidden factors are often at work in many service scopes, which not only cause peak-to-peak voltages to be indicated incor-

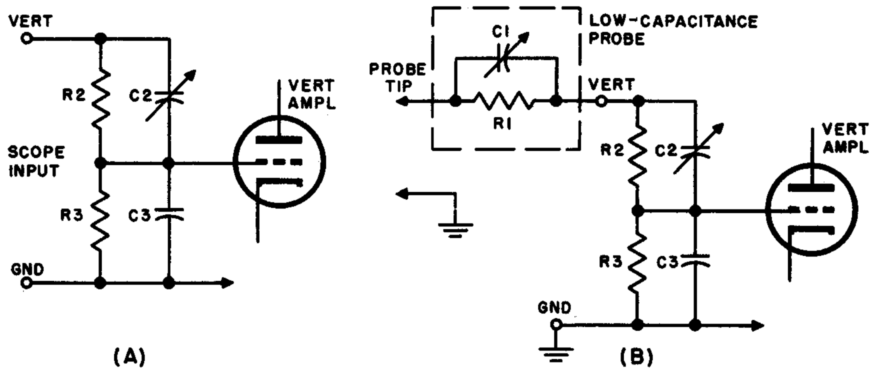


Fig. 5-6. (A) Typical circuit arrangement for one step of a simple frequency-compensated step attenuator in a service-type scope. C2 and C3 are the frequency-compensating trimmer capacitance (in the scope) plus the fixed and stray capacitances of the scope input circuit. The values of C2 and C3 used in each step of the attenuator are different. (B) When a 10-to-1 low-capacitance probe is applied ahead of the scope attenuator, the problem becomes somewhat complicated, and several factors must be taken into consideration if correct operation is anticipated. In practice, it is customary to make R1 = 9 (R2 + R3), since this relationship provides a basic probe attenuation factor of 10. However, the technician must remember that a commercial scope usually contains *three,* and sometimes *four,* individual attenuator steps, and these are to be accommodated by the probe. It may well be that a *different* value of *C1* will be required for use with each step, as explained in the accompanying text.

rectly when high-frequency signals of 1, 2, or 3 mc or over are under measurement with the probe, but which often cause the high-frequency response to be unequal to the low-frequency response, thereby distorting the waveform display on the scope screen.

Fortunately, this important matter may be very simply illustrated and clarified by first considering the response of the combination at very low frequencies, and then considering the response at high frequencies, and finally comparing the two responses. The reader will recall that a standard service scope input system often comprises a frequency-compensated 3-step attenuator. The typical circuit arrangement that exists for each individual step of such an attenuator is shown in Fig. 5-6A. Capacitor *C2,* an internal trimmer within the scope, is used for frequency compensation, and *C3* represents a fixed capacitor as well as circuit stray capacitance in the scope. These capacitances along with resistors *R2* and *R3* provide the required attenuation and avoid distortion in the reproduced waveform. This is a simple situation, and requires only that the product $R2 \times C2$ equal the product $R3 \times C3$. When the two time constants are made equal, no waveform distortion due to attenuator operation occurs in the reproduced pattern.

A somewhat obscure difficulty is encountered by the technician using a low-capacitance probe in combination with such a compensated attenuator, if the attenuator in his scope was *not* originally designed for use with this type of probe. This circuit, with the probe connected, is indicated in Fig. 5-6B, and a simplified explanation is given in the following paragraphs, along with the re-

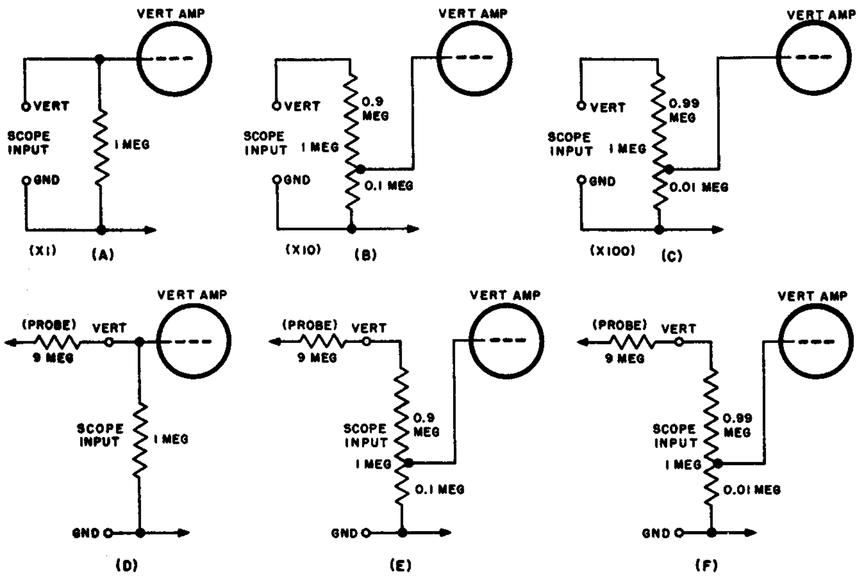


Fig. 5-7. The actions which take place in the scope attenuator at low-frequencies present no difficulty. At these frequencies, attenuation depends solely upon the values of the resistors in the attenuator circuit, and for this portion of the discussion, the capacitors may be properly neglected. They are omitted here. (A) Attenuator circuit when the gain selector switch is set for highest sensitivity (XI). The full voltage applied between the Vert and Gnd terminals of the scope is applied to the grid of the vertical-amplifier tube. (B) Attenuator circuit for X10) position of Gain selector. It is clear that only 0.1 of the voltage applied between the Vert and Gnd terminals of the scope is being imposed on the grid of the vertical amplifier tube, so that 10-to-1 attenuation results. (C) Attenuator circuit (for low-frequencies) for X100 position of Gain selector. Only 0.01 of the voltage applied between the Vert and Gnd terminals of the scope is being impressed upon the grid of the vertical amplifier tube, so that 100-to-1 attenuation results. (D) A typical 10-to-1 low-capacitance probe, with shunting capacitor neglected, provides 10-to-1 attenuation of low frequencies when the probe resistance has 9 times the value of the attenuator resistance, as shown. The step attenuator of the scope is here set for the most sensitive (X1) position. (E) This arrangement is similar to that of (D) but the step attenuator has now been set for 10-to-1 attenuation. The probe provides an additional 10-to-1 attenuation, so that the total attenuation is 100-to-1. Thus far, operation is evidently simple, and the attenuation factor is strictly correct. Of course, only low frequencies are under consideration here. (F) The step attenuator has now been set for 100-to-1 attenuation. The probe provides an additional 10-to-1 attenuation, making the total attenuation 1,000-to-1. As long as we restrict the Ohm's Law analysis to low freauencies only. the attenuation factor is still strictly correct.

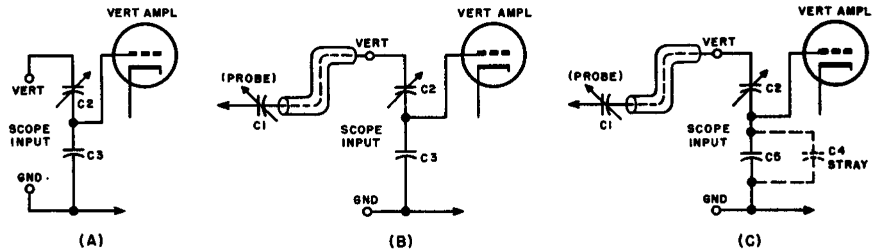


Fig. 5-8. Analysis of the action of the low-capacitance probe and scope-attenuator circuit combination at high frequencies. In some scopes the stray capacitance C4, and designs of the step attenuator, introduce difficulties which make it impossible to equalize the time constant of the low-capacitance probe to that of the overall input circuit of the scope for more than one setting of the attenuator (see text). In such cases, the frequency response of the combination suffers whenever the scope attenuator must be set at some other position.

quirements for obtaining satisfactory operation of a scope attenuator with the probe. It will be discovered that it is necessary, but not sufficient, that the time constant of the probe be made equal to the time constant of the scope attenuator. It is easily proven that certain relations are also required between the various capacitors.

This discussion can be simplified if the actions which take place for low frequencies, and for high frequencies, are considered separately. The low-frequency actions are illustrated in Fig. 5-7, and are explained in the caption. It can be seen that the operation of the attenuator and probe is quite straightforward, without any lurking "bugs" to complicate matters.

Let us next consider the actions which take place for high frequencies. In the high-frequency case, the attenuator resistance can be ignored since it is the relative values of the *capacitances* in each "step" circuit of the attenuator that determine the attenuation factor which apply for each position of the Gain selector. This is true because the reactances of the various capacitors are considerably lower at high frequencies than the resistances of the resistors which they shunt. Accordingly, for high-frequency study, the typical circuit arrangement in Fig. 5-6A which exists for each "attenuating" position of the Gain selector switch may be redrawn as in Fig. 5-8A to avoid the complicating presence of the attenuator resistances. For the *X10* position, *C3* is made 9 times as large as *C1* so that 0.1 of the applied high-frequency voltage is impressed upon the grid of the vertical input tube. The attenuation factor is therefore 10-to-1. For the *X100* position, *C3* is made 99 times as large as *C2*.

A low-capacitance probe is shown connected to the scope input in Fig. 5-8B. Since the high-frequency response of the probe is determined mainly by the capacitance, *C1*, in the probe, the probe resistance is omitted here for simplicity. If the probe is designed so that the value of *C1* is made equal to 1/9 the value of the over-all input capacitance of the scope (including the cable), the probe itself will then introduce an attenuation factor of 10-to-1. If the scope Gain selector were also set for 10-to-1 attenuation, the total attenuation factor of the probe and scope would be $10 \times 10 = 100$-to-1. This much is straightforward and uncomplicated. We would need to proceed no further with such considerations, *provided* there were only one step in the attenuator. However, such attenuators usually contain several steps, each employing capacitances of different values. The reasons why trouble is often encountered when a low-capacitance probe is used with scopes that employ simpler types of step attenuators will now be considered.

The capacitances *C2* and *C3* in Fig. 5-8A and B are the total capacitances existing in the respective branches of the circuit, and they include all of the stray capacitances. The circuit of Fig. 5-8B is redrawn in part C of the same figure to show for any one step, the stray capacitance *C4* which together with *C5* equals *C3* in Fig. 5-8B. Of course, other stray capacitances also exist in the circuit, but *C4* is the most important one for our study here. It can be seen that for each "step" setting of the scope Gain control, the values of *C2* or *C5* which must be used so that the attenuation factor will be the correct value designated for that step, are dependent upon the value of stray capacitance *C4* which exists for the particular physical circuit arrangement employed for that step.

If the scope attenuator had only one step, there would be no problem, because we would simply adjust the probe capacitance *C1* to the value required to produce the desired 10-to-1 probe attenuation factor when used in combination with the particular values of scope cable capacitance, *C2* and *C5* plus *C4*, that happened to exist in the scope input circuit. However, in actual scope attenuators we have several steps in the Coarse attenuator to contend with. Since the circuitry for each step largely contains a separate and different physical arrangement of components and wiring, a different value of stray capacitance *C4* exists for each step.

If the value of *C5* in each step could be adjusted to correct for the value of *C4* in that step, in conformity with the value in other steps, there would be no problem. But the technician will find that service scopes usually make no provision for correcting for the value of *C4* in this way. In fact, in the simpler attenuators *C5* is omitted entirely and capacitance *C3* consists wholly of the stray capacitance *C4* only. This is not a matter of concern in the general use of the scope when no probe is being used, because the high-frequency attenuation factor for each step may be adjusted to the correct value by attaining the required *C2*/*C3* capacitance ratio through adjustment of *C2* in that step (*C2* is always made adjustable for this purpose). Unfortunately, scopes that are designed so that adjustment of the attenuation produced by each step is achieved in this all-too-convenient manner usually exhibit a somewhat different scope input capacitance for each setting of the Gain selector. Because of this, when it is attempted to use a low-capacitance probe with such a scope, it is usually found impossible to equalize the time constant of the probe with that of the scope input circuit for more than any one setting of the scope Gain selector, because the different input capacitance of the scope at each Gain selector setting makes a different value of probe capacitance necessary. Frequency discrimination therefore results for all scope Gain selector settings at which the probe-scope equalization is poor. It is only a matter of chance if it is found that one probe-capacitor setting is exactly satisfactory on other than just one step setting of the attenuator. Of course, the probe can be adjusted correctly for one particular setting of the Gain control and used thereafter only with that scope setting, but this is a disadvantage in test work.

This difficulty can be overcome *in the scope design* by providing capacitor *C5*, in each step of the attenuator, and making it adjustable so that different values of *C4* in each step can be compensated.

However, for practical work, it is not necessarily required that *C5* be made adjustable. There is a "brute-force" design method utilized, in which capacitance *C2* and *C5* in each step are of the proper ratio, but they are chosen sufficiently large enough so that normal variations in the value of *C4* from step to step, due to lead dress, etc., can be disregarded. One advantage to this method is that the compensator requires no attention when the vertical-amplifier tube is changed. But there is also a disadvantage in that the value of the input impedance of the scope is somewhat lower at the high frequencies than would otherwise be the case. However, one of these two methods, or some other suitable one, *must* be used in the scope design to avoid this trouble when a low-capacitance probe is used.

5-4. Voltage Attenuation in the Low-Capacitance Probe

The attenuation of the input signal which accompanies the corresponding desirable increase in the input circuit impedance, is one of the features of the low-capacitance probe that is undesirable in some applications, but is actually required in others. It means that unless a special amplifier arrangement such as that described in Sec. 5-6 is employed with the probe, the low-capacitance probe can be used only in circuits which have sufficient signal strength so that even after the voltage attenuation caused by the probe occurs, there is sufficient signal voltage left to produce a trace of usable size on the scope screen if the gain control of the scope is advanced to the maximum-gain position. Most conventional service-type scopes have a vertical-deflection sensitivity of approximately 0.02 volt rms, or 0.057 volts p-p, per inch at full gain. When a 10-to-1 low-capacitance probe is used with such a scope, 1 inch of deflection will be produced by a 0.2-volt rms, or a 0.57-volt p-p signal applied to the probe. If the signal voltage is less than this, the trace will probably be too small for accurate waveform study or p-p voltage check.

Thus, in tv service work, the 10-to-1 low-capacitance probe is generally used in waveform and p-p voltage checking in the high-impedance sync, video-amplifier output, sweep and horizontal-deflection coil circuits because these circuits provide adequate signal voltage for the use of this probe with the scope. It is often found that when the conventional 10-to-1 probe is used with a wide-band type scope, only the strongest signals can be observed on the scope because such scopes usually have comparatively low gain as a result of the special design by which their extended frequency response is achieved.

The attenuation of the input signal by a low-capacitance probe is a desirable characteristic whenever the probe is to be used with a scope for checking high-impedance circuits where the voltage exceeds the input voltage at which the scope vertical amplifier begins to distort the signal (usually around 400 volts ac rms), since it helps to reduce the voltage to a value below this limit. An example of this is furnished by the deflection-coil circuit of a tv receiver, where a p-p voltage of approximately 1,500 volts is usually present.

It will be recognized that there is a basic electrical similarity between the low-capacitance probe (which is a compensated probe) and the uncompensated capacitance-divider type of high-voltage probe discussed in Chapter 2, because the capacitance divider action present in each of them results in a voltage stepdown. However, the latter type of probe is designed specifically to produce voltage stepdown, and its design is aimed at enabling it to safely withstand high voltages so that it may be used in high-voltage circuits, such as the horizontal output circuits of tv receivers. The accompanying impedance step-up that is achieved is incidental, although it is advantageous in some tests (see Sec. 2-7). The conventional low-capacitance probe is usually designed with a maximum voltage rating of only 1,000 to 2,000 volts p-p, and it must be used only in those medium-voltage a-c circuits whose voltage does not exceed this rating (see also Sec. 5-7).

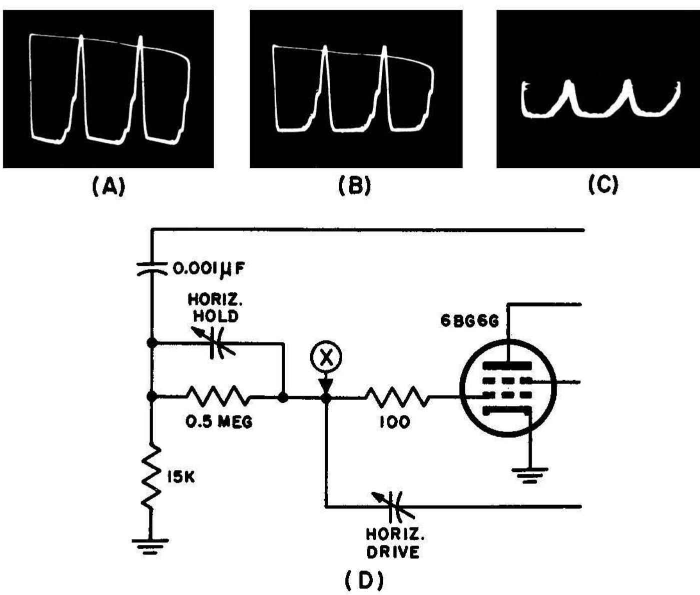


Fig. 5-9. Examples of the circuit-loading effects caused by three different types of probes used with a scope for checking the waveform and p-p value of the drive voltage to the grid of the horizontal-output tube in the self-oscillatory sweep circuit of a tv receiver. The checks were made at test point X in the circuit shown in (D). (A) The displayed waveform when a 100-to-1 low-capacitance probe is used; 166 volts (p-p) is indicated by the calibrated scope scale. (B) Waveform display obatined when a 10-to-1 low-capacitance probe is used instead (scope attenuator setting reduced); peak-to-peak value of displayed waveform is now only 140 volts, due to increased loading of the circuit under test. (C) Waveform display obtained when a direct probe is used (with scope attenuator setting reduced again); waveform now measures only 60 volts peak-to-peak, due to severe circuit loading. A voltage check made with a peak-to-peak vtvm indicates only 55 p-p volts because of the circuit loading imposed by its built-in rectifying network. It can be seen that only the 100-to-1 low-capacitance probe provides sufficiently light loading for an accurate waveform and p-p voltage check in this critical high-impedance circuit.

5-5. The 100-to-1 Low-Capacitance Probe and its Uses in Checking Critical High-Impedance Circuits That Are Loaded by a 10-to-1 Probe

We have seen how a 10-to-1 low-capacitance probe reduces the effective overall input capacitance of a scope by a factor of 10, so that if this input capacitance is, say 75 $\mu\mu$f, the use of a 10-to-1 probe with the scope will reduce this to an effective input capacitance of only 7.5 $\mu\mu$f.

However, there are some pulse and tv waveform circuits (for example, the horizontal sync-control circuits, and the ringing coil in the horizontal blocking-oscillator circuit) which are of sufficiently high impedance, or are critically resonant, so that they are adversely disturbed even by a shunting capacitance of only 7.5 $\mu\mu$f. An actual example of this is illustrated in Fig. 5-9.

When the waveform or the p-p voltage in such circuits must be checked by means of a scope, it is advantageous to use a low-capacitance probe of higher ratio, such as 50-to-1, or 100-to-1, which cuts down the over-all input capacitance of the scope to 1/50, or 1/100, of its normal initial value. Thus, if the scope has 75 $\mu\mu$f of overall input capacitance, the use of a 100-to-1 low-capacitance probe will reduce this to only 0.75 $\mu\mu$f. In order to achieve the 100-to-1 capacitance ratio, the series capacitance in the probe must be made equal to only 1/99 of the overall capacitance of the scope input system. This calls for careful design of the probe. The stray capacitance between the probe tip and other parts of the circuit must be kept at a minimum.

The 100-to-1 probe multiplies the effective impedance of the input circuit by a factor of 100, and correspondingly attenuates the signal by a factor of 100-to-1. Although the voltage-attenuation factor of 100 is too extreme for purposes of general circuit testing, it is usually found that considerable p-p voltage is available at high-impedance points in sync-control systems, so that over 2 volts p-p for a trace of adequate size is still available for application to the scope after the 100-to-1 attenuation by the probe. The compensated construction assures the absence of frequency distortion within the probe at any frequency within the normal response range of the scope.

The construction details of a 100-to-1 low-capacitance probe are shown in Fig. 5-10. The probe capacitor, *C1*, should be adjustable, and is adjusted upon the basis of a square-wave test (see Sec. 5-8).

Because the attenuation of the 100-to-1 probe is considerable, the scope must ordinarily be operated at high gain during most tests with it. If the scope has a maximum sensitivity of 0.02 volt rms per inch, its effective sensitivity is reduced to 2 volts rms per inch when the probe is used. Another solution is to employ a specially-designed amplifier with the probe, as explained in Sec. 5-6.

5-6. Use of Amplifier with High-Ratio Low-Capacitance Probes

The appreciable voltage attenuation which results when a 50-to-1, or a 100-to-1, low-capacitance probe is employed is a distinct disadvantage when using such probes in those circuits where the voltage under test is not sufficiently high to produce a scope trace of adequate size for accurate waveform study or measurement. This is especially true when a wide-band type scope is used, for such scopes have a comparatively low gain as a result of their extended fre-

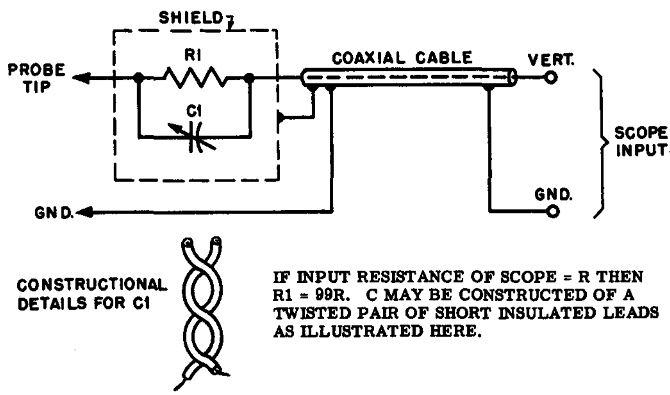


Fig. 5-10. A low-capacitance probe may be designed to produce an impedance step-up of 100 times, as shown in the diagram here. The small capacitor, C1, which has a value equal to approximately 1/99 of the value of the overall scope input capacitance, is adjusted experimentally for best square-wave response of the probe and scope at both 60 cps and at 10 or 15 kc. Because of the high impedance step-up, the 100-to-1 probe is very susceptible to hand capacitance and stray-field pick-up; thus the head of the probe must be of shielded construction. The components should be adequately spaced away from the shield walls of the probe head to avoid excessive stray capacitance from this source, which would result in lowered input impedance.

quency response. As a result, engineering interpretation of the observed signal, with its unavoidable guesswork, is often required. However, some high-impedance or resonant high-frequency circuits encountered in electronic devices are so critical that an extremely low value of input capacitance made possible in a well-designed high-ratio low-capacitance probe is absolutely essential when examining pulse and other type waveforms.

The obvious solution to this problem is to offset the high probe attenuation by means of an especially designed wide-band amplifier so that the overall insertion loss of the two may be reduced to zero. An amplifier for this purpose, designed to be used with the specially constructed probe shown in the foreground at the left, is illustrated in Fig. 5-11.

The circuit details are shown in Fig. 5-12 and are explained in the caption. In general, whenever the amplitude of the test signal is unknown, it is advisable to first operate the probe amplifier at *X0.01* gain setting and the oscilloscope at maximum gain when an amplifier of this type is used, permitting any overloads to occur in the oscilloscope where they are more easily recognized. If insufficient deflection is obtained, the step attenuator of the probe amplifier may then be turned to *X0.1* or *X1* to increase the signal input to the scope.

The extremely low input capacitance realized with the probe employed with this amplifier results from a unique method of utilizing the stray capacitances that are inherent in a low-capacitance probe. The construction, illustrated in Fig. 5-13, is of technical interest. Observe that it is the type of low-capacitance probe shown in Fig. 5-2; it contains no d-c path to ground through the probe itself. The use of a shield around the probe tip lead is necessary to

Fig. 5-11. Special amplifier for use with the high ratio (40-to-1) low-capacitance probe shown at the lower left, so that the practical advantages of the extremely low input capacitance of the probe (1.5 to 2 $\mu\mu$f) may be realized without the customary penalty of signal attenuation. The adjustable overall insertion loss of the probe and amplifier combination may be reduced to zero. See Fig. 5-12 for schematic circuit diagram. Construction details of the special probe are shown in Fig. 5-13. *Courtesy: Linear Equipment Laboratories, Inc.*

avoid excessive hum voltage pickup, since this will be amplified by the probe-amplifier and the scope amplifier. The application of conventional shielding here would result in a very undesirable increase in the stray capacitance across the probe input circuit. To avoid this, such stray capacitance is greatly reduced by the unique construction shown, in which the series capacitance, $C1$, of the probe is formed by the shielding around the input lead. The greatest portion of the stray capacitance is shunted in parallel with the overall cable capacitance which is large in any case as compared with $C1$. The probe is small and compact, permitting access to miniaturized circuitry. An insulating sleeve is supplied as standard equipment, and where an absolute minimum of circuit loading is desired, the hooked probe tip may be unscrewed and the exposed button used for the input contact to the circuit under test. A special semi-air spaced low-capacitance cable is used for all interconnections, together with standard uhf connectors.

This type of probe and amplifier combination is particularly useful for the examination of waveforms in critical high-impedance and resonant high-frequency circuits in color tv equipment.

5-7. Maximum Test-Voltage Limitations of Low-Capacitance Probes

The conventional 10-to-1 low-capacitance probe is usually designed with a maximum voltage rating of less than 1,000 to 2,000 volts p-p, or dc. However, a probe having such a limited voltage rating can be adapted for use in the testing of low- and medium-voltage a-c circuits which have a high d-c voltage component present, by adding a high-voltage blocking capacitor in series with the probe tip. For example, if it is desired to use a conventional 10-to-1 low-capacitance probe to check the ripple in the output from the high-voltage filter of a tv receiver, a 500-$\mu\mu$f 20,000-volt blocking capacitor can be used to advantage in series with the probe to avoid breakdown due to the high d-c voltage component which is

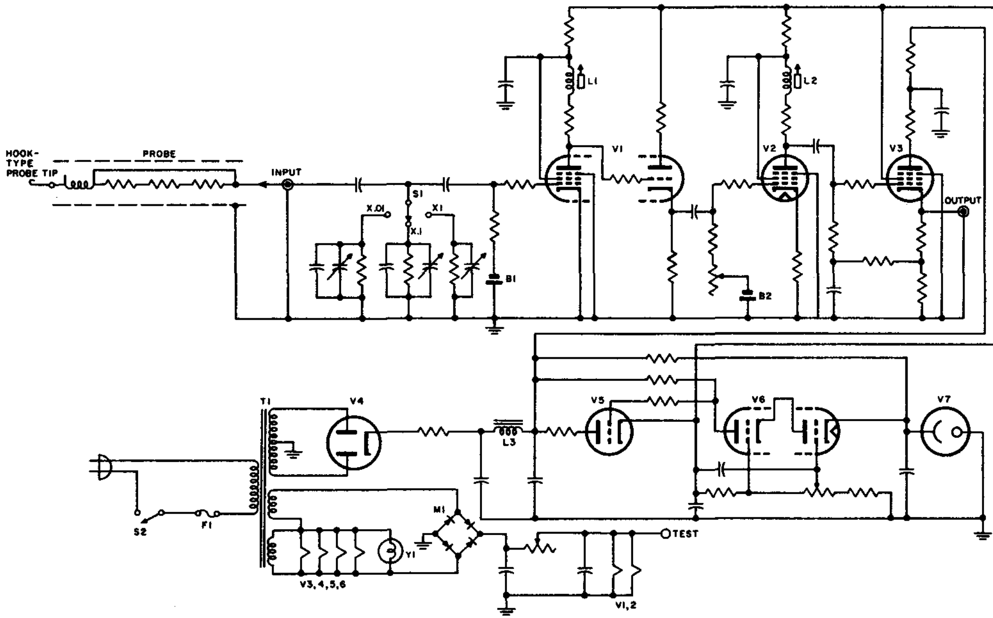
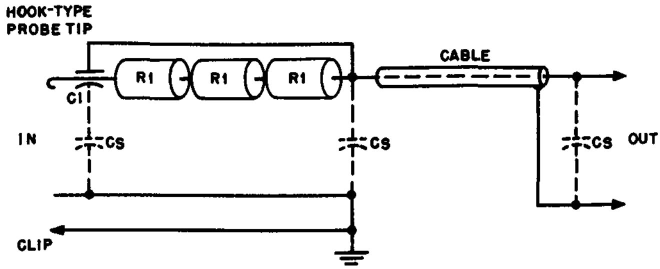


Fig. 5-12. Schematic circuit diagram of the special video amplifier illustrated in Fig. 5-11. In order to avoid any deterioration of the signal under observation, this amplifier is designed to have a band width in excess of that of most scopes on the market. In addition, it must have very low noise and hum level so that it can be run wide open when connected to the input of a high-gain scope without causing the trace to bounce around or become distorted. To achieve this, d-c is used on the heaters of the amplifier tubes. For stability, a fully-regulated B supply is employed to prevent jitter due to line-voltage surges. Two stages of voltage amplification drive a cathode follower output stage. All circuits are carefully adjusted for wide bandwidth, fast rise time, and good transient response. The dynamic output impedance is approximately 60 ohms, and the maximum undistorted output 3 volts rms. The input voltage range can be selected by a three-position switch. Signals up to 150 volts rms can be applied to the probe without overload. Input impedance on all ranges is 4.5 megohms shunted by 1.5 $\mu\mu$f. Excellent response from 5 cycles to 12 mc within 3 db is obtained. *Courtesy: Linear Equipment Laboratories, Inc.*



R1, R2 = 1.5 MEG, 1/3 W, 5%
Cs = STRAY CAPACITANCES

Fig. 5-13. Construction details of the special 40-to-1 low-capacitance probe shown at the lower left of Fig. 5-11. *Courtesy: Linear Equipment Labortories, Inc.*

present. If the low-capacitance probe is rated to withstand the ripple voltage which is present, the arrangement is satisfactory, provided proper precautions are taken when handling the probe.

Some commercial low-capacitance probes provide a 1,500-volt blocking capacitor within the probe housing. If higher d-c voltages must be withstood in certain applications, the technician can provide an additional external blocking capacitor, such as a 20,000-volt filter capacitor.

On the other hand, if the low-capacitance probe is to be used to test a circuit where the a-c voltage exceeds the rating of the probe, no advantage will be afforded by the use of the blocking capacitor, since the full a-c voltage will be applied to the probe as though the blocking capacitor were not present.

5-8. Check and Adjustment of the Time Constant and Frequency Response of the Low-Capacitance Probe

In order to use any low-capacitance probe with a minimum of distortion it is necessary to adjust the value of its series capacitor so that the time constant of the probe will be made equal to that of the over-all scope input circuit (including the cable) (see Sec. 5-2), i.e., so that $R1 \times C1 = R2 \times C2$. This adjustment is accomplished by applying a square-wave signal to the probe, and displaying the output on the particular scope which is to be used with the probe. A square-wave signal is employed because it contains the necessary range of low-, middle-, and high-frequency components for whose frequencies equalization needs to be effected. A square-wave generator having a fast rise time, negligible overshoot, and a frequency range which includes about 30 cycles, and 15 kc should be employed. The adjustment procedure is quite simple, and is as follows:

(1) Set up the square-wave generator to deliver a frequency of about 30 or 60 cycles, and feed its output to the vertical input terminals of the scope, as shown in Fig. 5-14A. Adjust the scope controls to provide a square-wave trace of two or three cycles and convenient amplitude on the screen. This test provides a check of the square-wave output of the generator and/or the frequency response of the scope. The latter is important, for the probe cannot compensate for limitations in the frequency response of the vertical amplifier system of the scope.

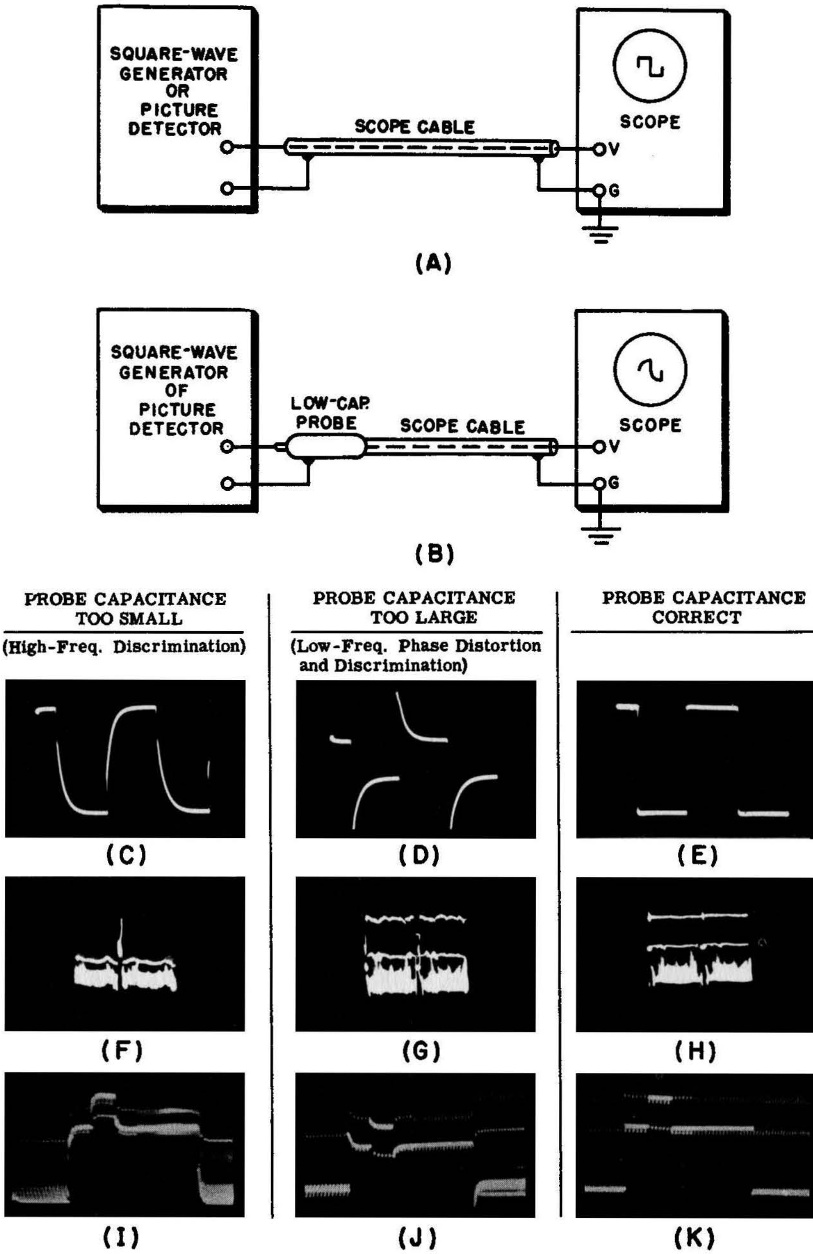


Fig. 5-14. (A), (B) Instrument setups for the two steps in adjusting the series capacitor of a low-capacitance probe to equalize the time constant of the probe to that of the overall input circuit of the scope and cable with which it is to be used. A square-wave signal is employed, and the best compromise adjustment is made for minimum distortion of the square wave as seen on the scope screen. (C), (D), (E) illustrate the types of trace produced for various adjustments of the series capacitor in the probe. (F) through (K) are obtained when a tv signal is employed rather than a square-wave generator.

(2) Now connect the low-capacitance probe output terminals to the vertical input terminals of the scope; if the probe is of the separable type, slip it on to the direct probe and cable instead (see Fig. 5-5). Connect the output of the square-wave generator to the probe input as shown in Fig. 5-14B. Increase the signal amplitude by adjusting the generator output. If the square wave obtained is now distorted as compared to the square wave previously observed, the response of the probe may be corrected by adjusting its series capacitor (by means of an insulated screwdriver) until the square wave most closely approximates the original (see Fig. 5-14C, D, E). Access to the adjustment screw of the capacitor is usually obtained through a hole in the probe or by unscrewing the probe tip from the front of the probe. If the observed waveform is considerably rounded on its leading edge, as illustrated in Fig. 5-14C, the presence of high-frequency discrimination is indicated and the capacitance must be increased by turning the adjustment screw clockwise. If the waveform is considerably pointed, as shown in Fig. 5-14D, low-frequency phase distortion and discrimination is indicated and the capacitance must be decreased by turning the adjustment screw counterclockwise.

(3) Steps (1) and (2) should now be repeated at a higher repetition rate by employing a 10- to 15-kc square-wave signal. A slight compromise adjustment of the capacitor may be found necessary and can usually be effected.

The method of checking and adjusting the square-wave frequency response of a low-capacitance probe and amplifier combination such as are described in Sec. 5-6 differs in some details from the foregoing description, and is fully described in the operating instructions accompanying the instrument.

In case a suitable square-wave generator is not available, a tv receiver known to be in good working order may be used instead. Apply the probe to either the grid terminal of the picture tube, or the video detector stage. Set the scope for displaying the composite video signal, and adjust the probe capacitor so that the amplitude of the horizontal and of the vertical sync pulses are equal. As an independent check, the scope sweep can be speeded up to the picture line rate (15,750 cps), and the horizontal sync pulse observed for rounding and tilt.

Parts F, G, and H of Fig. 5-14 show the effect of probe capacitance adjustment when a tv signal is used. In this case, the low-capacitance probe was connected to the load of the video detector and the scope was adjusted to a sweep frequency of one-half the vertical frequency. With the probe capacitance too small, the vertical-sync signal protrudes out of the video signal and the horizontal-sync pulses are highly attenuated (see part F). With the probe capacitance too large, vertical-sync pulses are compressed and video signals and horizontal-sync pulses are exaggerated, as shown in part G of the figure. When the probe capacitance is properly adjusted, the tips of the horizontal-sync pulses (appearing as the light horizontal line above the video-signal portion of the waveform) are lined up properly with respect to the vertical-sync pulses (see part H of the figure). An even clearer representation of these effects is shown in parts I, J, and K respectively, when a 60-cycle sine-wave sweep is employed to stretch out the waveform display. Note the similarity of these effects to the square-wave traces in parts C, D, and E of the figure.

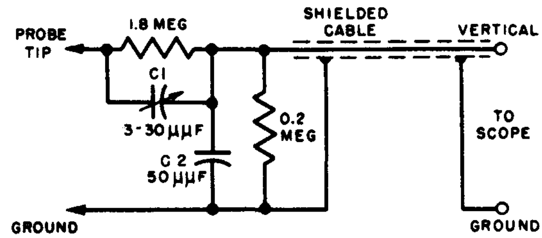


Fig. 5-15. Brute-force type 10-to-1 low capacitance probe that may serve two or more different scopes without need for readjustment of the probe components.

Once the probe has been adjusted for proper operation with a certain scope and cable, it should be used only with that instrument and cable; it must be readjusted if used with any other instrument and cable. In fact, when used with some scopes, it may be necessary to readjust the probe if the scope Gain selector setting is changed from that employed when the original adjustment of the probe was made. This is discussed in detail in Sec. 5-3.

5-9. Brute-Force, 10-to-1 Low-Capacitance Probe for Two or More Scopes

It is occasionally desired to make one low-capacitance probe serve two or more scopes. This can be done so that no readjustment of the probe components will be required, by using the brute-force circuit shown in Fig. 5-15. This probe offers a useful increase in impedance over a direct-cable connection.

A 4-foot length of conventional RG-59/U coaxial cable having a nominal capacitance of 21 μμf per foot is used. This provides considerable input capacitance to the scope, which is increased about 50 percent by the use of the shunt 50-μμf capacitor, *C2*. This capacitor is added so that the trimmer, *C1*, may effect proper compensation. The input resistance of the scope is also "swamped" by the use of a 0.25-meg shunt resistor. Accordingly, the attenuation ratio of the probe will remain 10-to-1, within practical limits, no matter what conventional service-type scope is used with the probe. Also, once trimmer *C1* has been adjusted for good square-wave response with one scope (see Sec. 5-8), it will not ordinarily require readjustment when the probe is used with other scopes.

5-10. Low-Capacitance Probe Applications and Practical Operating Hints

Low-capacitance probes are ordinarily used in conjunction with scopes during tests made in any audio, video, sweep or sync circuits (see Fig. 5-16), in which the normal capacitance of the scope input system would detune resonant circuits, or in which the normal current drain imposed by the scope input system (chiefly capacitive shunt current) would be sufficient to noticeably load the circuit under test and thereby produce phase shift and high-frequency attenuation, with resultant waveform distortion—provided that the voltage of the circuit under test does not exceed the maximum-voltage rating of the probe.

Although there is no waveform distortion encountered with a low-capacitance probe whose time constant is properly adjusted to be equal to that of the overall scope input circuit (see Sec. 5-8), its input impedance is not constant. As shown in Fig. 5-17, the impedance decreases somewhat through the audio-fre-

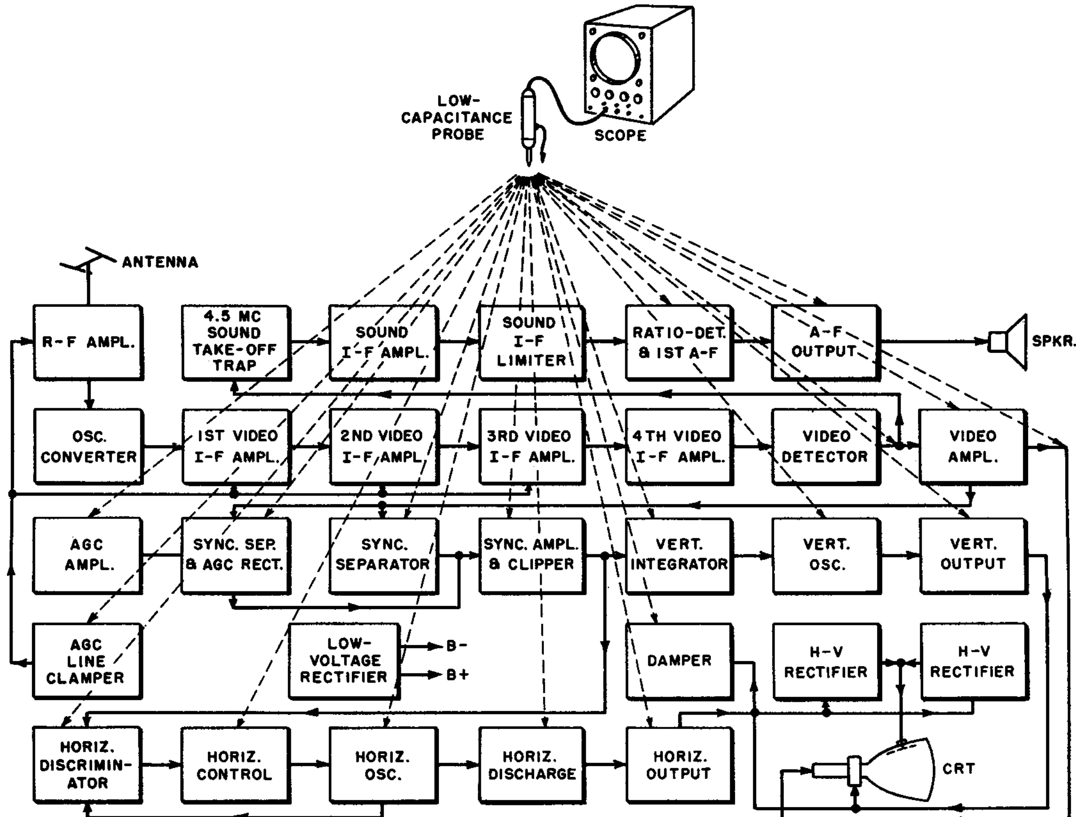


Fig. 5-16. Applications of the low-capacitance probe, used in conjunction with a scope, for waveform checks and p-p voltage measurements in a tv receiver.

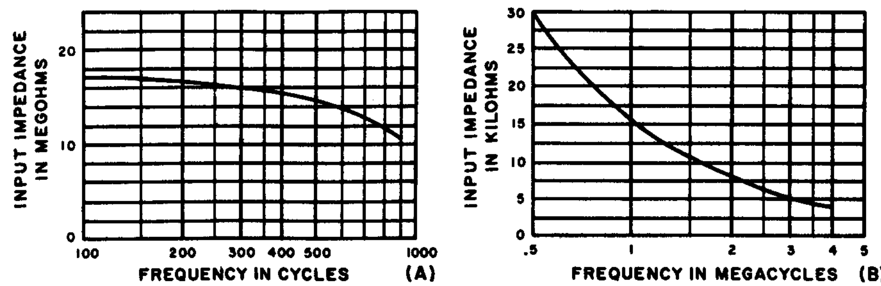


Fig. 5-17. How the input impedance of a typical low-capacitance probe decreases as the frequency increases through the audio-frequency and radio-frequency ranges up to video frequency (4 mc).

quency range, although it is still extremely high (see part A). In the radio-frequency range, the input impedance falls rapidly, as shown in Fig. 5-17B. At low audio frequencies the input impedance may be 15 or 20 megohms in some cases, but at the upper end of the video-frequency range (4 mc), it has decreased to approximately only 4,000 ohms or less. Although the latter may seem to be a very great decrease in input impedance, it must also be remembered that this amount of impedance is 8 times the 500-ohm input impedance which would be presented, at this frequency, by a service scope and direct cable whose overall input capacitance is 70 $\mu\mu$f. Higher input impedance at the higher frequencies may be obtained in scope tests that require it, by the use of a cathode-follower probe (see Sec. 5-11).

It should be recognized that the phase characteristics and the normal frequency range of a well-designed 10-to-1 low-capacitance probe far exceed those of most service-type scopes used by tv technicians, so it may be used at 60 cps, 15.75 kc, or 4 mc with equal facility. Accordingly, any distortion resulting at the higher frequencies will usually be localized to the vertical input and amplifier section of the scope rather than to the probe, or in the inability to equalize the time constant of the probe with that of the scope input circuit for all settings of the scope Gain selector.

(1) Use of Low-Capacitance Probe at Video Detector Output. When a scope is connected to the output of the video detector to display the composite video signal at that point, a low-capacitance probe should be used with it. Should the technician make an error and utilize another type of probe at this point, a highly distorted version of the waveform would probably be observed.

Unless a low-capacitance probe is used at the output of the video detector when checking the square-wave response of the video i-f amplifier, the input capacitance of the scope and shielded input cable will be sufficient to seriously disturb the detector operation at the high video frequencies. Accordingly, the normal square-wave response will not be evident at higher test frequencies unless a low-capacitance probe is used.

(2) Video Amplifier Troubleshooting. Because of the wide band of frequencies handled by a video amplifier, care must be used to avoid changing its

response characteristics when an oscilloscope is applied to a circuit in it for test. Whenever possible, if the usable frequency range of the scope employed for the particular test is sufficient to make the use of a demodulator probe unnecessary (see Sec. 7-30), a low-capacitance probe should be used with the scope for video-amplifier signal tracing, because of the low input capacitance and consequent negligible loading of this probe. The effect of connecting a scope which adds considerable capacitance to the video amplifier circuits of a color tv receiver is especially important, since it may disrupt the operation of the circuit so drastically that color synchronization may be completely lost.

One important typical application of the low-capacitance probe is in the testing of video amplifiers by means of low-frequency (100-kc or 500-kc) square waves (one method of video-amplifier testing). Unless the scope is applied to the picture tube grid through a properly compensated low-capacitance probe in this test, the response of the video amplifier will appear to be faulty at the higher video frequencies, because the input capacitance of the scope will load the output circuit of the video amplifier abnormally, and will round off the test square wave considerably. Of course, the scope must have adequate video frequency response for this use. In fact, the scope must have a better response than the video amplifier under test. Accordingly, if the vertical amplifier of the scope has too limited a response, the next best procedure is to apply the output from the video amplifier directly to the deflection plates of the c-r tube in the scope. In either of these procedures, the socket should be removed from the base of the picture tube, in order to eliminate this source of additional capacitance across the output of the video amplifier during the square-wave test.

(3) *TV Sync-Circuit Signal Tracing.* A tv station signal is almost always used in tracing sync-circuit troubles, except in some very difficult trouble cases where no signal at all can get through. Although the frequencies in the various circuits under test in the sync circuits are well within the direct response range of the scope amplifier, some of the sync circuits have a sufficiently high impedance so that application of the over-all input capacitance of the scope directly to them seriously disturbs their operation. By using a low-capacitance probe with the scope, progress of the horizontal and vertical sync pulses can be followed from the video detector (or video amplifier on through the d-c restorer, sync separator and integrating network (see Fig. 5-16). The vertical pulse can then be checked on through to the vertical oscillator, graphically revealing the operation of the pulse in triggering the vertical oscillator. A check of the effectiveness of the reactance-tube circuit in controlling the operation of the horizontal sync discriminator is another useful application of the low-capacitance probe and scope.

The important function of the low-capacitance probe in sync-circuit tests is to help the scope to achieve the effective reproduction of the various pulse shapes *as they actually* exist in each circuit. Waveform distortion caused by application of the scope cannot be tolerated, because the entire system of troubleshooting here is based on checking the displayed waveforms for shape and amplitude in order to determine whether or not they meet the waveform and p-p voltage specifications set forth in the servicing instructions of the receiver manufacturer.

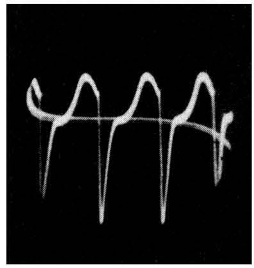
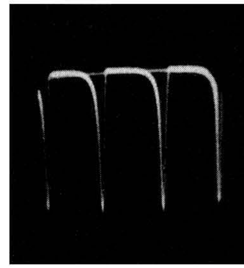



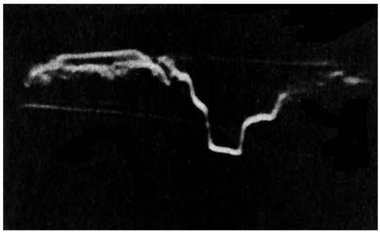
Fig. 5-18. (A) Waveform of the 1,300-volt signal appearing across the horizontal deflection coils of a tv receiver is distorted due to scope amplifier overload, when the direct probe and cable of the scope is applied to the test point. (B) The true waveform is obtained when a 10-to-1 low-capacitance probe is used. The probe attenuates the input voltage from 1,300 volts to 130 volts which the scope attenuator and amplifier are able to handle without overload.

(4) *TV Sweep Circuit Testing.* The grid of the vertical blocking oscillator is frequently a difficult test point, and is a good example of the application of the low-capacitance probe. The grid-leak in this circuit may have a value as high as 10 megohms. Furthermore, the waveform is sharply spiked, and the high-frequency content of the waveform is easily lost if a direct connection (or a direct probe) is used. However, the low-capacitance probe reduces the test capacitance applied across the circuit to 1/10 of the value imposed by a direct probe. As a result, the waveform displayed on the scope screen is essentially the true waveform, since the operation of the circuit is virtually undisturbed.

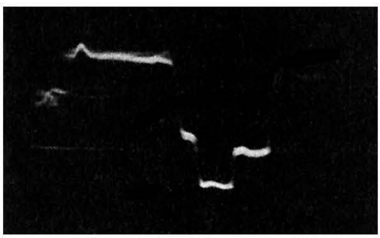
It should be noted that the high resistance of such circuits usually develops another source of difficulty, due to the fact that the input resistance of some low-capacitance probes (see Fig. 5-3A) causes excessive d-c bias voltage drain-off. Use of a blocking capacitor in series with the probe tip avoids this disturbance by preventing drain-off of the d-c bias voltage.

(5) *Use to Prevent Scope Overloading.* Although the chief function of the low-capacitance probe is to provide low input capacitance for scope applications and thus minimizing circuit loading and detuning effects, the 10-to-1 probe can also be used somewhat in tv troubleshooting procedures on the basis of its 10-to-1 voltage attenuation factor. In some tests, the peak-to-peak voltage may be a medium-high voltage which, even though not high enough to damage the scope input circuit, will cause the vertical amplifier of the scope to be overdriven, and the waveform developed on the scope screen will be distorted accordingly. Use of a 10-to-1 low-capacitance probe will attenuate such voltages down to the lower values which are well within the voltage-handling capability of the scope amplifier.

An example of overload of the vertical amplifier of the scope when a 10-to-1 attenuating probe is not used in a medium-high voltage circuit is shown in Fig. 5-18. In this case, the distorted waveform in Fig. 5-18A was observed when a service scope was applied directly across the horizontal-deflection coils in a tv receiver. Although the coarse Gain selector of the scope was backed off to the (X0.01) position, the input voltage was not attenuated sufficiently to avoid amplifier overload. As a result, the vernier attenuator in the cathode circuit of the cathode-follower input stage could not be used to avoid overload, although it kept the pattern on-screen. The overload was occurring in the grid circuit of the cathode-follower input stage.



(A)



(B)

Fig. 5-19. Effect of improper adjustment of the receiver controls when waveform checks are being made. (A) A horizontal sync pulse as it appears at the grid of the picture tube in a tv receiver, when the contrast control is adjusted for linear (Class A) operation of the amplifiers. (The shape of this sync pulse is not as good as is customarily observed in some tv receivers.) (B) The same pulse when the contrast control has been advanced into the region of non-linear operation. More output is obtained, but the waveform has undergone distortion; the illustration shows incipient distortion, before severe clipping starts. The chief distortion introduced by the non-linear operation at this particular level, is a change in the shape of the back porch which is now convex in shape as contrasted with its concave shape shown in (A) when the operation is linear.

When a 10-to-1 low-capacitance probe was used, the waveform appeared undistorted as shown in Fig. 5-18B. The 10-to-1 probe attenuated the 1,300-volt signal to 130 volts, which could be handled by the coarse attenuator satisfactorily, so that the grid of the cathode-follower input stage of the scope was not overoladed. Additional discussion of this subject appears in Sec. 5-4.

(6) *Effects of Improper Receiver-Control Adjustments When Waveform Checks are being made.* Just as the scope controls must be properly adjusted to avoid the possibility of limiting or clipping the input signal and thereby obtaining a false waveshape on the scope screen, so must the receiver controls be suitably adjusted to avoid limiting or clipping in the receiver amplifiers while the waveform checks are being made. An illustration of this waveform compression appears in Fig. 5-19A and B.

Accordingly, the technician must not only determine that the scope is operated correctly, but also that the controls of the receiver under test are properly adjusted. Otherwise, the receiver circuits would be incorrectly adjusted in an attempt to compensate for an observed distortion which would not be present during normal operation.

(7) *Abnormal Displays may be obtained with Low-Capacitance Probes.* Because the low-capacitance probe is not a rectifying probe, the technician is sometimes puzzled by the abnormal type of display shown in Fig. 5-20 which was obtained when the output from a sweep-frequency generator was applied directly to the probe. Similar types of displays are obtained when the output from a sweep-frequency generator is applied to a direct probe. While it is true that the output from an i-f or r-f sweep-frequency generator (at least in normal opera-

tion) consists of high frequencies to which the scope cannot respond directly, it must be observed that cable resonance which occurs at certain high frequencies causes resonant rises of voltage at these frequencies. As a result of the resonant rise of voltage, the input stage of the scope becomes overloaded at the resonant frequencies, and during this condition of non-linear operation, the stage rectifies as well as amplifies. Hence, an unexpected pattern is seen on the scope screen.

(8) *Application of Low-Capacitance Probe for Display of Current Waveforms.* Finally, it should be observed that a low-capacitance probe can be used in connection with the display of *current* waveform on the scope screen, as well as voltage waveforms. In order to display the waveform of a current in a circuit, a small resistance, *R*, is connected in series with the circuit under test, and the low-capacitance probe is applied across the resistance, as shown in Fig. 5-21. The resistance should be made as small as possible consistent with producing a scope trace of adequate size, in order to avoid circuit disturbances. The technician does not often have occasion to investigate current flow, but it is important to recognize that this can be done when necessary.

In all applications of low-capacitance probes it should be remembered that their use cannot extend the frequency response of the test instrument. Distorted waveforms seen on an oscilloscope, therefore, are not improved by the addition of a low-capacitance probe if the distortion is originating in the scope circuits due to overload, rectification, etc. The full value of the probe can only be realized when the response of the scope with which it is used does not impose any limitations on the test being made.

5-11. The Cathode-Follower Type Circuit-Isolation Probe

Another type of circuit-isolation probe which, in shop-constructed form, has been used to a considerable extent in laboratory work, consists of an r-f cathode-follower arranged in probe form. The schematic circuit diagram of a probe of this kind designed to be used with, and powered by, the service-type oscilloscope of the manufacturer is shown in Fig. 5-22. It will be recognized as a cathode-follower circuit, the output being taken off across the 750-ohm cathode resistor.

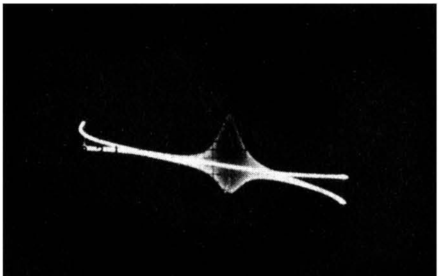


Fig. 5-20. Abnormal displays are sometimes obtained on the scope screen when a low-capacitance probe is being used. For example, because the shielded input cable to the scope becomes resonant at certain high frequencies causing resonant rises of voltage at these frequencies with consequent rectification occurring in the scope input stage, the unexpected pattern shown here may appear on the screen when the high-frequency output from a sweep generator is applied to a low-capacitance probe.

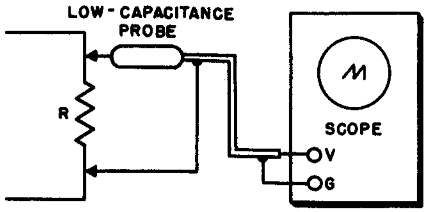


Fig. 5-21. A low-capacitance probe and scope may be used to display the waveform of the current in a circuit by connecting a small resistance in series with the circuit and applying the probe across the resistance.

The basic characteristics of a cathode-follower are that its grid-input capacitance is extremely low (in comparison with that of a conventional amplifier), and the input resistance is very high. Consequently the input impedance is high, even at comparatively high frequencies. A well-designed cathode-follower type of circuit-isolation probe can be built to provide a higher input impedance with less attendant attenuation than is obtained with the simpler conventional low-capacitance probe. Since it has excellent high-frequency response it is recommended for circuit-isolation use in testing high-impedance circuits whenever the test frequency is a determining factor.

Since its output impedance is lower than its input impedance, the cathode follower is in a sense an impedance transformer. The voltage attenuation resulting from its use is much less than that of a comparable conventional low-capacitance type probe; this is an important advantage in low-level circuit testing.

The cathode-follower probe of Fig. 5-22 is shown in commercial form in Fig. 5-23. A type 5703 sub-miniature tube is employed. The impedance of this probe has the high value of 6.2 megohms shunted by approximately only 8 $\mu\mu$f. This provides extremely low circuit loading, which is an absolute necessity in the servicing of some circuits of color tv receivers and very desirable in the servicing of some of those in monochrome tv receiver servicing. The attenuation ratio of the probe is only 2-to-1.

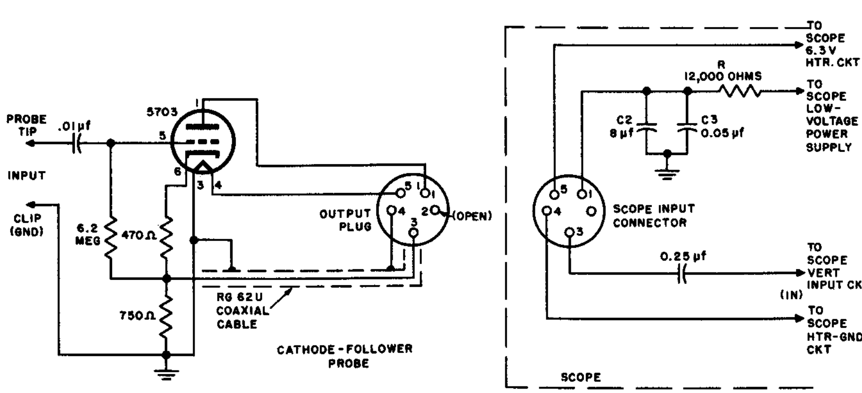
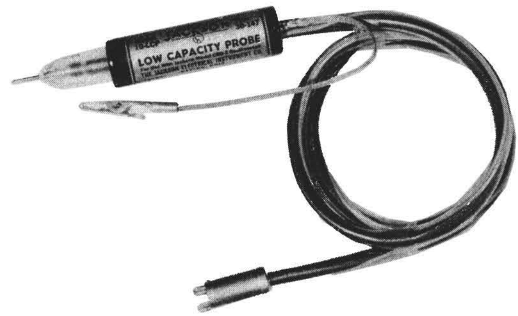


Fig. 5-22. Schematic circuit diagram of 10-LCP cathode-follower type of circuit-isolation probe which features a high input impedance, and comparatively low attenuation factor. *Courtesy: Jackson*

Fig. 5-23. The cathode-follower type probe whose circuit diagram is illustrated in Fig. 5-22. Observe the probe output plug designed to fit into the special input-circuit connector provided on the scope with which this probe is designed to be used. *Courtesy: Jackson*



The problem of providing heater and plate voltage supply for this particular cathode-follower probe has been solved by providing the scope with which it is to be used with a special shielded input connector (see Fig. 5-22) in place of the conventional Vert.-Input and Ground terminals. This connector supplies the necessary heater and plate voltages, and the scope vertical-input connections to the probe. The probe is provided with a special composite cable and 5-pin plug (as shown in the two illustrations) which fits into this connector. The 6.3-volt heater voltage for the probe is thereby automatically taken from the scope heater circuit, and the plate voltage is taken from the low-voltage power supply of the scope. The latter voltage is dropped to the proper value required by the probe tube by means of resistor R, and it is well filtered by 8-μf, 450-v, electrolytic capacitor $C2$ and the 0.05-μf, 400-v, paper-type high-frequency bypass capacitor $C3$. These three components are located within the scope. The hot lead in the output cable of the probe is the inner conductor of a low-capacitance coaxial cable; the shield of this cable serves as the ground conductor and also as one leg of the heater-supply circuit (see Fig. 5-22).

A cathode-follower probe is sometimes used to precede a crystal demodulator probe in order to present a much higher input impedance to the circuit under test than would be presented by the crystal demodulator probe alone. This results in decreased circuit loading which is required in some applications of demodulator probes.

Chapter 6

RECTIFYING PROBES FOR THE VTVM

6-1. Rectifier Required for A-C Voltage-Measuring Function of a VTVM

Almost all present-day vacuum-tube voltmeters are basically d-c voltage-indicating devices. As shown in Fig. 6-1, the d-c voltage to be measured (or a definite fraction of it selected by the d-c voltage-divider network) is applied to the input-grid circuit of an amplifier-type d-c bridge circuit. The bridge-potential unbalance produced by the application of this voltage causes current to flow through a conventional moving-coil type d-c microammeter. Consequently, when a-c voltage is to be measured, *it must first be rectified* so that it may be applied as *d-c* voltage to the voltage divider and d-c metering circuit of the vtvm. The meter scales are calibrated to indicate in terms of the magnitude of the a-c voltage. Use of a rectifier that produces linear rectification is preferable, so that the d-c meter indication will be directly proportional to the magnitude of the a-c voltage, and linear scales will result.

6-2. Typical Rectifier Arrangements Employed

Two types of rectifiers are employed; these are the vacuum-tube diode and the crystal diode. Although the application principles are the same for each type, each possesses certain advantages and disadvantages for specific applications. Several rectifying circuits, and several arrangements of them with respect to the d-c indicator portion of the vtvm are in use. Their choice is influenced mainly by the *waveform* and the *frequency* of the a-c voltages that the combination will be called upon to measure. A review of the typical rectifier bridge circuit arrangements most widely used in modern vtvm's will be helpful here, before proceeding with the detailed study of the circuitry and operating characteristics of the various forms of rectifiers employed.

A simple half-wave (diode) rectifier arranged in a peak-indicating type rectifying circuit is usually employed in the peak-indicating type of vtvm's whose a-c voltage-measuring function is intended mainly for measurement of the peak values of any waveform, or the rms values of *sine wave* voltages only. This rectifier precedes the d-c voltage divider of Fig. 6-1, in the circuit. Another voltage divider (usually an a-c frequency-compensated type) may or may not be provided

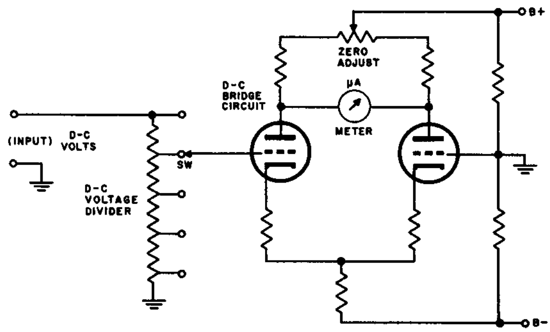


Fig. 6-1. Voltage divider, and simplified version of basic amplifier-type d-c bridge metering circuit of a vtvm. This is the d-c voltage indicator. When a-c voltage is to be measured, it must first be rectified so that it may be applied as d-c voltage to the input terminals of this circuit. Several types and arrangements of rectifiers are used with modern vtvm's; the choice is influenced mainly by the waveform and the frequency of the a-c voltage that is to be measured (see Fig. 6-2 and 6-3).

ahead of the rectifier to reduce high a-c input voltages under measurement to a value within the maximum voltage rating of the diode.

The rectifying circuit and the a-c voltage-divider may be built in as an integral part of the vtvm, as illustrated in Fig. 6-2A. One widely used vtvm that employs this rectifier arrangement has a rated frequency response flat to approximately 3 mc, which includes power-line, audio, supersonic, and radio-frequency voltages up to the medium-frequency band. For measurement of sine-wave a-c voltages of higher frequency, with an accuracy of ± 10 percent from 50 kc to approximately 250 mc, a calibrated half-wave germanium crystal-diode rectifier built into the form of exterior probe is used. This is attached to the instrument cable at the point of test, as shown in Fig. 6-2B. It is connected to the D-C Volts input terminals of the vtvm, so that the rectified voltage is then measured the same as d-c voltages. Observe that when this rectifying probe is used, it takes the place of the low-medium-frequency built-in rectifier shown in Fig. 6-2A.

Another version of the peak-indicating vtvm arrangement of Fig. 6-2A is illustrated in part C of the same figure. Here, the frequency range over which accurate voltage measurements may be made is increased by arranging a calibrated vhf type tube-diode rectifier in an exterior probe at the point of test. Accurate measurement of peak and rms values of sine wave voltages of frequencies up to approximately 110 mc, and useful voltage-presence indication (not measurement) of voltages up to 300 mc, is achieved in some popular-priced versions of this arrangement. (Such *voltage-presence* indication is useful in signal-tracing work when it is necessary only to determine the presence, absence, or relative magnitudes, of a signal at certain test points in the equipment under test.) By employing a special probe construction and a special uhf type of diode, one vtvm (Hewlett Packard 410A) which uses this arrangement is rated to provide accurate a-c voltage measurement to 700 mc, and useful voltage-presence indication to 3,000 mc.

Some vtvm's are designed especially to indicate directly the peak-to-peak voltage values of sine waves and also of all complex waveforms and recurrent pulses such as are present in various circuits in television, radar and other pulsed

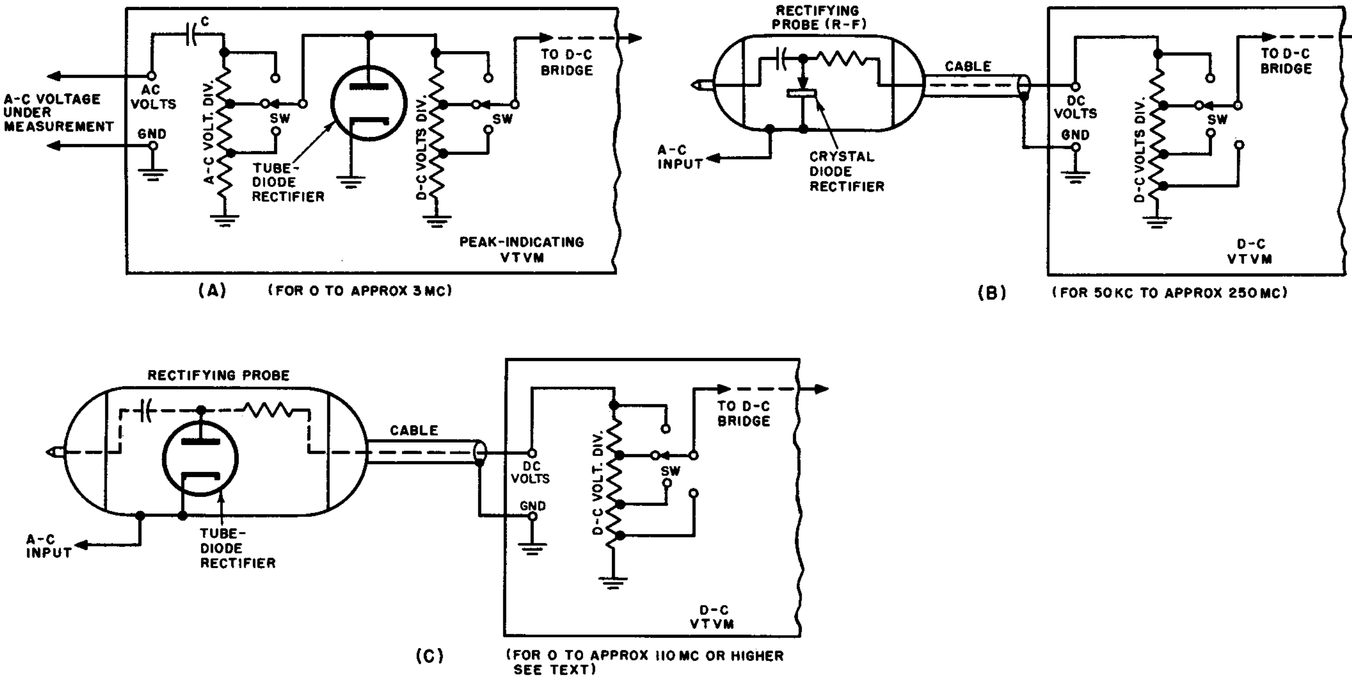


Fig. 6-2. Typical rectifier arrangements employed with peak-indicating type vtvm's. (A) Built-in tube-diode rectifier used for low and medium-frequency a-c voltage measurements. (B) Crystal diode rectifier, arranged in the form of an accessory exterior probe, used for high-frequency a-c voltage measurements to approximately 250 mc. (C) Alternate type of probe rectifier that employs a diode tube.

electronic systems. In tv receivers, the voltages usually measured range in value from about 1 volt p-p at the video-detector load resistor to over 1,200 volts p-p at the horizontal-deflection coils. The peak-to-peak indicating vtvm is particularly useful in tv receiver service work because service manuals and notes for tv receivers usually include illustrations of the correct waveforms that should exist at many specified points in the circuit, and these illustrations are frequently labeled with the correct peak-to-peak voltages. The latter are useful for reference when making checks with a vtvm, since receiver faults that alter the voltage waveform usually also alter its peak-to-peak value appreciably. Separate scales are also provided for indicating directly the rms values of sine waves only.

Peak-to-peak vtvm's usually employ a voltage-doubler type of rectifying circuit that is either built into the instrument case as shown in Fig. 6-3A, or is contained in a separate probe as shown in part B of the same figure. The frequency range over which accurate voltage measurement is possible with the former arrangement ordinarily extends to approximately 3 mc; that of the latter arrangement to approximately 110 mc, although it may usually be used up to about 300 mc for a-c voltage-presence indicating (not measurement) purposes in signal-tracing work.

Some service-type vtvm's which use the arrangement in Fig. 6-3A, for example the RCA Master and Senior Volt-Ohmysts, also make it possible to employ an accessory calibrated crystal-diode rectifying probe instead to provide peak-indicating operation over the extended usable frequency range to approximately 250 mc. This is connected to the D-C Volts terminals of the vtvm, as shown in Fig. 6-2B, so that it feeds directly into the d-c voltage divider and thence to the d-c bridge circuit. A calibrated high-frequency type of tube-diode rectifying probe, as illustrated in Fig. 6-2C, is used instead with some vtvm's, for this purpose.

Another rectifier arrangement of technical interest, illustrated in Fig. 6-3C, is used in the Hickok 209A vtvm and is explained in the caption. By means of this single exterior rectifying probe, with its unique switching arrangement located inside the vtvm, direct measurement of the peak-to-peak voltage value (up to 300 volts) of complex waveforms, and direct measurement of the rms value (up to 300 volts) of sine-wave voltages, over a frequency range to 100 mc, with useful voltage-presence indication to 300 mc, is obtained. A 4-wire cable is used between the probe and the vtvm, as shown.

6-3. Operation of the Shunt Type, Peak-Indicating, Tube-Diode Rectifying Circuit

Peak-indicating type vtvm's which use a tube-diode as the rectifier for a-c voltage measurements usually employ this in a *shunt* diode rectifying circuit (so named because the diode is shunted across both the input and the load circuits). The resulting d-c output voltage is applied to the d-c voltage divider of the vtvm, from which a definite fraction of it is applied to the input circuit of the amplifier-type d-c bridge circuit in the vtvm, as shown in parts A and C of Fig. 6-2. It is the function of the rectifier and the associated filter circuit *to deliver smooth d-c output voltage that is proportional to the peak value of the applied sine-wave a-c input voltage*. A disassembled tube-diode rectifier in probe form is illustrated in Fig. 6-4.

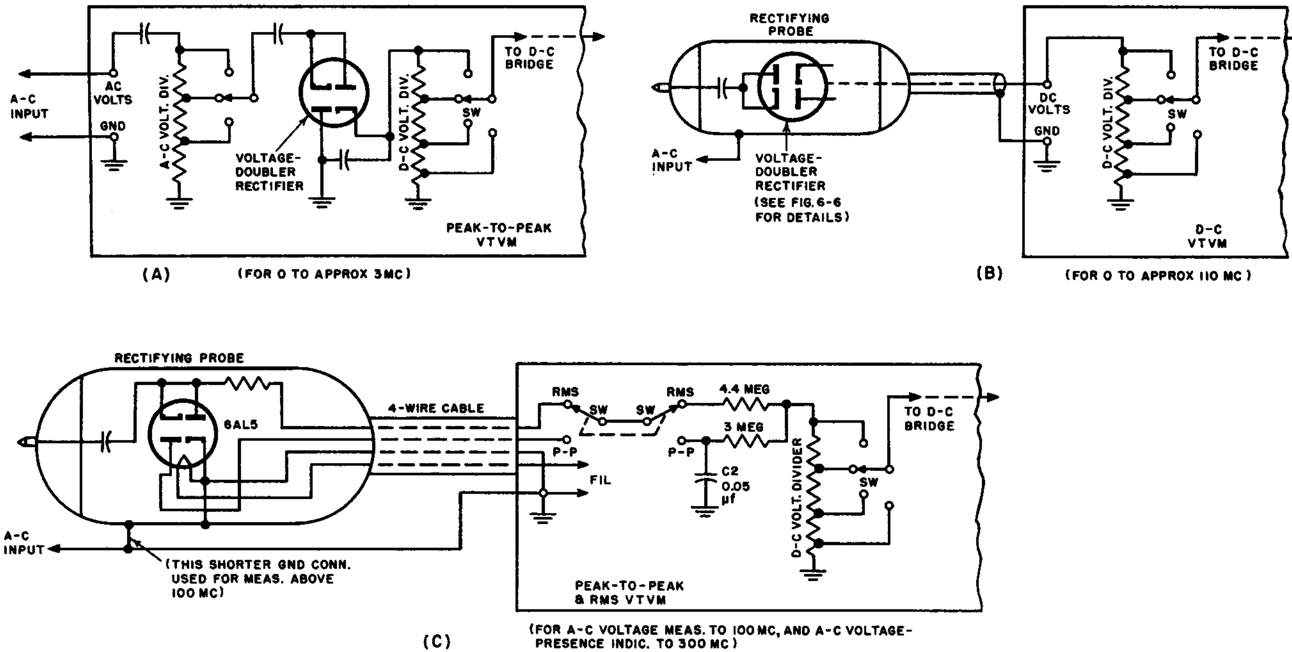


Fig. 6-3. Typical rectifier arrangements employed with peak-to-peak type vtvm's. (A) Internal voltage-doubler rectifier used for low- and medium-frequency a-c voltage measurements to approximately 3 mc. (B) Voltage-doubler rectifier, arranged in the form of an accessory exterior probe, used for peak-to-peak a-c voltage measurements to approximately 110 mc. (C) An interesting rectifier probe which employs a switching arrangement, located in the vtvm, for utilizing one-half of a twin-diode rectifier tube as a peak-indicating type rectifier for providing measurement of the peak or rms values of sine-wave voltages up to 300 volts, or utilizing the entire twin-diode as a voltage-doubler rectifier in order to provide peak-to-peak measurement of voltages of complex waveform, or sine waveform up to 300 volts. (*C*) *Courtesy*: *Hickok Elec. Inst.*

It is necessary to understand the basic operation of the shunt-diode type of rectifier circuit so that the important effects of its time constant upon the magnitude and waveform of the d-c output voltage will be clear. This is important, since the same basic circuit is also used in some crystal-diode rectifier probes and demodulator probes, as will be explained later.

The schematic diagram of a simple shunt diode rectifier is illustrated in Fig. 6-5A. No input a-c voltage-divider has been included here, it being assumed for simplicity that the rectifier is arranged in probe form without such a voltage divider, as in Fig. 6-2C. The a-c input voltage waveform (a sine-wave is assumed here), the voltage across the diode, and that across the output circuit composed of *R1* and *R2* in series, are illustrated in part D of the same figure.

When the instantaneous value of the applied a-c voltage swings *positive* as shown in Fig. 6-2A, the plate of the diode becomes positive with respect to the cathode, and the tube conducts. Its plate resistance falls to a comparatively low value at this time. During the initial half, *a-b,* of the first positive alternation (see Fig. 6-2D), the increasing applied voltage causes a transfer of electrons to take place quickly from plate *F* of capacitor *C1* around through the circuit, and through the low resistance of the diode, to plate *G* of capacitor *C1* as is indicated in Fig. 6-2A. This causes the capacitor to charge, with the polarity shown,

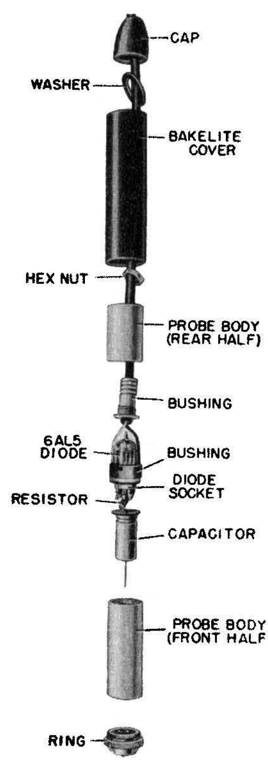


Fig. 6-4. Disassembled twin-diode tube-type peak-indicating rectifier arranged in probe form, for measurements for audio frequencies up to about 250 mc. The second diode section is used to balance out the contact potential of the first one. *Courtesy: RCA*

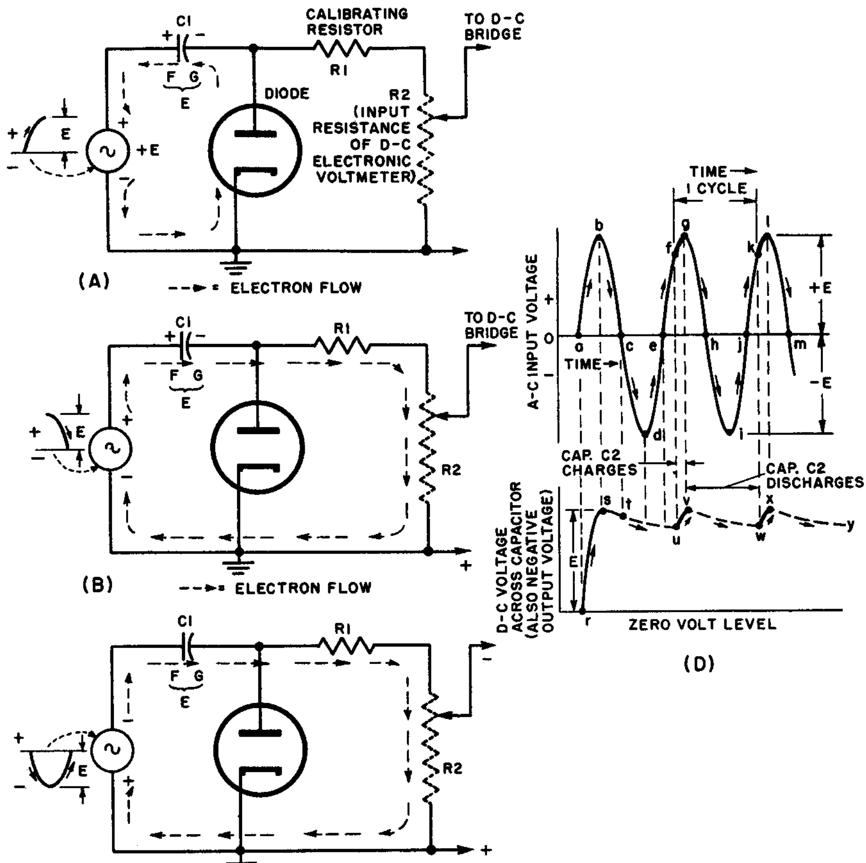


Fig. 6-5. (A), (B), (C) Basic circuit arrangement and action of a tube diode rectifier for a vtvm, during one cycle of the a-c input voltage. (D) If an a-c voltage (lower graph) is applied to the input circuit, a practically smooth d-c voltage (upper graph) that is proportional to the peak value of the a-c voltage, can be made to appear across the output circuit by proper choice of the time constant of the R-C circuit network.

and the voltage across its terminals increases correspondingly. When the applied voltage reaches its positive-peak value at *b* the capacitor has received its maximum charge, and the voltage across it (represented by point *s* in Fig. 6-2D) has risen to approximately the peak value, *E*, of the applied a-c voltage.

During the next half (*b-c*) of the *positive* alternation, the a-c input voltage decreases to zero, so that the voltage across the capacitor (due to its retained charge), now being greater than the input voltage, causes discharge current (electrons) to flow around the *R-C* network through the comparatively high resistance of *R1* and *R2* in series, as indicated in Fig. 6-2B. This *partial, slow* discharge of the capacitor causes its voltage to decrease, as indicated by the slope of *s-t* in part D of Fig. 6-2. Electron flow through the diode is cut off during this interval, because the sustained high negative charge on capacitor plate *G* makes the plate of the diode more negative than its cathode.

During the entire succeeding *negative* alternation *c-d-e* of the a-c input voltage, electron flow through the diode is still cut off, the capacitor *continues* to discharge slowly through the high-resistance *R-C* network as shown in Fig. 6-2C, and the voltage across it decreases along line *t-u* in part D of the same figure.

During the succeeding *positive* quarter-cycle *e-f-g* of the input voltage, the diode again begins to conduct when the input voltage reaches value *f* at which it equals the remaining capacitor voltage (the capacitor still has an appreciable proportion of its initial charge left). As the input voltage increases from *f* to its positive-peak value *g*, it charges the capacitor again, through the conductive diode, causing the voltage of the capacitor to increase from *u* to *v*, the latter being approximately equal to *g*, the positive-peak value of the a-c input voltage. Thus, during this short interval the conditions are once again as illustrated in Fig. 6-5A.

The foregoing actions repeat cyclically; while the a-c input voltage continues to go through its amplitude and polarity variations *g-h-i-j-k-l-m*, the d-c voltage which appears across the capacitor, *and across R2, plus R1*, varies in accordance with the graph *v-w-x-y*, etc.

It is evident that once the circuit assumes its steady operating conditions, the diode current (which is also the capacitor charging current) consists of a series of short bursts or pulses occurring on the successive *positive* peaks of the a-c input voltage. Each current pulse lasts for only a small fraction *f-g*, *k-l*, etc., of the total time required for the applied voltage to go through one cycle. While a tube diode is not conducting, its plate resistance is very high. It is this fact, combined with the fact that the shunting resistor network *R1*, *R2* usually has a comparatively high resistance (of the order of 10 megohms and upwards in practical vtvm's), which makes possible the high input impedances which are achieved in practice with such tube-diode rectifier circuits. That part of the capacitor charge which leaks off through the resistance network *R1*, *R2* is utilized for the voltage measurement since it causes voltage drops across the individual resistances. These voltage drops are directly proportional to the capacitor voltage and thus, the d-c voltage output of the rectifying circuit is directly proportional to the *peak* value of the applied a-c voltage.

It will be seen that resistors *R1* and *R2* in Fig. 6-5 act as a voltage divider, so they may be designed to apply any desired proportion of the total output voltage of the rectifier circuit to the input of the d-c voltage-measuring circuit of the instrument. This is very convenient whenever the rectifier is arranged in probe form (see Fig. 6-2C) to be connected to the D-C Volts terminal of a d-c vtvm. In this case, *R1* and *R2* may be so proportioned that only 0.707 of the peak value of the a-c input voltage actually appears across *R2* and is applied to the d-c voltage input terminals of the d-c vtvm. The d-c voltage scales of the vtvm will then indicate directly the *rms* values (for sine waves only) of the a-c voltages presented to the rectifier probe for measurement. These scales may also be calibrated to indicate the peak values. *R1* therefore functions as a convenient calibrating resistor.

In addition to the function already described, capacitor *C1* serves also as a blocking capacitor to keep out of the instrument any d-c voltage component present in the circuit under test, so that only the a-c component of the voltage is measured. Consequently, this circuit may be used to advantage to measure peak values of a-c voltages that may be accompanied by a d-c component.

This is a peak-indicating rectifying circuit, and whether the vtvm indicates the positive-peak voltage or the negative-peak voltage depends on the polarity with which the diode tube is connected into the circuit. If connected as shown in Fig. 6-5 with its cathode tied to ground, the rectifier will respond to the *positive*-peak value of the a-c input voltage, since the diode will conduct only during the positive half-cycles of this voltage. If the rectifying circuit is in the form of a separate probe, the center lead of the shielded cable will then be ***negative*** with respect to ground, see Fig. 6-5B and C, so that the vtvm polarity must be set accordingly. No output is then produced by the probe if a series of negative pulses are applied to it. If the diode were to be connected into the circuit with its elements reversed to that shown here, the probe would respond to the *negative*-peak value of the input voltage, and the center lead of the shielded cable would be ***positive*** with respect to the shield (Gnd).

The half-wave shunt type of vtvm rectifier is also constructed in crystal-diode form. This is discussed in Sec. 6-14.

6-4. Time Constant Requirements of VTVM Rectifying Circuits

Examination of Fig. 6-5D shows that the capacitor charges through the very low resistance of the diode tube only during the short portions *f-g*, *k-l*, etc., of the a-c input voltage cycles, and it discharges through the high resistance of *R1* plus *R2* during the much longer remainder of each cycle. It is evident that the conduction interval is very short as compared with the non-conduction interval. For this reason, the mean diode current is very low, which means that the input resistance of the probe is very high. By limiting the conduction time of the diode to just a very small portion of each r-f cycle through the use of an R-C network which has a relatively long time constant, and by reducing the shunt input capacitance to a low value by suitable probe construction, a very high impedance may be presented to the source of signal. Therefore, very light loading of r-f circuits under measurement results. It is important to remember this.

One charge and one discharge of the capacitor occurs during each cycle of the a-c input voltage. It is apparent that the time constant[1] of the R-C network *must be designed to be sufficiently long so that the capacitor retains practically its full charge during the intervals s-u, v-w, etc. (Fig. 6-5), during which this discharge takes place.* If this condition is realized in the design of the network, the voltage across the capacitor and that across network *R1* plus *R2*, will remain substantially constant during these intervals instead of dropping as much as has been indicated in the exaggerated upper graph in Fig. 6-5D. A substantially smooth d-c voltage that is proportional to the peak value of the applied a-c input

[1] For discharge of a capacitor through a resistor, the *time constant*, *T*, is defined as the time it takes the voltage across the capacitor to decrease by 63.2% from the initial value, i.e., the time it takes to discharge down to 36.8% of the voltage it had when it first started to discharge. In series *R-C* circuits, T = RC; T is in sec., where *R* is in meg, and C is in μf. Example: In the circuit in Fig. 6-5A, how long does it take for *C1* to discharge to 36.8% of the original voltage across it, if *C1* is 0.01 μf and *R1* plus *R2* is 40 meg.? T = RC = 40 x 0.01 = 0.4 sec.

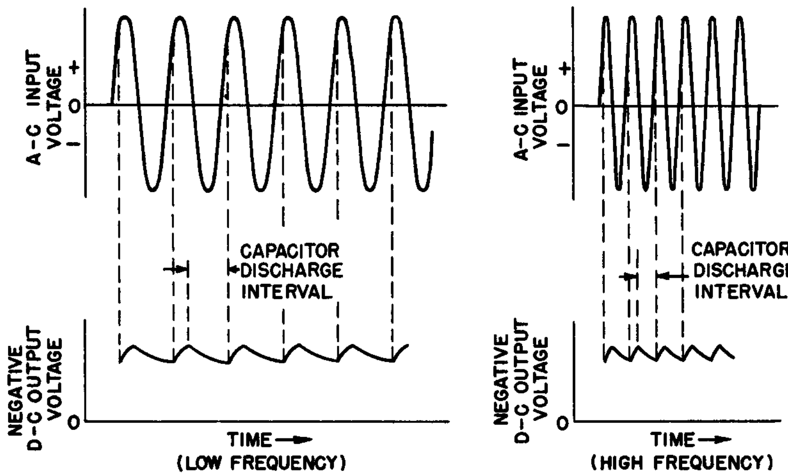


Fig. 6-6. Effect of the frequency of the voltage under measurement on the time constant requirements of the rectifier circuit of a vtvm. A longer time constant is required when a low-frequency voltage is to be measured, since the time duration of the interval during which the R-C circuit capacitor is required to discharge during each cycle is longer, the lower the frequency.

voltage will then appear across *R2,* and will be applied to the d-c bridge circuit of the d-c vtvm for measurement. This is the key to the proper functioning of a rectifier circuit for a vtvm. If the time constant is not sufficiently long, the rectified output of the probe gradually falls off in amplitude at the lower frequencies. This attenuation at the lower frequencies results in a lowered voltage reading on the meter. Although the low-frequency attenuation can be decreased by using a larger value of capacitance for *C1,* this means an increase in the physical size of the capacitor and an increase in stray capacitance which may decrease the response at very high frequencies. Hence a practical compromise must be effected.

6-5. Effect of Input-Voltage Frequency Range on the Time Constant Requirements

Study of Fig. 6-5D shows that the value of capacitance *C1* that is required to perform the smoothing function with practical completeness in a vtvm having a given input-resistance network, will depend on: (1) the frequency range of the a-c voltages that the vtvm will be called upon to measure; (2) the waveform of these voltages.

It is apparent that the higher the frequency of the a-c input voltage, the shorter is the duration of the discharge periods *s-u, v-w,* etc., of the capacitor, and therefore the less is the capacitance required to maintain a smooth d-c output voltage. This is illustrated by direct comparison in Fig. 6-6. Consequently, a value of capacitance that is sufficient for adequate smoothing at the lowest frequency to be measured, will be ample for all higher frequencies.

In general, for the measurement of sine-wave voltages, this capacitance should be made sufficiently large so that the time constant of the R-C circuit is approximately 100 times as long as the time required for the lowest frequency a-c input voltage to go through one cycle. To satisfy this condition, the capacitance of C should be *not less than*

$$C = \frac{100}{fR}$$

where, C is in μf, f is in cps, and R is in megohms. If the capacitance is too small (time constant too short), the capacitor loses too much of its charge during each cycle, the average value of the voltage that appears across resistor $R2$ during each cycle will therefore decrease, and both the peak and the rms voltage indications of the vtvm will be lower than the true values of the applied voltage. For this reason, a proper combination of values of capacitance $C1$ and resistance $R1 + R2$ used in the rectifier circuit of a vtvm is chosen by the designer to achieve a discharge characteristic that provides accurate meter readings over the rated frequency range of the vtvm. For the measurement of pulse-type waveforms, a value of C larger than that specified in this frequency equation may be required, for the reasons explained in Sec. 6-10.

6-6. Waveform Error in RMS Voltage Measurements

In a peak-indicating type vtvm, the rectifying circuit response is on the basis of the *peak* value of the a-c input voltage. However, it is customary to design the resistance network $R1$, $R2$ so that only 0.707 of this voltage is applied to the d-c measuring circuit of the vtvm, so that the *rms* values of the ac may be indicated directly on the d-c voltage scales of the meter. *This is done on the assumption that the waveform of the a-c voltage being measured is sinusoidal,* in which case the 0.707 relationship holds true. However, if the waveform is not sinusoidal, that is if it contains appreciable *harmonic* voltage components, or other spurious voltages, the meter indication of the rms value may deviate from the true rms value by an amount that may be as large as the percentage of harmonic present, depending upon the phase relation between the fundamental and harmonic voltages. To illustrate the errors in measurement which may be caused by departure from sinusoidal waveform, the experimentally determined values in Table 6-1 (courtesy of Hewlett-Packard Co.) are presented.

For example, when a voltage of about 100 volts rms whose waveform contains 10 percent of third harmonic voltage is measured on such a peak-indicating type vtvm, the scale rms indication on the meter may be any value between 90 and 110 volts, depending upon the phase relation existing between the fundamental and the harmonic voltages.

Likewise, peak-to-peak type vtvm's are calibrated to indicate the p-p values of the a-c input voltage (regardless of the waveform). In addition, such vtvm's are usually provided with a scale calibrated in rms volts for a sine-wave input only. The readings obtained on this scale will be subject to the same error mentioned above if the waveform of the input voltage is appreciably distorted from true sine-wave form by the presence of harmonics.

6-7. Contact Potential of the Tube Diode

One fact has been neglected in the discussion of the operation of the tube-diode rectifier in Sec. 6-3. Even when no a-c voltage is being applied to the input terminals of the rectifier circuit, a minute current flows around the circuit comprising the diode tube and resistors $R1$ and $R2$ in Fig. 6-5A. This current is

TABLE 6-1

ERROR IN RMS VOLTAGE MEASUREMENTS
CAUSED BY HARMONICS

Harmonic Percentage in Voltage Being Measured	*True RMS Value (Volts)*	*RMS Value as Read on a Peak, or Peak-to-Peak, Type VTVM (Volts)*
0	100	100
10% 2nd harm.	100.5	90 to 110
20% 2nd harm.	102	80 to 120
50% 2nd harm.	112	75 to 150
10% 3rd harm.	100.5	90 to 110
20% 3rd harm.	102	80 to 120
50% 3rd harm.	112	108 to 150

caused by the fact that some electrons leaving the heated cathode of the tube have initial velocities sufficient to carry them over to the nearby plate even when the plate is at zero potential, or even slightly negative, with respect to the cathode. Although this current is extremely small, it is usually enough to cause a small potential (typically 1-2 volts) to be developed across the resistors. This potential is *negative* with respect to the cathode. The result is that this small value of negative potential, called the *contact-potential,* is applied to the input grid of the d-c bridge circuit of the vtvm even when no a-c voltage is being applied for measurement. The contact potential is sufficient to slightly unbalance the bridge, and a small zero-volts deflection results. Therefore, a slight zero-adjustment of the meter would always have to be made when switching from d-c to a-c voltage measurement, or vice versa.

In order to permit the zero-volts adjustment of the meter to remain the same for both a-c and d-c voltage measurements, the contact potential of the tube diode must be neutralized by incorporation of a "bucking voltage" in the vtvm to cancel out the contact potential. Several methods of accomplishing this are employed. One method uses bucking voltage obtained from a dry cell and potentiometer combination. In another method, the contact potential of another diode is applied to the other grid of the bridge tube in order to balance the contact potential from the rectifier diode. Still another method taps the bleeder resistor in the power supply circuit to obtain the necessary small bucking potential.

6-8. Rectifying-Circuit Requirements for Peak-to-Peak VTVM

The need for measuring the peak-to-peak voltage of both sinusoidal and complex non-sinusoidal waveforms and recurrent pulses found in tv circuits is discussed in Sec. 6-2. Several typical complex waveforms for which such measurements are frequently required are illustrated in Fig. 6-9. Although the oscilloscope is widely used for p-p voltage measurement of complex waveforms, it is sometimes desirable to also have a type of vtvm which will do this.

It might be supposed that the peak-to-peak value of any voltage waveform could be obtained by measuring the voltage with a peak-indicating type voltmeter, reading the *rms* voltage value on its scale, and then multiplying this by the factor 2.83 to convert this rms reading to the peak-to-peak value. This is satisfactory *only if the waveform under test is a sinewave,* for only in this case is the rms value read on the peak-indicating type meter correct, and only in this case is the conversion factor 2.83 correct. This method is *not* correct for voltages having nonsinusoidal waveforms. Furthermore, nonsinusoidal waves usually have vertical dissymmetry (the positive-peak voltage is not equal to the negative-peak voltage), so that the conversion from rms to peak-to-peak voltage cannot be made at all for such waveforms unless the vtvm makes full provision for inherent measurement of the peak-to-peak voltage. Another type of rectifying circuit, the voltage-doubler, must be employed for this purpose.

It is sometimes thought, that a peak-indicating type vtvm can be employed to measure the peak-to-peak voltage value of a waveform by first measuring the positive peak value of the waveform with it, then measuring the negative peak value, by reversing its connections to the test circuit, and finally adding the two readings together to arrive at the peak-to-peak value. Commercial half-wave peak-indicating service-type vtvm's cannot usually be thus "turned over" to measure the positive and negative portions of a waveform. Their rectifier circuits are such that they can indicate only the positive-peak value (or the negative-peak value, if the rectifier tube is wired up suitably), and one side of the a-c input circuit is generally grounded to the instrument case (see Fig. 6-2). Accordingly, if it is attempted to "turn over" a positive-peak instrument by reversing the connections to the circuit under test in order to measure the negative peak voltage, the ground terminal of the instrument is then applied to the "hot" side of the signal circuit under test, which capacitively shunts the signal circuit. This circuit loading frequently "kills" the signal voltage under test, with the result that a basic error in the reading results (the instrument reads low).

It is evident that a type of vtvm rectifier circuit is required which will respond inherently on the basis of the peak-to-peak voltage of the signal under test, and so permit actual peak-to-peak voltage measurement to be made *directly.* A voltage-doubler type rectifier having a suitably long time constant meets this requirement satisfactorily, since its d-c output voltage is equal approximately to the peak-to-peak value of the a-c input voltage, *regardless of its waveform.*

6-9. Tube-Diode Type Voltage-Doubler Rectifying Circuit for P-P Voltage Measurement

Voltage-multiplying rectifiers make it possible to obtain a higher direct voltage from a given a-c input than is possible with normal rectifier circuits. These circuits involve the principle of charging capacitors through rectifiers from the a-c input circuit, and adding their voltages in series for the d-c output; the switching is accomplished automatically by the rectifiers. Two capacitors and two diode rectifiers are used in a voltage-doubler rectifier. The diodes may be either the tube or the crystal type. When tubes are used, a twin-diode type is employed for convenience. Despite some operating advantages possessed by the full-wave type and by the conventional form of half-wave voltage doubler, the *cascade* type of half-wave voltage doubler is customarily employed, because the cascade circuit has the advantage of employing a common terminal between the input and the output circuits (see Fig. 6-7). Thus, both may be grounded simultaneously.

Built-in, and exterior-probe, arrangements of such rectifiers, and their connections to the d-c voltage divider and the amplifier-type d-c bridge circuit in the vtvm, are illustrated in Fig. 6-3A and B, and are described in the text relating to these illustrations.

The voltage-doubler rectifying circuit operates as follows: Referring to Fig. 6-7A, when the instantaneous value of the applied a-c voltage swings negative, an electron flow takes place as indicated, and *C1* charges through diode *V1* to the *negative-peak* value of the applied voltage. The polarity of the charge on *C1* is as indicated. *V2* is non-conducting during this interval, because its plate is negative with respect to its cathode.

On the succeeding *positive* half cycle of the a-c input voltage, diode *V1* becomes non-conducting; therefore the charge on capacitor *C1* cannot leak off through this path. Also, an inspection of Fig. 6-7B shows that the polarities are such that the a-c input voltage and the voltage of capacitor *C1* are now in series with each other and therefore are additive. Accordingly, the *negative-peak-value* charge-voltage of *C1*, and the applied input voltage (up to its *positive-peak* value), added together are applied to the plate of *V2*. This tube now becomes

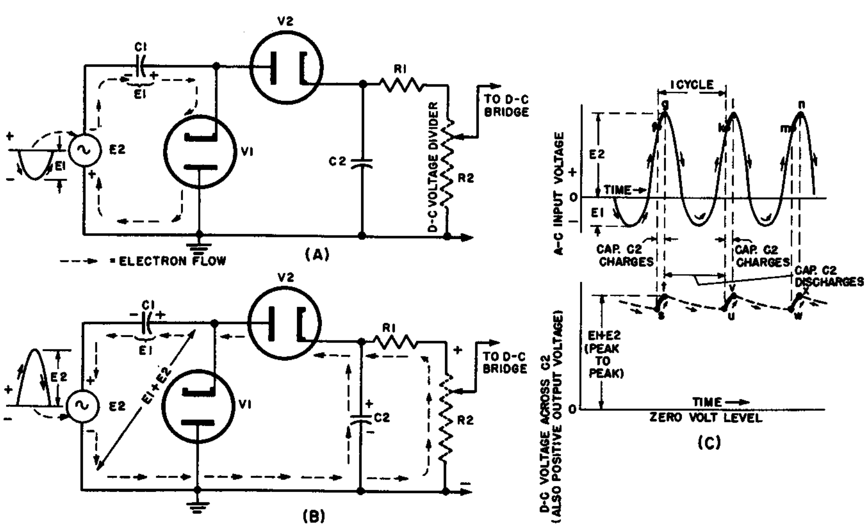


Fig. 6-7. (A), (B) Basic circuit arrangement and action of a cascade-type tube diode half-wave voltage-doubler rectifier circuit during successive negative and positive half-cycles of the a-c input voltage. (C) Graphs of the a-c voltage input, and the d-c voltage output, showing the inherent peak-to-peak response of this type of rectifier for any waveform.

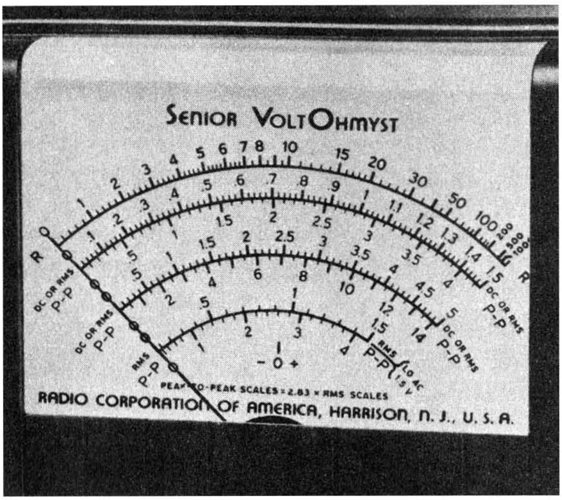


Fig. 6-8. Convenient direct-reading d-c, rms (sine-wave), and peak-to-peak (sine or complex wave) voltage scales available in a typical service-type peak-to-peak vtvm. *Courtesy: RCA*

conducting and permits a transfer of electrons to take place through the circuit, as shown in Fig. 6-7B, thus charging capacitor *C2* to a voltage equal *to the sum of the negative and positive peak* voltages—which is the *peak-to-peak value* of the a-c input voltage (regardless of its waveform). As shown in Fig. 6-7B, *C2* is able to slowly discharge continuously through resistances *R2* and *R1*, and it actually continues to do so throughout the negative half-cycle action illustrated in Fig. 6-7A. This is shown more clearly in the graph in part C of the same figure. The resulting current flowing through *R2* produces a voltage drop across it which is applied as the actuating potential to the d-c bridge amplifier in the vtvm.

Examination of Fig. 6-7C shows that once the circuit gets into operation, capacitor *C2* charges only during the short peak portions *f-g, k-l, m-n,* etc., of the applied a-c voltage cycles, and it discharges through the load resistance, *R1* + *R2*, during the much longer remainder of each cycle. Also, one short charge, and one long discharge, of the capacitor occurs for each cycle of the a-c input. By properly designing the *R-C* circuit *C2, R1, R2* to have a time constant sufficiently long for the input-voltage frequency involved, the voltage across *C2* may be maintained practically constant at the *peak-to-peak* value of the applied a-c voltage *regardless of the waveform* and what the proportions of the positive and negative peak are. Thus, the qualifications for an inherent peak-to-peak voltage-measuring circuit are realized.

If the peak-to-peak voltmeter is to be arranged to indicate directly the rms values of sine waves, as well as the p-p values of both sine waves and complex waves, calibrating resistor *R1* is usually included in the output of the doubler circuit. This is used to reduce the d-c output voltage of the doubler (across *R2*) to the rms value of a sine wave which has a p-p value equal to the p-p value of the complex wave. The d-c and rms (sine-wave) voltage scales of the vtvm are then identical, and another set of scales whose numerical values are 2.83 times those on the corresponding d-c and rms (sine-wave) scales are included to indicate the actual peak-to-peak value of the measured voltage (sine or complex wave). This convenient arrangement is possible only because the d-c voltage output of the voltage-doubler rectifier used here is proportional to the *peak-to-peak* value of the voltage wave under measurement. A set of scales for a typical vtvm of this type is illustrated in Fig. 6-8. Observe that both the rms and the p-p values of sine waves are indicated simultaneously (on adjacent scales) which is very convenient for some measurements.

The diode tube employed in the voltage-doubler rectifier is subject to the same contact potential effect that is discussed in Sec. 6-7, and this is usually counteracted by one of the methods discussed there. A voltage-doubler peak-to-peak rectifying circuit has a lower input impedance than a peak-indicating type probe has, and its application may accordingly be limited to medium- and low-impedance circuit testing. The voltage doubler also has a more limited frequency response. The maximum allowable input voltage is approximately the same as for a peak-indicating probe using the same type of rectifier.

Commercial variations of the voltage-doubler type of peak-to-peak rectifying circuit for vtvm's differ in form and in the range of signal voltages which may be accommodated. Both built-in, and exterior probe, arrangements (see Fig. 6-3) are in common use. This type of rectifying circuit, as explained in Sec. 6-17, has a counterpart in a similar circuit that employs germanium crystal diodes instead of tube diodes.

The peak-to-peak rectifying circuit can be provided with a switch to make available a choice of *peak* response or *peak-to-peak* response from one vtvm. This arrangement is shown in Fig. 6-3C. Peak response is obtained when the switch is set to take the output from across the right-hand diode of the twin-diode tube. Peak-to-peak response is obtained when the switch is set to utilize the entire twin-diode as a voltage-doubler rectifier. Details concerning the various indications obtained, etc., are the same as those explained in Sec. 6-18 for a crystal-diode version of this circuit.

The useful frequency range of most commercial service-type vtvm's which employ a twin-diode tube as a voltage-doubler rectifier extends to approximately 110 mc. For measurement of a-c voltages above this frequency, a peak-indicating type rectifier arrangement using either a tube diode or a crystal diode (which have lower interelectrode capacitances than does the twin diode, see Table 6-2 in Sec. 6-11), is usually employed. Details regarding such probes will be found in Sec. 6-3 and Sec. 6-14.

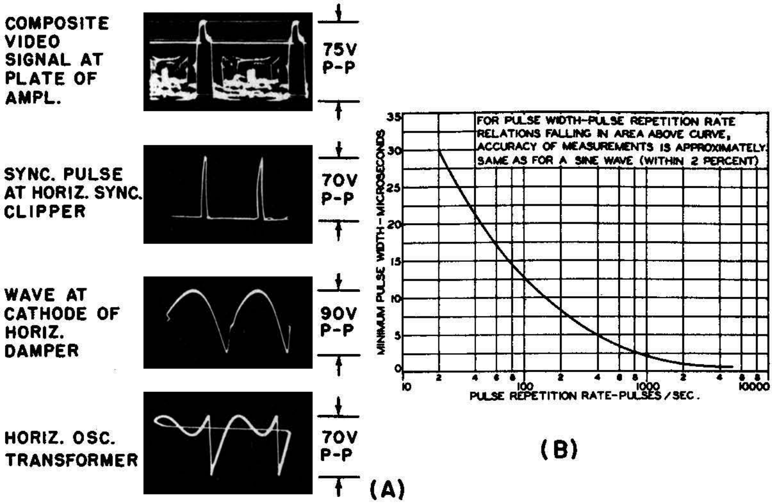


Fig. 6-9. (A) Typical narrow-pulse voltage waveforms of low repetition rate encountered in tv receivers. Use of a p-p vtvm to measure the p-p voltages of such waveforms may result in inaccurate readings. (B) Typical pulse-response capability of a high-quality service-type vtvm. The graph shows the inherent capability of the instrument. *(B) Courtesy: RCA*

6-10. Pulse-Response Capability of the Peak-to-Peak VTVM

Many of the non-sinusoidal voltage waveforms encountered in tv and other electronic equipment consist of narrow pulses having low repetition rates, as illustrated in Fig. 6-9A. If the peak-to-peak voltage values of such waveforms are measured with a peak-to-peak vtvm, it must be remembered that the capacitor in the voltage-doubler rectifier circuit may not be allowed sufficient time in which to charge fully during the extremely short-duration maximum-voltage period of the pulse, and the time interval between successive pulses may be too long for the *partially charged* capacitor to retain sufficient charge to maintain the d-c output voltage constant (see Fig. 6-7C). As a result, beyond certain limits of pulse width/pulse repetition rate, the peak-to-peak readings obtained will be lower than the true p-p value of the applied voltage. This is one of the reasons why a cathode-ray oscilloscope is widely used instead of a vtvm for measuring the p-p values of narrow-width low-repetition-rate pulse voltage encountered in tv service work.

The magnitude of this error caused in a typical high-grade service-type p-p vtvm is shown in Fig. 6-9B, which holds for essentially rectangular pulses obtained from a voltage source of 50 ohms impedance or less. For higher impedance sources, the error will be greater.

Since the rate at which the rectifier output capacitor discharges is determined by the input resistance of the d-c voltage-measuring circuit of the vtvm, it is apparent that the ability of a peak-to-peak vtvm a-c probe to measure the p-p value of very narrow pulses can be improved by increasing the time constant of the circuit. This may be done by adding series resistance in the output circuit of the probe to effectively double or triple the input resistance of the vtvm.

TABLE 6-2

OPERATING CHARACTERISTICS OF TUBE DIODES
WIDELY USED IN VTVM's

Type Number	*Type*	*Max. RMS Plate Voltage*	*Max. Peak Inverse Voltage*	*Plate-Cathode Capacitance*
6AL5 / 12AL5	twin-diode	117v	330v	3.2 $\mu\mu$f
9005	uhf-diode (Acorn)	117v	——	0.8 $\mu\mu$f
9006	uhf-diode	270v	750v	1.4 $\mu\mu$f

Then the discharge current is small enough to permit the charging capacitor to maintain practically its full charge from the peak of one pulse to the peak of the next one. However, in such cases, the a-c scale range of the instrument is also doubled or tripled, by this "multiplier" resistance so that low voltages can no longer be read accurately. An alternative is to use the rectifying probe with a vtvm having a higher input resistance if the voltages of narrow pulses are to be measured.

6-11. Important Operating Characteristics of the Tube Diode

(1) *Curvature of Lower End of Diode Characteristic.* The typical plate-voltage plate-current characteristic of a tube diode is shown in Fig. 6-10. It will be seen that the characteristic is linear over most of the plate-voltage range. However, beyond a certain value of plate voltage, additional plate voltage has little effect in increasing the plate current. This is the saturation voltage area of the tube operation. Also, note that a small current flows when the plate voltage is zero, or even slightly negative, leading to the contact potential effects discussed in Sec. 6-7. Furthermore, the lower end of the characteristic is curved, causing the current to become less in proportion to the plate voltage, at low plate voltages. Consequently, when a diode tube is used as the rectifier for a vtvm, the low-volts portion of the a-c voltage scale is non-linear—usually in the region below approximately 3 volts. The same operating characteristic, non-linearity at low input voltage, also occurs for crystal diodes.

(2) *Electron Transit Time and Diode Behavior at UHF.* In diode-rectifier applications at comparatively moderate frequencies, the transit time of the electrons (time required to travel from the cathode to the plate) is short compared with the period (time required for one cycle) of the applied a-c voltage. As the frequency is increased, this becomes less and less true until finally, frequencies are reached for which an appreciable fraction of a cycle is required for an electron to pass from the cathode to the plate. When this happens, the behavior of the tube changes markedly. The dynamic plate resistance of the diode drops (at certain frequencies it may even become negative), and there are also modifications produced in the effective plate-cathode interelectrode capacitance. Several uhf type miniature diodes designed especially for satisfactory operation at uhf are widely used in the rectifying circuit of peak, and peak-to-peak type vtvm's.

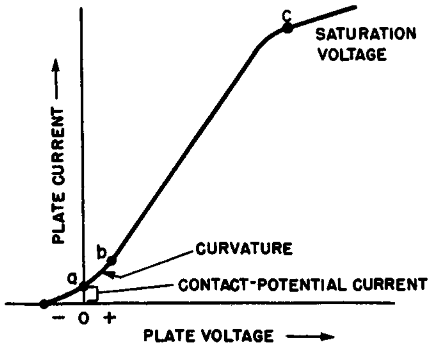


Fig. 6-10. Contact potential and curvature of the lower end of the operating characteristic are shown here for a typical tube diode.

(3) *Input Resistance and Capacitance.* The diode tubes employed in vtvm's must have high input resistance (when not conducting) and low plate-cathode capacitance so that the input impedance of the rectifier circuit will be sufficiently high to prevent excessive loading of the circuit whose voltage is to be measured. The modern miniature uhf diodes commonly used are satisfactory in this respect (see Table 6-2 for typical values). It must be remembered that when the diode rectifier is built into the vtvm case, necessitating the use of a shielded direct cable to the test point, the comparatively large input capacitance of the shielded test cable is added to that of the diode and is applied across the circuit undergoing test.

(4) *Peak Voltage Rating.* The diode tube will be damaged by the application of excessive input voltage, but it is much less susceptible to permanent damage from this cause than is the crystal type diode. The maximum rms plate voltage ratings for several diode tubes that are widely used in vtvm's are tabulated in Table 6-2. If voltages in excess of these ratings are to be measured, an a-c voltage-divider must be employed ahead of the rectifier, as in Fig. 6-2A and Fig. 6-3A, and then both the divider and the rectifier must be located within the instrument case. This must be a frequency-compensated type divider if good high-frequency response is to be maintained. It can be seen that the maximum voltage ratings of tube diodes are very much higher than the approximately 28-volt (peak) rating of the germanium crystal diodes most widely used in rectifying probes.

(5) *General.* The important characteristics of several types of tube diodes that are widely used in the rectifying circuit of service-type peak and p-p vtvm's are tabulated here:

6-12. The Crystal Diode and its Operating Characteristics

The germanium crystal diode is a compact, light weight, heaterless diode that is widely used for low-power rectification at frequencies up to approximately 250 mc. It has a low shunt capacitance of approximately 1 $\mu\mu$f, and is extremely efficient in applications where low-voltage a-c signals must be rectified. The general-purpose 1N34 (and 1N34A) type is widely used as the rectifier in the high-frequency rectifying probes for vtvm's (see Fig. 6-11, and Fig. 6-2B). The circuitry and mode of operation of the rectifier circuits are basically the same when the crystal diode is employed as when the tube diode is used. However, there are some minor differences, and these will be pointed out. One of the advantages of the use of a crystal diode instead of a tube diode in a rectifying circuit constructed in probe form, is that the former is very small in size and does not require any heater circuit wiring to be brought up to the probe through the connecting cable. Its excellent high-frequency characteristics also, make it useful for high-frequency voltage measurement, or indications up to approximately 250 mc.

When an alternating voltage is applied to a germanium diode, it tends to cause electrons to flow through the diode, in opposite directions, during each half cycle. The diode presents a certain resistance to the flow of electrons in the direction from the germanium wafer (cathode) to the cat whisker (anode), but it presents a much higher resistance (approximately 1,000 times as much) to the flow of electrons in the opposite direction. This action is repeated for each cycle. Consequently, almost complete rectification takes place. The direction of electron flow for which the crystal diode is most conductive (least resistance offered) is called the *forward direction;* the applied-voltage polarity which produces electron flow in this direction is called the *forward voltage;* the current which is then flowing is called the *forward current;* the resistance to electron flow in this direction is called the *forward resistance.* The opposite electron-flow direction, voltage-polarity, current, and resistance are called, respectively, the *reverse direction, reverse voltage, reverse current,* and *reverse resistance.* The term back is sometimes used instead of *reverse.*

A comparison of the crystal versus the tube diode reveals that they are basically similar in their effect on the current flow in the circuit, except that because the crystal diode offers a finite value of resistance to the flow of electrons (current) in the *reverse* direction, it allows a small reverse current to flow, whereas the tube diode does not (compare Fig. 6-12 with Fig. 6-10).

The voltage-current characteristic of a 1N34 general-purpose type germanium crystal diode is shown in Fig. 6-12. (Important notes concerning the scales employed on this illustration will be found in the caption). It will be seen that there is no current flow at zero applied potential; therefore the crystal diode is free from contact potential effects, and no bucking-voltage source is required. This is an advantage over the tube diode.

The characteristic is curved quite appreciably for low input voltages up to approximately 1 volt (point *A*), so the output is less in proportion to the

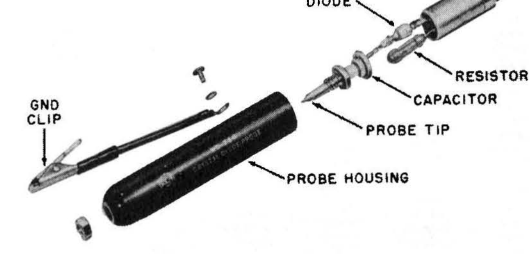


Fig. 6-11. High-frequency crystal-diode rectifying probe for vtvm disassembled to show the construction and various component parts. *Courtesy: RCA*

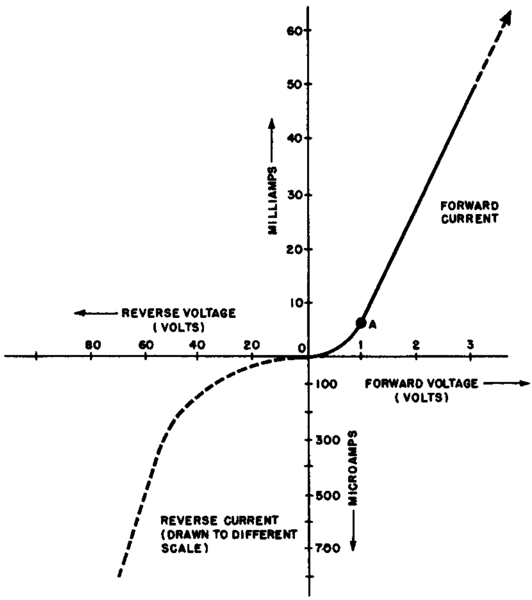


Fig. 6-12. Average voltage-current characteristic (static) of the 1N34 and 1N34A crystal diode which is widely used in high-frequency rectifying and demodulating probes. Observe that there is no contact-potential current for the tube diode; also that some reverse current flows when the applied voltage is reversed. The conduction in the forward direction is over 1,000 times greater than that in the reverse direction. Note that in the graph above, the forward conduction is plotted in milliamperes, while it was necessary to plot the small reverse conduction in microamperes (only 1/1000 as much) in order to show the reverse-current magnitude at all. Also, the voltage scales are unequal. *Courtesy*: Sylvania *Elect. Prod. Inc.*

input voltage at low signal levels, as in the case of the tube diode. In fact, for input voltages up to approximately 0.2 volt, the output is usually proportional to the *square* of the input voltage. For this reason, a crystal diode is a typical *square-law* rectifier for very small input voltages of this order. Above the 1-volt region, the output becomes practically proportional to the input voltage, as evidenced by the straight-line characteristic, so the crystal diode is regarded as a *linear* device at input voltages over this range. It is important to remember this in the application of crystal-diode type rectifying or demodulating probes.

The 1N34 germanium crystal diode, which is the type most widely used in crystal probes, has a nominal shunt capacitance of approximately 1 $\mu\mu$f. This is somewhat lower than that of the widely used tube type 6AL5 or 12AL5 twin-diodes, but slightly greater than that of the 9005 uhf tube diode (acorn type), see Table 6-2.

The electrical specifications of the 1N34 crystal diode are as follows:

Maximum continuous reverse working voltage	60 v
Maximum reverse current at −10v	50 μa
Maximum reverse current at −50v	500 μa
Forward current at +1v	5 *ma*
Average anode current	50 ma max.
Recurrent peak anode current	150 ma max.
Instantaneous surge current	500 ma max. 1 sec.

Germanium crystal diodes permit the construction of rectifying probes which have low input capacitance, but they will not withstand as much input voltage as does a tube diode. The maximum a-c voltage which should be applied to the input of a conventional rectifier probe that employs a 1N34 germanium crystal diode is approximately 20 volts rms, or 28 volts peak. If a d-c component is present, it should not exceed the voltage rating of the series capacitor in the rectifier circuit. On the other hand, a tube diode used in such an application can be used with input voltages in excess of 100 volts (see Table 6-2). When necessary, a number of crystal diodes may be connected in series to raise the maximum voltage capability of the rectifier.

The 1N34 germanium diode characteristic illustrated in Fig. 6-12 is an *average* characteristic. The characteristic of a specific crystal diode unit depends on the particular germanium crystal used, the contact, the contact pressure, etc. Consequently, the characteristics from unit to unit, especially the forward resistance and the back resistance, will be found to show comparatively large variations. Variations in crystal forward resistance affect the calibration of the associated meter directly if a simple series rectifying circuit is used, but if a peak-indicating rectifying circuit is employed, only the small difference between the peak applied voltage and the developed d-c voltage depends upon the crystal characteristics.

The standard schematic symbol employed for a crystal diode is shown in Fig. 6-13A, alongside of that for a tube diode, for comparison. It can be seen

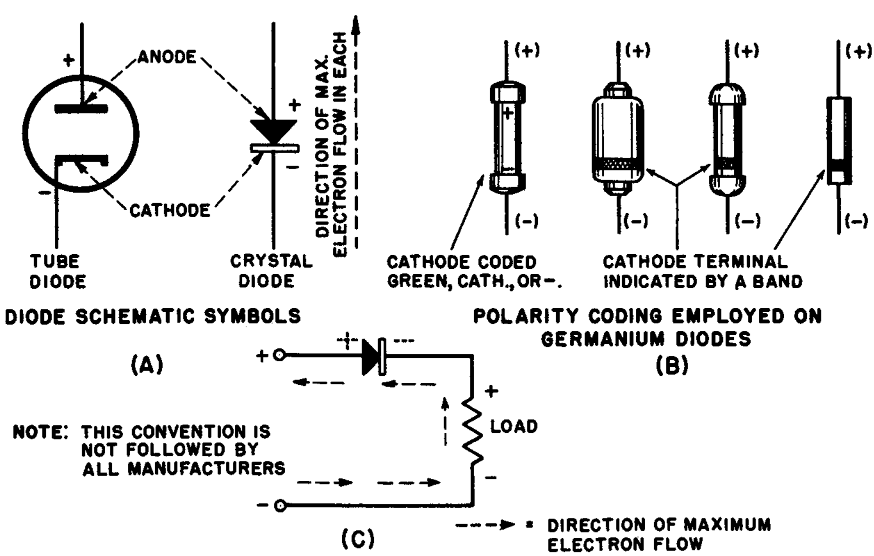


Fig. 6-13. (A) Standard crystal-diode and tube-diode symbols arranged side by side for comparison. The direction of maximum electron flow is from the cathode to the anode, inside the diode, in both types. The arrow in the crystal diode symbol thus points opposite to the direction of the maximum electron flow within the diode. (B) The polarity coding employed on various models of germanium diodes. The cathode terminal is always indicated by either a minus sign or a colored band. The polarity coding on germanium diodes indicates the voltage polarity that must be applied to obtain maximum current flow. (This should not be confused with the polarity coding of selenium rectifiers, which is the output polarity developed across a load.)

TABLE 6-3

COMPARISON OF IMPORTANT PROBE-PERFORMANCE FACTORS OF CRYSTAL DIODES & TUBE DIODES

Performance Factor	*Crystal Diodes*	*Tube Diodes*
Contact potential	None	Enough to require a bucking-voltage circuit
Input resistance (forward direction)	Low (order of a few hundred ohms)	High (ranges from 15,000 to 120,000 ohms)
Back resistance	Relatively low (100,000-to 200,000-ohms range)	Very high (open circuit)
Tolerance on characteristics	Fairly wide variation from one unit to another	Greater uniformity
Max. permissible input voltage	20 v rms for 1N34	Approx. 117 to 300 v
Susceptibility to voltage-overload damage	Quickly damaged	Less easily damaged
High-frequency response	Good	Poorer, due to transit time
Small-signal Efficiency	Good	Poorer, due to less curvature of characteristic
Ability to make relative-value readings above resonant frequency of probe	Good	Poor, due to variation of transit time with signal level
Temperature stability	Relatively poor	Good

that the direction of maximum internal electron flow is from the cathode to the anode in each case. The standard polarity coding employed on germanium diodes is illustrated in Fig. 6-13B. Important details concerning both are explained in the caption. The polarity of the d-c voltage developed across a load connected in series with a crystal diode is shown in Fig. 6-13C.

The pertinent performance factors of the types of crystal diodes and tube diodes that are commonly employed in rectifying and demodulating probes are presented here in Table 6-3 for direct comparison and study.

6-13. Series-Type Peak-Indicating Crystal-Diode Rectifying Probe

The *series* type of rectifying circuit utilizes the diode rectifier in series with the input circuit.

(*1*) *Single-Ended Type.* Two versions of this type of circuit arranged as a probe for use with a vtvm are shown in Fig. 6-14. In the simplified version in part A of the figure, the crystal diode feeds directly into the shielded test cable whose internal capacitance *C* serves as the charging capacitor. This simplified construction avoids the loss due to voltage drop in the isolating resistor *R1* in Fig. 6-14B, but it is not useful at frequencies above which the cable operates as a tuned stub (usually above the i-f frequency range), because the pulsating rectified output voltage undergoes sharp increases and decreases at some frequencies due to resonance effects which occur in the cable. Also, the value of *C* is not easily controlled.

The rectified current which flows through the crystal diode on alternate half cycles charges capacitance *C* to almost the peak value of the a-c input voltage. The capacitor discharges through the d-c voltage-divider resistance of the vtvm, and also through the path presented by the back resistance of the crystal diode, during the remainder of the cycle. The resulting d-c voltage developed across the d-c voltage divider of the vtvm is applied to the d-c bridge tube in the vtvm for measurement. Obviously, the time constant of the R-C circuit must be made long enough to produce a smooth d-c output voltage for a-c input voltage of any frequency within the rated frequency range of the instrument.

This is a peak-indicating rectifying circuit, and whether the vtvm will indicate the positive-peak, or the negative-peak, value of the a-c input voltage depends upon which way the crystal diode is connected into the circuit. If it is connected with the polarity as indicated by the crystal-diode symbol in Fig. 6-14A, the probe will respond to the *positive-peak* value of the input voltage,

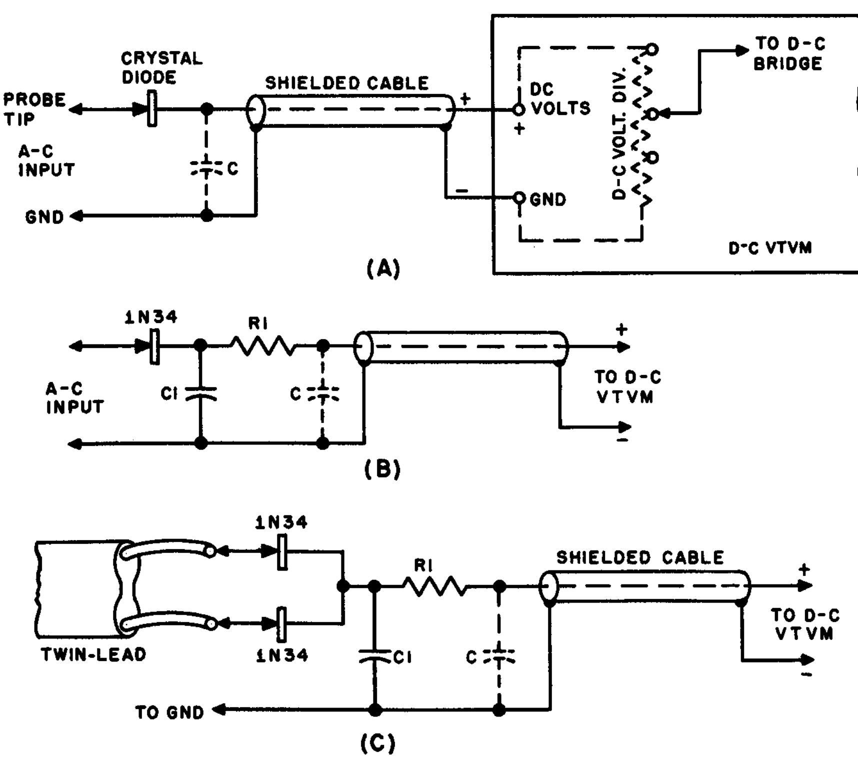


Fig. 6-14. Three versions of the series type crystal-diode peak-indicating rectifying circuit arranged in a probe for use with a vtvm. The double-ended circuit in (C) is useful for checking voltage in a 2-wire transmission line.

for the diode will be conducting only during the half cycles when the probe tip is *positive* with respect to the Gnd terminal. The center lead of the shielded cable will be *positive* under this condition, so that the vtvm must be set accordingly. No output is produced by this probe if a series of negative pulses are applied. If the diode were to be connected into the circuit with its polarity the reverse of that shown here, the probe would respond to the *negative-peak* value of the input voltage, and the center lead of the shielded cable would be *negative.*

An improved, preferred arrangement of the series-rectifying circuit in which a charging capacitor, *C1,* and an isolating resistor, *R1,* are used is shown in Fig. 6-14B. This is useful to higher frequencies, because isolating resistor *R1, C,* and *C1,* form a low-pass filter which helps to prevent voltage pulses from entering the shielded cable, hence cable resonance effects are minimized. (Resistor *R1* may be made to serve also as a calibrating resistor for the vtvm.)

Neither arrangement is suitable for uses in which a d-c component is present along with the a-c voltage, because this will cause the crystal diode to be damaged or to bias off, thereby causing the a-c operating-voltage swing to occur over a region of the characteristic curve that may produce very incomplete rectification or, even none at all.

The series rectifier arrangement has the advantage of providing minimum input capacitance to the probe.

(2) *Double-Ended Series-Type Peak-Indicating Rectifying Circuit.* The series-type crystal-diode rectifying circuit is often used by the technician in the form illustrated in Fig. 6-14C. The double-ended probe is used to measure voltages on 2-wire transmission lines, for example, and is useful because it applies a minimum of input capacitance across the line under test, and causes the least disturbance of line impedance. It is quite possible to use a shunt type of rectifying arrangement to measure transmission line voltages, but the stray capacitance and input capacitance are greater, and since d-c voltages are seldom present in the line, the series arrangement is practical and to be preferred. The two crystal diodes do not conduct simultaneously. Insofar as the instantaneous voltages which appear across the line are concerned, when the input voltage to one diode is positive, that to the other diode is negative. These polarities alternate at the carrier frequency; hence the diodes conduct alternately. Charging-capacitor *C1* is charged alternately through the two diodes. Resistor *R1* effectually isolates the shielded cable from the high-frequency portion of the circuit.

6-14. Shunt-Type Peak-Indicating Crystal-Diode Rectifying Circuit

The shunt type of peak-indicating rectifying circuit in which a crystal diode is employed is widely used in probe form as a high-frequency rectifier for vtvm's. When so employed, it is frequently referred to by the somewhat vague term "r-f probe." The circuit is shown in Fig. 6-15, and it will be apparent at once that the circuit arrangement and operation are basically similar to that of the shunt-type tube-diode rectifying circuit described in detail in Sec. 6-3, and illustrated in Fig. 6-5. The voltage which appears across the terminals of input capacitor *C1,* as a result of the charge developed in it, constitutes a bias on the crystal diode. This shifts the operating point of the crystal to a more negative (lower current) region of its characteristic curve. The charge on the input capacitor

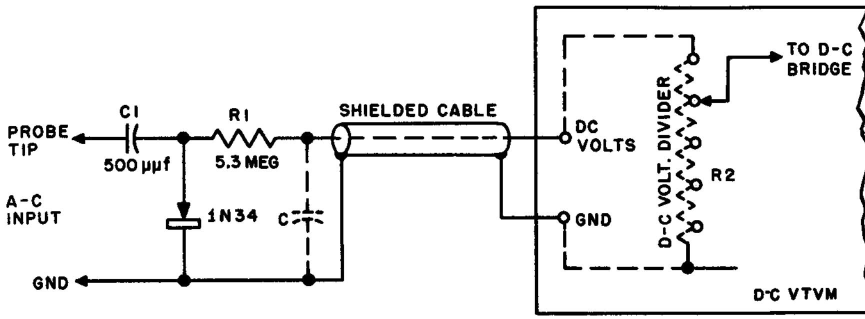


Fig. 6-15. Shunt-type crystal-diode peak-indicating rectifying circuit widely used in probe form for measuring sine-wave radio-frequency voltages with a d-c vtvm. Rectifying circuits of this type, constructed in probe form, can usually be used up to 100 to 250 mc with an accuracy of ±10%. Observe the simplicity of this arrangement—no heater-supply wiring, or contact-potential bucking-voltage circuit is required as it is when a tube type diode rectifier is employed.

escapes slowly through the parallel circuit composed of the back resistance of the crystal and *R1* plus *R2* in series. The operating level comes to equilibrium at a point where the small charging current pulses exactly equal the total leakage losses. For this reason, the input capacitor charges up to a voltage almost, but not quite equal to, the peak voltage of the applied signal.

Referring to Fig. 6-15, it will be observed that series resistor *R1* serves the important function of r-f isolation, as well as its usual calibrating function. It is plain that if *R1* were omitted, the cable capacitance, *C,* would shunt and tend to short-circuit the crystal at high radio frequencies.

Radio-frequency input voltages as high as 20 volts rms, or 28 volts peak, may be applied directly to the input of such a rectifying circuit when a 1N34 crystal diode is used. If a d-c component is present in the a-c voltage to be measured, it should not exceed the safe voltage rating of capacitor *C1,* which serves the dual role of charging capacitor and d-c blocking capacitor. The upper operating frequency range is approximately 250 mc, but the exact value depends greatly on the mechanical and electrical design of the probe.

This type of rectifying probe is customarily used to measure high-frequency sine-wave voltages when it is plugged into the D-C Volts terminals of a vtvm. It is customary to specify sine-wave voltages in rms values (0.707 of peak value). Accordingly, if the vtvm is to indicate the rms values, and these are to be read directly on the existing d-c voltage scales of the vtvm, the value of calibrating resistor *R1* must be selected so that only 0.707 of the full d-c output voltage of the rectifier circuit will be applied across the d-c voltage divider *R2* inside the vtvm. If the d-c voltage-measuring network of the vtvm is designed on the basis of using the usual circuit-isolation resistor in the "d-c probe" supplied with the vtvm (see Chapter 4), the value of this isolation resistor, which we shall call *R3,* must be added to the calculated value for *R1,* for the a-c probe will be feeding directly into the vtvm without this isolating resistor. For rms readings on the d-c voltage scales then, *R1* must equal $0.414 \times (R3+R2)+R3$. (Note: The ratio

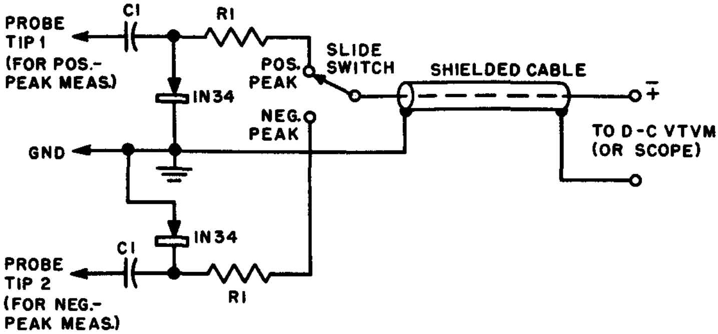


Fig. 6-16. A special peak-indicating probe arranged to provide either positive-peak or negative-peak indication, as desired. This general circuit arrangement, employing suitable values for C1 and R1, may also be employed with a scope.

between 1−.707 and .707 is 0.414.) For a 10-megohm input instrument that normally employs a 1-megohm isolating resistor in the d-c probe, $R1 = 0.414 \times (1+10)+1 = 5.554$ megohms. In practice, a slightly lower value would be used, as shown in the figure, to compensate for the fact that slightly less than peak rectification occurs.

Because of the inherent non-linearity of the crystal-diode operating characteristic at low input voltages, a special calibration is required for a-c scales on which voltages below about 1 volt are to be read.

The meter scale rms readings can be multiplied by 1.414 in order to convert to peak voltage (to which the probe actually responds).

The lowest frequency that can be handled satisfactorily by the rectifying circuit will depend on the time constant of the R-C circuit. In general, for the measurement of sine-wave voltages, the capacitance of *C1* should be not less than $C1 = 100/fR$ in order that a sufficiently long time constant be provided for adequate filtering of the output voltage (see Sec. 6-4 and Sec. 6-5).

The calculation for *C1* should not neglect the effect of the back resistance of the crystal diode in allowing some of the charge of capacitor *C1* to leak through it during the non-conducting half cycles. This back resistance, being in parallel with *R1* and *R2*, tends to shorten the time constant somewhat. With the 500-$\mu\mu$f capacitor employed, as shown in Fig. 6-15, the lowest usable frequency is in the order of 50 kc. The breakdown-voltage rating of *C1* determines the amount of d-c voltage that may be present along with the r-f signal that is to be measured. A typical value is 250 volts.

The highest frequency which can be handled is limited by several important factors related to the probe and test cable design. These are discussed in Sec. 6-21.

This probe employs a peak-indicating rectifying circuit, and whether the vtvm indicates the *positive-peak* or the *negative-peak* voltage depends on the polarity with which the crystal diode is connected into the circuit. If it is connected as in Fig. 6-15, with its cathode connected to ground, the probe will respond to the *positive-peak* value of the a-c input voltage, since the crystal diode will then conduct only during the positive half-cycles of this voltage. The center lead of the shielded cable will then be *negative* with respect to ground; so that the vtvm must be set accordingly. No output will be produced by the probe if a series of negative pulses are applied. If the diode were to be connected into the circuit with its polarity the reverse of that shown here, the probe would respond to the *negative-peak* value of the input voltage, and the center lead of the shielded cable would be *positive*.

6-15. Combination Positive-Peak or Negative-Peak Probe

The foregoing principles may be applied in a special form of peak-indicating probe designed to provide, conveniently, either positive-peak or negative-peak indication. This feature is frequently quite useful in testing the output of a signal generator. For example, one where the waveform may not be a true sine wave, and the positive and negative peaks are unequal. A switching arrangement is employed to reverse the polarity of the crystal diode for either type of indication.

Because it is impractical to switch the crystal diode (due to introduction of excessive stray capacitance in the high-frequency circuit), the polarity switching is accomplished in the output d-c network, and two crystal diodes are employed as shown in Fig. 6-16. Each of the diodes is connected to an individual probe tip, so that the input capacitance to either of the diodes is no greater than in the case of a simple single-diode probe.

For use with a vtvm, *C1* and *R1* may have values of approximately 0.01 μf and 5 meg, respectively. For scope use, values of approximately 0.00025 μf and 200,000 ohms may be employed in order to provide a more suitable time constant.

6-16. High-Impedance Type Peak-Indicating Crystal-Diode Rectifying Circuit

When a crystal-diode probe is used with a vtvm, the probe may excessively load down a high-impedance circuit under test and disturb its operation. In such a case, the technician needs a probe having a higher input impedance.

The input impedance may be increased by employing two or more crystal diodes in series, as shown in Fig. 6-17. The impedance of this type of crystal

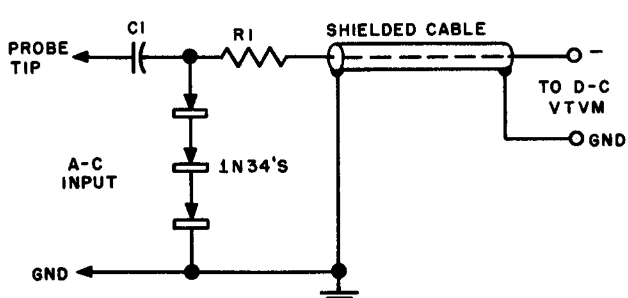


Fig. 6-17. High-impedance peak-indicating crystal probe which employs a number of crystal diode rectifiers in series.

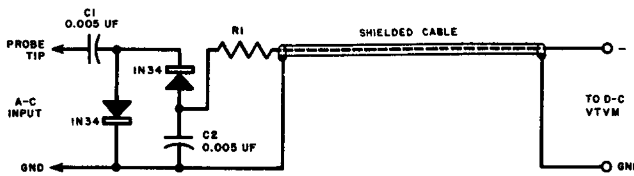


Fig. 6-18. A basic peak-to-peak indicating probe employing two crystal diodes in a voltage-doubler rectifying circuit. This arrangement is very useful in tv troubleshooting to measure the peak-to-peak voltage values of complex waveforms in order to compare them with the specified values.

probe is higher than usual because the rectifier resistance is increased by a factor equal to the number of rectifiers employed, and also because the input capacitance is decreased by the series arrangement of the rectifiers. The fact that the maximum allowable input voltage is also increased in proportion to the number of rectifiers used may be advantageous in some applications.

Several precautions must be observed in the construction of a probe of this type in order to minimize the input capacitance so that the input impedance will be high. First, a button-type capacitor should be used for *C1;* second, the crystal diodes, *C1,* and isolating resistor, *R1,* should be kept well spaced from the shield of the probe; third, a short probe tip should be used, and it should not be terminated with a test clip.

6-17. Peak-to-Peak Crystal-Diode Rectifying Probe

A peak-to-peak rectifying probe which employs two crystal-diode rectifiers in a basic cascade type voltage-doubler rectifying circuit, is shown in Fig. 6-18. The circuit action is similar to that described in Sec. 6-8 and Sec. 6-9, and illustrated in Fig. 6-7 for the tube-diode voltage-doubler rectifier. As before, a calibrating resistor *R1* is included, and this also serves the function of minimizing disturbances due to cable resonances within the rated frequency range of the probe. The calibrating resistor value is chosen so that when operating in conjunction with the input resistance of the vtvm, the rms value of a sine-wave voltage is indicated directly on the d-c voltage scales of the vtvm (see Sec. 6-9).

A voltage-doubler peak-to-peak probe has a considerably lower input impedance than a peak-indicating type probe, and its application may accordingly be limited to medium and low-impedance circuit testing. The voltage-doubler probe also has a more limited frequency response. The maximum allowable input voltage is approximately the same as for a peak-indicating probe using the same type of rectifier. The various considerations concerning pulse-response capability, which are discussed in Sec. 6-10, apply to the crystal-diode type of peak-to-peak probe as well as the tube-diode type.

Before undertaking to make peak-to-peak voltage measurements using a crystal-diode type voltage-doubler probe in combination with a particular vtvm, the operator should check the scale indication of his vtvm against a known source of peak-to-peak voltage in order to determine the attenuation factor of the probe. Since the input resistance of various vtvm's is different, and since the front-to-back resistance ratio of individual crystal diodes is different, the voltage-doubler probes should be individually calibrated for insertion loss.

6-18. Combination Peak and Peak-to-Peak, Crystal-Diode Rectifying Probe

The peak-to-peak crystal-diode rectifying circuit can be provided with a switch to make available a choice of positive-peak or negative-peak, and peak-to-peak voltage measurements, by means of an arrangement such as that shown in Fig. 6-19. The switching takes place on the d-c side of the rectifying circuit and thus does not impair the frequency response of the probe.

When the circuit-selector switch is set at the *P* position, the rectifier circuit will respond on the basis of the positive-peak voltage. If calibrating resistor *R1* has the proper resistance value, so that 0.707 of this peak voltage is applied to the vtvm, the vtvm will indicate the rms values directly on the d-c voltage scale (for sine waves only). However, even if the input voltage waveform is nonsinusoidal, the scale indication is still meaningful if multiplied by 1.414 to yield the positive-peak voltage of the applied signal.

When the switch is set at the *P-P* position, the circuit operates as a voltage-doubler rectifier and the rectifier circuit responds on the basis of the peak-to-peak value of the input voltage, regardless of its waveform. Resistor *R3* is made equal to the value of the isolating resistor employed in the "d-c probe" of the d-c vtvm. The vtvm then indicates peak-to-peak values directly on the d-c voltage scale. The negative-peak voltage may be obtained by first calculating the positive-peak value as explained above, and then subtracting this from the measured peak-to-peak voltage.

6-19. VOM R-F Peak-Indicating Rectifying Probe

The a-c voltage-measuring function of a typical service-type non-electronic vom usually employs a built-in copper-oxide rectifier. The frequency response of such a combination decreases gradually as the frequency increases. In a typical case, the readings obtained on a 20,000 ohm-per-volt vom decreased to 70 percent of the correct value at a frequency of 60 to 90 kc (depending on the voltage amplitude being measured). However, a conventional simple crystal-diode peak-indicating type rectifying circuit, built in the form of an external probe, can be used in place of the copper-oxide rectifier. In this case, the vom becomes a very handy instrument for indicating the presence, or comparative values, of

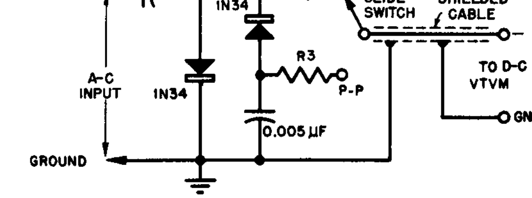


Fig. 6-19. Crystal-diode probe switching arrangement for obtaining either the peak value, or the peak-to-peak value, of a complex waveform. By providing a vtvm with such a probe, some of the facility afforded by a scope is realized. Although the probe-plus-vtvm combination does not give information concerning details of the waveshape, it can be used to reveal any dissymmetry which may be present, by developing information concerning the positive-peak voltage, the peak-to-peak voltage, and hence also, the negative-peak voltage of the waveform.

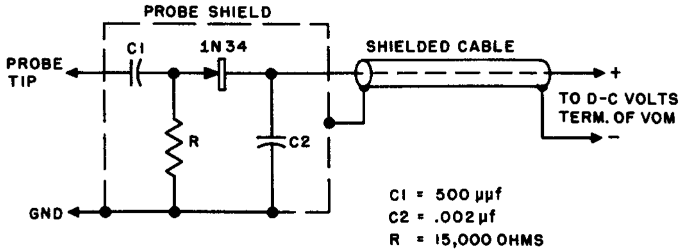


Fig. 6-20. R-F probe which makes possible the use of a service-type vom for indicating the presence, or comparative values, of r-f voltages of almost any waveform.

r-f voltages of almost any waveform. Such voltage indication is useful in some signal tracing and other work when it is necessary only to determine the presence, absence, or relative magnitudes of a signal across certain test points of medium or low impedance in the equipment under test.

A peak-indicating rectifier suitable for this purpose when used with a vom of at least 5,000 ohms-per-volt sensitivity, is illustrated in Fig. 6-20. Its output is connected to the D-C Volts terminals of the vom.

The input resistance of this combination is necessarily quite low because of the comparatively large current drain imposed by the low-voltage ranges of the vom that would be used (as compared with the current drain of a d-c vtvm). As a result, it appreciably loads any high-impedance voltage source to which it is applied. Consequently, the actual voltage readings obtained when checking such circuits, are likely to be so far below the potentials actually present before the combination is applied that any attempt at actual r-f voltage calibration of the meter for use in such circuits is useless. Consequently, use of the combination must be limited to r-f voltage-presence and relative-strength indications only, for such circuits. However, if the meter is suitably calibrated, measurement of r-f voltage in low-impedance circuits, such as signal-generator output cables, etc., can be accomplished satisfactorily.

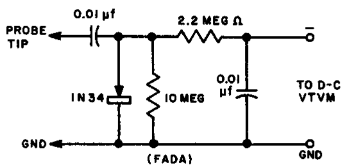
6-20. Typical Shop-Constructed VTVM R-F Rectifying Probes

Peak, and peak-to-peak rectifying probes for use with d-c vtvm's are available in manufactured form, or they may be assembled by the service technician to meet his own requirements. The schematic circuit diagrams of a number of very useful shop-constructed vtvm probes recommended by tv receiver manufacturers are shown in Fig. 6-21. They are designed to have the various operating characteristics specified, and perform useful functions in tv receiver service work.

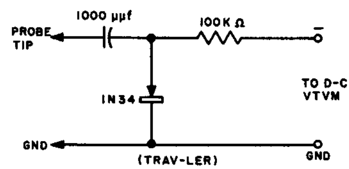
If these probes are employed for voltage-presence or relative-strength indications only, no calibrating resistor need be used with them. However, if actual voltage measurements are to be made, a calibrating resistor whose value depends on the input resistance of the vtvm with which the probe is to be used will be required. The method of calculating the value required for peak, and for peak-to-peak, indicating circuits is explained in the sections of this chapter devoted to these types of circuits. Probe construction details are discussed in Sec. 6-22, and measurement accuracy considerations are explained in Sec. 6-23.

6-21. High-Frequency and Low-Frequency Operating Characteristics of VTVM Rectifying Probes

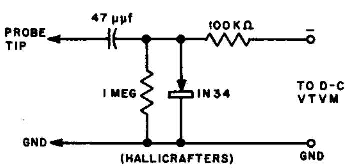
The a-c voltmeter function of many modern vtvm's that employ a built-in rectifying circuit is suitable for accurate voltage measurement over a frequency range whose upper value is only 15,000 cycles in one service-type instrument, and approximately 3 mc in several other models. One of the chief reasons for this limited frequency range is that the r-f energy to be measured must pass through



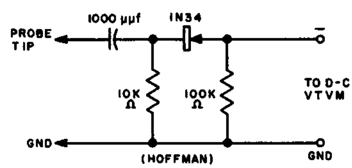
HIGH IMPEDANCE, HIGH SENSITIVITY, PEAK-INDICATING TYPE. SHUNT RECTIFIER. CAN BE USED DOWN TO RELATIVELY LOW FREQUENCIES.



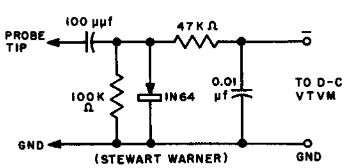
HIGH IMPEDANCE, HIGH SENSITIVITY, PEAK-INDICATING TYPE. SHUNT RECTIFIER. INTENDED FOR HIGH-FREQUENCY APPLICATIONS.



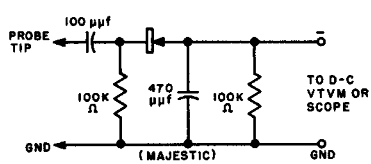
HIGH IMPEDANCE, RELATIVELY HIGH SENSITIVITY, PEAK-INDICATING TYPE. SHUNT RECTIFIER. INTENDED FOR HIGH FREQUENCY APPLICATIONS.



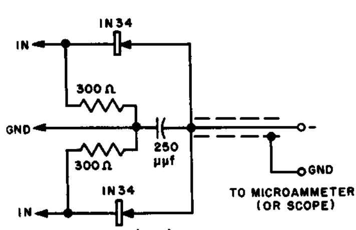
MODERATELY HIGH IMPEDANCE, MEDIUM SENSITIVITY, PEAK-INDICATING TYPE. SERIES RECTIFIER. INTENDED FOR HIGH-FREQUENCY APPLICATIONS.



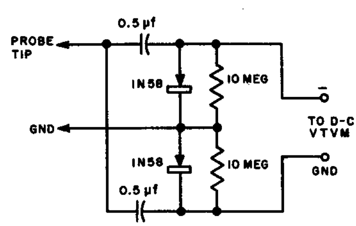
RELATIVELY HIGH IMPEDANCE, MEDIUM-HIGH SENSITIVITY, PEAK-INDICATING TYPE. SHUNT RECTIFIER. INTENDED FOR HIGH-FREQUENCY APPLICATIONS.



(PEAK-INDICATING OR DEMODULATOR PROBE – DEPENDING UPON SIGNAL FREQUENCY). RELATIVELY HIGH IMPEDANCE AND SENSITIVITY. SERIES RECTIFIER.



BALANCED-INPUT LOW IMPEDANCE, RELATIVELY LOW SENSITIVITY, PEAK-INDICATING TYPE. BALANCED SHUNT RECTIFIER. MICROAMMETER OR SCOPE INDICATOR. USEFUL FOR CHECKING STANDING-WAVE RATIO ON LINE, IMPEDANCE MATCH, FLATNESS, ETC.



PEAK-TO-PEAK INDICATING PROBE, MEDIUM-HIGH SENSITIVITY. SHUNT RECTIFIERS, VOLTAGE-DOUBLER CIRCUIT. INTENDED FOR P-P MEASUREMENT OF COMPLEX WAVEFORMS.

Fig. 6-21. A number of useful shop-constructed r-f rectifying probes for use with d-c vtvm's in tv receiver servicing, as suggested by the various tv receiver manufacturers noted.

TABLE 6-4

EFFECT OF RECTIFIER ARRANGEMENT ON INPUT RESISTANCE & CAPACITANCE OF VTVM's

	Input Resistance and Capacitance	
VTVM	With built-in tube-diode rectifier, using direct shielded test cable supplied	*With r-f rectifying probe*
A	2.7 meg shunted by 194 $\mu\mu$f	2.3 meg shunted by 3 $\mu\mu$f*
B	0.275 meg shunted by 210 $\mu\mu$f	Shunting capacitance 2.5 $\mu\mu$f**
C	From 0.83 meg shunted by 70 $\mu\mu$f to 1.5 meg shunted by 60 $\mu\mu$f (depending on voltage-range selector setting)	6,000 ohms shunted by 1.75 $\mu\mu$f (at 200 mc)**
D	From 0.2 meg shunted by 75 $\mu\mu$f, to 2 meg shunted by 50 $\mu\mu$f	6,000 ohms shunted by 1.75 $\mu\mu$f (at 200 mc)**

* = tube-diode type rectifiers used in probe
** = crystal-diode type rectifier used in probe

the shielded test cable before it reaches the rectifying circuit. The shunting effect of the comparatively large distributed capacitance (ranging between approximately 50 and 200 $\mu\mu$f) of the cable causes appreciable attenuation of the input voltage as the frequency of the voltage undergoing measurement increases. Quite aside from this is the appreciable error introduced by the severe circuit-loading and detuning effects which the comparatively low input-impedance of such a test cable causes if it is applied to most types of high-impedance r-f circuits (see Chapter 3).

These difficulties are partially overcome by the exterior-probe arrangement where the rectifying circuit is brought as close to the point of measurement as is feasible thus eliminating the long connection circuit between the r-f voltage source and the rectifier. This reduces the input capacitance to a very much lower value, and at the same time reduces resonance effects in the test cable since the test cable now serves to conduct mainly filtered rectified current instead of the r-f energy. The data in Table 6-4 is compiled from the manufacturers' specifications for several representative service-type vtvm's which employ a built-in rectifying circuit for a-c voltage measurements over the lower-frequency range of the instrument, and use an exterior rectifying probe for voltage measurements over the higher-frequency range to several hundred megacycles. It serves to illustrate the marked reduction in input capacitance (with resulting increase in input impedance) that is achieved mainly by arranging the rectifying circuit in an exterior probe. Thus, the r-f rectifying probe not only presents a means of measuring higher-frequency r-f voltages more accurately, but with proper design its input impedance may be kept high so that it presents a comparatively light load to the a-c circuit under test. The amount of error due to circuit loading is dependent, of course, on the impedance of the source of the a-c voltage being measured.

(1) *High-frequency Response Characteristics.* At high frequencies, the rectifying probe circuit becomes complex due mainly to stray capacitances. As a result of the complex circuit, the effective input capacitance and impedance fall to relatively low values at very high frequencies, and if the frequency is increased sufficiently, the output voltage from the probe eventually drops to zero. This is illustrated in Fig. 6-22. At frequencies where both vary with the frequency, the probe presents a complex, low-impedance, non-linear circuit to the source of voltage under test.

Some rectifying probes are subject to important residual resonances (especially above 100 or 200 mc) before the input impedance drops to an excessively low value. This resonance will cause excessive peaks and valleys in the high-frequency characteristic of the probe, with the result that the voltage indication on the vtvm becomes higher or lower than the actual value of the voltage under test.

The cause of these resonances is that at very high frequencies even a short length of connecting lead develops appreciable inductive reactance, which, in combination with the stray capacitance of the circuit produces series and parallel resonant conditions within the probe at various frequencies. The crystal or tube diode also has a resonant frequency, depending upon the particular type and unit employed. The magnitude of the resonance peak (and occasionally its existence) will vary with the applied voltage. For example, the percentage of error due to development of a resonant peak at 200 mc can vary from 0 percent at 5 volts, to 10 percent at 0.5 volt, in a typical case. As a rule, the frequency at which a rectifying probe begins to exhibit resonance effects is considerably higher for a crystal-diode type probe than for a tube-diode type. If the instrument is to be used only as an indicator of the presence of, or the relative values of, r-f voltage, such resonance conditions do not limit its usefulness, and it can be used

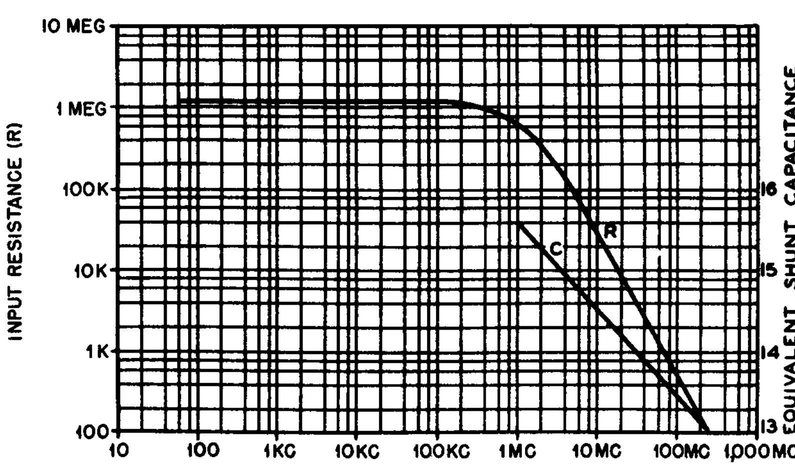


Fig. 6-22. Variation of the effective input resistance and capacitance, with frequency, for a peak-to-peak rectifying probe employing a 6AL5 twin-diode rectifier. *Courtesy: RCA*

(A)

(B)

Fig. 6-23. (A) R-F crystal-diode rectifying probe provided with its own shielded cable end connector for attaching to the D-C Volts terminal of the vtvm. The short ground lead and clip are attached to the metal end-shell. (B) Separable type of r-f crystn-diode rectifying probe designed to be slipped onto the standard direct probe and shielded cable used with all models of RCA Volt-Ohmyst vtvm's. This probe has a rated frequency range of 50 kc to 250 mc. Its interior construction is illustrated in Fig. 6-11. (*A*) *Courtesy: Precise Development Corp.* (*B*) *Courtesy: RCA*

at frequencies up to and beyond those for which accurate voltage *measurement* is possible.

In general, use of good-quality high-frequency type capacitors and resistors, short leads, a short probe tip and a short input ground lead, careful physical layout of the components and wiring, and design of the probe head for minimum stray capacitance and minimum r-f dielectric losses (which increase with frequency), will appreciably push up the higher frequency limit to which the probe is useful for voltage measurement. Comparatively inexpensive, well-designed probes of this type with frequency ratings ranging up to approximately 300 mc are available. More costly probes containing special design refinements are available with a much higher rated useful range to approximately 3,000 mc.

One method frequently used to increase the useful frequency range of an existing probe is to reduce its input stray capacitance by removing the probe tip and using an external small button-type high-frequency capacitor instead of the series capacitor which is ordinarily built into the tip of the probe. One lead furnished with the button-type capacitor is cut off as short as is practicable, and is used as the probe tip. The other one is connected to the center conductor of the probe.

The upper limit of frequency response when a tube-diode is used as the rectifier is also determined by transit-time action (see Sec. 6-11). When the time of transit of the electrons from cathode to anode becomes appreciable with respect to the time of a signal cycle, the input resistance of the probe falls to a low value. The higher the operating frequency, the lower is the input resistance of the probe. It is found that the effect of transit time depends upon the signal voltage as well as the signal frequency. When the anode voltage is high, the electrons travel faster, and the effect of transit time is lessened.

If a tube-diode is employed as the rectifier, use of one of the newer types of miniature diodes designed especially for operation at uhf (see Table 6-2 in Sec. 6-11) will provide a rectifier having very short electron-transit time, low anode-cathode capacitance, and a high resonance frequency.

(2) *Low-Frequency Response Characteristics.* At frequencies below some nominal value, depending on the effective time constant of the R-C circuit consisting of charging capacitor *C1* and the load resistance, the rectified d-c output of the particular probe, and the meter indication, gradually fall off. This occurs, because at the lower frequencies the time constant becomes shorter in comparison with the time required for the applied voltage to go through one cycle (see Sec. 6-5). This attenuation can be reduced by the use of a larger value for charging capacitor *C1*, but this results in an increase in the physical size of the capacitor, with resultant increase in the stray capacitance to it. Consequently, the input capacitance of the probe is increased thereby and the high-frequency response will be decreased. It is evident that a compromise must be effected in the final design, depending on whether the low-frequency or the high-frequency response is the more important for the intended applications of the probe.

This low-frequency attenuation does not limit the usefulness of the instrument at low frequencies if it is to be used as merely an indicator of the presence, or relative-values, of voltages, as in signal-tracing work.

6-22. Design and Construction of Conventional Rectifying Probes

The most important considerations in the mechanical and electrical design of the probe have been discussed in Sec. 6-21, especially as regards the necessity for minimizing inductance and stray capacitances. A metal shell usually encloses and shields the rectifier and associated circuit components. (A test to determine the adequacy of the shielding is explained later in Sec. 7-16.) The ground lead from the probe should be kept as short as possible when high-frequency voltages are being measured. For low-frequency measurements, where lead inductance and stray capacitances are not quite so important, a longer ground lead, or even a longer probe tip, may be employed if these facilitate the use of the probe.

In general, ½-watt resistors will suffice for the probe, unless otherwise specified. They should preferably be of the metalized-ceramic or similar type whose distributed capacitance and dielectric losses are low, with resultant improvement in their high-frequency characteristics. It should be remembered that the effective resistance of some types of resistors decreases quite markedly as the frequency is increased above approximately 20 mc. The capacitors also should be of the high-frequency variety having minimum inductance and losses. The resistors and capacitors should be as small in physical size as is practicable, and the layout of all parts and wiring in the r-f portions of the circuit should be such that all distributed capacitances are reduced to a minimum. Polystyrene or polyethylene insulation should be employed on those parts which carry r-f energy, in order to keep high-frequency dielectric losses to a minimum.

Two arrangements with respect to the test cable are in common use. One provides the probe with its own test cable and end connector which must be of

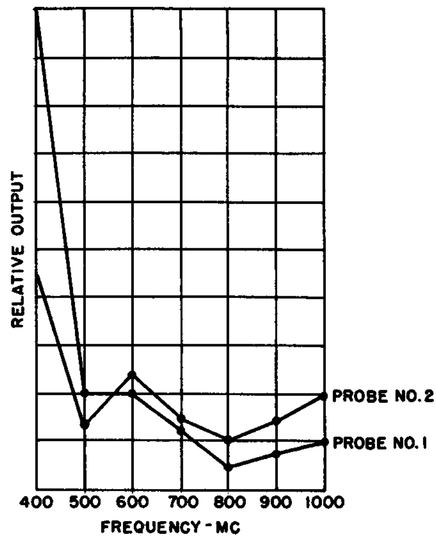


Fig. 6-24. Actual response of two typical commercial r-f crystal-diode rectifying probes at uhf. These probes, which are designed for application in the 30- to 300-mc vhf range, develop sharp peaks and valleys in the response characteristic, due to multiple resonances, and also an appreciable drop in output, when used in the uhf range. The input impedance of such probes is also very low at uhf.

a type to match the D-C Volts terminal provided on the d-c vtvm with which the probe is to be used (see right-hand column of Table 1-3 in Sec. 1-4). A commercial rectifying probe of this type is illustrated in Fig. 6-23A. When d-c voltage measurements are to be made, the cable of the d-c probe (which usually contains the isolating resistor as explained in Chapter 4) is attached to the D-C Volts terminal of the vtvm. For r-f voltage measurements, the end connector of the rectifying probe cable is attached to this terminal instead.

In the arrangement illustrated in Fig. 6-23B, the auxiliary rectifying probe is made in separable slip-on form designed to be slipped onto the standard direct probe and cable that is used with the instrument for all d-c voltage measurements. This construction makes it unnecessary to change the probe cable connections at the vtvm when changing from d-c to r-f voltage measurement.

6-23. Rectifying-Probe Insertion Loss and Measurement Accuracy

Before undertaking to make voltage *measurements* with a d-c vtvm to which an external shop-constructed, or separately purchased, rectifying probe has been added, the operator should determine the attenuation factor or *insertion loss* introduced by the probe. This may be done by checking the scale indication of the vtvm against the value of a known source of peak, or peak-to-peak voltage, when the latter is applied to the probe input. Any such insertion loss is added to the inherent error of the instrument. For example, if a d-c vtvm whose accuracy is ±3 percent is used with a peak-to-peak probe whose accuracy is ±2 percent, the accuracy of the combination may be ±5 percent.

The pulse-response capability of a p-p probe and vtvm combination may also have to be taken into consideration if the p-p voltage of very narrow pulses of low repetition rate are to be measured (see Sec. 6-10). For example, a d-c vtvm having an accuracy of ±3 percent may be used with a peak-to-peak rectifying probe having an accuracy of ±2 percent. Narrow pulses are applied to the input of the probe, and reference to a chart supplied by the vtvm manufacturer shows that the pulse width and pulse repetition rate are such as to introduce an error of ±2 percent. The accuracy of measurement may then be $3+2+2=\pm 7$ percent.

6-24. Rectifying Probe for UHF Voltage Measurement

Well-designed conventional crystal-diode rectifying probes intended for use in the uhf band generally remain non-resonant "flat" at frequencies below 100 or 200 mc, but if it is attempted to use them in the uhf region (300 mc to 3,000 mc) such probes develop multiple resonances resulting in sharp peaks and valleys in the frequency characteristic, and their output also decreases very appreciably, as shown in Fig. 6-24. The input impedance of a conventional probe of this type is also very low at uhf.

It is generally recognized that application of probes of conventional construction at frequencies appreciably above 100 mc is difficult because of the attenuation, resonances, and radiation of the exposed leads. At the higher frequencies, it is almost mandatory that measurements be made on voltages which are confined to transmission-line circuits. For use in the thousands of megacycles range, the probe arrangement may be conveniently built into a coaxial line as

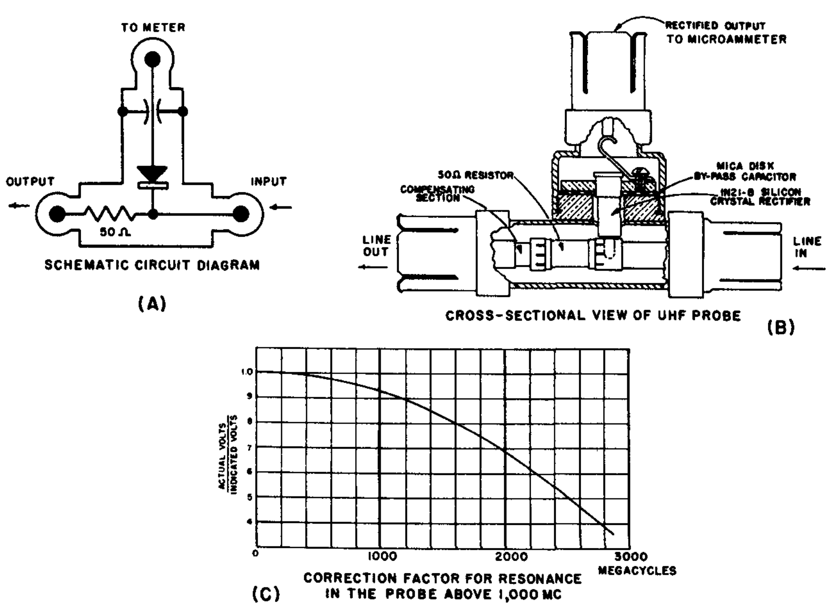


Fig. 6-25. When uhf voltages are to be measured with accuracy, it usually becomes necessary to build the rectifying probe in the form of a coaxial-line arrangement, as shown here. The resonant frequency of this particular unit is approximately 3,600 mc. The working-frequency range for voltage measurement is 15 mc to 2,500 mc, subject to resonance correction above 1,000 mc as provided by the chart in (C). Indications of the presence of voltage and correct voltage ratios, can be obtained at frequencies both lower and higher than this range. The maximum voltage input rating is 2 volts. *Courtesy: General Radio Co.*

is done in the General Radio 874-VR voltmeter rectifier illustrated in Fig. 6-25. This arrangement consists of a short coaxial line with a 1N21B silicon crystal-diode mounted in the inner conductor leading to the meter, and with a 50-ohm cylindrical resistor in series with the line inner conductor at the output end. A bypass capacitor is incorporated in the crystal mount.

The crystal rectifies the high-frequency voltage applied across the line, and the rectified output is brought out to a coaxial connector which feeds it to a microammeter that is suitably calibrated. Placed in a coaxial system, the rectifier can also be used to monitor voltage levels. The 50-ohm resistor provides an effective termination for a 50-ohm cable or line extension connected to the resistor end of the unit, so that at the far end of the cable or line extension, the open-circuit voltage equals the voltage at the crystal, less attenuation, and the effective source impedance is 50 ohms. The resistor can be replaced by a suitable metal tube if no termination is desired.

A separate voltmeter indicator is used to provide a means for measuring the voltage by a substitution method. It includes a 60-cycle circuit for calibrating the crystal at any desired level between 0.1 volt and 2 volts, so that the accuracy of the voltage measurement is independent of the crystal characteristic.

6-25. VTVM Rectifying-Probe Selection and Application Hints

(1) *Probe Selection.* VTVM rectifying probes find wide application in making signal-generator and oscillator r-f output measurements, checking receiver stage gain, tracing signals, locating spurious oscillations, and many other servicing operations in radio, tv, and other electronic equipment. One of the first precautions to be observed in probe selection for a particular voltage measurement application is to use a peak-indicating type probe only when the peak value, or the rms value, of sine-wave voltages is to be measured. When it is desired to measure directly the peak-to-peak value of complex waveforms (or the rms value of sine-wave voltages), a peak-to-peak indicating type probe, or a positive-peak negative-peak probe, should be employed. The reasons for this are fully explained in Sec. 6-8.

The second precaution to be observed is to make certain that the maximum voltage which can be safely applied to the probe, and the frequency range throughout which its indications are reliable, will not be exceeded by the voltage under test. The maximum voltage and frequency-range ratings specified by the probe manufacturer should be ascertained and not exceeded. It should be remembered that there is no voltage divider ahead of the rectifier in a vtvm probe; the full voltage under measurement is applied to the rectifier input circuit.

Most probes which employ a 1N34 crystal diode have a maximum safe voltage rating of approximately 20v rms, 28 v peak, and 250 volts dc. Probes which employ tube diodes generally have maximum voltage ratings ranging from approximately 100 to 300 volts, depending on the particular unit. When higher r-f voltages are to be checked, an oscilloscope may usually be used more advantageously than the vtvm-plus-probe combination.

(2) *Probe Application Hints.* One of the most important things to be kept in mind at all times when using an r-f rectifying probe to make quantitative

measurements at high frequency, is to take every precaution to make sure that the outer shell of the probe is well grounded as close as possible to the point from which a measurement is desired, or to a common ground if possible. Also, the probe tip should make contact at a point which is the nearest available one to the point whose r-f potential is to be measured.

The physical placement of the circuit components and the wiring around the measurement and grounding points should be disturbed as little as possible by the introduction of the probe tip and the grounding clip.

Do not make any conductor extensions to either the probe tip or the grounding lead when using it for high-frequency voltage measurements, because inaccuracies will result from the added inductance and stray capacitance of even a small length of wire.

The technician who has both a peak-indicating probe and a voltage-doubler (peak-to-peak) probe available, is sometimes puzzled by the apparent ability of the peak-to-peak probe to provide *more* than double the output of the peak-indicating probe in some tests. In other tests, the peak-to-peak probe provides *less* than this amount of output. Such apparent discrepancies in operation of the two probes are due to the fact that the waveform of the voltage under test is not sinusoidal, and accordingly the wave has a greater positive excursion than negative excursion (or vice versa). The peak-indicating probe may be polarized so that it is measuring the smaller excursion of the voltage (or vice versa), which is less than half the peak-to-peak value (or vice versa). To make a meaningful check of a peak-to-peak probe against a peak-indicating probe, the operator should utilize a signal generator which provides r-f output of good waveform (small harmonic content).

A d-c vtvm may be used with any rectifying probe as a voltage *indicating* rather than a measuring device. If it is desired to use it as a voltage *measuring* device, it is necessary that the isolating resistor used in the probe be of a correct value for proper voltage division with the input voltage divider of the particular vtvm with which the probe is to be used. Its value depends on the input resistance (including that of the d-c probe normally used with the vtvm for d-c voltage measurement) of the vtvm, as explained in Sec. 6-14.

Chapter 7

DEMODULATOR PROBES

7-1. High-Frequency Response Limitations of Service-Type Scopes

The carrier frequencies of some of the test signals that it is desirable to display on a scope during visual sweep alignment and troubleshooting of the r-f, i-f, and video amplifier sections of tv receivers, are far too high to permit the conventional medium-cost service-type scope to display them directly. For example, the r-f alignment of vhf tuners may involve the use of sweep carrier frequencies in excess of 200 mc; of video i-f amplifiers, sweep carrier frequencies of approximately 20 to 50 mc; of video amplifiers, to 4 or 4.5 mc.

The majority of such present-day service-type scopes combine a relatively high deflection sensitivity (sensitivity through vertical amplifier approx. 0.01 to 0.02 volts rms per inch of deflection), which is required in practical r-f stage alignment work, with a somewhat limited vertical-amplifier frequency response that usually does not exceed 1 or 2 mc at the –3 db point. However, for some purposes most of these types of scopes are useful for frequencies somewhat beyond the ones just mentioned because their frequency-response characteristic falls off gradually. More costly wide-band scopes, which have a frequency response to 4.5 mc (or somewhat higher) at the –3 db point, and are usable at frequencies somewhat beyond this, are available. However, it will be found that the deflection sensitivity of such scopes is generally only 30 to 50 percent of that of the scopes referred to above, usually being of the order of approximately 0.03 or 0.04 volts rms per inch. This reduces their usefulness somewhat in some types of tests, for example in the alignment of r-f amplifier stages where a low signal level exists.

An answer to this problem is provided in the dual-band type of scope which provides dual bandwidth and dual sensitivity suitable for all tv servicing requirements. The specifications of a typical service type scope of this kind are as follows:

Wide Band: Frequency response flat, within –1 db, from 3 cps to 4.5 mc, with direct sensitivity of 0.035 volt rms per inch.

Narrow Band: Frequency response flat, within –3 db, from 3 cps to 500 kc, with direct sensitivity of 0.0035 volt rms per inch.

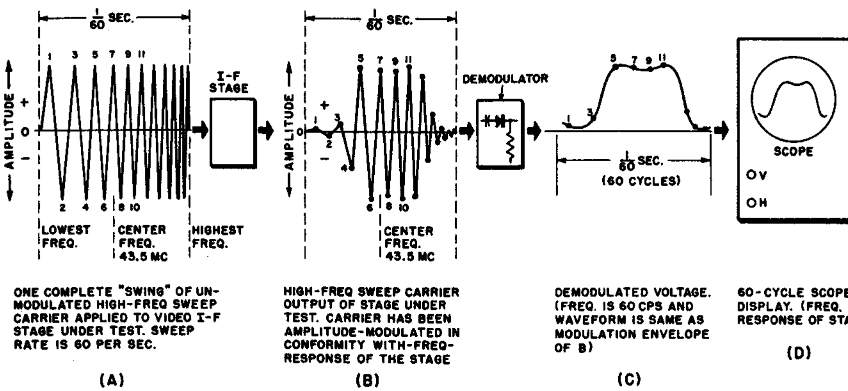
Such a scope is even suitable for checking the 3.58-mc color sync burst and the 3.58-mc oscillator signals in color tv receivers.

It is well known that a scope can be used at very much higher frequencies than those defined by the frequency-response characteristic of its vertical-deflection amplifier, provided that the signal voltage is applied *directly* to the deflecting plates of its cathode-ray tube. In fact, many scopes are arranged so that this can be easily accomplished by opening a jumper provided on the scope terminal board (or in the rear) which ordinarily connects the scope vertical amplifier to the vertical deflection plates. Service technicians often take advantage of this feature when it is necessary to make careful analyses of the equalizing pulses and the vertical pulses, or the fine detail of the horizontal sync pulse, with a scope whose vertical-amplifier frequency response is inadequate. However, in most testing and circuit-alignment procedures that involve the higher frequencies, the available voltage is not sufficient to obtain a deflection that is large enough to be useful when direct connection to the deflecting plates is resorted to, because the deflection sensitivity for this mode of operation is very low, being of the order of approximately 12 volts rms per inch in 5-inch scopes, and 24 volts rms per inch for the 7-inch size.

7-2. Function of Demodulator Probes

If the high-frequency voltage that is to be displayed happens to be *modulated,* as is usually the case, it is unnecessary to have the scope display a complete trace of each individual cycle of the high-frequency carrier. If the modulated high-frequency signal is first *demodulated* (detected), and the modulation voltage which is recovered in the process is applied to the scope input terminals, the scope will display a trace of the modulation envelope. Fortunately, this happens to be the waveform that is usually of interest to the service technician in his work. Since most of the modulation frequencies encountered in tv receiver operation and test work are comparatively low, and within the normal response ranges of the vertical amplifiers of conventional service-type scopes, the modulation voltage may be applied to the input of the vertical amplifier of the scope, and advantage may be taken of the gain provided by this amplifier. Thus, the demodulator makes possible effective testing in high-frequency circuits which would otherwise be closed to a conventional service scope.

To illustrate the typical actions which take place in an arrangement of this kind, consider the example illustrated in Fig. 7-1. The constant-amplitude sweep signal (Fig. 7-1A) having a center carrier frequency of 43.5 mc, with 5-mc deviation and a 60-cps sweep rate, is applied to the input of a video i-f amplifier stage for the purpose of checking and adjusting its response characteristic by the visual alignment method. The sweep signal which appears at the output circuit of the stage is shown in part B of the figure. Observe that it is amplitude-modulated in conformity with the response characteristic of the stage under test. Since the carrier frequency of this signal has much too high a frequency for passage through the vertical amplifier of a scope, we must demodulate it. The waveform



7-1. Operational steps in the functioning of a demodulator probe when employed to ascertain the frequency-response characteristic of a circuit to which is applied a test sweep-signal of too high a carrier frequency to be applied directly to the scope. The demodulator accepts the modulated carrier-frequency output of the circuit under test, demodulates it, and delivers the low-frequency modulation envelope as a voltage to the vertical amplifier of the scope which displays it. In the example illustrated here, the scope can display the 60-cycle output from the demodulator, although it is unable to reproduce the 43.5-mc carrier output from the circuit under test.

of the demodulator output voltage, shown in Fig. 7-1C, is substantially the same as that of the envelope of the high-frequency carrier at the i-f stage output. This waveform represents the frequency response of the stage. Since the frequency shown in Fig. 7-C is only 60 cps, it may be applied to the vertical amplifier of the scope, and a trace of this voltage, (that is, a trace of the frequency response of the stage) will be displayed on the screen.

In some of the alignment and test procedures where this problem is encountered, one of the detectors (demodulators) of the receiver happens to be conveniently located at the output of the circuit under test, in which case it may be used to perform the required demodulation. For example, if the response characteristic of the last video i-f stage, or of this stage together with others preceding it, is being checked, the video detector which follows it may be used to perform the required demodulation of the test signal. In this case, the test signal is taken off at the output circuit of this detector, and applied to the scope. However, such a detector is not always conveniently present at the output of the circuit under test. For example, if the frequency response of one of the earlier video i-f stages, or of the video amplifier, is being checked, there is no receiver detector immediately following it. In such cases, an external demodulator must usually be used ahead of the scope input terminals if the scope being employed does not have a frequency-response characteristic that is practically flat out to the carrier frequency of the test signal being employed. In order to apply this demodulator as close as possible to the high-frequency signal take-off point in the receiver, it is usually constructed in probe form.

It may be noted in passing that there are some scopes in use which have a built-in demodulator which may be switched into the input circuit of the vertical amplifier when desired. However, since a shielded test cable having a rather substantial capacitance must then be used between the demodulator input and the point of test, successful demodulation with this arrangement is limited to signals of relatively low-frequency. The majority of service technicians prefer to use external demodulator probes which may be applied directly at the point of test, since the input capacitance of the demodulator, which is applied across the circuit under test, is thereby greatly lessened.

Demodulator probes are usually built around crystal-diode rectifiers, because the crystal diode possesses desirable features such as: (1) compactness; (2) good frequency response to as high as 250 mc or more; (3) no heater involved, so a possible source of hum as well as heater wiring and heater voltage source are eliminated; (4) operation far above ground potential is possible; and (5) it has an input voltage rating that is sufficiently high for most of the ordinary applications of such probes. The crystal diodes used must be types that not only have a relatively high front-to-back resistance ratio, but are also able to accommodate reasonably high a-c signal voltages without loss of sensitivity or burn-out. The 1N34, 1N34-A and 1N48 crystal diodes are types widely used in such probes.

7-3. Basic Time Constant Requirements of the Demodulator Probe

A diode demodulator consists essentially of a diode rectifier associated with a load resistor and filter circuit. The time constant of the filter must be chosen to be sufficiently long so that the carrier-frequency variations in the output voltage are filtered out, but *not long enough* to filter out the lower-frequency variations which represent the modulation. Thus, it is evident that the essential difference between a demodulator probe, and the vtvm rectifying probes discussed in Chapter 6, is that a demodulator probe is designed to have a short time constant as compared with that of a rectifying probe, insofar as the signal to be ob-

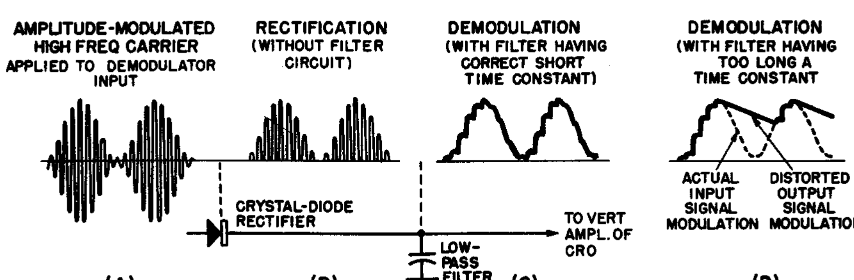


Fig. 7-2. Principle of operation of the diode demodulator, and effect of the time constant of the filter circuit on the waveform of its output voltage.

served or measured is concerned. Perhaps this may be better understood by comparing the illustrations in Fig. 6-5C, Fig. 6-6C, and Fig. 6-7C, with those in Fig. 7-2 which summarizes the action of a demodulator in some detail. Illustration D in Fig. 7-2 shows that the demodulator output actually consists of a low-frequency component superimposed on a d-c component.

Thus, a *rectifying* probe for use with a vtvm is designed to have a comparatively *long* time constant, so that it will deliver a smooth d-c output proportional to the peak (or peak-to-peak) amplitude of the carrier wave. A demodulator probe for use with a scope is designed to have a long time constant with regard to the carrier wave, but a *short* time constant with regard to the modulating wave so that it will deliver a d-c output which retains the low-frequency fluctuations which constitute the amplitude-modulation of the high-frequency carrier wave.

The time constant of the filtering circuit of a demodulator probe must fall within a suitable range for the rate of change of the modulation envelope that will be encountered in the application in which the probe is to be used. Otherwise, a distorted response trace will be obtained on the scope. If the probe time constant is too short, the output waveform will tend to follow the high-frequency carrier wave rather than the envelope. Also, the shape of the scope trace for *falls* in the modulation envelope will be correct, but it will be incorrect for rises in the modulation envelope. If the time constant is too long, even the modulation envelope tends to be smoothed out. Under these conditions, the shape of the scope trace for *rises* in the modulation envelope will be correct, but the trace will be *incorrect* for *falls* in the modulation envelope (see Fig. 7-2D).

A simple method of checking the suitability of the time constant of a demodulator probe for use with an intended test-signal is explained in Sec. 7-18.

7-4. The Series-Rectifier Type Demodulator Probe

The series rectifier, the shunt rectifier, and the voltage-doubler rectifier, whose operation is discussed in Chapter 6, are the basic circuit arrangements employed in demodulator probes. Several variations of these are employed for specialized applications. All of them will be reviewed here, with particular emphasis placed on both the desirable and the undesirable characteristics of each that may determine its suitability for specific intended applications in tv service work.

(1) Simplified Form of Series-Rectifier Probe, and its Action. The series-rectifier demodulator utilizes a crystal-diode rectifier in *series* with the input circuit. It is inherently more sensitive than the shunt demodulator arrangement. As shown in Fig. 7-3A, the simplest possible probe of this type consists of a crystal diode feeding into the capacitance, *C*, of a shielded test cable.

The capacitance of the shielded test cable together with the input capacitance of the scope, is equivalent to a shunt capacitance *C* having a value of approximately 75 to 100 $\mu\mu$f for typical service-type scopes. The crystal diode charges this capacitance as the modulation envelope rises (see enlarged detailed view in Fig. 7-2C), and little distortion is encountered in this portion of the operating cycle. Next, as the modulation envelope falls, the charged capacitance

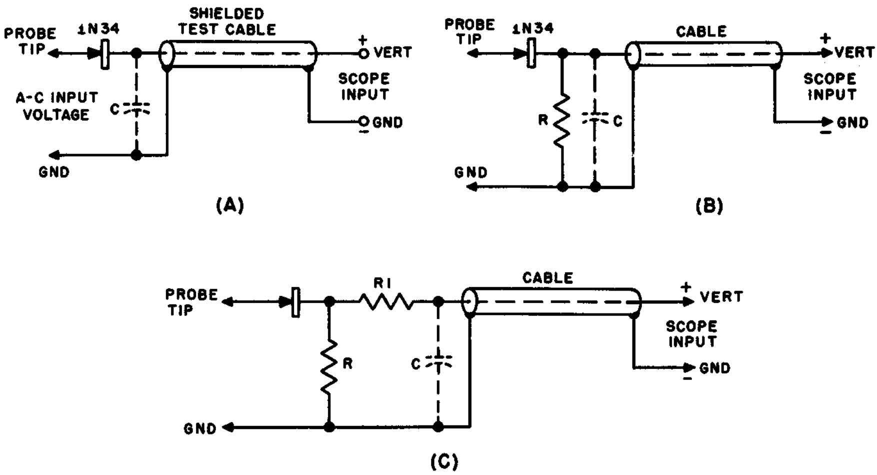


Fig. 7-3. (A) The simplest, and also the most sensitive arrangement for a conventional crystal-diode demodulator probe consists of utilizing the crystal diode as a series rectifier whose output charges the capacitance, C, of the shielded cable. (B) A bleeder resistor, R, is added to reduce the time constant of the circuit sufficiently so that effective demodulation is obtained. (C) A series isolation resistor R1 is added to provide further r-f filtering in order to remove the sawtooth ripple from the output voltage and thereby minimize possible erratic frequency-response characteristics caused by resonance and anti-resonance effects in the cable.

can discharge only through the back-resistance of the crystal and through the voltage-source resistance. If the crystal is in good condition (has a substantial front-to-back resistance ratio), and no bleeder resistor is provided, capacitance *C* tends to hold its charge as the modulation envelope drops. In practice, *C* will not hold its charge indefinitely because the crystal diode has a back resistance of approximately 100,000 ohms, and *C* discharges slowly through this back resistance and the resistance of the voltage source. (If the scope input circuit is not provided with a d-c blocking capacitor, this circuit draws some discharge current also.) However, the waveform distortion usually encountered in conventional tv test work with an arrangement of this kind is considerable, as negative-peak clipping results from the long discharge time-constant which results. Also, like any oversimplified device, such a demodulator is normally subject to several objectionable operating characteristics, such as output-waveform distortion, relatively high hum-voltage conduction, and susceptibility to shift of rectifier operating point due to a bias voltage developed by possible d-c leakage through the scope input blocking capacitor.

To overcome the negative-peak clipping condition in service applications, a bleeder resistor, *R*, is usually connected across the circuit, as shown in Fig. 7-3B. This resistor allows the charge to dissipate at a faster rate, thus decreasing the time constant of the filter circuit sufficiently so that the output voltage will definitely follow the low-frequency modulation envelope of the applied high-frequency carrier voltage (see Fig. 7-2). However, it should be remembered that a crystal diode which has a low value of back resistance may not require a

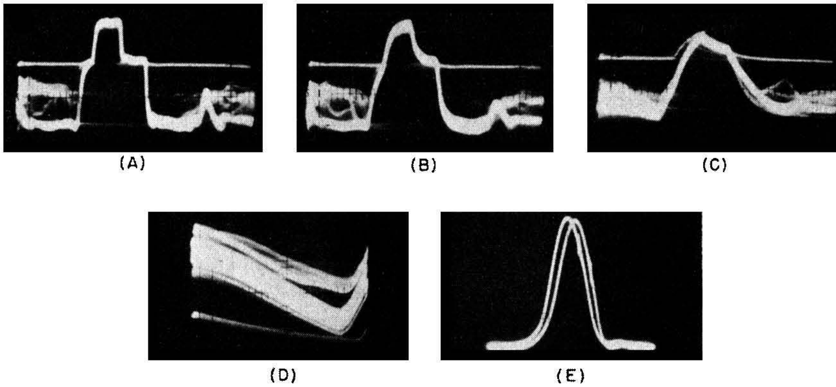


Fig. 7-4. Effects of the use of an excessively large value of isolating resistance in a demodulator probe. Progressively increased waveform distortion to which horizontal sync pulse (A) is subjected as the value of isolating resistance R1 is increased (B), increased more (C), and increased still more (D). Use of an excessively large isolating resistor also causes vertical displacemnt of the position of a marker used on the steep side of a response curve, as shown in (E). The two response traces shown here were made with different values of isolating resistor in the probe. Observe the shift in the vertical position of the marker.

bleeder, and will cause a demodulator probe to have low sensitivity if a bleeder is used.

Figure 7-2C shows the demodulation action in detail. The rectifier charges up the capacitor to the peak voltage of the high-frequency carrier cycle, and the bleeder immediately starts to discharge the capacitor; however, the charge does not fall far before the next carrier cycle peak appears and brings the charge up to that peak voltage. The output voltage thus has the shape of the modulation envelope, with a sawtooth ripple present. This ripple appears because the bleeder always discharges the capacitor a little faster than the rate of change of the envelope (at least in the normal operation of the probe.) The important consideration is that the bleeder must discharge the capacitor fast enough between successive carrier peaks to allow the output to drop as fast as any envelope drop which may occur. However, if the bleeder resistance is too small, the probe will be insensitive.

(2) *Probe-Cable Resonances and Use and Effect of the Isolating Resistor.* Sawtooth ripples present in the demodulated output of any form of demodulator probe represent r-f variations which can lead to serious disturbances in the operation of the probe at the higher r-f and i-f carrier frequencies, depending on whether the shielded-cable length happens to be an odd, or even multiple of 1/4 of the operating wavelength. Resonances and anti-resonances may occur in the probe cable at certain frequencies; see Sec. 3-2. These cause the probe to have abnormal output (increased sensitivity) at certain carrier frequencies and decreased output (subnormal sensitivity) at other frequencies. In severe cases, the output may be practically zero at some carrier frequencies, while at others the output may be several times the voltage of the input. The probe is not generally

useful above frequencies at which the resonant characteristic of the cable begin to affect the output to the scope. Consequently, it should be designed so that such abnormalities in frequency response do not occur within the carrier-frequency range over which it is intended to be used.

The sawtooth ripple variations may be removed by providing a suitable low-pass filter in the output network. Addition of isolating resistor *R1* in Fig. 7-3C may provide such a filter, with the test-cable capacitance *C* acting as the shunting capacitor. This filter isolates the shielded cable (and the scope) from the high-frequency circuit of the probe. The constants of the filter must be selected to provide adequate carrier-frequency filtering action, but not too much. If the filtering is excessive (time constant too long), a 60-cycle square-wave modulation envelope, for example, will be distorted. It will be shown later (see Sec. 7-8) that a demodulator probe used for tv circuit-alignment work must be able to pass a 60-cycle square-wave envelope essentially without distortion. Demodulator probes distort the modulation waveform increasingly as the modulation frequency increases. This is illustrated later.

The effect of the increase of isolating-resistance value upon the waveform distortion produced in the output of a demodulator probe is shown in parts A to D of Fig. 7-4, for a horizontal sync pulse.

Another effect of using an excessively large isolating resistance is that it may cause a vertical shift in the position of any frequency markers that are used on the steep side of the demodulated response curve, as shown in Fig. 7-4E. The displacement results because it then takes too long a time for the cable input capacitance to charge and discharge through the excessively large isolating resistance.

The cable resonance problem may also be attacked by the use of suitably low values of shunt resistance across the cable input to damp or "swamp" out the resonant response of the cable, but of course this decreases the probe sensitivity. Another possibility is the use of a shunt capacitor instead of a series isolating resistor.

Better waveform reproduction and greater sensitivity are obtained from a series-type demodulator probe by omitting the isolating (or shunt swamping) resistor. However, the improvement in waveform and sensitivity is obtained at the expense of a reduced carrier-frequency range, since the probe is then not useful above frequencies at which the resonant characteristics of the scope input cable begin to affect the operation of the probe. If greater sensitivity is required, it is usually a better practice to use a suitable audio-frequency pre-amplifier between the probe output and the scope input terminals to obtain the required overall sensitivity. This may be a conventional audio amplifier which has a low hum level, since the frequency range of the modulation waveform is usually relatively limited.

(3) *The D-C Blocking Capacitor.* Most scopes are provided with a d-c blocking capacitor, *C2,* in series with the input circuit, as shown in Fig. 7-5. When this capacitor is present in the scope, its quality and operating condition are very important to the operation of a series-type demodulator probe that is to be used with the scope. If the probe tip is applied to the plate terminal of a tube

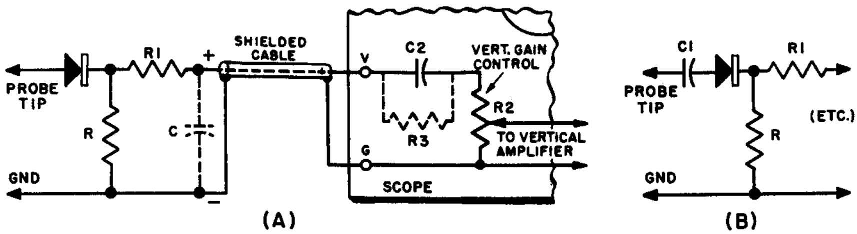


Fig. 7-5. (A) The simplified type of series-crystal demodulator probe appears very insensitive if the scope input blocking capacitor C2 has appreciable leakage, represented by R3. A d-c path for the flow of current is then provided through the crystal diode, R1, and the scope input resistance R2. This produces a bias across the diode, shifting its operation to a relatively insensitive portion of the crystal characteristic. This may be prevented by use of a series blocking capacitor C1 in the probe itself, as shown in (B).

in the tv receiver during a test, a d-c voltage component of the order of 90 to 250 volts or more may be present. The presence of leakage resistance, *R3,* in this blocking capacitor will cause any d-c voltage applied to the probe tip to produce a direct-current flow to ground through the continuous series circuit provided by the crystal diode, isolation resistor *R1,* leakage resistance *R3,* and the input resistance *R2* of the scope.

Service scopes receive hard usage, and the blocking capacitor will sometimes be found to be in a defective condition. The flow of dc through the crystal diode, which results from a defective blocking capacitor having excessive leakage, produces a voltage drop or bias across the crystal diode, which moves the operating point to a relatively insensitive portion of the crystal characteristic, resulting in reduced sensitivity of the probe. In severe cases, the current may be large enough to damage the crystal. For this reason, a series blocking capacitor *C1* is usually included in the series demodulator probe itself, as shown in Fig. 7-5B, although this arrangement is somewhat less sensitive.

(*4*) *Susceptibility to Hum Voltage.* Considerable hum voltage exists in many video-amplifier circuits. The hum level may not be sufficient to adversely affect the picture quality of the tv receiver to a noticeable extent, even though it may be high enough to interfere with video-amplifier signal-tracing and adjustment procedures. A demodulator probe that is susceptible to hum voltage is especially troublesome when used in video-amplifier applications.

The series type of demodulator probe will be found to be more susceptible to 60-cycle and 120-cycle a-c hum voltage reproduction than is the shunt type, although use of a small value of capacitance for *C1* does afford some relief. This series capacitor is the dominant factor in hum rejection in this type of probe. In fact, series type probes are designed especially to have fairly good hum-voltage rejection characteristics for use in special applications. These probes differ from the more conventional general-purpose series-type probes only in the low value of series capacitor they employ. Use of shunt resistors in the probe circuit is also often resorted to for reducing the amount of hum voltage which gets through. In general, the series type demodulator probe is less desirable in video amplifier work than is the shunt type.

7-5. Practical Forms of Series-Type Demodulator Probes

Although the shunt type of demodulator probe provides far greater immunity from hum voltages than does the series type, there are applications, such as in some signal-tracing work, where the series type of probe has greater utility because of its greater sensitivity.

Numerous variations of the simple form of series demodulator probe discussed thus far are possible and are useful in tv service work. Each employs a proper choice of probe constants to achieve useful display of the modulation envelope of the signal to be checked. A probe having a relatively high input impedance is illustrated in Fig. 7-6. No series isolation resistor is employed. The 100,000-ohm shunt resistors greatly reduce the amount of hum voltage which gets through the probe.

Some series-type demodulator probes are purposely designed to have a low input impedance. Those are considered in detail in Sec. 7-10.

7-6. The Shunt-Rectifier Type Demodulator Probe

(1) Basic Form of Shunt-Rectifier Probe, and its Action. The shunt-rectifier type of demodulator probe (see Fig. 7-7), which employs a crystal diode in *shunt* with the input circuit, is inherently less sensitive than the series type but it possesses certain operating advantages which make it more widely used. Its basic circuit operation, insofar as the actions of the rectifier, the series charging capacitor, the load resistor, and the series isolating resistor are concerned, is similar to that of the shunt *rectifying probe* (see Sec. 6-3 and Sec. 6-14), so this explanation will not be repeated here. Note that the crystal is so polarized as to produce a *positive* output voltage for the scope. This is in contrast with most rectifying probes for vtvm's, where the probe responds to positive peak input voltages and produces a *negative* output voltage for the meter. The circuit constants are such that the time constant of its filter circuit is considerably shorter than that employed in the rectifying probe. The time constant is made short enough so that the output voltage follows the modulation envelope of the applied carrier, as illustrated in Fig. 7-2.

As in other types of probes that employ crystal diodes, the value of the back-resistance of the crystal diode employed determines whether or not a bleeder resistance must be used in the shunt-type demodulator probe. A crystal diode which has a very high value of back resistance may cause a demodulator

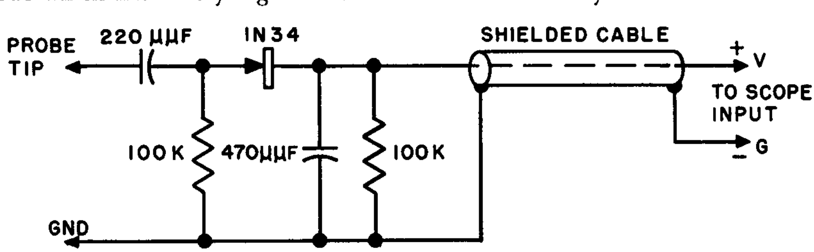


Fig. 7-6. Practical series-type demodulator probe having a relatively high input impedance and provided with a blocking capacitor, a bleeder resistor, and a shunting resistor for hum-voltage reduction.

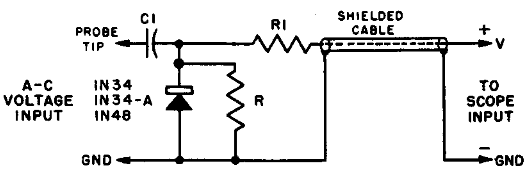


Fig. 7-7. Basic practical form of the shunt-type demodulator probe. The input capacitance depends upon the mechanical design of the probe, the value of charging capacitance C1, the value of bleeder resistance R, and to some extent upon the front-to-back resistance ratio of the crystal diode. The probe input capacitance varies slightly with the applied input voltage. Isolating resistance R1 should be as large as practicable, not only to retain reasonably good 60-cycle demodulation response, but to isolate all voltages of input-carrier frequency from the cable, so that more uniform high-frequnecy response free from cable-resonance effects throughout the rated operating-frequency range of the probe can be realized. Proper choice of the probe constants must be employed to achieve a useful display of the modulation envelope on the scope screen, from the modulated signal employed in the test.

probe to be unworkable unless a bleeder resistor is provided, as in Fig. 7-6. A crystal diode which has a low value of back resistance does not require a bleeder, and will cause a demodulator probe to have low sensitivity if a bleeder is used.

(2) *Probe-Cable Resonances and their Elimination.* Since the output waveform of a shunt type demodulator contains sawtooth ripples similar to those in the series-demodulator output, the same cable-resonance possibilities exist (see part 2 in Sec. 7-4). Use of the customary series isolating resistor *R1* added to the filter network, or use of suitably low values of shunt resistance across the cable input to "swamp" out its resonance response, are the two methods generally employed to combat this problem. The demodulated waveform is also improved when shunting resistance is used, but, of course some probe sensitivity is sacrificed.

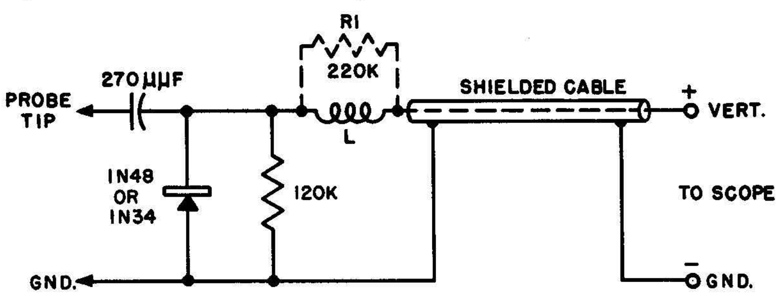
(3) *Susceptibility to Hum Voltage.* In general, a probe that employs a shunt rectifier (or rectifiers) in combination with relatively low values of series charging capacitance will provide far greater attenuation of 60-cycle and 120-cycle hum voltages, with respect to r-f or i-f voltages, than does a series-rectifier type probe. Because of this, it is usually possible to use a shunt-rectifier type probe to develop a video-response curve in a tv receiver whose video amplifier has a relatively high hum level, without perceptible hum interference appearing in the scope trace. This is one of the important advantages of the shunt type of probe in this work. Tests for the presence of spurious voltages in heater circuits, agc lines and d-c supply lines are also greatly facilitated.

7-7. Fidelity of the Output Waveform is Improved by Use of R-F Choke Isolation

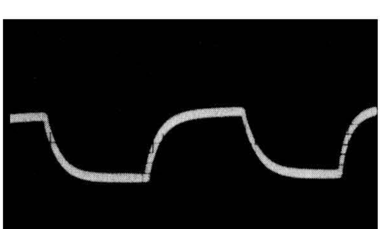
When an isolating resistance is employed in a demodulator probe, the output-waveform fidelity for square-wave modulating voltages appreciably above 60 cps, is usually only moderately good. The output-waveform fidelity for higher modulating frequencies may generally be improved substantially, when necessary, by using a video-frequency choke, or a rudimentary filter, in place of the conventional isolating resistor, as shown in Fig. 7-8A. The improvement results from a substantial reduction effected in the time constant of the probe filter circuit.

Choke *L* may be used alone, or it may be combined with resistor *R1*, as shown. The choke may be any conveniently available r-f choke selected to provide reasonably high impedance over the carrier-frequency range at which the improvement is to be effected. However, it may have to be selected carefully if "ringing" is encountered in square-wave response. (Among a group of available eligible chokes, the one of highest impedance will be the one which is found to provide maximum deflection on the scope screen over the chosen band of carrier frequencies.)

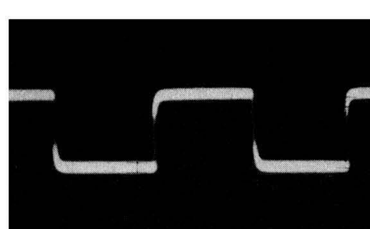
An example of the marked improvement in the fidelity of the output waveform, for a modulating voltage of comparatively high frequency, that is attainable by this method, is illustrated by the results of the rather severe test in



(A)



(B)



(C)

Fig. 7-8. (A) To obtain improved fidelity of the output waveform from a demodulator probe, an r-f choke L can be utilized in place of (or with) the customary isolating resistor. A general-purpose probe employing the conventional isolating resistor only, produced the distorted demodulated output waveform shown in (B) when a 20-mc r-f voltage modulated by a 10-kc square wave was applied to the probe. The improved square-wave output waveform fidelity shown in (C) resulted when r-f choke isolation was used instead.

parts B and C of Fig. 7-8. More elaborate low-pass filter arrangements can be utilized for this purpose, but the increased complexity of such networks is scarcely justified in service applications.

7-8. Varied Demodulator-Probe Operating Requirements in TV Applications

A general-purpose demodulator probe intended to be used with a scope in tv service applications, unlike a rectifying probe designed for use with a vtvm, is subjected to a variety of operating requirements. For example, when it is used in a sweep-frequency check of a video-amplifier, the probe is called upon to rectify and completely filter all video frequencies from approximately 100 kc to 4.5 mc, but it must pass a 60-cycle square-wave modulation envelope, essentially undistorted, to the vertical amplifier, of the scope. This calls for a high degree of output-waveform fidelity, and a probe designed to have sufficiently good fidelity will generally have rather low sensitivity. Fortunately, since ample signal voltage is present in the video amplifier, high probe sensitivity is not required for this application.

The input capacitance (or impedance) of the probe also becomes a matter of some importance in this application, for the shape of the response curve will be distorted unless the input capacitance of the probe is approximately the same as the capacitance of the input-grid circuit of the picture tube.

The input capacitance of a crystal probe is determined by its electrical constants and its mechanical construction; that is, the mounting of the probe components with respect to the shielded probe body, value of the blocking capacitor which is used, and the combined effective resistance of the crystal diode and its shunting resistor. These must be suitably related, so that when the socket is removed from the base of the picture tube, and the demodulator probe is contacted to the grid terminal of the socket, the output of the video amplifier will work into substantially the same impedance as if the picture tube were connected.

For use in video i-f amplifier signal tracing, the demodulator probe should have a relatively high input impedance at carrier frequencies from 20 mc up to 50 mc. Fidelity of output waveform is not particularly important in this work, and it can be sacrificed to attain the high probe sensitivity usually required for probing a low-level circuit such as the mixer and first i-f stage. Thus, the demodulator probe characteristics most desirable in video i-f amplifier signal tracing are not compatible with those desirable in video-amplifier checking.

For use in testing the flatness of the output of a conventional sweep generator, the probe must have an output which is proportional to signal input at frequencies up to about 220 mc (and sometimes higher); that is, the probe response must be "flat" over this extremely wide frequency range.

In most cases, good output waveform fidelity from a crystal demodulator probe is obtained at the expense of lowered input impedance. It is never possible to obtain extremely high input impedance to a crystal probe, in view of the operating characteristics of crystal diodes. However, relatively low input impedance is not necessarily a drawback in all uses of a crystal probe, as it is found advantageous to have a low input impedance in certain applications, as in testing the response of a single stage.

A crystal demodulator probe can be designed to provide any *one* of a number of special operating characteristics that may be desirable in a particular application, such as high input impedance, low input impedance, high sensitivity, excellent output-waveform fidelity, wide carrier-frequency response, etc. However, it is not possible to combine all of them into a single design of probe. Use of certain demodulator probes which have special characteristics is often advantageous in service work, and several of the more useful special types are described later in this chapter. However, each of these is generally useful for not more than a few particular applications.

Since many service technicians do not care to invest in a number of specialized demodulator probes, and prefer to utilize a single probe (or perhaps a couple of probes), for all of their work, commercial demodulator probes generally represent a compromise design in order to meet the greatest number of application requirements in a satisfactory manner even though they may not be perfect. The following characteristics of such a *general-purpose* demodulator probe should meet the requirements of the application, in the order indicated: (1) input impedance; (2) reproduction of demodulated 60-cps square wave;

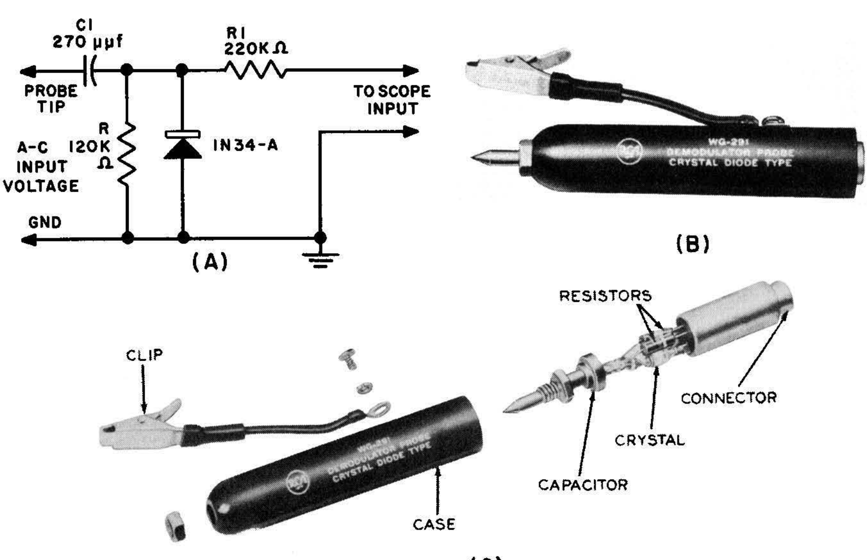


Fig. 7-9. (A) Schematic circuit diagram of a good-quality general-purpose shunt-rectifier type commercial demodulator probe designed to be especially useful in tv service work. (B Exterior) view of the probe, which is constructed in convenient slip-on form. The short ground-return lead and clip are visible at the top. (C) An exploded view of the probe, showing the compact internal construction and carefully designed arrangement of the various components to achieve low input capacitance and wide carrier-frequency response range. *Courtesy: RCA*

(3) sensitivity; (4) waveform fidelity (above 60-cps square wave); (5) ruggedness to overload and mechanical shock; and (6) hum suppression. Because of the first and second requirements, most general-purpose crystal probes utilize the basic shunt-rectifier type design shown in Fig. 7-7. Its sensitivity will be found to be moderate, and not equal to that available from the elementary series-rectifier type arrangement shown in Fig. 7-3, but its hum-rejection characteristics are superior. The time constant is designed to be suitable for demodulating carriers which have been modulated by frequencies as low as 60 cycles. Shunt-type probes are generally found most suitable for general signal tracing as well as for video-amplifier checking.

7-9. General-Purpose Shunt-Type Demodulator Probes

An example of a practical commercial shunt-type demodulator probe designed to be useful for a variety of tv servicing applications when modulated carriers are present, is illustrated in Fig. 7-9. The schematic circuit diagram is shown in Fig. 7-9A. The assembled probe, illustrated in part B of the figure, is constructed in a slip-on form designed to fit the standard direct probe and cable supplied with several models of the manufacturer's service type scopes and vtvm's. An exploded view showing the internal construction and component arrangement is illustrated in Fig. 7-9C. The specifications of a demodulator probe of this type are very instructive, and are presented here.

SPECIFICATIONS

Frequency Response Characteristics:	
RF carrier range	500 kc to 250 mc
Modulated-signal range	30 to 5,000 cycles
Input Capacitance (Approx.)	2.25 $\mu\mu$f
Equivalent Input Resistance (Approx.):	
At 500 kc	25,000 ohms
At 1 mc	23,000 ohms
At 5 mc	21,000 ohms
At 10 mc	18,000 ohms
At 50 mc	10,000 ohms
At 100 mc	5,000 ohms
At 150 mc	4,500 ohms
At 200 mc	2,500 ohms
Maximum Input:	
A-C voltage	20 rms volts 28 peak volts
D-C voltage	250 volts

The short time constant filter network in the probe has a rated output frequency (modulation frequency) range of 30 to 5,000 cps. The probe will, therefore, develop the wave envelope of a signal having 60-cycle square-wave modulation, without appreciable distortion. The results of a check on the actual influence of the probe network upon a 1,000-cycle square-wave modulation envelope are presented in Fig. 7-10. It can be seen that although the lower frequencies in the square wave are passed by the probe network, the higher frequencies in it are attenuated somewhat and shifted in phase. However, in tv servicing practice the probe is usually called upon to pass only 60-cycle square waves or equivalent waveforms, so this characteristic is satisfactory and the probe is especially useful

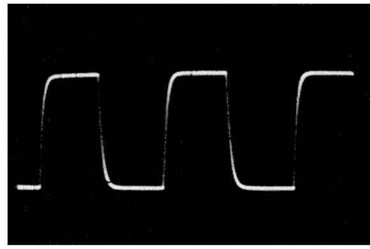


Fig. 7-10. Influence of the filter network of the probe illustrated in Fig. 7-9 upon a 1,000-cycle square-wave modulation envelope. The input to the probe is a 100-mc carrier, modulated by a 1,000-cycle square wave. The slight rounding of the diagonal corners is caused by the filter network in the output circuit of the probe.

for the observation of sweep-curve response in tv alignment work (in which a 60-cycle sweep is usually employed).

The frequency response over the r-f carrier range is rated as essentially flat from 500 kc to 250 mc, enabling the probe to demodulate any video, video i-f, and tv-channel sweep carriers, or audio amplitude-modulated carriers, within that range. Thus, when used with a sweep generator and an oscilloscope, this probe permits observation of the video i-f amplifier, sound i-f amplifier, video-amplifier, and overall-response curves of a tv receiver. This combination may also be used to obtain the response curves for single stages.

Because the input capacitance of the probe is lower than that of the picture tube, the probe may be connected to the output of the video amplifier with negligible effect on the circuit. The input resistance is satisfactorily high for most service tests.

7-10. Low-Impedance Demodulator Probe for TV I-F Amplifier Work

One of the most useful special-purpose demodulator probes is the low-impedance type, also sometimes called the "traveling detector" because of its particular usefulness as a demodulator in stage-by-stage amplifier alignment and signal-tracing work.

To view the response of a single i-f amplifier stage on a scope when performing stage-by-stage alignment or signal-tracing in the amplifier, the modulated i-f output signal of the stage is usually taken off across the plate circuit of the i-f tube *following* the stage under test. One difficulty which often presents itself when a typical general-purpose demodulator probe is employed for this purpose is that the input capacitance of the probe may be large enough to cause substantial detuning of the tuned circuit across which it is connected. This detuning may even cause severe regeneration or violent oscillation in some cases. (The subject of probe application in video i-f amplifier work is discussed in greater detail in Sec. 7-29.)

One practical solution to this difficulty is to employ a demodulator probe designed especially to have a comparatively low input impedance. This low impedance swamps out the resonant response of a tuned circuit across which it is applied. It has been found in practice that this approach is one of the best answers to problems of circuit disturbance which occasionally vitiate the test by causing oscillation or severe regeneration. It often happens that it is better to *swamp out the resonant response of a critical circuit completely, if the response of this circuit is not in question, rather than to partially detune the circuit.*

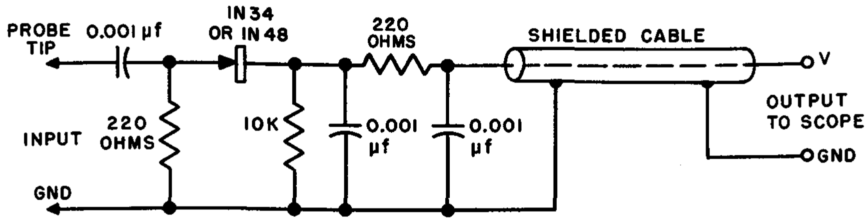


Fig. 7-11. Shop-constructed, low-impedance (traveling detector), series-rectifier type of demodulator probe designed especially for stage-by-stage signal-tracing or alignment work in r-f amplifiers. The output is well filtered by the pi-filter section provided.

The sensitivity of the low-impedance type demodulator probe is less than that of the more conventional medium-impedance and high-impedance probes, so the output voltage is less. However, its sensitivity is usually quite adequate when a sensitive scope is used. If greater output is required, an audio amplifier having suitable response characteristics may be employed between the probe output and the scope input terminals. The advantage of the low-impedance type demodulator probe for this type of application far outweighs its disadvantages. It does not throw the amplifier into oscillation and, moreover, the display on the scope screen is always the true response of the circuits up to, but not including, the plate circuit across which the probe is applied.

The schematic circuit diagram of a low-impedance series-rectifier type demodulator probe that has good frequency response and is extremely useful in i-f amplifier individual-stage work is illustrated in Fig. 7-11. Since this type of probe is not available commercially, it must be shop-constructed by the technician. It is recommended that the technician should not attempt to enclose a low-impedance probe in a housing if it is to be used for r-f (head-end) applications. However, when used for i-f work it may be enclosed in a suitable metallic case and provided with a flexible ground lead and clip.

One advantage of the circuit shown in Fig. 7-11 is that the charging capacitor acts also as an input blocking capacitor and permits the use of the probe with scopes which may have appreciable d-c leakage in their own blocking capacitor (see Fig. 7-5). The frequency response to carrier-wave frequencies is improved by inclusion of the pi-filter comprising the pair of 0.001-μf capacitors and the 220-ohm series resistor. For reproduction of video waveforms only, this filter may be omitted.

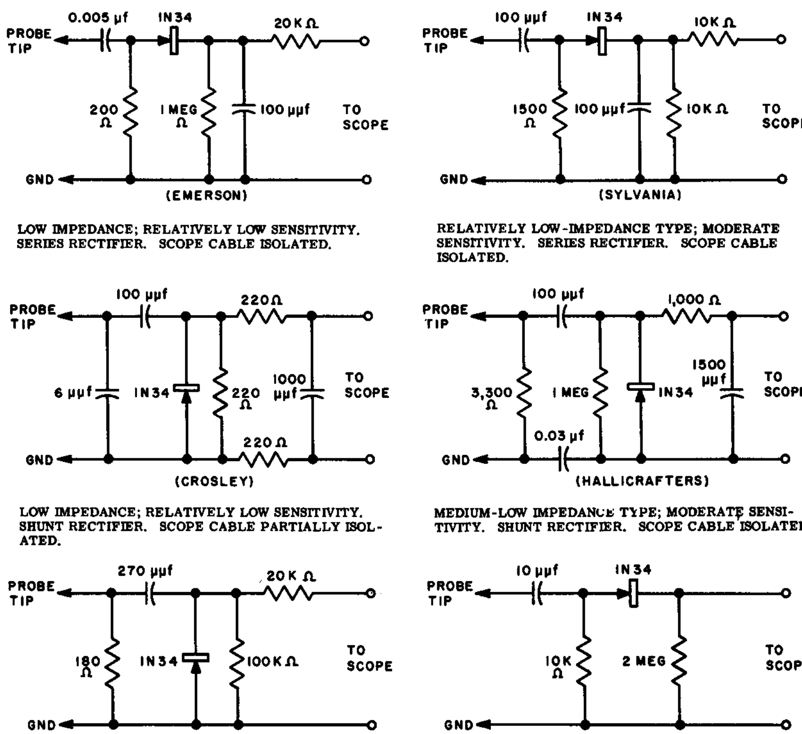
The use of a low-impedance type demodulator probe is specified for individual stage alignment in the service manuals for many tv receivers. In such cases, the circuit constants of the probe used must conform to the receiver manufacturer's recommendations. Otherwise, the demodulated waveform seen on the scope may not have the referenced shape even when the circuit is properly aligned. Six different designs for shop-constructed low and medium impedance demodulator probes recommended for i-f work in the servicing instructions of six tv receiver manufacturers are presented in Fig. 7-12. Some are series type probes; the others are of the shunt type. All are arranged to produce a positive output voltage for the scope.

In the absence of a low-impedance demodulator probe, or in the absence of specific receiver manufacturers' instructions for the construction and use of one, the technician may generally employ his general-purpose high-impedance demodulator probe for such work. If no indication is obtained at a test point in the i-f amplifier, and if oscillation is suspected, a 200- or a 300-ohm damping resistor and a blocking capacitor may be shunted across its input terminals to shunt down and flatten the response of the tuned plate-circuit load to which the scope is applied. This is illustrated in Fig. 7-13. The damping resistor lowers the sensitivity of the probe, but it prevents oscillation.

Use of a cathode-follower with a demodulator probe is discussed in Sec. 7-12.

7-11. The Low-Impedance Demodulator Probe for TV Front-End Work

A detuning problem similar to that described in Sec. 7-10 for i-f amplifiers exists when a conventional general-purpose demodulator probe is applied across the tuned plate circuit of an r-f amplifier tube during the course of tv front-end



EMERSON: LOW IMPEDANCE; RELATIVELY LOW SENSITIVITY. SERIES RECTIFIER. SCOPE CABLE ISOLATED.

SYLVANIA: RELATIVELY LOW-IMPEDANCE TYPE; MODERATE SENSITIVITY. SERIES RECTIFIER. SCOPE CABLE ISOLATED.

CROSLEY: LOW IMPEDANCE; RELATIVELY LOW SENSITIVITY. SHUNT RECTIFIER. SCOPE CABLE PARTIALLY ISOLATED.

HALLICRAFTERS: MEDIUM-LOW IMPEDANCE TYPE; MODERATE SENSITIVITY. SHUNT RECTIFIER. SCOPE CABLE ISOLATED.

ARVIN: LOW IMPEDANCE; RELATIVELY LOW SENSITIVITY. SHUNT RECTIFIER. SCOPE CABLE ISOLATED.

FADA: MEDIUM-IMPEDANCE TYPE; MEDIUM SENSITIVITY. SERIES RECTIFIER. SCOPE CABLE UNISOLATED.

(NOTE: ALL RESISTORS 1/2 WATT)

Fig. 7-12. Shop-constructed low- and medium-impedance demodulator probes suggested by various tv receiver manufacturers for stage-by-stage i-f amplifier work.

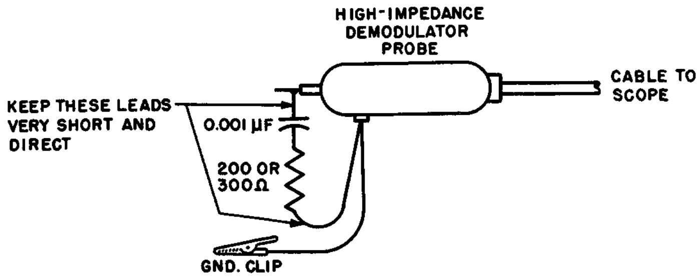


Fig. 7-13. A low-impedance demodulator probe is often required for proper i-f stage-by-stage alignment or signal tracing. In the absence of this type of probe, the technician may make use of a conventional high-impedance general-purpose demodulator probe, in combination with a 200-ohm damping or swamping resistor and blocking capacitor connected across it, to shunt down and flatten the response of the tuned plate-circuit load to which the scope is applied.

work. A special design of low-impedance probe suited for operation at the high tv station carrier frequencies is desirable in this work.

The circuit arrangement for a special shop-constructed low-impedance demodulator probe which has proved quite satisfactory for front-end work is shown in Fig. 7-14B. It can be seen that this is a low-impedance device which flattens the resonant response of any r-f circuit across which it may be applied. To cut lead length to an irreducible minimum, it is suggested that the probe be constructed without a housing or tip as would be done in the case of i-f probes. Instead, the components should be joined with the shortest possible leads, as illustrated in Fig. 7-14A, and the probe tip should consist of a very short length of pigtail lead protruding from the button capacitor. If desired, a small hook may be bent in the lead for convenient connection. There is no ground lead, instead, there is a very short length of pigtail left protruding from the 1N34A crystal diode which may be soldered to a clamp fitted around a small Alnico magnet. The magnet will serve to make connection to the receiver chassis near the base of the tube without adding the mechanical bulk and stray reactance of an alligator clip. The output lead labeled *S* connects to the input cable of the scope.

In use, the small hook at the button capacitor terminal is hooked over the r-f plate lead at the tube-socket plate terminal, and the magnet is placed on the chassis near the tube base. The r-f tube provides isolation between the low input impedance of the probe and the grid circuit of the tube; thus the circuit response up to and including the grid circuit of the tube is truly displayed. At the same time, the low input impedance of the probe flattens out the resonant response of the plate load of the tube, which would be partially detuned by any other type of probe, leading to substantial distortion in the display.

Another special front-end probe arrangement, and details concerning its use, are discussed in Sec. 7-28.

7-12. Use of a Cathode-Follower with a Demodulator Probe

Although cathode-follower probes are not in general use in service work, the use of a cathode-follower is often suggested as another means of reducing the loading and detuning effects of demodulator probes. The use of a cathode-follower ahead of a demodulator probe is especially helpful if it is desired to do quantitative work on high-impedance tuned circuits, since the demodulator probe loads the tuned circuits rather heavily and as a result the true voltage of the test signal is not indicated. The cathode-follower provides a very high input impedance even at 4 or 5 mc, and does not disturb circuit operation. For this reason, it should be noted that two arrangements of the demodulator probe and the cathode-follower are possible:

(1) Cathode-follower feeding directly into demodulator probe, and from demodulator probe into shielded cable and scope.

(2) Cathode-follower feeding directly into shielded cable, and from shielded cable to demodulator probe located at the vertical-input terminals of scope.

Chief characteristics of these arrangements are:

(1) Extends effective frequency-response range of scope vertical amplifier by demodulating the signal. Cathode-follower provides high input impedance to test circuit. Demodulator probe tends to distort the reproduced waveform at some modulating frequencies due to the effect of capacitance of probe cable on the time constant of the demodulator.

(2) Accomplishes the same purpose as (1), but eliminates the effect of cable capacitance on the demodulator probe. Therefore, reproduced waveform is much less distorted.

The cathode-follower described in Sec. 5-11 and illustrated in Fig. 5-22 is suitable for this purpose. The tube can be powered from the heater- and plate-supply circuits of the scope.

When the response characteristic of the vertical amplifier of the scope being used is sufficiently wide so that the amplifier can satisfactorily respond directly to the carrier frequencies comprising the modulated signal being checked, the demodulator probe is not required. The cathode-follower working into a shielded cable may then be applied directly to the vertical-input terminals of the scope

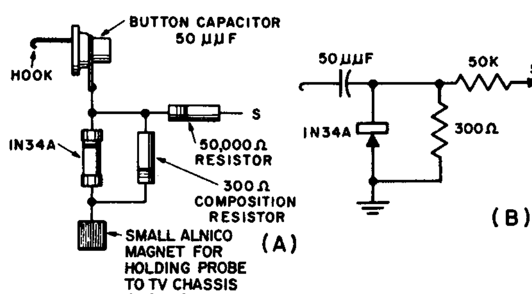


Fig. 7-14. (A) Parts and wiring arrangement, (B) schematic circuit diagram of a special low-impedance demodulator probe utilizing a button-type capacitor and very short leads, for effective application in circuits operating at frequencies above 100 mc. The button capacitor receives the terminal stud of the crystal diode directly, thus minimizing lead length. The button capacitor is of the type which is provided with a stud which serves conveniently as a probe tip. This probe will be found very useful in making operational checks of tv front-end circuits, and also permits practical stage-by-stage investigation and alignment to be performed.

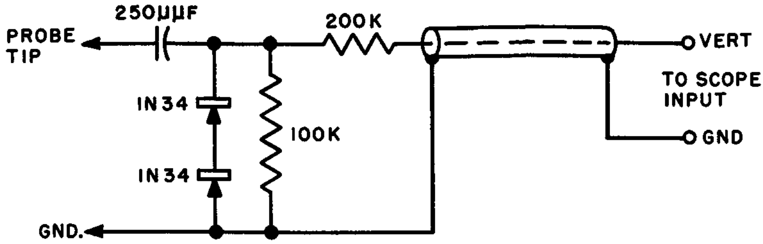


Fig. 7-15. By employing two crystal diodes in series, the voltage-handling capability of the demodulator probe is doubled.

and the arrangement, which has very high input impedance even at 4 or 5 mc, may be used to good advantage to minimize loading of the circuits under test when signal-tracing the video-amplifier or sync circuits.

7-13. Demodulator Probe with Large Voltage-Handling Capability

When a crystal probe is to be used in a relatively high-level signal circuit, such as at the output of a video amplifier having a substantial margin of output, it is sometimes found that the signal voltage applied to the probe is sufficient to weaken or burn out the crystal diode. In such applications, it is possible to connect two crystal diodes in series, to double the voltage-handling capability of the probe, as shown in Fig. 7-15.

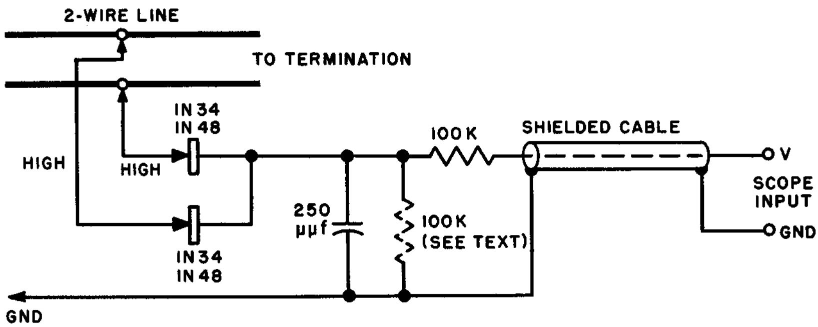
7-14. Balanced-Input Crystal Demodulator Probes

An easily constructed balanced-input crystal demodulator probe, of the type shown in Fig. 7-16A, is very useful for checking the modulated voltage existing at any point along a balanced transmission line, or at a balanced output circuit such as that of a balun, the output of a tv converter or booster, etc. The probe offers a balanced input to such a circuit, while the output is an unbalanced one to match the scope input circuit. The series-rectifier arrangement employed, provides minimum input capacitance to the probe, and hence the least disturbance of line impedance. Because d-c voltage is seldom present in such lines, a series arrangement is practical; also no blocking capacitor is required. The 250-μμf charging capacitor is charged alternately by the diodes, and the series resistor serves to isolate the shielded cable from the high-frequency portion of the circuit.

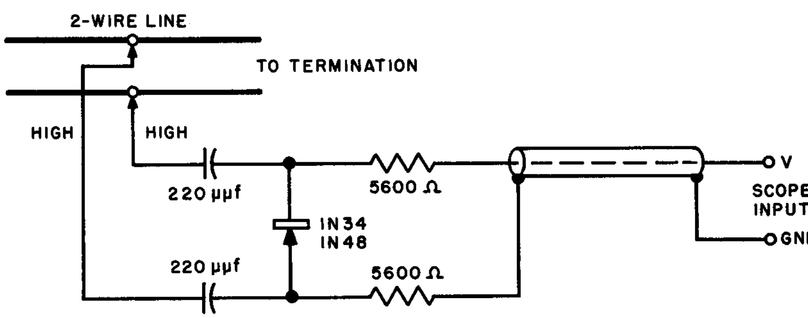
Observe that the two diodes in the probe do not conduct simultaneously. Insofar as the instantaneous voltages in the 2-wire line are concerned, when the input signal to one diode is positive, the input signal to the other is negative. These polarities alternate at the carrier frequency, thus the diodes conduct alternately. The output of the probe, is the modulation envelope of the line voltage, and may be displayed on a scope (or a d-c vtvm may be employed for purposes of voltage indication).

The r-f ground lead to the line termination carries r-f voltage and should be kept as short as the "high" leads.

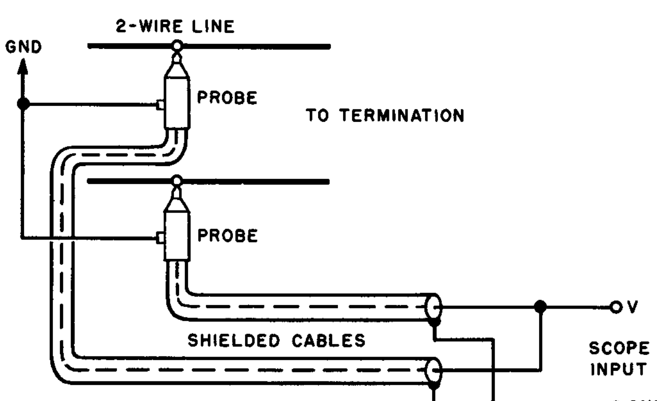
Although it appears, with the balanced-input shown here, that no d-c return path exists when a scope with an input blocking capacitor is used, such is not the case. The d-c return path is provided through the finite back resistance of the crystal diodes and the voltage-source resistance. If diodes with unusually high



(A)



(B)



(C)

Fig. 7-16. (A) Shop-constructed balanced-input probe arrangement for checking the voltage existing at any point along a 2-wire line. Such probes are useful for impedance-match (standing-wave) testing procedures. (B) Sensitive arrangement employing only one diode and requiring no ground return. (C) Method of using two conventional general-purpose demodulator probes for the purpose, instead of a special balanced-input probe.

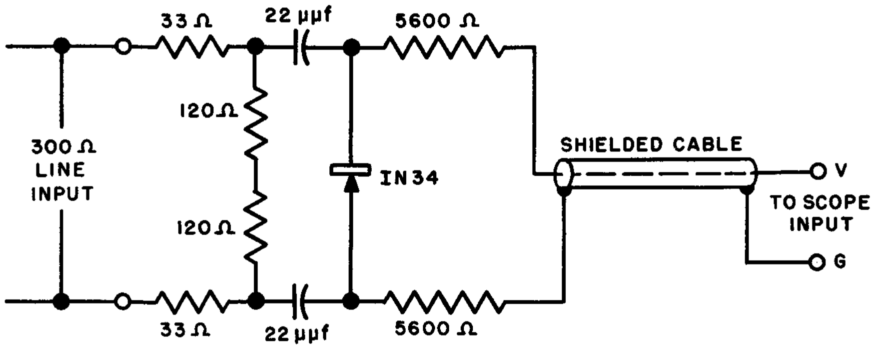


Fig. 7-17. When operating at uhf, the balanced-input demodulator probe network can be tapped down on the load, as shown here, so that the capacitance of the network does not seriously disturb the line termination. *Courtesy: RCA*

back resistance are used, it may be necessary to shunt the 250-$\mu\mu$f capacitor with the 100,000-ohm bleeder resistor indicated.

A simplified, though somewhat less sensitive arrangement employing only one diode, is shown in Fig. 7-16B. It also has the advantage that a ground return is not required to a center tap on the line termination.

A pair of conventional general-purpose demodulator probes may also be employed, instead of a special balanced probe, in the manner shown in Fig. 7-16C.

It is sometimes stated that the elaboration represented by the balanced-input type probe is unjustified, and that a single-ended probe contacted to one side of the line would serve the purpose just as well. However, a single-ended probe will give the same information as the balanced-input probe only if the line is actually balanced to ground. In many cases, twin-lead lines are not balanced to ground, and different voltages may be found between each conductor and ground. Accordingly, if a single-ended probe is used in such cases, it might be falsely concluded that the standing-wave ratio is low, whereas a test with a balanced-input probe will show the actual standing-wave ratio which is present. What is more, the use of an unbalanced probe will usually alter the actual balance of the line itself.

Practical applications and test setups for the use of the balanced-input demodulator probe are discussed in Sec. 7-27.

When the frequency of test is high, and the input capacitance of the balanced-input demodulator probe arrangement disturbs the termination of the line, it is good practice to tap the probe network down on the load, as shown in Fig. 7-17. This arrangement is satisfactory for tests at uhf. A probe of this type is useful for demodulating the output sweep voltage from a uhf converter during alignment of the converter. This probe is arranged to offer a balanced input of 300 ohms.

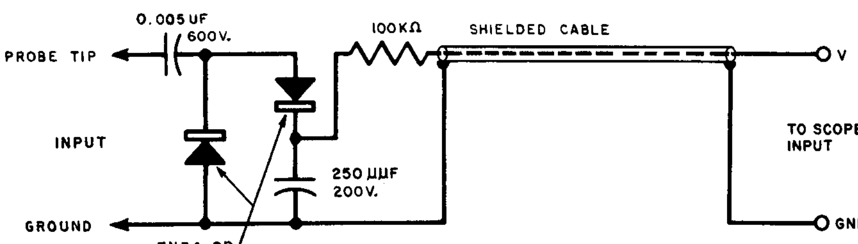
7-15. Voltage-Doubler Crystal Demodulator Probe

Increased probe sensitivity over that obtainable with conventional series-type or shunt-type demodulator probes is often required in some applications.

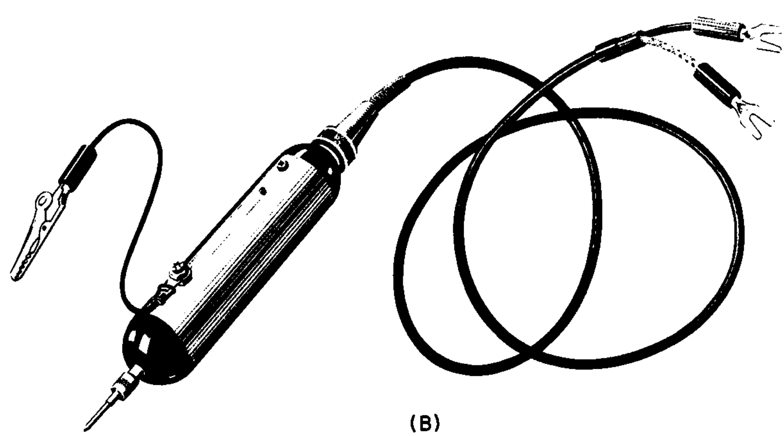
This can be obtained by utilizing the voltage-doubler principle explained in Sec. 6-9 and Sec. 6-17. This circuit adds the positive-peak value of the modulating waveform to the negative-peak value, and thereby delivers an output proportional to the peak-to-peak value of the modulating waveform. If the modulating voltage has a symmetrical waveform (such as a sine wave or a square wave), double the amount of deflection will then be obtained on the scope screen. When the modulating-voltage waveform is asymmetrical, a value less than this will be obtained, depending upon the degree of disymmetry present.

The schematic circuit diagram of a useful voltage-doubler type demodulator probe which has considerable utility in some of the tv troubleshooting procedures described later in this chapter is shown in Fig. 7-18A. A representative commercial probe is illustrated in Fig. 7-18B.

Although the voltage-doubler feature makes the sensitivity of this type of probe quite high, its input impedance is relatively low, and the waveform distortion may be appreciable. It is possible to construct a practical probe of this type with a frequency response flat to approximately 150 mc; such a probe will be useful for comparative indication at still higher frequencies. This probe will also offer a high degree of 60-cycle hum-voltage rejection.

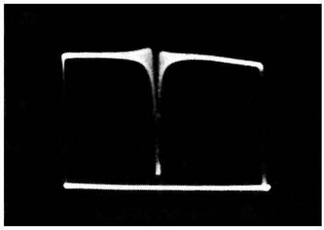


(A)

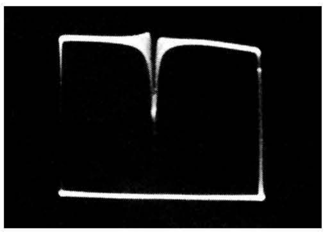


(B)

Fig. 7-18. (A) Voltage-doubler type of demodulator probe for obtaining increased output and greater deflection on the scope than is provided by conventional type of demodulator probes. (B) A typical commercial probe of this type. This probe is provided with its own shielded cable for connection to the scope input terminals. (*B*) *Courtesy: Scala Radio Co.*



(A)



(B)

Fig. 7-19. Effect of front-to-back resistance ratio of the crystal diode in a demodulator probe upon the modulation-waveform fidelity of the probe. (A) Modulation - waveform output obtained when a crystal diode having a low front-to-back ratio was employed. (B) When a crystal diode having a high front-to-back ratio is employed. The high front-to-back ratio provides more output voltage, but the longer time constant which results from the higher back resistance makes the probe filter circuit unable to follow rapid changes in the shape of the modulation envelope. Consequently, only part of the long sharp dip at the center of the modulation waveform appears in (B).

The maximum allowable safe input voltage for a voltage-doubler probe is approximately the same as for a conventional type probe using the same type of crystal diode. For a 1N34 diode, this is approximately 20 volts rms and 28 volts peak. If a d-c component is present, this component should not exceed approximately 600 volts (which is the rating of the series capacitor specified here).

In general, when a conventional type of demodulator probe does not provide ample deflection on the scope screen, the voltage-doubler type may be utilized for greater output, even though its comparatively low impedance has a tendency to load down the circuits to which it is applied. The technician should keep in mind however, that a conventional type of probe will provide flat frequency response up to much higher carrier frequencies. Some technicians use a voltage-doubler type as their most useful general-purpose demodulator probe. Since a voltage-doubler demodulator probe utilizes shunt rectifiers in combination with relatively low values of series charging capacitance, a 60-cycle hum voltage is greatly attenuated with respect to r-f or i-f voltage. For this reason, special tests in heater circuits, agc lines, and d-c supply lines are greatly facilitated. The technician can usually check for "hot" bypass or decoupling capacitors, heater "hash", or video voltage in agc lines without encountering serious disturbance of the scope screen pattern from hum voltage or heater voltage (see Sec. 7-32).

The technician who has both a conventional-type demodulator probe and a voltage-doubler demodulator probe available, is sometimes puzzled by the apparent ability of the voltage-doubler probe to provide *more* than double the output of the conventional probe in some tests. In other tests, the voltage-doubler probe provides *less* than double the output of the conventional type of probe. Such apparent discrepancies in the operation of the two probes is due to the fact that the carrier wave of the signal under test is not a symmetrical wave, and accordingly the wave has a greater positive excursion than negative excursion (or vice versa). To make a meaningful check of a voltage-doubler probe against a half-wave probe, the operator should utilize a signal generator which provides a signal having good symmetrical waveform (small harmonic content).

7-16. Design and Construction Hints for Shop-Constructed Demodulator Probes

Satisfactory performance of a demodulator probe is dependent upon proper mechanical construction, as well as the use of a suitable circuit arrangement and circuit constants. The construction is simple in most cases, provided that the required consideration is given to high-frequency factors such as the proper layout of components to insure short leads, use of composition resistors and suitable capacitors for the high-frequency circuits, and minimizing of stray capacitance in mounting the components in the probe case. The exploded-view illustration in Fig. 7-9C, and illustration B in Fig. 7-18, reveal a considerable amount of information concerning how these requirements are met in successful commercial demodulator probes.

The crystal diode (s) used must have a relatively high front-to-back resistance ratio, and also be able to accommodate reasonably high a-c signal voltage without loss of sensitivity or burnout. The 1N34 or 1N34A, and the 1N48 type crystal diodes are widely used in these probes because of their satisfactory characteristics. The crystal diode should be selected, as the front-to-back ratios of commercial diodes vary considerably, affecting both the sensitivity and the input impedance of the probe.

The effect of low front-to-back ratio of a crystal diode used in a demodulator probe is illustrated in Fig. 7-19. Even when comparatively strong signal-generator signals are employed in the tests, excessive hash resulting from pickup of strong stray 60-cycle and 15.75-kc fields about a tv chassis may obscure the scope trace unless the probe is properly shielded and a shielded output cable is used. Because the probe must be used in cramped spaces, it must be well insulated to avoid shorts during use.

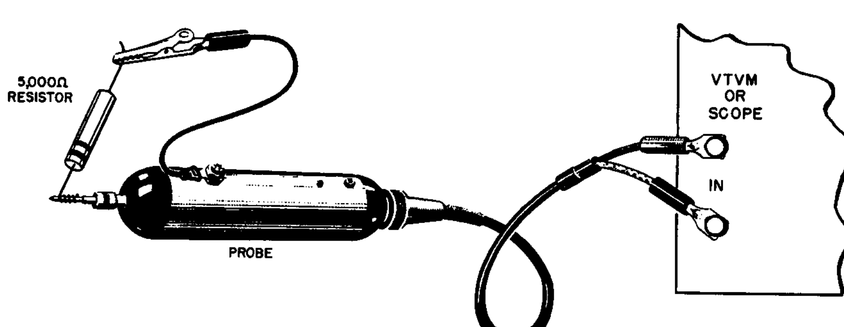


Fig. 7-20. Method of testing a probe to determine if its shielding is adequate to prevent spurious-voltage induction into its components or wiring by the extraneous fields around a tv chassis. Use the very smallest amount of exposed resistor leads in this arrangement.

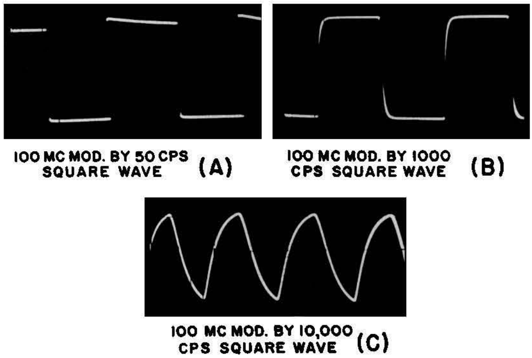


Fig. 7-21. Demodulating ability of a conventional type demodulator probe for modulation of various frequencies. It can be seen that the demodulating ability of the probe decreases as the modulation frequency increases, and distortion of the modulation waveform results. A voltage-doubler type of probe is usually more unfavorable than the conventional type in this respect.

A simple method for checking a shop-constructed or a commercial probe to determine whether or not its internal shielding is adequate to prevent spurious voltage induction into its components or wiring by extraneous fields around a tv receiver is illustrated in Fig. 7-20. The terminals of the probe are shunted by a 5,000-ohm resistor (to simulate typical circuit impedance), and the probe housing is then moved about the receiver chassis. In particular, the vtvm or scope to which the probe is connected, should be watched while the probe is brought near the output transformers, picture tube, oscillator transformers, yoke, and power transformer. If the probe is adequately shielded, no deflection will be obtained on the instrument.

7-17. Demodulating Ability of Crystal Demodulator Probes Somewhat Limited

The output network of a demodulator probe is a low-pass filter as has been explained. Its contents must be selected to provide adequate r-f filtering action, but if the filtering is excessive (time constant too long), a 60-cycle square-wave modulation envelope, for example, will be distorted by the probe.

Both conventional and voltage-doubling demodulator probes distort the modulation waveform increasingly as the modulation frequency increases. Referring to Fig. 7-21A, it is apparent that the output filter of a conventional demodulator probe may be designed to pass a 50-cycle square-wave modulation envelope practically without distortion. This means that the probe is entirely satisfactory for use in video-amplifier adjustment, single-stage response checks, and similar applications where the sweep of the test signal is made to occur at a rate in the vicinity of 50 to 60 cps, thus creating an output wave envelope of the same frequency, and of the same general class as a square wave.

However, if the square-wave modulation frequency is raised to 1,000 cps, high-frequency attenuation and phase shift begin to make their appearance and the diagonal corners of the reproduced square wave exhibit rounding, as shown in Fig. 7-21B. When the square-wave modulation frequency is increased to 10,000 cps as in Fig. 7-21C, it is seen that severe high-frequency attenuation and phase shift occur. (A voltage-doubler type probe is usually more unfavorable than the conventional type of probe in this respect.) Accordingly, the technician would not expect the demodulator probe to reproduce a horizontal sync pulse, for example, without severe distortion.

The ability of the probe to deliver higher-frequency modulation waveforms with improved fidelity may be increased by eliminating the series isolating (filter) resistor so that the probe circuit works directly into the scope input cable. Unfortunately, when this is done, the probe does not usually respond satisfactorily to the higher i-f and r-f carrier frequencies because the shielded probe cable is then enabled to exhibit resonance effects at various frequencies, as is explained in part 2 of Sec. 7-4. Consequently, the improvement in probe ability to reproduce the modulation waveform with better fidelity is then partially offset by the reduction in carrier-frequency range over which the probe will operate without disturbing cable-resonance effects. The effect on the fidelity of the modulation waveform, of employing various values of isolating resistance in a typical demodulator probe is illustrated in Fig. 7-4.

7-18. Check of Probe Time-Constant Suitability for an Intended Test-Signal Sweep Width

When the sweep width of a sweep generator used in a test is increased, any variations present in the slope of a response curve being displayed on a scope by means of the sweep input signal become *steeper*. Therefore the R-C filter in the output circuit of the demodulator probe being used is called upon to charge and discharge more rapidly, if the output voltage is to rise or fall in accord with very rapid changes in the modulation waveform.

For a practical illustration of this situation refer to Fig. 7-22, which shows a video response curve obtained by applying the output from a video sweep generator to the input of a video amplifier, and connecting a demodulator probe and scope to the output of the video amplifier. Because the sweep width used here is considerable, the rate of change of the response curve is also considerable in the middle portion, where the output of the generator goes through zero frequency. Because of this rapid change, the R-C filter network in the output circuit of the demodulator probe is unable to respond quite as fast as necessary, and the result is that the two curves do not appear at the same height. At lesser sweep widths, this difference disappears.

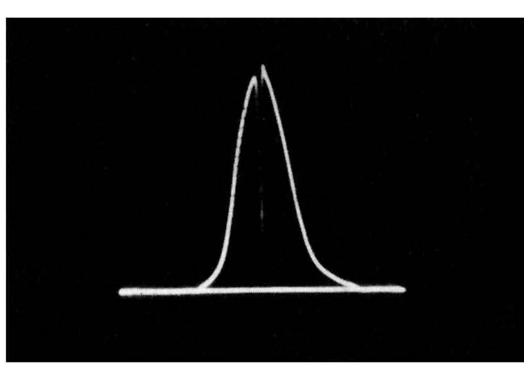
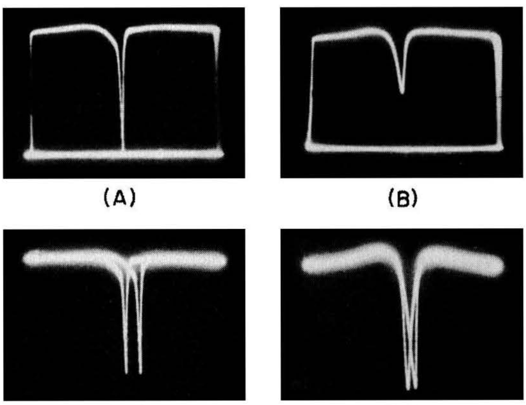


Fig. 7-22. Example of video response curve distortion resulting from too long a time constant in the demodulator probe for the video sweep-width employed. The video sweep generator is operating at considerable sweep width; the output from the demodulator probe does not drop to zero voltage at the zero-frequency point (center), and the two responses differ in height, because of the excessive charge and discharge time of the probe filter for the high rate of modulation change which occurs at this point.



(A) (B) (C) (D)

Fig. 7-23. Traces of demodulated output from a video sweep generator in a test to determine whether the time constant of the demodulator-probe filter is suitable for the sweep width that will be employed in the test. (A) Probe time constant is suitable for the application, since the zero-frequency point falls to zero voltage. (B) Probe time constant too long for the application, since the zero-frequency point does not fall to zero voltage. The extent to which the zero frequency point remains above zero voltage is an indication of the excess in the time constant of the demodulator probe. (A) and (B) taken when a zero-volt reference line is used. (C) When zero-volt reference line is not used (retrace unblanked), the trace and retrace are exact replicas, if the probe time constant is satisfactory, showing that any difference in the shape of the curve when going toward and away from zero frequency is caused by the sweep generator, and not by the demodulator probe. (D) The trace and retrace are not exact replicas here, and the extent to which the shape of one differs from that of the other is an indication of how excessive is the time constant in the demodulator probe.

This is a useful test to determine whether the constants of the demodulator probe filter are suitable for the job at hand. The method of interpreting such a test is illustrated in Fig. 7-23.

7-19. Effect of Crystal-Diode Nonlinearity upon Demodulator Probe Low-Voltage Response

A crystal demodulator probe is nonlinear for input signals of low voltage level (the same as a rectifying type of probe), due to the curvature of the crystal-diode characteristic at low voltage inputs. The curvature of the characteristic from 0 to approximately 0.75 or 1 volt is quite appreciable (see Fig. 6-12). As a practical example of the effect of this nonlinearity of a crystal demodulator probe at low signal levels, when a 50 percent modulated signal of 0.6 volt peak-to-peak being applied to a crystal demodulator probe was reduced to one-tenth of its value, or 0.06 volt peak-to-peak, the output from the probe might have been expected to drop to one-tenth of its first value. However, because of the nonlinearity of the crystal diode, the output from the probe actually dropped to one-twenty fifth of its first value.

One result of this inherent nonlinearity is to make the apparent observed output variation from a video sweep generator greater than it is in fact, and greater than it would appear were the output from the generator applied through a linear amplifier. Accordingly, when the technician is checking the output from a sweep generator with a demodulator probe and scope, substantial observed variations from flatness must first be considered with respect to the possibility of being exaggerated due to the nonlinearity of the crystal diode characteristic, before the generator is blamed for the departure from flatness.

This nonlinearity will also cause some waveform distortion at the high-attenuation portions of frequency response curves, if the voltage input to the demodulator probe during the taking of such curves falls to a value low enough to cause the crystal diode to operate nonlinearly.

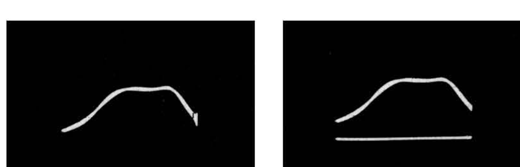
7-20. Effect of Accidental Application of D-C Bias to Crystal Diode in Probe

A small d-c bias voltage applied accidentally to the crystal diode of a demodulator probe (or a rectifying probe) while it is being used in a test can render it useless for most tv test work. A d-c bias can result when the grid bias on the first vertical-amplifier tube in the scope backs up into the probe through a leaky scope input blocking capacitor. This bias may effectively disable the crystal diode. A leaky probe input series capacitor may also be responsible for allowing a bias voltage to be applied to the crystal diode from the circuit under investigation.

If the crystal in a "defective" probe is replaced and the probe still does not work with the new crystal, check for the presence of d-c voltage across the output terminals of the probe, using a vtvm for this check. If the presence of such voltage is indicated, check for leakage in the blocking capacitor in the probe and scope input circuits.

7-21. Position of Demodulated Waveform on Scope Screen

It should be observed that when a demodulator probe is used with a d-c scope, the same facility is obtained as if a zero-volt reference line were available from the sweep generator employed with it. This principle is illustrated in Fig. 7-24, where a single-stage i-f response characteristic is shown displayed on an a-c scope in part A, and on a d-c scope in part B. The zero-volt level is unknown when the a-c scope is used, and the operator will have difficulty in checking the gain of this stage. However, when a d-c scope is used, the curve rises up above



(A) (B)

Fig. 7-24. Stage checks with a demodulator probe are facilitated by the use of a d-c scope, since the resting level indicates the zero-volt reference, and the peak, or peak-to-peak, voltage is indicated on the screen. (A) A single-stage response as seen on an a-c scope. (B) The same response characteristic as seen on a d-c scope. This photo is a double exposure in order to show the zero-volt reference line.

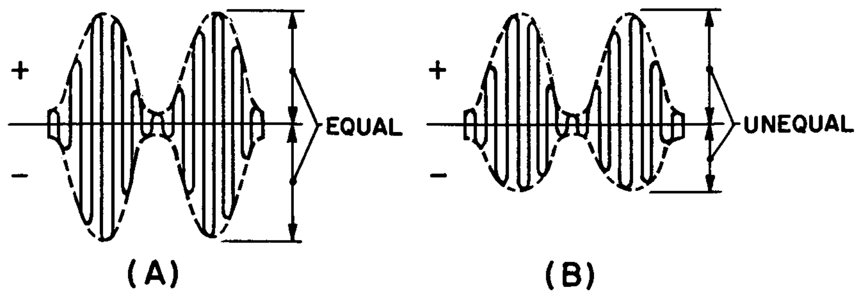


Fig. 7-25. (A) Symmetrical modulated r-f output signal waveform usually approached only by costly laboratory-type signal generators. (B) Service technicians find that the modulation envelopes of the modulated signals supplied by typical service-type signal generators are often unsymmetrical, as shown here. This influences the proper crystal-diode polarity which must be used for greatest sensitivity in a single-diode type demodulator probe when operating with such signals. The probe will appear to be insensitive if polarized to accept the negative-peak excursion, and to reject the positive-peak excursion, of the type of signal shown in (B).

the resting level of the trace and indicates the peak voltage values of the output when a conventional type demodulator probe is employed, and the peak-to-peak value when a voltage-doubler type demodulator probe is used. *The resting level of the trace is the zero-volt level, when a d-c scope is used.* Of course, the same information can be obtained on an a-c scope, if the sweep generator provides a zero-volt blanking function.

7-22. Effect of the Polarization of the Crystal Diode in Demodulator Probes

The crystal diodes in Figs. 7-3, 7-6, 7-7, 7-9, etc. are shown connected into the probe circuit with the proper polarity to make the center conductor of the probe cable *positive.* This will produce a right-side-up trace of the modulating waveform on any scope which is correctly polarized for *upward* deflection from a *positive* voltage. Reversing the crystal polarity in a series or a shunt type of single-diode demodulator probe causes the waveform to invert on the scope screen.

Of greater importance, is the fact that the crystal polarity must be correct if maximum sensitivity is to be realized when viewing modulated waveforms having unequal positive and negative amplitudes. The modulated output signals of some signal generators employed by service technicians are frequently of this type, and when a demodulator probe is used with a scope to view them, the polarization of the crystal diode in the probe is a matter of importance.

Consider the illustrations shown in Fig. 7-25. In part A we see a highly modulated r-f wave which has a symmetrical waveform. If all signal generators delivered a symmetrical waveform of this sort, the polarization of the crystal in the demodulator probe would not be a matter of concern, since both the positive and the negative peaks of the modulated signal have the same amplitudes. However, the technician will frequently be under the necessity of utilizing test signals having modulated waveforms of the character shown in Fig. 7-25B. Since the positive peak voltage of this modulated wave is considerably greater than its negative peak voltage, the probe output would be less and the crystal probe would be judged to be insensitive if the crystal diode were to be connected in the circuit with a polarity so as to accept the negative-peak excursion and to reject the positive-peak excursion. For general work, some technicians keep on hand a positive-peak general-purpose probe and a negative-peak probe.

These considerations also affect the sensitivity of signal-tracing operations when the modulation envelope of the signal generator output is asymmetrical, as well as when generators are being calibrated against crystal oscillators. In a typical instance, three times as much deflection was obtained on the scope merely by reversing the polarity of the crystal diode in the demodulator probe. Other cases have been observed in which the difference was considerably greater.

Service technicians frequently find, therefore, that the apparent sensitivity of conventional types of crystal demodulator probes is greatly affected by the polarity with which the crystal diode is connected into the probe circuit. The foregoing considerations apply only to probes utilizing a single crystal diode. They do not apply to voltage-doubler probes which effectively add up the positive peak and the negative peak value of the waveform. With them, the output is proportional at all times to the peak-to-peak value of the waveform.

7-23. Demodulator Probe Exhibits Feed-through at Low Carrier Frequencies

A conventional crystal demodulator probe exhibits a certain amount of feed-through at low frequencies. This feed-through to the output consists of unrectified and unfiltered voltage having the same waveform as the applied voltage.

To consider a simple example, it might be supposed that if the output from an audio oscillator were applied to a crystal demodulator probe, that the scope would display half cycles of rectified voltage on the screen. Actually, such a test will quickly convince the reader that there is a substantial amount of sine-wave feed-through voltage at these comparatively low frequencies.

The maximum feed-through for one conventional crystal demodulator probe tested was found to occur around approximately 10,000 cycles. At 500 cycles, the feed-through fell to a very small value, because of the reactance of the particular value of series input capacitor used in this probe. At 200,000 cycles, the feed-through again fell to a very low value because the R-C filter in the output of the probe did not permit appreciable passage of frequencies in the vicinity of 0.2 mc.

7-24. Stray-Field Interference Intensified when a Demodulator Probe is Used in High-Impedance Circuits

Upon occasion, the technician finds it more convenient to do a signal-tracing job top-chassis, by placing a floating tube shield over successive tubes, and using a demodulator probe to demodulate the modulated high-frequency voltage induced in the tube shield, for display on the scope. This method depends for operation upon the fact that a floating tube shield is capacitively coupled to the plate of the tube over which the tube shield is placed. This is a high-impedance arrangement, and is susceptible to pick-up of stray fields from the vertical

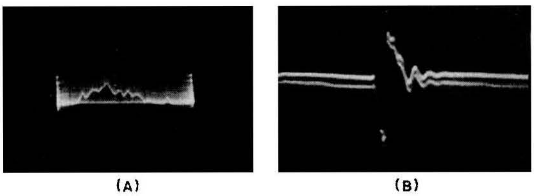


Fig. 7-26. An attempt to obtain signal pickup for a demodulator probe by means of a floating tube shield may be disappointing unless the horizontal- and vertical-sweep circuits of the tv receiver are first disabled. (A) Interference from stray field of horizontal sweep circuit. (B) Interference from stray field of vertical sweep circuit.

and horizontal sweep-circuits of the receiver, which interfere with the test. Typical interference situations are shown in Fig. 7-26. The method works satisfactorily only if the sweep circuits are disabled to prevent the interference.

The floating tube-shield method is usually more satisfactory than the use of testpoint adapters in making high-frequency circuit tests (such as those at the front end of the tv receiver) from top-chassis, because the additional lead inductance introduced by the testpoint adapters often seriously detunes the circuits under test. Top-chassis tests are very convenient for preliminary troubleshooting procedures in the customer's home.

7-25. Use of a Demodulator Probe for Checking TV High-Frequency Current Waveform

The technician should remember that a scope is a microammeter as well as an electronic voltmeter. However, it is not always recognized that the scope may be used as a *high-frequency* microammeter in tv testing, as well, when it is applied in a suitable manner with a crystal demodulator probe. In order to develop the *current* waveform in a high-frequency circuit, the current must be passed through a non-inductive resistor.

Many video i-f amplifiers utilize cathode degeneration in order to stabilize the circuit operation. In a typical receiver, the cathode resistors have a value of 82 ohms. The video signal current passes through these resistors and develops a voltage drop across them. This voltage drop may be applied to a demodulator probe to display the waveform of the video current in the cathode circuit, as shown in Fig. 7-27. (If these resistors are not already present in the circuit, they can be introduced for the test.)

This method of test can also be employed in the cathode circuits of the 4.5-mc sound i-f circuits where probe loading, when the probe is connected in the more conventional manner in the plate circuit (see Sec. 7-10), is a more severe problem than in the picture i-f amplifier, due to the narrow bandwidth and higher Q of the 4.5-mc circuits.

From the practical point of view, it is often necessary to use a scope preamplifier to obtain satisfactory deflection when high-frequency currents are displayed by this method. However, the use of a voltage-doubler demodulator probe, with its relatively high output, is of some help in this respect. A high-quality audio amplifier having low hum level makes a very satisfactory scope preamplifier.

7-26. Demodulator Probe Application in TV Receiver Servicing

Crystal demodulator probes can be used in a number of practical and important circuit-alignment and test procedures in tv service work. Figure 7-28 shows the receiver sections in which they are usually applied. They can be used in signal tracing in the r-f, i-f and video amplifiers; in buzz-pulse analysis in 4.5-mc amplifiers, or in the sound i-f amplifier strips (split-sound tv); in ratio-detector curve marking; in marker-generator calibration; in stage-by-stage alignment, and in any other test which requires demodulation of the signal, so long as the peak test voltage does not exceed approximately 28 volts.

Signal tracing is a straightforward procedure, and can be done in the same general manner as conventional signal tracing of a broadcast receiver. The demodulator probe picks up the modulated high-frequency signal at any point in the tuned circuits or in the video amplifier, and will display the waveform upon the scope screen.

It should be noted that if signal tracing is necessary in tv r-f circuits, it will often be necessary to use a swept signal, rather than a tv station signal, because the signal voltage may otherwise be too low for satisfactory deflection on the scope screen—especially in the early stages of the receiver.

By the use of the signal-tracing techniques, it is possible to pinpoint a dead or weak stage, a regenerative stage, or an oscillating stage, in the r-f, i-f, video, and sound amplifiers. A dead stage develops no deflection on the scope screen. A weak stage will exhibit less deflection than the previous stage, i.e., a *loss* instead of a gain. A regenerative stage will show up in either of two ways, depending upon whether a sweep signal or a tv station signal is being used in the circuits. A sweep signal which passes through a regenerative stage will show an extremely large response at one end or in the middle, but very low response over the rest of the curve. If the regeneration is excessive, spurious markers may also appear. An oscillating stage shows up as a response curve which has gone to pieces and also often exhibits undershoot due to the grid overdrive and flow of grid current. Strong oscillation may paralyze the stage, which may then be confused with a

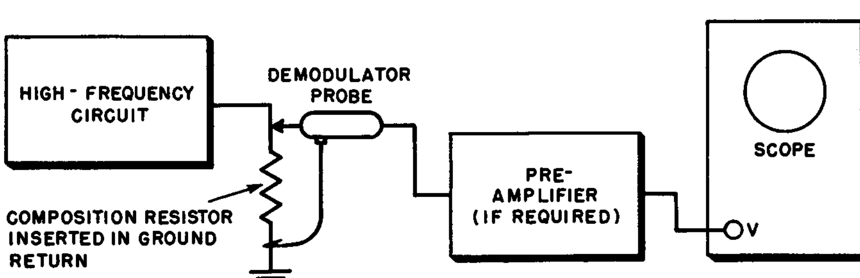


Fig. 7-27. The waveform of modulated high-frequency currents in a tv receiver can be displayed on a scope screen with the aid of a demodulator probe and a small resistor. A pre-amplifier will often be necessary to obtain sufficient deflection on the scope screen when a small resistor is used. A large value of resistance is likely to disturb the circuit action, and will also result in a distorted waveform due to the effect of the input capacitance of the demodulator probe.

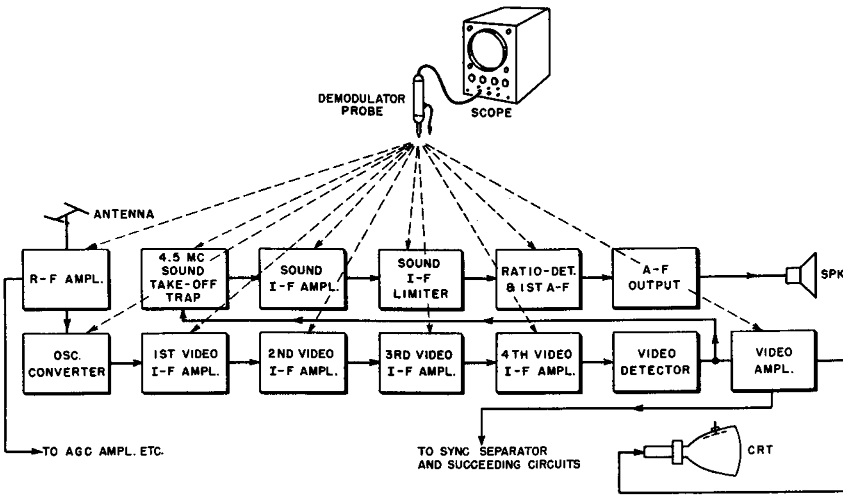


Fig. 7-28. Sections of a tv receiver in which demodulator probes are widely used in visual circuit-alignment and troubleshooting procedures.

dead stage. However, the supplementary use of a vtvm and a high-frequency rectifying probe will distinguish between the two cases, since the oscillating stage will cause a large deflection on the vtvm (when connected to the grid), whereas a dead stage causes no deflection of the pointer.

If a station signal is used for the tracing procedure, regeneration may show up as severe distortion of the composite video signal, either with the equalizing pulses much lower than the level of the vertical sync probe, or with severe overshoot and ringing along the top of the vertical sync pulse.

Some of the more important operating requirements of demodulator probes for use in various tv servicing applications have been outlined in Sec. 7-8, and the reader is advised to review them at this point. Additional requirements will be pointed out in the discussions which follow. Both series- and shunt-type demodulator probes are employed in this work; the series type being the more sensitive for general signal-tracing purposes, but also providing less attenuation to objectionable 60-cycle and 120-cycle hum voltage with respect to r-f or i-f voltage. This latter characteristic, plus the output-waveform distortion it produces, makes the series-type probe the least suitable one for video-amplifier testing. Consequently, shunt-type demodulator probes are more widely used in this particular work. The voltage-doubler type demodulator probe provides increased sensitivity that is advantageous in many tests, but its useful carrier-frequency response range is lower than that of the other types.

It should be remembered that any probe which employs crystal diodes can be damaged by excessive input voltages. Ordinarily, such probes will not be damaged by application of the signal voltages from the r-f, i-f, or 4.5-mc circuits.

Any contact with the high-voltage sweep circuits, accidental or otherwise, will immediately burn out the crystal diode (s).

Practical general-purpose demodulator probes designed for tv receiver work usually have moderate sensitivity, an input capacitance approximately equal to that of a picture tube, are non-resonant out to at least 225 mc, and have a time constant suitable for demodulating carrier frequencies which have been modulated by frequencies as low as 60 cps.

The service technician should never forget that a crystal demodulator probe not only introduces an insertion loss in the circuit, but also causes a certain degree of output-waveform distortion. Therefore, whenever the carrier frequencies comprising the modulated signal under observation *are within the flat frequency-response range of the vertical amplifier of the scope which is to be used, the demodulator probe should not be employed.* The test signal should be applied *direct* to the scope input terminals instead, and the carrier of the signal displayed directly. (A capacitance-divider type high-voltage probe, or a low-capacitance probe, may be required ahead of the scope in some circuits, such as the high-voltage horizontal-output circuit and the horizontal-oscillator circuits, respectively, see Chapters 2 and 6.)

A number of helpful demodulator probe selection and application hints pertaining to several of the more important uses of such probes in tv service work, are presented in the following sections of this Chapter.

7-27. Use of Balanced-Input Type Probe for Checking Impedance Match of Transmission Line to Antenna or Receiver

A balanced-input demodulator probe arrangement, such as is described in Sec. 7-14, is very convenient for use with a scope to quickly check the frequency response of a transmission line; or the degree of mismatch existing between the

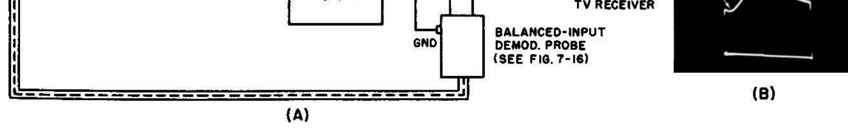


Fig. 7-29. (A) Checking for mismatch between the characteristic impedance of the antenna lead-in and the input impedance of the tv receiver, by means of a balanced-input type demodulator probe and scope. Note that the lead from the center-tapped sweep-generator cable termination to the Gnd terminal of the probe carries the r-f sweep voltage. It therefore should be kept as short as the "high" leads to the probe, in order to avoid distortion in the response trace. (B) Mismatch between the lead-in impedance and the input impedance of the front end of a tv receiver is indicated here by the bump in the response trace. If perfect impedance match exists over the swept-frequency range, a flat response trace will result.

characteristic impedance of an antenna lead-in and the impedance of the antenna, or between it and the input impedance of the front end of the tv receiver, converter, or booster with which it is associated. The balanced output circuits of signal generators, the characteristics of interference-elimination stubs, the impedance match between a balun and its load, or that between a converter or booster output circuit and the tv receiver front end input circuit, may also be checked in the same manner. The equipment setup for checking impedance mismatch between an antenna lead-in and the input circuit of the tv receiver's front end is illustrated in Fig. 7-29A. Similar setups may be used for other tests of this type.

A sweep voltage of suitable center frequency and deviation is fed to the input end of the lead-in, balun, or other device, by a properly terminated sweep generator, and the balanced-input demodulator probe is arranged to pick off the signal voltage appearing at either the input end as shown or at the other end (which is connected to the load to which it is supposed to be matched). If line mismatch is being checked, the transmission line should be at least 20 or 25 feet long so that appreciable standing waves can be developed at representative tv signal frequencies. The line should be kept away from metallic objects and have no sharp bends. If a perfect impedance match exists at all of the frequencies swept through (and a sweep generator which has a flat output characteristic is used), no variations in voltage will occur at the input to the balanced demodulator probe at any of the frequencies swept through, and a flat trace will therefore appear on the scope screen. If an impedance mismatch exists and standing waves are set up, the input voltage rises and falls in accord with the rise and fall of impedance seen at the source end of the line. This produces a response curve having pronounced peaks and valleys.

The degree of mismatch often encountered in practice is shown in Fig. 7-29B; here the highest voltage point resulting from the standing-wave pattern is approximately twice the voltage at the lowest point. However, much more severe conditions of mismatch may often be encountered. Such mismatch can be partially corrected by sliding a piece of tinfoil along the line to a suitable point. However, a better method is to adjust the coupling of the antenna coil properly with respect to the r-f grid coil in the tuning strip. In this way, discontinuities are not introduced into the lead-in which could affect operation on other channels.

7-28. Demodulator Probe Application in TV Front-End Work

The signal-substitution method may be employed for troubleshooting tv receiver front ends. To determine whether the antenna signal is proceeding through th r-f stage to the mixer grid, connect a scope *directly* to the tap ("looker" point) usually provided on the mixer grid-leak. (It may be necessary to insert an isolating resistor of about 50,000 ohms at the end of the scope cable to avoid loading of the mixer grid circuit and detuning of the grid coil.) The grid of the mixer is usually operated at zero bias, so that a nonlinear or heterodyning action can take place. In consequence, there is a demodulated component at the mixer grid, as well as sum-and-difference frequencies, the difference frequency being accepted by the first i-f tuned circuit. Thus, the grid circuit of the mixer operates as a diode detector, and the plate circuit operates as an amplifier.

Therefore, with the scope connected to the mixer grid-leak "looker" point, the r-f and mixer input response curve should appear on the scope screen when a sweep signal is applied to the antenna terminals of the receiver. If a fixed-frequency signal of a frequency approximately equal to that of the local oscillator is applied to the antenna terminals instead, a demodulated Lissajous pattern will be produced on the scope screen that is useful for adjusting the local oscillator to correct frequency. If a strong tv station signal is applied to the antenna terminals instead, a demodulated video signal display will be produced on the scope screen. In each case, the demodulated output from the mixed grid circuit is being used for display instead of the modulated r-f carrier, or the sum-and-difference frequencies, or their harmonics, which are normally present.

If it is not possible to obtain a response trace at the mixer grid, it is necessary to check the response of the antenna and r-f grid coils separately, and to check the mixer coupling transformer separately. To check the antenna and r-f grid coils, the setup shown in Fig. 7-30A may be used. The special low-impedance high-frequency probe described in Sec. 7-11 is particularly well suited to this

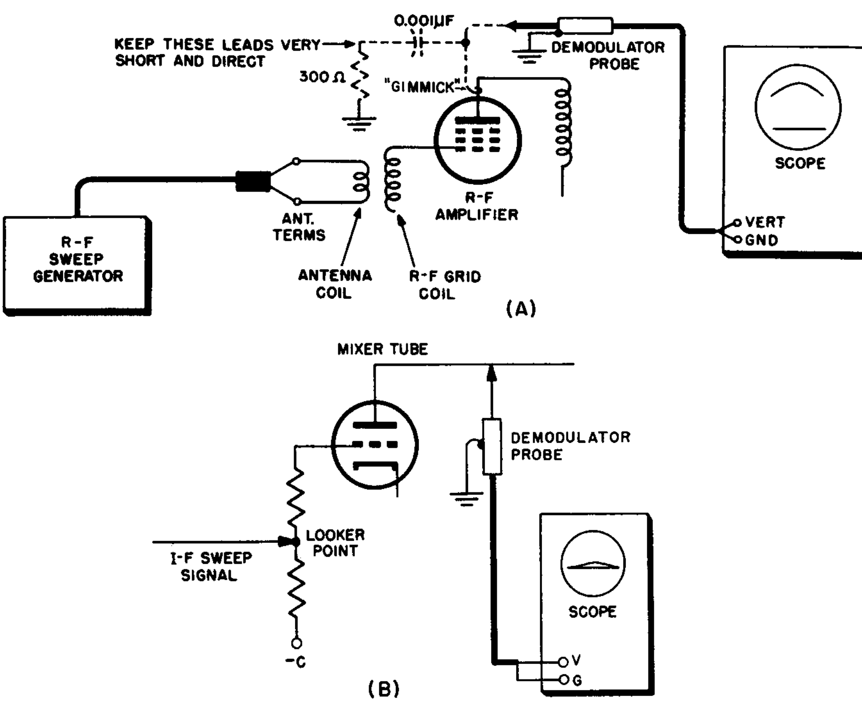


Fig. 7-30. (A) If the test signal does not arrive at the mixer grid when troubleshooting the front end, the response of the antenna coil and r-f grid coil can be separately checked by the instrument setup shown here. A low-impedance demodulator probe arrangement is required (see text). (B) A test setup which utilizes the "looker" point on a front end as a signal-injection point to check the progress of an r-f sweep signal through the mixer circuit. A demodulator probe and scope are used to display the mixer output signal.

work. If a general-purpose type demodulator probe is employed instead, its input should be shunted with the 300-ohm swamping resistor and B+ blocking capacitor shown to load down the plate circuit of the r-f amplifier so that the response of the r-f input circuit appears only on the scope. Both resistor and capacitor leads must be very short and direct. If a special low-impedance probe of the type described in Sec. 7-11 is used, the swamping resistor and blocking capacitor are not required. Connection to the plate of the tube may be made by means of a "gimmick" consisting of a small loop of wire slid under the tube base and hooked over the plate pin. The demodulator probe is required here because the signal now being sampled for test is the modulated sweep output of the r-f tube.

In case it is inconvenient to use a "gimmick" for connection to the plate of the r-f amplifier tube, lift up the tube shield over the r-f tube far enough to clear the grounding ring, and apply the demodulator probe between the floating tube shield and chassis. The response curve will be distorted, but indication of the presence of test signal will be definite.

The "looker point" on a front end is also useful as a signal-injection point to check the mixer operation. Circuit (B) in Fig. 7-30 shows the test setup for this check, using a demodulator probe applied at the mixer tube plate. The output from the mixer is quite small, as the sweep signal is attenuated by the resistance associated with the looker point. However, comparative gain measurements can be made as for the r-f stage.

Somewhat more output is obtained in this test, and misleading spurious cross beats on certain channels will be prevented, if a dummy tube is used in the front end to disable the local oscillator. When the oscillator is operating, rectified voltage from the local oscillator appears across the crystal diode in the demodulator probe and biases the crystal to a less favorable operating point on its characteristic.

Alternately, the mixer stage can be checked in combination with the local oscillator, by injecting r-f sweep voltage at the looker point with the local oscillator operating, and permitting it to beat with the local-oscillator voltage. The difference beat is then accepted by the mixed plate circuit, and displayed on the scope screen.

Regeneration, or oscillation present in the r-f or mixer stages can be tracked down by the methods outlined in Sec. 7-26 for such troubles.

7-29. Demodulator Probe Application in Video I-F Amplifier Work

The demodulator probe finds some of its most important applications in visual stage-by-stage alignment and signal-tracing operations performed in the i-f amplifiers of tv receivers (see Fig. 7-28), because the carrier frequencies of the test signals (up to about 50 mc) used in such work are usually well beyond the frequency range of the vertical amplifiers of service-type scopes.

The danger of the possible harmful circuit loading, stage detuning, and regeneration or oscillation which may be caused by the indiscriminate use of a conventional general-purpose demodulator probe in i-f amplifier work has already been discussed in Sec. 7-10, and will not be repeated here. In the discussion that follows, it is assumed that if such a probe is used, it will be properly shunted

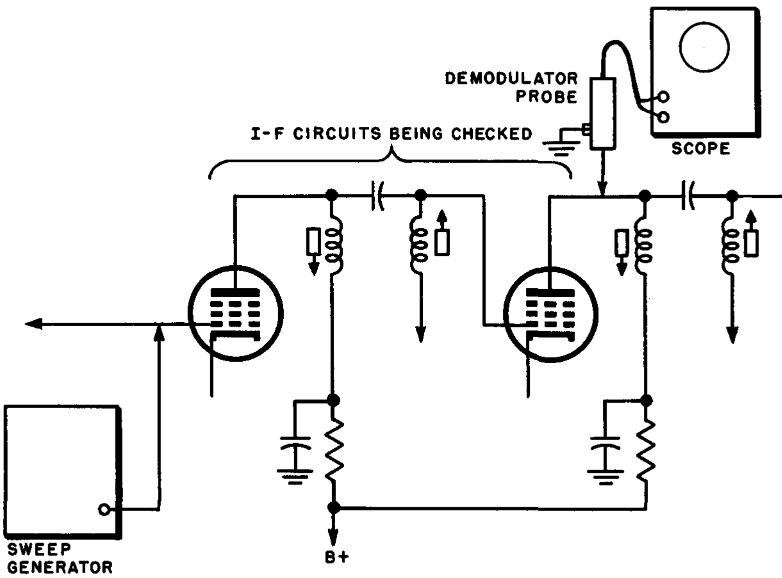


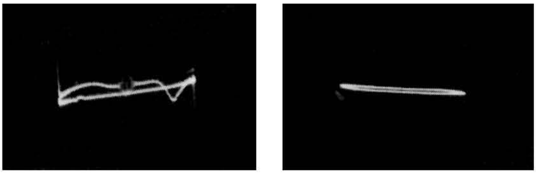
Fig. 7-31. Conventional method of checking the alignment, or testing the response, of a single stage of a video i-f amplifier, using a demodulator probe and scope for visual indication.

in the manner shown in Fig. 7-13, or that one of the low-impedance type probes discussed and illustrated in Sec. 7-10 will be employed instead.

(*1*) *Stage-by-Stage I-F Amplifier Alignment.* Stage-by-stage visual alignment of i-f amplifiers is recommended by some tv receiver manufacturers, as they provide stage-by-stage response curves for guidance. This method is also frequently resorted to if severe difficulty is being experienced in obtaining the proper overall response curve for the entire i-f amplifier. There are two general methods of making such a stage-by-stage alignment. In the first method, the video detector serves as the demodulator for alignment, and the alignment must proceed from the last i-f stage back to the first. The video detector output signal is fed directly to the scope. Consequently, no demodulator probe is required.

In the other methods, a demodulator probe is used and the individual stages may be aligned separately in any desired order. A sweep signal of proper frequency (determined by the i.f. employed in the receiver), is applied to the grid of the tube ahead of the tuned circuits under test, and the demodulator probe and scope are applied to the plate of the tube following the circuit under test, as shown in Fig. 7-31.

The technician will find that various types of crystal signal-tracing demodulator probes produce varying degrees of distortion (of a horizontal sync pulse, for example). Although a demodulator probe which produces minimum waveform distortion may be preferred for signal-tracing work, such a probe may be rather disappointing when used to demodulate a visual-response curve, as the marker indication will be very broad. Accordingly, a demodulator probe which



(A) (B)

Fig. 7-32. Typical patterns obtained when the demodulator probe detunes an i-f stage and throws it into oscillation. Since the scope deflection becomes so small, an oscillating stage due to probe loading can easily be confused with a weak or a dead stage.

provides some degree of filtering at the scope input circuit will usually be preferred for visual-alignment applications.

(2) *Stage-by-Stage I-F Signal Tracing.* When the gain of the i-f amplifier is subnormal and cannot be restored by realignment, when the specified bandwidth cannot be obtained, or when regeneration or oscillation is present and the proper response curve shape cannot be obtained, the technician often wishes to make a stage-by-stage signal-tracing check to localize the trouble in an i-f amplifier. The receiver is then energized at the antenna terminals by a suitable modulated r-f signal, or by a sweep-frequency signal, or by a sufficiently strong tv station signal. The signal should have the same frequency as the channel to which the tv receiver station selector is set. To trace this signal through the i-f circuits of the receiver, a demodulator probe and scope combination is applied successively to the plate terminals of the mixer, first, second, third and fourth i-f tubes, watching the pattern on the scope screen. If the pattern disappears at any point, the stage can be assumed to be dead (or oscillating), and troubleshooting is in order.

The type of pattern observed on the scope screen during signal-tracing procedures depends on the type of signal applied to the antenna terminals of the receiver. If a tv station signal is used as the signal source, the composite video signal will be seen on the scope screen. (A reasonably strong station signal must be used in order to obtain satisfactory scope deflection when testing early i-f stages, or a scope preamplifier must be used, because the signal level in the earlier i-f stages is relatively low.) If the signal source is a sweep-frequency generator, the frequency-response curve of the stage will be traced on the scope screen. For each of these signal sources, the height of the pattern from a zero-volt baseline from one i-f stage to the next is a measure of the gain of that stage. If a modulated r-f signal is utilized instead, the modulation waveform of the signal will be observed on the scope screen, and the height of this waveform from one stage to the next is a measure of the gain of that stage.

The result of a stage-by-stage check may reveal a dead, weak, regenerative, or oscillating stage by the analysis methods outlined in Sec. 7-26 for such troubles[1].

Occasionally, when a demodulator probe is applied to the grid or plate terminal of an i-f stage, little or no indication is obtained on the scope screen, despite the fact that the stage is not weak or dead. This situation may be the

[1] For a comprehensive discussion of the alignment and signal-tracing of r-f, i-f and video amplifiers, see TV TROUBLESHOOTING AND REPAIR GUIDEBOOK, Vols. 1 and 2, by Robert G. Middleton, published by John F. Rider Publisher, Inc., New York, N. Y.

result of excessive loading of the stage by the probe, or may be the consequence of stage detuning which happens to throw the stage into oscillation, with the result illustrated in Fig. 7-32. When trouble of this kind is encountered and a low impedance type demodulator probe is not available, a conventional single-diode probe, or a voltage-doubler probe, properly shunted as shown in Fig. 7-13 should be used. If the trouble still persists, a very small capacitor (approximately 1 $\mu\mu$f) should be connected in series with the tip of the probe to reduce the detuning of the stage. A short length of 75-ohm 2-wire lead-in can serve as this capacitor. One conductor is connected to the test point while the probe is connected to the other conductor.

(3) *Importance of Proper Grounding of Demodulator Probe.* Spurious scope patterns due to oscillation and other causes may also be produced in i-f amplifier alignment and signal-tracing work by the use of too long a ground-return lead to the demodulator probe, and most of the difficulty experienced by beginners is due to this cause alone. It should be remembered that this ground-return lead is part of the carrier-frequency circuit of the probe, and it therefore *conducts current of carrier frequency.* A demodulator probe with a moderately long gound lead is quite satisfactory for video-amplifier checking, where the highest carrier frequency to be accommodated is 4 or 4.5 mc. However, for use in video

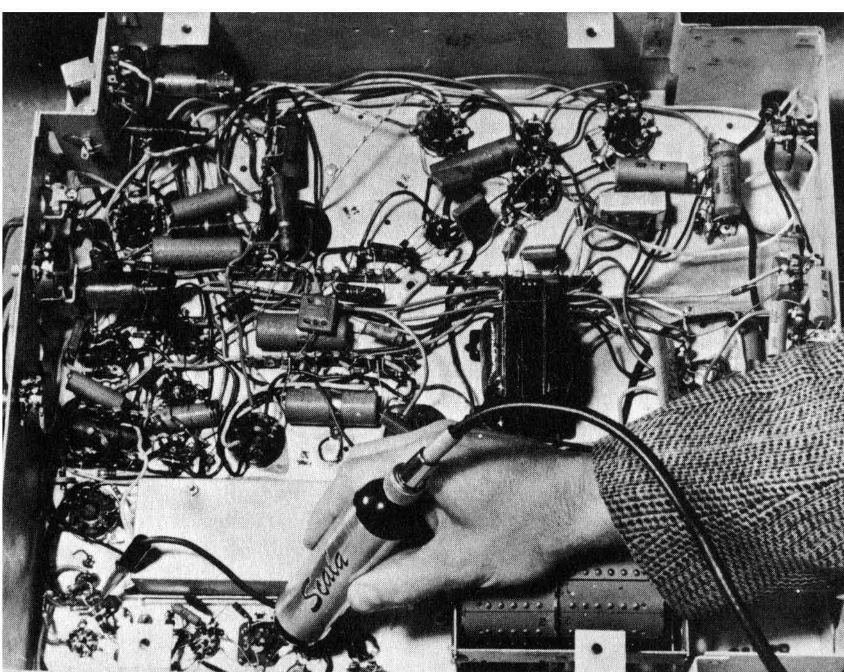
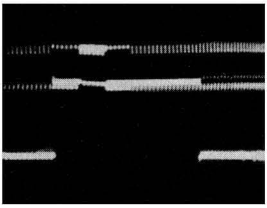
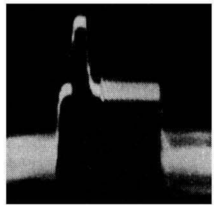


Fig. 7-33. Signal-tracing in a video i-f amplifier with a crystal demodulator probe and scope. Observe that the probe ground-return is clipped to chassis ground (at lower left) as close as possible to the signal take-off point. ***Courtesy: Scala Radio Co.***



(A)



(B)

Fig. 7-34. (A) Display of demodulated composite video i-f signal obtained when scope is connected via a low-capacitance probe at the output of the video detector in a tv receiver. (B) Stripped appearance of the display of the demodulated composite video r-f signal obtained when the scope is connected via a demodulator probe at one of the video i-f amplifier stages. There is a definite reason for the difference in the appearance of the two displays (see text).

i-f circuit work, where the operating frequency ranges from about 20 to 50 mc, a short ground-return lead to the probe is essential (see Fig. 7-33).

A parallel requirement is that the probe grounding connection be made as close as possible to the signal take-off point in the receiver, especially at frequencies above 100 mc. Unless this is done, there may be spurious patterns due to ground-current effects at high frequencies. Those may take the form of considerable standing-wave voltage developed along ground leads, or even along a grounded metallic surface. Many technicians think they can dispense with the annoyance of progressively connecting and disconnecting the probe ground in i-f alignment or signal tracing work, simply by running a permanent ground lead from the scope case to the receiver chassis. In practice, a ground lead this long almost invariably causes erratic operation.

The matter of proper probe grounding is of great concern in r-f amplifier alignment and signal-tracing work when the signal source is of tv station frequency, since the carrier frequency may then be appreciably above 54 mc. The accuracy with which tests can be made at these frequencies often depends on the way in which the demodulator probe is used. It is often found necessary to dispense with the short ground-return lead that is provided with the probe, and to make the ground return directly to the shielded case of the probe.

(4) *Appearance of Composite Video Signal When Demodulator Probe is Used.* The technician often finds it difficult to understand why the composite video signal looks different when viewed on a scope fed by a demodulator probe which picks the video signal off one of the video i-f amplifier stages, as compared with the appearance of the composite video signal when the scope is connected via a low-capacitance probe at the output of the video detector in the receiver (thereby employing the video detector as the demodulator in the test circuit). This difference is shown in Fig. 7-34, and there is a definite reason for it.

It might be supposed, for example, that a demodulator probe could be built with exactly the same circuit arrangement as is employed in a typical video detector, in order to obtain an excellent waveform of the demodulated video i-f signal. Unfortunately however, this demodulator probe would have to work into the scope input capacitance (including that of the scope cable), which is many times higher than the input capacitance of a video amplifier. The video-detector arrangement in a tv receiver, with its peaking coils, etc., works into the relatively small capacitance presented by the input grid circuit of the video amplifier; the demodulator probe, on the other hand, must work into as much as 50 to 100 $\mu\mu f$ of cable and scope input capacitance. For this reason, it is unfair to expect the same demodulating ability from a simple, uncompensated demodulator circuit that works into a scope cable as from the more complex, compensated demodulator circuit working into the video amplifier in the receiver. In fact, if the bandwidth of a demodulator probe is excessive, the probe will not be useful for video-amplifier adjustment.

7-30. Demodulator Probe Application in Video-Amplifier Work

The video amplifier carries the actual picture or video frequencies, ranging from 0 to 4 mc. In intercarrier receivers, it also usually carries the 4.5 mc sound-carrier signal. One method of effectively signal tracing, or checking the frequency response of, a video amplifier is by applying a sweep signal to its input circuit and displaying its output on the scope screen. The video sweep signal used in such tests usually varies from a low frequency of approximately 100 kc to 5 or 6 mc, 60 times a second.

Whether or not it will be necessary to use a demodulator probe with the scope depends upon the frequency-response characteristic of the vertical amplifier of the particular scope employed. A demodulator probe is not required for the response display when a wide-band scope is used, provided, of course that the scope has adequate sensitivity (see Fig. 7-35) and a flat frequency response out to well over 4.5 mc. In this case, the sweep voltage is displayed directly. In the discussions which follow, it will be assumed that the limited frequency-response characteristics of the scope to be employed makes the use of a demodulator probe necessary. Because of its greater hum-voltage attenuation and better waveform-fidelity characteristics in this service, the shunt-rectifier type of demodulator probe is generally considered the most suitable for video-amplifier work.

(1) Sweep-Signal Testing of Video Amplifiers. The typical instrument setup for a frequency-response check, or signal-tracing, in a video amplifier by means of an applied sweep signal is shown in Fig. 7-36. The video detector is removed, or the grid capacitor to the first video amplifier is disconnected from the detector. The demodulator probe is connected at the signal-electrode (usually the grid) terminal of the picture tube socket. The picture tube should be removed from

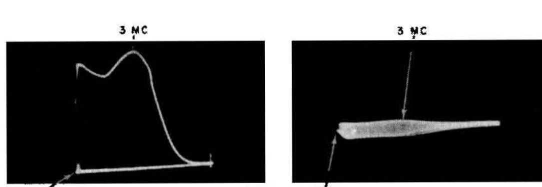


Fig. 7-35. (A) Response curve of a swept video amplifier as seen on the scope screen when a demodulator probe is utilized and the scope vertical amplifier is being employed. (B) Relatively small deflection obtained on scope screen when the output of a swept video amplifier is applied directly to the deflection plates of the cathode-ray tube in the scope. No demodulator probe or scope vertical amplifier is employed. The video-frequency sweep voltage is displayed directly here.

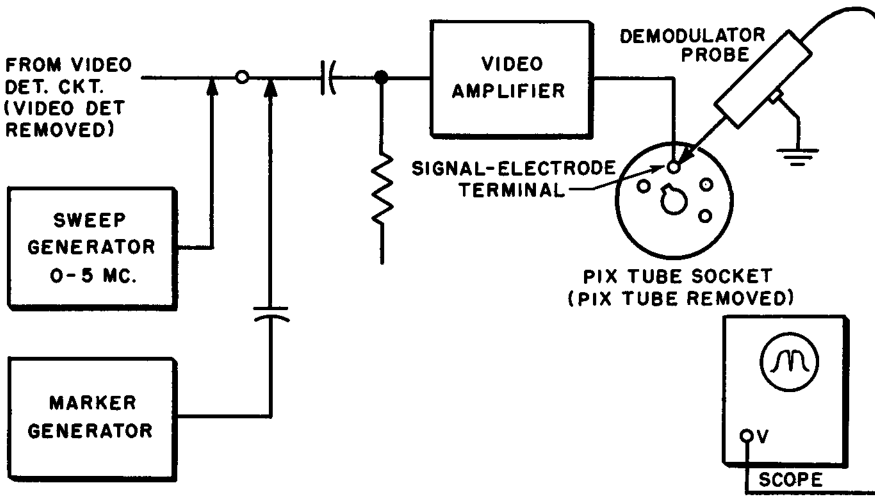


Fig. 7-36. Instrument setup for frequency-response check, or signal tracing, in a video amplifier by means of a sweep signal, if the video detector is not to be included. The demodulator probe used in this work must meet several important requirements (see text).

the socket so that the output circuit of the video amplifier is not loaded excessively during the test. This results in the first important requirement of the demodulator probe employed in this work, and is one reason why a demodulator probe which is satisfactory for video i-f amplifier signal tracing and alignment work may well be quite useless for video-amplifier work. The reason is that the frequency response characteristic of the video amplifier depends in great part on the *shunt capacitance* of the load connected across its output circuit, that is, upon the capacitance loading. If this shunt capacitance is appreciably greater than the input capacitance of the picture tube, the high-frequency response will appear to be very poor. On the other hand, if the shunt capacitance of the test circuit is appreciably less than the input capacitance of the picture tube, the frequency response will appear to be better than it really is when the receiver is in operation.

Obviously, the input capacitance of the demodulator probe used in this work should be approximately the same as the picture tube input capacitance, so that the capacitance loading on the output circuit will be the same as exists during normal operation of the receiver.

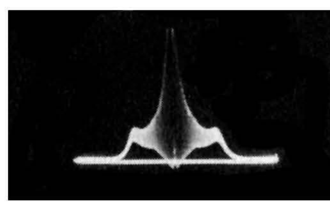
The probe must also have good response to 60-cycle square waves, because the demodulated sweep output is of the same general form as a 60-cycle square wave. If the time constant of the probe is too long, the scope will indicate a true rise, and a false fall, of the response curve.

The frequency characteristic of the demodulator probe is largely controlled by the value of the series isolating (filter) resistor which forms part of the probe filtering circuit. Unless this value falls within a suitable range to make the time constant of the filter suitable, a distorted reproduction of the video response curve will result, as shown in Fig. 7-37. The circuit constants shown in the demodulator probe circuit in Fig. 7-9A are found to provide generally satisfactory probe operation in this work.

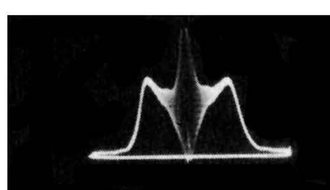
The video response curve produced by this test setup does not include the response of the video detector. If it is required to check the response of this circuit along with that of the video amplifier, a sweep generator and a single-frequency r-f generator are employed to apply their signals ahead of the video detector. In this case, the two signals beat together in the video detector and produce a sweep output modulated in accordance with the response characteristic of the circuit under test. The output of the video amplifier is then applied through a demodulator probe to the scope.[1]

The results of a signal-tracing check of the video amplifier by the foregoing method may show a dead, weak, regenerative, or oscillating stage.

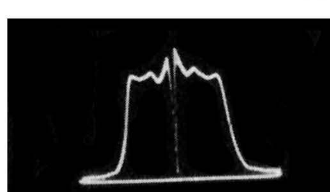
When making regeneration tests in video amplifiers, it is sometimes found that the available deflection on the scope screen is somewhat small, due to the fact that only one stage is being swept, and also because the output from the video sweep generator is attenuated by the isolating resistor which must necessarily be used. In such cases, it will be found that a voltage-doubler type of



500 Ω FILTER RESISTOR (INSUFFICIENT) (A)



5,000 Ω FILTER RESISTOR (INSUFFICIENT) (B)



200,000 Ω FILTER RESISTOR (GREATLY IMPROVED) (C)

Fig. 7-37. The series filtering resistor in the output circuit of the demodulator probe must have a value which makes the time constant of the filtering circuit fall within a suitable range for the maximum rate of change of the signal that will be encountered in the application. Otherwise a distorted response trace will be obtained. (A) Filter resistor value much too low (time constant much too short) for the application. This causes the scope to indicate a true fall, but a false rise, in the actual video amplifier response, so a distorted response trace results. The broad, fuzzy interference near zero frequency (at the center of the trace) is excessive unfiltered response displayed due to inadequate filtering action provided by the probe output circuit. (B) Less probe distortion when a higher value of series filter resistance (longer time constant) is used. (C) Greatly improved response curve when a resistance value close to the correct one for this application is employed. If the time constant of the probe is made too long (by the use of too high a series filter - resistance value) the scope will indicate a true rise, but a false fall, in the actual video amplifier response.

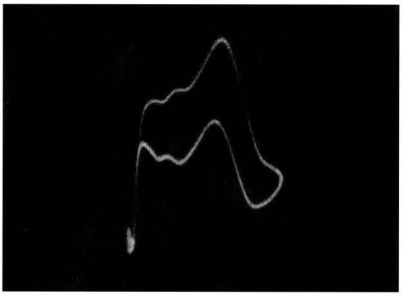


Fig. 7-38. Distorted video response trace obtained when a simple series-type demodulator probe is used to demodulate the output sweep signal from a video amplifier in which strong hum voltage is present. The hum distortion is seen to be severe, and the time constant of the probe is excessively long for the rate of change of the modulation envelope.

demodulator probe will provide approximately double the deflection on the scope screen, and thereby often facilitate the test considerably.

(2) *Hum-Rejection Requirements for the Demodulator Probe.* If 60-cycle or 120-cycle hum voltage is introduced into the test signal in some manner by the receiver, the visual response curve will be distorted accordingly. If a sweep signal having the customary 60 cps repetition rate is being employed, the trace and retrace will not lay over each other but will be displaced by an amount proportional to the hum voltage as it goes through its cyclic changes. The result is that distortion and displacement of the trace and retrace relative to each other occur. The resulting pattern (see Fig. 7-38) depends on the magnitude and the frequency of the hum voltage, and upon the phase relationship between the hum voltage and the test signal. It is evident that hum distortion in the video-amplifier response trace can be a troublesome problem unless a suitable type of demodulator probe which discriminates against 60-cycle or 120-cycle a-c hum voltage present in the signal to be displayed, is used with the scope. The shunt type of probe is generally found to have the best hum-rejection properties.

(3) *Square-Wave Testing of Video Amplifiers.* A square-wave test for video amplifiers is preferred by some technicians over the foregoing sweep-frequency test. This is true because the larger harmonic content of the square-wave test signal enables the amplifier characteristics to be checked over a wide frequency range, and also because it shows up important phase distortion as well as frequency distortion in the amplifier. A demodulator probe is not required in this test, but a wide-band scope must be used.

7-31. Demodulator Probe Application in Sound-Section Work

A d-c scope converts an a-m demodulator probe into an f-m peak-indicating probe. Therefore, an f-m demodulator probe, although practical, is not needed in troubleshooting or adjusting the f-m circuits of the sound section of a tv receiver (or of an f-m aural receiver).

(1) *Demodulator Probe Used to Develop Visible Marker for S-curve.* The demodulator probe also finds useful application in ratio-detector work in the f-m section during sweep alignment of the tuned circuits. Because of the inherent a-m rejection by a properly operating ratio-detector circuit, it is often found difficult or impossible to distinguish the 4.5-mc marker employed on the S-curve in this work. This situation is illustrated in Fig. 7-39A. The 4.5-mc point on the S-curve can be easily located, as shown in part B of the figure, by applying the sweep voltage in parallel with the marker voltage, through a demodulator probe,

into the vertical amplifier of the scope. The probe has no a-m rejection properties, so the 4.5-mc marker now appears along the swept trace, as shown. By tuning the sweep generator, or by adjusting the horizontal centering control of the scope, the marker can be brought to the exact center of the screen, as shown in Fig. 7-39B, so that the vertical center line of the scope screen indicates the 4.5-mc point. Next, the demodulator probe can be disconnected and the ratio-detector circuit placed in the test setup. Although the 4.5-mc marker is now invisible, it is known that the point of intersection of the S-curve with the vertical center line of the scope screen marks the 4.5-mc point on the S-curve.

Use of a voltage-doubler type general-purpose demodulator probe has an advantage in this application in case the marker voltage is quite weak, as the marker will appear a double-height on the scope screen when this type of demodulator probe is used (see Sec. 7-15).

(2) *Use of Demodulator Probe to Reveal Presence of Spurious Voltages.* A d-c scope and a general-purpose demodulator probe make a useful combination for revealing the presence of spurious voltages in the f-m sound system. For example, it may be used to reveal any modulation which may be impressed on the 4.5-mc f-m sound signal by the picture signal (mainly by the vertical sync pulse) during the course of passage of the signals through the video i-f circuits. The resting position of the scope beam is first noted on the screen before any signal is applied. Next, the f-m sound signal just ahead of the ratio detector is applied to the demodulator probe, and the sound signal pattern appears on the scope screen, rising above the zero-volt level by an amount which is determined by the d-c component of the signal. This in turn is determined by the percentage of the modulation. The latter is measured directly from the pattern. If its value is more than about 35 to 40 percent, trouble should be sought in the video i-f circuits, or possibly the video amplifier circuits, before the sound circuits are investigated.

It is sometimes observed during such tests, that the scope trace appears at some distance above the zero-volt level when the demodulator probe is applied to the sound circuits under test and no sound signal is present. The deflection in this case is due to spurious voltages present in the amplifier, which may be caused by internal or external interference. The possibility of external interference entering the receiver can be checked by switching to other tv channels, or by removing the video-detector tube.

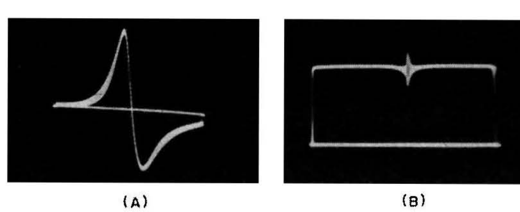


Fig. 7-39. (A) A ratio-detector S-curve is often difficult to mark because the a-m rejection of the ratio-detector circuit rejects the beat marker. (B) A general-purpose demodulator probe may be used to make the 4.5-mc marker visible on a separate swept trace, thus calibrating the horizontal baseline of the scope. The marker may be made to appear at the exact center of the screen, as shown.

Internal interference is usually caused by some form of oscillation in the sound amplifier or video amplifier, or both. Tubes can be removed progressively, to find out which stages are involved, or a bypass capacitor can be shunted from the grid of each tube, in turn, to ground. The shunting method breaks the feedback path, and causes the scope trace to drop to the zero-volt level.

(3) *Buzz-pulse Tracing in the Sound I-F Amplifier.* A scope, together with a conventional general-purpose demodulator probe of the type illustrated in Fig. 7-9, or a voltage-doubler type as in Fig. 7-18, can be used to view troublesome 60-cycle buzz voltage that may be present in the 4.5-mc f-m circuits of the sound amplifier, in order to localize it to its origin. The circumstance leading to the production of the buzz pulses determines the appearance of the waveform. When the 4.5-mc sound signal is displayed on the scope screen, excessive buzz voltage in this circuit will become apparent as a 60-cycle pulse which usually has a vague resemblance to the vertical sync pulse from which it is derived (see Fig. 7-40). This occurs in the case of tunable buzz. In the case of untunable buzz, the pulse more often appears as a sharply pointed 60-cycle spike voltage.

Buzz problems are frequently difficult to solve, because there are a large number of points in a receiver where buzz pulses may originate and be introduced. Tuned heads are required in conjunction with the demodulator probe when checking for buzz in circuits that normally carry picture signals.[2]

(4) *The Demodulator Probe Should be Applied in Low-Impedance Circuit.* It is always advisable to apply the demodulator probe in a low-impedance circuit in the sound i-f amplifier or ratio-detector circuit. If the receiver does not afford low-impedance test points, it is practical to insert a resistor having a value of 5 or 10 ohms between the cathode of the tube being tested and chassis. The small voltage drop across the resistor has no practical effect on the circuit operation, but provides enough signal voltage for full-screen deflection on a sensitive scope. The blocking capacitor in the demodulator probe blocks off the d-c drop, but passes the spurious a-c voltage which is then demodulated for display on the screen of the d-c scope.

7-32. Special Demodulator Probe to Test for Presence of Spurious Voltages in Heater Lines

The technician will obtain much additional utility from demodulator probes if he is alert to the possibility of special applications for them. For example, difficulty in receiver operation is sometimes encountered because of feedback of high-frequency voltages through heater lines. Direct application of the scope to the heater line in order to detect or study such spurious voltages cannot be resorted to because the vertical amplifiers of conventional service-type scopes usually do not respond to the high frequencies ordinarily involved in this type of trouble. Also, the 60-cycle heater voltage which is present, is not appreciably attenuated with respect to the high-frequency spurious voltage which is being sought. It will be found that direct application of the scope merely displays the 6.3-volt a-c heater voltage.

[2] For a comprehensive discussion of the causes, and the methods of tracing, the origin of buzz pulses in a tv receiver, see TV TROUBLESHOOTING AND REPAIR GUIDEBOOK, Vol. 1, Chapter 9 by Robert G. Middleton, published by John F. Rider Publisher, Inc., New York, N. Y.

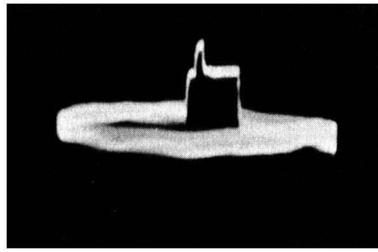


Fig. 7-40. Appearance of a 60-cycle sync-buzz pulse at the input of the ratio-detector circuit. Display obtained by using demodulator probe and a-c scope. If a d-c scope is used, the d-c component in the signal output from the demodulator probe is utilized.

However, when a demodulator probe is used in the test, (especially if it employs a relatively small value of series capacitance) it greatly attenuates the 60-cycle component, and the demodulation action of the probe develops the wave envelope of the high-frequency spurious voltage, which then becomes visible upon the scope screen. In most checks of this type, the attenuator of the service scope must be advanced to maximum gain, or a pre-amplifier must be used. Use of a voltage-doubler type demodulator probe is especially useful in this work, because of its high sensitivity. If the heater-bypass capacitors open up, or if the r-f chokes in the heater string become shorted, or are improperly dressed with respect to other components, spurious voltages will increase in value, and cause obscure difficulties in receiver operation. The demodulator probe and scope, accordingly, serve to provide definitive answers to the cause and location of such troubles in case the heater string falls under suspicion.

When testing for the presence of spurious high-frequency voltages in heater lines and similar circuits in this manner, it is desirable to obtain a high degree of 60-cycle hum-voltage rejection in the demodulator probe employed, so that the hum-voltage trace will not interfere with the high-frequency wave-envelope trace. Hum rejection is greatly increased by the use of a small value of series capacitor in the demodulator probe, and special probes may be shop-constructed with this feature exaggerated for this particular type of work. The voltage-doubler probe shown in Fig. 7-41 is of this type. (Compare the relatively small value of series capacitance used in it with the much larger value employed in the general-purpose voltage-doubler demodulator probe shown in Fig. 7-18.)

The same method of probe design can be used to obtain square-wave rejection when testing the output from a simple square-wave modulator.

7-33. Demodulator Probe Use in Marker and Signal-Generator Checking

(1) Marker-Generator Accuracy Check. Questions frequently arise concerning the accuracy of a marker generator. If a crystal oscillator is available (some sweep generators have a built-in crystal oscillator), this can be used with a 1- or 2-mc crystal, a sensitive demodulator probe, and a scope, for calibration of the marker generator. The output from the marker generator is paralleled with that from the crystal oscillator. The mixed outputs are applied to the demodulator probe which feeds into a scope that is being internally swept at any convenient low-frequency rate, such as 60 cycles. Although the frequencies of the signals from the marker generator and oscillator are too high to affect the scope directly, the demodulator probe develops a beat envelope which will be visible on the scope screen.

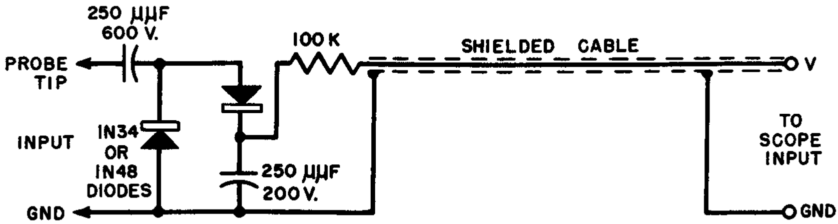


Fig. 7-41. Special shop-constructed voltage-doubler demodulator probe designed to have a high degree of 60-cycle voltage rejection due to the small size of series capacitance employed in it. This type of probe is extremely useful for localizing spurious high-frequency voltages in 60-cycle a-c heater lines.

As the marker-generator frequency is changed so that a beat is produced that is within the frequency range of the scope, some vertical deflection occurs and the waveform of the beat note appears on the screen. Therefore, as the marker-generator frequency is varied through the frequency of the crystal oscillator (or its harmonics), the difference frequencies and the zero-beat produced in the probe circuit are clearly visible on the scope screen. In this manner, calibration of the marker generator is made possible. If a 2-mc crystal is used, beats will be encountered at 2 (strongest), 4, 6, 8, 10 . . . 30 mc. Above 30 mc the harmonics will usually be rather weak for practical application, although use of a voltage-doubler type demodulator probe in this work will enable the operator to work further out on the harmonics from a given crystal oscillator since this type of probe gives approximately double the deflection on the scope screen as is provided by a conventional single-diode probe.

(2) *Calibrating a Signal Generator at 4.5 mc.* A conventional signal generator may be calibrated accurately at 4.5 mc to be used as an accurate marker source for sound-detector alignment, although a calibrating crystal oscillator may not be available. Mix the *input* to the sound detector in a tv receiver that is receiving a station signal, with the *output* of the signal generator, and apply the beating waves to a pair of earphones through a demodulator probe. The strongest component on the sound-detector input is the 4.5 mc sound carrier, and an easily distinguishable beat note will be heard as the signal generator is tuned through 4.5 mc. In this manner, the signal generator may be calibrated accurately at 4.5 mc.

(3) *Checking Output of a Signal Generator for Presence of Hum Voltage.* The presence of hum voltage in the output of a signal generator is usually very objectionable. It appears as either a simple *mixture* of 60-cycle hum voltage with the r-f voltage, or as a *modulation* of the r-f voltage by the hum voltage. Either type of hum can be displayed and measured on a scope screen, but different test arrangements must be used for the two conditions, as shown in Fig. 7-42. Observe that a crystal diode is used in the second arrangement, and it is inserted at approximately the middle of the shielded connecting cable.

(4) *Demodulator-Probe Crystal Polarity.* When testing the output from a test oscillator, or a signal generator, with a single-diode type demodulator probe and scope (or vtvm), it is often found that the indicated voltage differs considerably when the crystal diode is reversed in polarity. This difference of indication

with reversal of the crystal in the probe is an indication of even-harmonic distortion in the generator output voltage (see Sec. 7-23 and Fig. 7-25).

Although the presence of even-harmonic distortion is easily revealed in this manner, the presence of odd-harmonic distortion must be determined by other means. A field-strength meter tuned to the frequency of an odd harmonic can be used to measure the odd-harmonic output voltage.

7-34. Demodulator Probe Use in Checking Sweep-Signal Generators

(1) Checking the Flatness of Output. One type of sweep-generator fault which is serious in most applications of such generators concerns an output signal which contains some amplitude modulation. In this case, the amplitude of the output varies as the frequency is swept over the sweep range.

The service technician may check the amplitude of the sweep generator output by using a demodulator probe to demodulate the output of the sweep generator, and applying the probe output to a scope. If there is no variation in the sweep generator output over the frequency range through which it is being swept, then a perfectly straight horizontal line appears on the scope screen, as shown in Fig. 7-43A. (A high gain-setting should be used on the scope for this check.) If a sloping line is produced as in part B of the figure, or if a line occurs which has peaks or valleys along its length as in part C, then the sweep generator has an output whose amplitude is not constant over the range of frequencies being swept. If such an output sweep signal is used for checking the frequency-

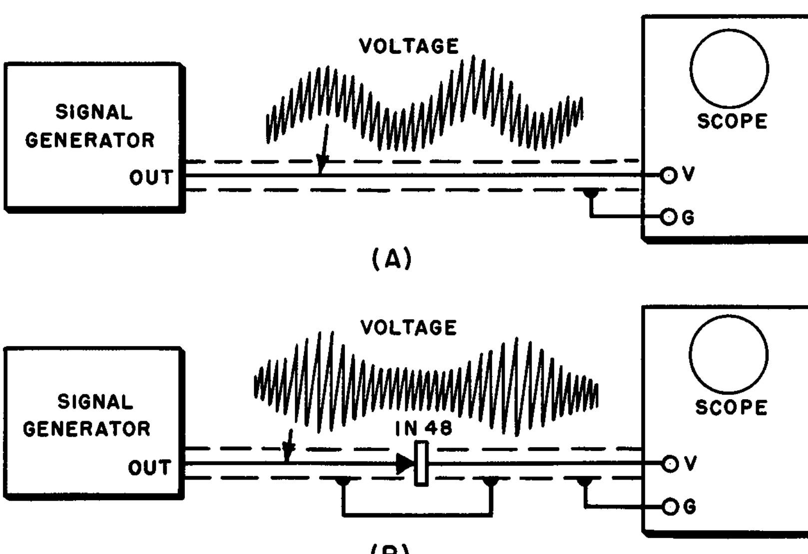
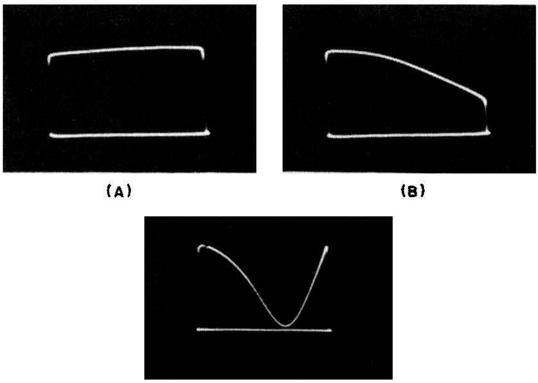


Fig. 7-42. Methods of displaying and measuring hum voltage appearing in the output of a signal generator. (A) Test setup if the hum voltage appears as a simple mixture of the hum voltage and the r-f voltage. (B) Demodulator test setup required if the hum voltage is modulating the r-f output voltage of the generator. The modulated r-f voltage is demodulated by a crystal diode, and the hum-voltage envelope is displayed on the scope screen. In either check, the hum voltgae appears as a 60-cycle sine-wave pattern on the scope screen.



(A) (B) (C)

Fig. 7-43. Typical patterns obtained when checking the flatness of the sweep-signal output from sweep generators by means of a demodulator probe and a scope. (A) Reasonably flat output over the swept range. (B) Output slump-off at one end of the swept range. (C) Output with very bad slump-off at mid-sweep region. In all cases, sweep-generator blanking was employed to produce the zero-volt baseline.

response characteristic of an amplifier, a false response trace will be obtained. For ordinary service work, the output voltage from a sweep generator should be flat within approximately plus-or-minus 10 percent over the swept band.

Some sweep generators are blanked during retrace so that no output is produced during this time. In this case, *two* horizontal lines appear on the scope screen if the amplitude of the generator output is constant (see part A of Fig. 7-43). One of these lines represents the demodulated output of the generator during the active time, while the other represents the zero output of the generator during retrace time (it is actually the zero-level trace).

A note of caution on the use of this method is that the response of the demodulator probe employed may not be uniform within the frequency range being checked. Under these conditions, the type of pattern shown in Fig. 7-43B might be the result of the response of the probe falling off at the high frequencies, rather than the output of the sweep generator falling off. Also, the probe-and-cable may have resonance effects at various frequencies within the swept range. Under these conditions, the peaks or dips in the pattern shown in Fig. 7-43C might be the result of these resonance effects.

To check this, construct several different demodulator probes (or check several commercial varieties of demodulator probes if possible). The various probes should be constructed using different components and crystal diodes, but of course with high-frequency capacitors and composition resistors. Also the probe components should be properly isolated from the input cable. The mechanical arrangement should be varied slightly, and different shield housings can be tried. The effects of these changes on the scope pattern produced should be noted in each case. If two or three probes are found to give substantially the same pattern on the scope screen, and if the outside of the cable is "cold" the technician can be reasonably certain that the probe is satisfactory, and that the output cable termination and r-f ground lead are satisfactory.

The output flatness test should not be employed at the higher frequencies provided by the sweep generator, since misleading results are more likely to be obtained due to the likelihood of poor high-frequency response and the presence of resonance effects in the probe at these frequencies. For example, a voltage-doubler type probe which is reasonably flat up to 80 or 100 mc should not be used to check a sweep generator operating above this frequency. A single-diode demodulator probe which is reasonably flat up to about 200 mc should be used only below this frequency in the test.

The basic circuit arrangements for making this test are shown in Fig. 7-44. When the sweep generator has single-ended output, a simple single-ended shunt-

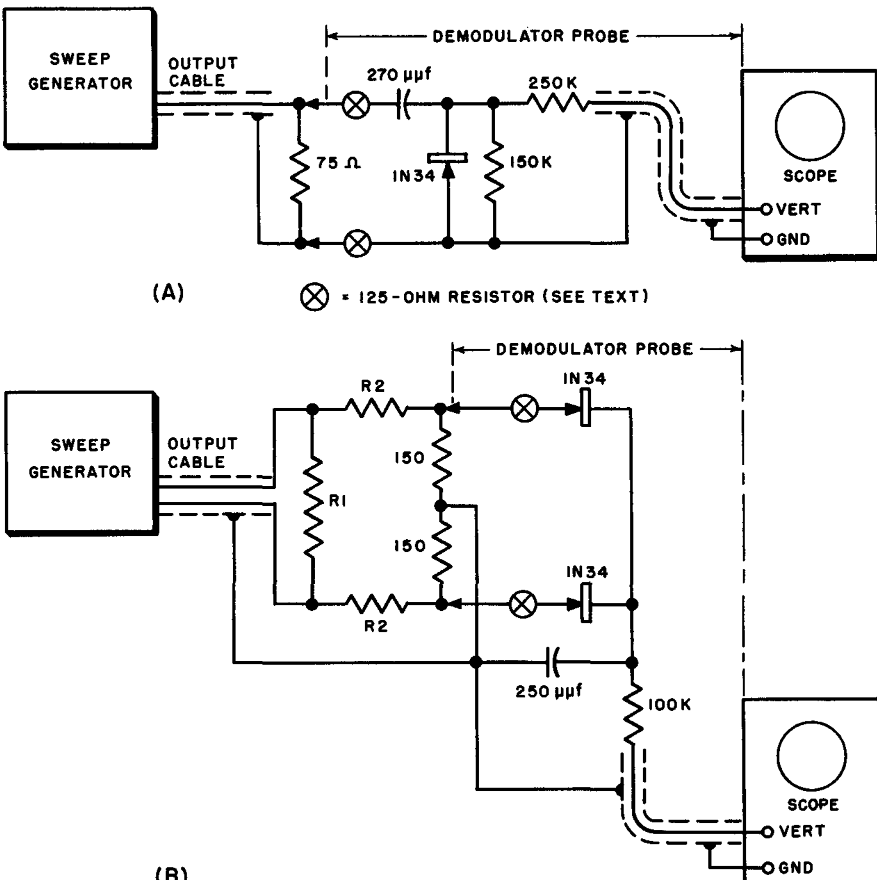


Fig. 7-44. (A) Suitable arrangement for checking flatness of the output of a single-ended sweep generator. The sweep-generator cable termination shown in the diagram has a value of 75 ohms; in some cases, the cable termination should be 50 ohms, and in still other cases, 100 ohms. The requirement is for the cable termination to match the characteristic impedance of the cable. (B) Suitable arrangement when sweep-generator has double-ended output. In this example, the generator is intended to work into a 300-ohm load. The 300-ohm load is a pair of 150-ohm resistors connected in series to provide a center-tap for the ground-return of the demodulator probe. Resistors *R1*, *R2*, and *R2*, are usually provided by the sweep-generator manufacturer, and serve to match a 300-ohm load to the characteristic impedance of the output cable.

type demodulator probe arrangement which is flat up to about 200 mc is utilized as shown in Fig. 7-44A. When the sweep generator has double-ended output, a double-ended demodulator probe similar to the one shown in Fig. 7-16A is used, as shown in Fig. 7-44B.

When testing the output from sweep generators where the grounding system is slightly "hot", with the result that the shape of the scope trace changes every time the operator changes his position or grasps the generator output cable, it is often of considerable assistance in stabilizing the test setup to partially isolate the demodulator probe from the sweep-generator output cable termination by means of a 125-ohm composition-type series resistor connected at point X in each of the demodulator input leads as shown in the diagrams.

It should be recognized that these test arrangements are most useful when the output from the sweep generator is a pure and unmixed output. Some caution should be observed when checking the output from very simple types of beat-frequency type sweep generators, since their output is often a mixed output comprising feed-through frequencies from the beating oscillators, sum-and-difference beat frequencies, and harmonics of these frequencies.

When used to align a receiver, the receiver tuned circuits reject the unused frequencies in the output of the generator, but a demodulator probe applied directly to the sweep-generator output will necessarily accept all frequencies present. In consequence, the output flatness check using a demodulator probe and scope will not necessarily provide a check of the output voltage for only those frequencies which the setting of the dial of the generator would indicate. Output voltage of other frequencies may be present also and is recorded on the scope. Under such circumstances, the flatness check is not necessarily valid unless the operator utilizes suitable output filters to remove the unwanted frequencies.

It is quite possible, for example, for the fundamental output from a sweep generator to be quite flat, while the second-harmonic output may be far from flat, due to partial resonances in the output system. For this reason, the operator should be certain to study the circuit diagram of the sweep generator before tests are made, and to provide suitable filters, if required. Sometimes low-pass filters are built into the generator, and sometimes they are provided as accessory units. In other cases, the technician will have to make use of 75-ohm or 300-ohm filters (as the case may be) which have been designed primarily for other applications.

The technician sometimes falls into the error of assuming that because a sweep generator is flat on a fundamental frequency, it must also be flat on the second harmonic, or on the third harmonic. This is not true, because it is very possible for residual resonances to impair the flatness of the output on a harmonic, while leaving that on the fundamental unaffected. In other words, when the flatness of a sweep generator is being checked by means of filters to remove all frequencies but one (swept band) from the output, it cannot be assumed that because the difference output is flat, that the sum output must also be flat, or that because a fundamental output is flat, that the harmonics of the fundamental output are flat. Independent checks must be run on each of the mixed frequencies present in the output of the instrument.

(2) *Checking the Sweep Width.* When it is desired to check the sweep width of a sweep generator that is to be used for i-f alignment, connect the output cable from the sweep generator in parallel with the output cable from a marker generator. Next, feed this combined output through a demodulator probe to the scope. The sweep-generator output display (see Fig. 7-43), having the marker superimposed at some point, will be observed. Then tune the marker generator to run the marker from one end of the sweep-generator trace to the other. The difference between the two indications on the marker-generator dial for these two extreme positions of the marker is the sweep width.

7-35. Use of Demodulator Probes with VTVM's

Conventional-type demodulator probes, such as those shown in all illustrations preceding Fig. 7-17 in this chapter, may also be used with a vtvm. When the output of such a probe is applied to any vtvm set to its D-C Volts position, the scale indication is proportional to the average amplitude of the *r-f a-c carrier voltage, or of the modulation waveform,* of the modulated signal applied to the probe. When used with a peak-indicating, or a peak-to-peak indicating, a-c vtvm set to its A-C Volts position, the scale indication is proportional to the *peak voltage of the modulation waveform* of the signal under test, because the demodulator probe rectifies the voltage under test before it reaches the vtvm.

When the output from a voltage-doubler demodulator probe is applied to any vtvm set to its D-C Volts position, the scale indication is proportional to the numerical sum of the positive and negative values (*peak-to-peak value*) of the r-f a-c *carrier voltage* of the modulated signal applied to the probe. When the probe output is applied to either a peak-indicating, or a peak-to-peak indicating, a-c vtvm set to its A-C Volts position, the scale indication is proportional to the peak-to-peak voltage *of the modulation waveform* of the signal under test.

A crystal demodulator probe introduces an insertion loss in the circuit to which it is applied. The loss of signal voltage encountered varies considerably, but is typically of the order of 5-to-1 in a single-rectifier type probe. Consequently, demodulator probes are generally designed to be used as *indicating* rather than as *measuring* devices. If it is desired to use a demodulator probe as a measuring device, it is necessary to calibrate it for the scope or vtvm with which it is to be used, by first checking the indication of the vtvm or scope when a known source of peak, or peak-to-peak, voltage is applied to the probe input, in order to determine the attenuation factor of the probe. Since the front-to-back ratios of various crystal diodes are different, demodulator probes must be individually calibrated for insertion loss with the particular vtvm or scope they are to be used with whenever they are to be used as voltage-measuring devices.

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