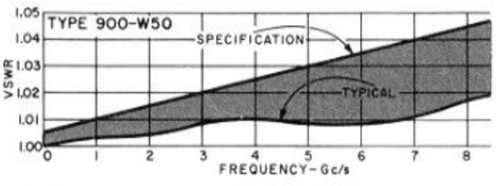
TYPE 900-W50 50-OHM STANDARD TERMINATION

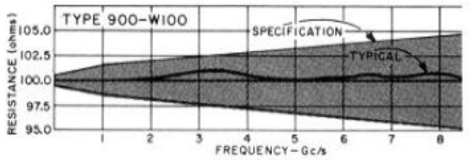
A precision, low-VSWR, 50-ohm standard for calibration of bridges, slotted lines, admittance meters, and reflectometers. Can also be used as a precision dummy load or as a termination in measurements of networks with more than one port. With appropriate GR900 precision adaptor, can be used as a low-VSWR, precision type N, BNC, C, etc, termination. A VSWR calibration chart is supplied with each unit.



VSWR: Less than 1.005 + 0.005 f_{Gc} up to 8.5 Gc/s.
Dc Resistance: 50 Ω ± 0.3%.
Maximum Power: 1 W with negligible change; 5 W without damage.
Temperature Coefficient: Less than 150 ppm/°C.
Over-all Length: 2 in (51 mm). **Net Weight:** 3½ oz (100 g).

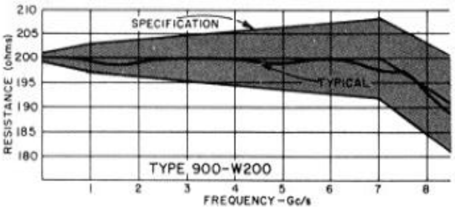
TYPE 900-W100 100-OHM AND TYPE 900-W200 200-OHM STANDARD TERMINATIONS

These known resistive terminations are especially useful in the calibration of bridges, admittance meters, reflectometers, etc. Position of pure resistance nominally 4 cm from the TYPE 900-BT reference plane. Short- and open-circuit terminations with a corresponding 4-cm offset are available (TYPES 900-WN4 and -WO4; see below). A calibration chart is supplied with each unit.



Resistance vs frequency, Type 900-W100 100-Ohm Standard Termination.

Magnitude of Mismatch: See curves.
Dc Resistance: TYPE 900-W100, 100Ω ± 0.3%
TYPE 900-W200, 200Ω ± 0.3%.
Maximum Power: 1 W with negligible change; 5 W without damage.
Temperature Coefficient: Less than 150 ppm/°C.
Over-all Length: 2 in (51 mm). **Net Weight:** 3½ oz (100 g).

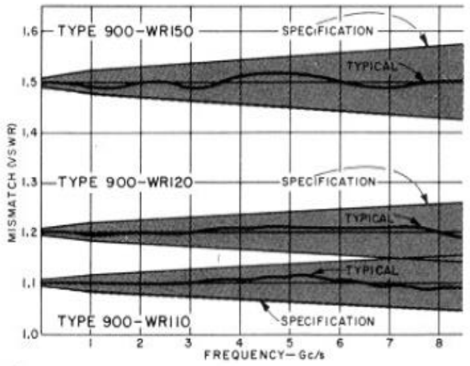


Resistance vs frequency, Type 900-W200 200-Ohm Standard Termination.

TYPES 900-WR110, -WR120, -WR150 STANDARD MISMATCHES

Introduce reflections of known VSWR value (1.1, 1.2, and 1.5) into a 50-ohm transmission line. Useful in calibration of reflectometers and other VSWR-measuring instruments. Mismatch calibration data (in VSWR) are provided with each unit.

Magnitude of Mismatch: See curves.
Dc Resistance: TYPE 900-WR110, 45.45Ω ± 0.3%
TYPE 900-WR120, 41.67Ω ± 0.3%
TYPE 900-WR150, 33.33Ω ± 0.3%.
Maximum Power: 1 W with negligible change; 5 W without damage.
Over-all Length: 2 in (51 mm). **Net Weight:** 3½ oz (100 g).



Mismatch in VSWR, Types 900-WR110, -WR120, -WR150 Standard Mismatches.

Catalog No.	*Description*
0900-9953	**Type 900-W50 50-Ohm Standard Termination**
0900-9957	**Type 900-W100 100-Ohm Standard Termination**
0900-9959	**Type 900-W200 200-Ohm Standard Termination**
0900-9961	**Type 900-WR110 Standard Mismatch**
0900-9963	**Type 900-WR120 Standard Mismatch**
0900-9965	**Type 900-WR150 Standard Mismatch**

SHORT- AND OPEN-CIRCUIT TERMINATIONS

TYPE 900-WN PRECISION SHORT-CIRCUIT TERMINATION

The standard 50-ohm precision termination, with the position of short circuit right at the mating plane of the GR900 Connector. Reflection coefficient is greater than 0.999 at 8.5 Gc/s.

TYPE 900-WO PRECISION OPEN-CIRCUIT TERMINATION

Presents an open circuit 0.26 cm (±0.02 cm) from the mating plane of the GR900 Connector. (For short-circuit termination with corresponding 0.26-cm offset, see TYPE 900-WNE below.) Useful in establishing reference plane and in loss measurements. Reflection coefficient is greater than 0.999 at 8.5 Gc/s).

TYPE 900-WNE
PRECISION SHORT-CIRCUIT TERMINATION

Similar to TYPE 900-WN Termination, except that reference plane is displaced 0.26 cm to correspond to position of open circuit in TYPE 900-WO Precision Open-Circuit Termination. Reflection coefficient is greater than 0.998 at 8.5 Gc/s.

Type 900-WNE

TYPE 900-WNC
REFERENCE-LINE SHORT-CIRCUIT TERMINATION

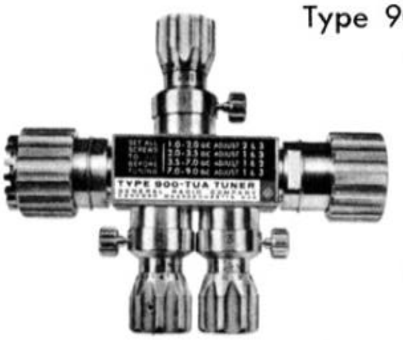
Similar to TYPE 900-WN Termination, except that it includes a GR900 center contact to support the inner conductor of a beadless TYPE 900-LZ Reference Air Line (page 102). The reference plane of the termination is exactly at the reference plane of the GR900 Connector. Reflection coefficient is greater than 0.999 at 8.5 Gc/s.

TYPE 900-WN4 AND TYPE 900-WO4
PRECISION SHORT- AND OPEN-CIRCUIT TERMINATIONS

These terminations are similar to the TYPES 900-WN and -WO, except that the reference plane is displaced 4 cm (±0.01 cm) to correspond to the 4-cm offset of the TYPES 900-W100 and -W200 Standard Terminations.

Catalog No.	*Description*	*Length*	*Net Weight*
0900-9971	**Type 900-WN Precision Short-Circuit Termination**	1¹⁄₁₆ in (27 mm)	2½ oz (75 g)
0900-9981	**Type 900-WO Precision Open-Circuit Termination**	1¹⁄₁₆ in (27 mm)	2 oz (60 g)
0900-9979	**Type 900-WNE Precision Short-Circuit Termination**	1¹⁄₁₆ in (27 mm)	2½ oz (75 g)
0900-9977	**Type 900-WNC Reference-Line Short-Circuit Termination**	1¹⁄₁₆ in (27 mm)	2½ oz (75 g)
0900-9975	**Type 900-WN4 Precision Short-Circuit Termination**	2 in (51 mm)	4 oz (115 g)
0900-9985	**Type 900-WO4 Precision Open-Circuit Termination**	2⁵⁄₁₆ in (59 mm)	4 oz (115 g)

GR900 TUNERS AND AIR LINES



Type 900-TUA and Type 900-TUB TUNERS

USES: The Types 900-TUA and -TUB Tuners are compact, broadband, screw-type tuners useful in matching out small residual reflections in low-VSWR measuring instruments and devices.

DESCRIPTION: Each tuner has three smoothly adjustable tuning screws, used in pairs to tune out reflections of any phase throughout the tuner's frequency range. Each screw has a "neutral" setting, independent of frequency, at which it is effectively out of circuit. Screws can be locked at any setting, permitting excellent VSWR resettability, protection against accidental disturbance, and friction driving (with screws partially locked) if desired.

SPECIFICATIONS

	900-TUA	900-TUB
Frequency Range	1 to 8.5 Gc/s	0.25 to 2.5 Gc/s
Characteristic Impedance	50 Ω	50 Ω
VSWR Matching Range (worst-case minimum)	1.00 + 0.012 f_{Gc}	1.00 + 0.05 f_{Gc} to 1 Gc/s 1.05 from 1 to 2.5 Gc/s
VSWR Resettability	<1.0005 ± 0.0003 f_{Gc}	<1.0005 + 0.0003 f_{Gc}
Residual VSWR (all controls at neutral)	<1.03 to 5 Gc/s, <1.05 from 5 to 7 Gc/s	<1.03 to 1.5 Gc/s
Insertion Loss	<0.1 dB to 4 Gc/s <0.3 dB to 9 Gc/s	<0.1 dB
Repeatability of Connection	0.05%	0.05%
Electrical Length	12.0 cm	18.5 cm
Dimensions	4½ × 3½ × 1 in (115, 88, 25 mm)	6½ × 4¾ × 1 in (165, 120, 25 mm)
Net Weight	1 lb (0.5 kg)	1¼ lb (0.6 kg)
Shipping Weight	3 lb (1.4 kg)	4 lb (1.9 kg)

Catalog Number	*Description*
0900-9635	**Type 900-TUA Tuner** (1.0 to 9.0 Gc/s)
0900-9637	**Type 900-TUB Tuner** (0.25 to 2.5 Gc/s)

PRECISION AIR LINES

TYPE 900-L10, -L15, -L30 PRECISION AIR LINES

Short sections (10, 15, and 30 cm) of precision 50-ohm air line with a Type 900-BT Connector on each end. Useful as low-VSWR line extenders, as aids in checking the VSWR of precision connectors, and as 50-ohm impedance standards at frequencies at which the electrical length is an odd multiple of a quarter wavelength. Also useful as absolute impedance references in time-domain-reflectometer systems and as time-delay standards.

VSWR: Less than 1.0013 + 0.0013 f_{Gc} up to 8.5 Gc/s.

Characteristic Impedance: 50Ω ± 0.1%.

Accuracy of Electrical Length: Within ± 0.02 cm of nominal.

Catalog No.	*Type*	*Electrical Length*	*Time Delay — ps (±1 ps)*	*Physical Length in — mm*	*Net Weight oz — g*
0900-9605	**900-L10**	10 cm	333	4–102	6.5–180
0900-9607	**900-L15**	15 cm	500	6–155	10–285
0900-9613	**900-L30**	30 cm	1000	12–305	15–425

TYPE 900-LZ REFERENCE AIR LINES

Beadless, virtually reflectionless coaxial air lines, with spring-loaded tips on the ends of the inner conductor to mate with GR900 Connectors; microfinished outer-conductor ends butt-contact the mating connectors. VSWR is held to 1.0005 + 0.0002 f_{Gc}. Such near-perfect specifications make these air lines most useful in calibration applications, and especially in substitution measurements. The lines can also be used as precision capacitance or time-delay standards, as well defined reactance standards, and as dielectric sample holders for dielectric-constant and loss measurements with the slotted line.

SPECIFICATIONS

Frequency Range: Dc to 8.5 Gc/s.

Characteristic Impedance: 50 Ω ± 0.050%. Additional skin-effect error is calculable.

VSWR: Less than 1.0005 + 0.0002 f_{Gc}; calibration data supplied.

Repeatability: Within (0.010 + 0.003 f_{Gc})%.

Leakage: Better than 130 dB below signal.

Insertion Loss: Less than 0.0008$\sqrt{f_{Gc}}$ dB/cm.

Maximum Voltage: 3000 V peak.

Maximum Power: 20 kW/$\sqrt{f_{Mc}}$.

Dc Contact Resistance (each end, mated with GR900); Inner conductor, less than 0.5 mΩ; outer conductor, less than 0.07 mΩ.

Catalog Number	*Type*	*Electrical Length — cm (±0.002 cm)*	*Capacitance — pF (±0.07%)*	*Time Delay — ps (±0.1 ps)*	*Odd λ/4 Frequencies* — Gc/s*	*Physical Length in — mm*	*Net Weight oz — g*
0900-9600	**900-LZ5**	4.997	3.3333	166.7	(2n + 1)1.50	2⅛– 55	4.0–115
0900-9601	**900-LZ6**	5.996	4.0000	200.0	(2n + 1)1.25	2½– 65	5.0–145
0900-9602	**900-LZ7H**	7.495	5.0000	250.0	(2n + 1)1.00	3 1/16– 80	5.5–160
0900-9604	**900-LZ10**	9.993	6.6667	333.3	(2n + 1)0.75	4 1/16–105	7.0–200
0900-9606	**900-LZ15**	14.990	10.000	500.0	(2n + 1)0.50	6 –155	10.5–300
0900-9612	**900-LZ30**	29.979	20.000	1000.0	(2n + 1)0.25	12 –305	20 –570

* Frequencies at which air-line section is an odd multiple of a quarter wavelength, where n is zero or any integer.

Type 1640-A SLOTTED LINE RECORDER SYSTEM

FEATURES:

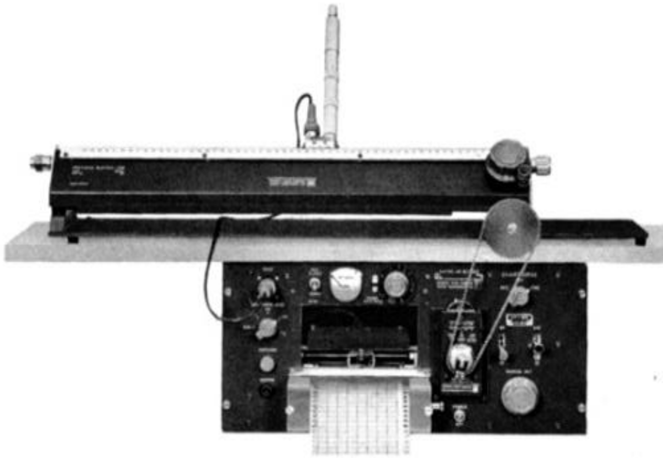
Measures VSWR with full-scale resolution as low as 1.008 on a 4-inch chart; VSWR full-scal range continuously adjustable from 1.008 to 1.20.

True precision slotted line, with residual VSWR of $1.001 + 0.001 f_{Gc}$.

Furnished complete with all accessories. Stable 1-kc-modulated rf source only additional requirement.

USES: The TYPE 1640-A Slotted Line Recorder System automatically produces a strip-chart record of standing-wave patterns and other slotted-line measurement phenomena. Such a recording far exceeds, in resolution and in usefulness, the conventional meter readout. The chart record can be stored, reproduced, or analyzed graphically.

A direct measurement of VSWR or phase with the slotted line recorder system is quick and easy. At any frequency from 0.6 to 9 Gc/s, two full cycles of the standing-wave pattern can be scanned in 10 seconds, without perceptible distortion of the pattern. Multiple recordings can be run to measure repeatability and insertion VSWR, and to make measurements by the substitution-air-line method,[1] by which accuracy can be increased by a factor of from 2 to 5, depending on frequency.



DESCRIPTION: The TYPE 1640-A comprises a TYPE 900-LB Precision Slotted Line (page 100), a TYPE 1521-SL Slotted Line Recorder, and the necessary connecting linkage. The recorder is a transistorized, servo-type instrument, whose accuracy depends only on three stable, custom-calibrated, wire-wound potentiometers in the servo loop. The chart drive has four speeds, which, combined with the two sprockets supplied, permit a total of eight possible slotted-line carriage drive speeds, from 5 to 0.08 centimeters per second.

The recordings shown on this page are all actual char records made with a TYPE 1640-A Slotted Line Recorde System. They represent some, but by no means all, of th measurements possible with this new concept in instrumentation.

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[1] A. E. Sanderson, "A New High-Precision Method for the Measurement of the VSWR of Coaxial Connectors," *IRE Transactions on Microwave Theory and Techniques*, Vol MTT-9, No 6, November 1961, p 524–528. (Reprint A-92.)

SPECIFICATIONS

SLOTTED LINE: (See TYPE 900-LB Specifications, page 100.)

RECORDER (TYPE 1521-SL)

Sensitivity: Continuously adjustable from 0.05 to 2.0 mV full-scale.

Frequency: 990 c/s ± 2%.

Bandwidth: 35 c/s ± 7 c/s (at 3 dB).

VSWR Range: Continuously adjustable from 1.008 (0.8%) to 1.20 (20%) full-scale; accurate to within one minor division. Can be adapted to higher values.

Noise Level (referred to input): Short-circuit, less than 0.1 μV; open-circuit, less than 3.0 pA. Noise figure less than 5 dB at optimum source resistance (about 30 kΩ).

Power Required: 105 to 125 or 210 to 250 V, 60 c/s, 35 W. TYPE 1521-SLQ1 Recorder, supplied with TYPE 1640-AQ1 System, 50 c/s.

Chart paper: 4-inch recording on 5-inch paper; 50 minor and 10 major vertical divisions. Horizontal scale ruling, ¼ inch.

Paper Speeds: Adjustable, 2.5 to 75 inches per minute; plots correspond to 5- to 300-cm/min carriage travel on slotted line. Two interchangeable sprockets advance paper 1 or 2 horizonta divisions per cm probe travel.

Servo Bandwidth of Pen Drive: More than 4 c/s.

Input Connector: GR874 Coaxial Connector, locking, recessec

Accessories Supplied: Two pens, 2 oz red ink, 2 oz green ink potentiometer cleaner, 10 100-ft rolls of chart paper, eyedropper for filling pen, power cord, spare fuses.

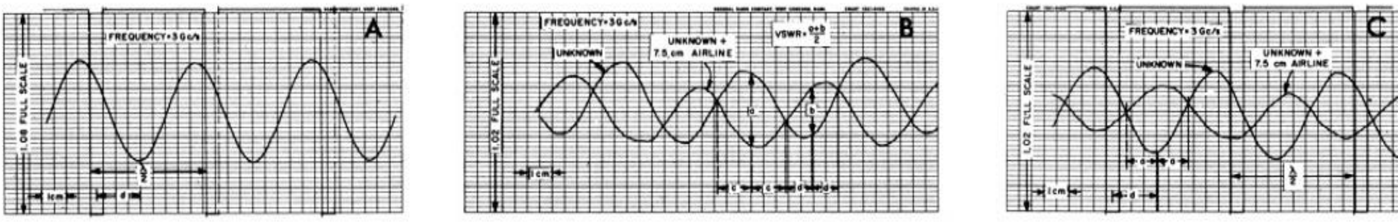
SYSTEM

Bench Space Required: Width 48, depth 14 in (1220, 355 mm height above bench 12 in, depth below bench 9 in (315, 230 mm

Net Weight: 67 lb (31 kg). **Shipping Weight:** 120 lb (55 kg

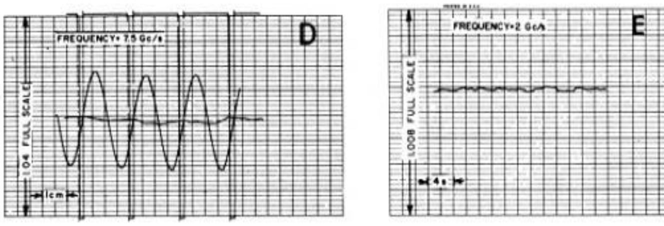
Catalog No.	*Description*
1640-9701	**Type 1640-A Slotted Line Recorder System** (60-cycle)
1640-9494	**Type 1640-AQ1 Slotted Line Recorder System** (50-cycle)
1521-9310	**Chart Paper,** 100-foot roll

PATENT NOTICE. See Notes 1, 4, and 18, page 11.



Actual recordings illustrating some of the measurements possible with the Slotted Line Recorder System.

A. VSWR and phase (direct method).
B. VSWR (substitution method).
C. VSWR and phase (substitution method).
D. Insertion VSWR of a mated pair of GR900 Adaptors.
E. System noise, with Type 1360-B Microwave Oscillator as signal source.



TYPE 874 COAXIAL COMPONENTS

TYPE 874 CABLE CONNECTORS

APPLICABLE CABLE TYPES	CONNECTOR TYPE	CABLE	CABLE LOCKING	PANEL FLANGED	PANEL LOCKING	PANEL LOCKING RECESSED
50-OHM	874-A2	-CA	-CLA	-PBA	-PLA	-PRLA
	RG-8A/U	-C8A	-CL8A	-PB8A	-PL8A	-PRL8A
	RG-9B/U					
	RG-10A/U					
	RG-87A/U					
	RG-116/U					
	RG-156/U					
	RG-165/U					
	RG-166/U					
	RG-213/U					
	RG-214/U					
	RG-215/U					
	RG-225/U					
	RG-227/U					
NON-50-OHM	RG-11A/U					
	RG-12A/U					
	RG-13A/U					
	RG-63B/U					
	RG-79B/U					
	RG-89/U					
	RG-144/U					
	RG-146/U					
	RG-149/U					
	RG-216/U					
50-OHM	874-A3	-C58A	-CL58A	-PB58A	-PL58A	-PRL58A
	RG-29/U					
	RG-55/U (Series)					
	RG-58/U (Series)					
	RG-141A/U					
	RG-142A/U					
	RG-159/U					
	RG-223/U					
NON-50-OHM	RG-59/U	-C62A	-CL62A	-PB62A	-PL62A	-PRL62A
	RG-62/U (Series)					
	RG-71B/U					
	RG-140/U					
	RG-210/U					
50-OHM	RG-174/U	-C174A	-CL174A	-PB174A	-PL174A	-PRL174A
	RG-188/U					
	RG-316/U					
NON 50-OHM	RG-161/U					
	RG-187/U					
	RG-179/U					

Example: For a locking cable connector for RG-8A/U, order Type 874-CL8A.

TYPE 874 ADAPTORS

TO TYPE		874-
BNC	plug jack	QBJA QBJL* QBPA
C	plug jack	QCJA QCJL* QCP
HN	plug jack	QHJA QHPA
LC	plug	QLJA QLPA
LT	plug jack	QLTJ QLPT
Microdot	plug jack	QMDJ QMDJL* QMDP
N	plug jack	QNJA QNJL* QNP QNPL*
OSM/BRM	plug jack	QMMJ QMMJL* QMMP QMMPL*
SC (Sandia)	plug jack	QSCJ QSCJL* QSCP
TNC	plug jack	QTNJ QTNJL* QTNP
UHF	plug jack	QUJ QUJL* QUP
UHF 50-Ω Air Line	7/8-in. 1-5/8-in. 3-1/8-in.	QU1A QU2 QU3A

*Locking Type 874 Connector

Example: To connect Type 874 to a type N jack, order Type 874-QNP.

CONNECTOR ASSEMBLY TOOLS

TYPE 874–	FUNCTION
TOK	Tool Kit
TO58	Crimping Tool
TO8	Crimping Tool

OTHER COAXIAL ELEMENTS

TYPE 874-		TYPE 874-	
A2	50 Ω cable (low loss)	ML	component mount
A3	50 Ω cable	MB	coupling probe
D20L, D50L	20-, 50-cm adjustable stubs	MR, MRL	mixer-rectifier
EL, EL-L	90° ell	R20A, R20LA	patch cord, double shield
F185L	185-Mc/s low-pass filter	R22A, R22LA	patch cord, double shield
F500L	500-Mc/s low-pass filter	R33, R34	patch cord, single shield
F1000L	1000-Mc/s low-pass filter	T, TL	tee
F2000L	2000-Mc/s low-pass filter	TPD, TPDL	power divider
F4000L	4000-Mc/s low-pass filter	U	U-line section
FBL	bias insertion unit	UBL	balun
G3, G3L, G6, G6L G10, G10L G20, G20L	3-, 6-, 10-, and 20-dB attenuators	VCL VI VQ, VQL	variable capacitor voltmeter indicator voltmeter detector
GAL	adjustable attenuator	VR, VRL	voltmeter rectifier
JR	rotary joint	W100	100-Ω termination
K, KL	coupling capacitor	W200	200-Ω termination
L10, L10L L20, L20L L30, L30L	10-, 20-, and 30-cm rigid air lines	W50B, W50BL WN, WN3 WO, WO3	50-Ω termination short-circuit terminations open-circuit terminations
LAL	33-58 cm adjustable line	X	insertion unit
LK10L, LK20L	constant-Z adjustable lines	XL	series inductor
LR	radiating line	Y	cliplock
LTL	trombone constant-Z line	Z	stand

MISCELLANEOUS COAXIAL CONNECTORS

CONNECTOR TYPE	TYPE NO.	USED WITH
Basic	874-B	50-ohm Air Line
Basic Locking	874-BBL	50-ohm Air Line
Panel Locking	874-PLT	Wire Lead
Panel Locking Recessed	874-PRLT	Wire Lead
Panel Locking Feedthrough	874-PFL	Type 874 Patch Cords

L suffix indicates locking Type 874 Connector.

FOR COMPLETE DETAILS, REFER TO THE GENERAL RADIO CATALOG.

GENERAL RADIO COMPANY

WEST CONCORD, MASSACHUSETTS 01781

617 369-4400

617 646-7400

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METROPOLITAN NEW YORK*
Broad Avenue at Linden
Ridgefield, New Jersey 07657
Telephone N.Y. 212 964-2722
N.J. 201 943-3140

SYRACUSE
Pickard Building
East Molloy Road
Syracuse, New York 13211
Telephone 315 454-9323

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Rockville, Maryland 20852
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* Repair services are available at these offices.

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Printed in USA

INSTRUCTION MANUAL

TYPE 900-LB

PRECISION SLOTTED LINE

900-LB

900-LB

GENERAL RADIO COMPANY

B

900-LB

Serial No. 779 ID No. B28

Date: November 22, 1966

The 900-LB Slotted Line is equipped with a GR900 Connector in place of the GR874 at the Generator (left) side of the line. The slotted line, therefore, differs from the catalog and instruction book description. This additional GR900 Connector provides more flexibility in applications of the line and improves the stability. No VSWR specification is given for this connection, but the VSWR is typically the same as the Load (right) side up to about 5 GHz, and 1.006 + 0.0025 f_{GHz} from 5 GHz to 8.5 GHz.

An adaptor to GR874 is provided with the line for connection to the generator with the standard GR874 patch cords.

Service Note:

Section 7.5 Supplement

If the flatness check indicates that negligible bow in the probe-coupling characteristic exists but that the pickup at the extreme left differs from that at the right, a simple adjustment may be made.

First, record the level difference. Then, at the GENERATOR (left) side of the line, loosen the GR900 coupling nut holding the connector body with a wrench to maintain its original orientation. With the generator still connected, and the slotted-line carriage at the extreme left, rotate the connector body until the level is the same as at the right side. Retighten the coupling nut holding the body in the required orientation. The coupling nut should be tightened to 7 to 8 ft-lb torque. This may be estimated when employing the GR900 torque wrench which has been set for 6 ft-lb.

This same adjustment procedure should not be attempted at the LOAD (right) side of the line, because there not only is the body keyed but the inner conductor is locked to the connector and should not be rotated.

September 28, 1966

Portions of Section 7.5 and 7.6 of this Instruction Book have been deleted because of a design change. In this instrument, Serial No. 779, the inner conductor has been locked to prevent rotation. Do not attempt to rotate the inner conductor of the GR900 connector as was previously indicated as a servicing procedure. Epoxy has been employed to lock the inner conductor. This Epoxy, which can be seen looking into the GR900 connector at the right, should not be removed. If removed, the residual VSWR of the line will change.

Removal or installation of the GR900 inner contact is not affected by this change. The contact can be replaced, if damaged, according to the normal procedure; the contact should be tightened very lightly.

INSTRUCTION MANUAL

TYPE 900-LB

PRECISION SLOTTED LINE

Form 0900-0140-B
ID B215
May, 1966

IMPORTANT: THIS INSTRUCTION BOOK WITH SUPPLEMENT DATED NOVEMBER 22, 1966, IS FOR USE ONLY WITH INSTRUMENTS BEARING THE IDENTIFICATION NUMBER (I. D. NO.) B289 FOUND INSIDE THE INSTRUMENT.

West Concord, Massachusetts, USA

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

TABLE OF CONTENTS

NOTE

Early production units of the Type 900-LB Precision Slotted Line differ slightly from the unit depicted in this manual. The difference is purely mechanical in nature and in no way affects electrical performance. The positions of the probe and the output connector on the carriage have been interchanged. Thus, in current production the probe is at the right, closer to the load end of the line.

CAUTION

The contact surfaces of the inner and outer conductors of the Type 900-BT Precision Coaxial Connector must be protected, as nicks or dents can impair electrical performance.

Use the plastic cap supplied.

Several copies of Smith Charts are supplied with the Slotted Line. Additional copies can be obtained from General Radio at the following prices.

Price per unit of 50 (minimum quantity sold)

No. of units	1	2–3	4–9	10–19	20 and over
Price	**$2.00**	**$1.90**	**$1.75**	**$1.40**	**$1.25**

Catalog Number	*Description*	
5301-7568	**Type Y Smith Chart**	(20-mmho admittance coordinates)
5301-7569	**Type Z Smith Chart**	(50-ohm impedance coordinates)
5301-7560	**Type N Smith Chart**	(normalized coordinates)
5301-7561	**Type NE Smith Chart**	(normalized expanded coordinates)
5301-7562	**Type HE Smith Chart**	(normalized highly expanded coordinates)

CAUTION

Do not leave the RF Probe Accessory mounted in the carriage, when the slotted line is to be reinstalled in the storage case.

The Adjustable Probe-Tuner assembly should be used only with a Type 900-LB that has the same serial number.

SPECIFICATIONS

Characteristic Impedance: 50.0 ohms ±0.1%.

Probe Travel: 50 cm. Scale calibrated in centimeters from the reference plane. Attached vernier scale can be read to 0.1 mm.

Scale Accuracy: ±(0.1 mm +0.05%).

Frequency Range: 300 Mc to 8.5 Gc. At 300 Mc, covers a half wavelength. Operates below 300 Mc with Type 900-L or -LZ Air Lines.

Constancy of Probe Pickup: ±0.5%.

Residual VSWR: Less than $1.001 + 0.001 \times f_{Gc}$ (e.g., 1.002 at 1 Gc) with Type 900-BT. As Type 874 (with Type 900-Q874 Adaptor), less than $1.001 + 0.016 \times f_{Gc}$ up to 1 Gc; $1.011 + 0.006 \times f_{Gc}$ from 1 to 8.5 Gc. As type-N (with Type 900-QNJ or -QNP Adaptors), less than $1.005 + 0.005 \times f_{Gc}$.

Repeatability: Within 0.05% or 0.0005 in VSWR.

DC Contact Resistance at Type 900-BT Connector: Inner conductor, less than 0.5 milliohm; outer conductor, less than 0.07 milliohm.

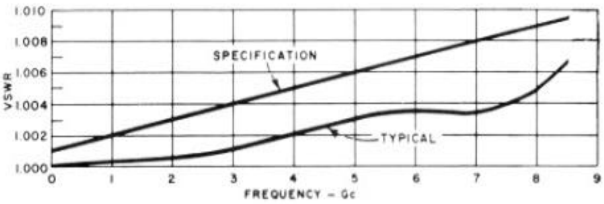
Accessories Supplied: Type 874-R22A Patch Cord; Type 900-WN Precision Short-Circuit Termination; Type 900-WO Precision Open-Circuit Termination; Adjustable Probe-Tuner Assembly; 1N21C and 1N23C detector diodes; RF Probe Accessory (with Type 874-BL connector); Micrometer Carriage Drive (accurate to 0.01 mm); storage case; sample Smith charts.

Accessories Required: Generator and detector.

Dimensions: Width 27½, height 10, depth 4¾ inches (700 by 255 by 125 mm).

Net Weight: 10¾ pounds (4.9 kg).

U.S. Patent No. 2,548,457.



Residual VSWR of Type 900-LB (including Type 900-BT connector).

TYPE 900-WO PRECISION OPEN-CIRCUIT TERMINATION

Frequency Range: DC to 8.5 Gc.

Reflection Coefficient: Greater than 0.999.

Location of Open Circuit: 0.26 ±0.02 cm beyond Type 900-BT connector junction.

Leakage: Better than 130 db below signal.

Dimensions: Length, 1-1/16 inch (27 mm); maximum diameter, 1-1/16 inch (27 mm).

Net Weight: 2 ounces (60 grams).

TYPE 900-WN PRECISION SHORT-CIRCUIT TERMINATION

Frequency Range: Dc to 8.5 Gc.

Reflection Coefficient: Greater than 0.999.

Location of Short Circuit: At Type 900-BT connector junction.

Leakage: Better than 130 db below signal.

Dimensions: Length, 1-1/16 inch (27 mm); maximum diameter, 1-1/16 inch (27 mm).

Net Weight: 2½ ounces (75 grams).

General Radio Experimenter References:

Volume 37 No. 2&3, February-March, 1963;
Volume 37 No. 11, November, 1963.

SECTION 1

INTRODUCTION

1.1 PURPOSE.

The Type 900-LB Precision Slotted Line is a coaxial instrument basic to the precise measurement of the impedance, VSWR, and reflection coefficient of distributed and lumped elements (from 300 Mc to 8.5 Gc). It is particularly recommended for the calibration of coaxial standard impedances and mismatches, as well as for measurements made during the design of components of the lowest possible VSWR. The accuracy of this slotted line eliminates the tedious, time-consuming calibration procedures required with less accurate instruments. The line, which has a true coaxial cross-section, serves as a standard of characteristic impedance dependent only upon mechanical dimensions that are machined to microinch tolerances. It is fitted with a GR900 connector.

Additional applications include:

(1) Measurement in type-N and other connectors through the use of precision adaptors.

(2) Measurement of dielectric constant and loss tangent of dielectric materials.

(3) Determination of small-signal characteristics of diodes and transistors.

(4) Precision phase shifting.

(5) Measurement of source impedance.

1.2 EQUIPMENT SUPPLIED.

The Type 900-LB Precision Slotted Line equipment is a comprehensive combination of a coaxial slotted line (complete with carriage, probe, tuner, and detector) and essential GR900 coaxial accessories. All are shipped in a specially fitted storage case. Table 1-1 lists and describes the equipment supplied; see also Figure 1-1.

The Type 900-LB is a slotted section of 9/16-inch, precision coaxial transmission line whose characteristic impedance is 50.0 ohms ±0.1%. The load end of the line is equipped with a Type 900-BT Precision Coaxial Connector, and the signal-source end with a locking Type 874 connector; both are General Radio connector designs.

The line is fitted with a movable carriage which provides a mount for a detector diode, a tuning stub, an adjustable probe, and a Type 874 output connector. The carriage, which has a 50-cm travel over the slot, is driven by a fixed-position, crank-type knob.

The position of the probe relative to the reference plane is directly indicated by the coincidence of the ten-division vernier scale on the carriage and the fixed main scale. Calibrated in centimeters, the main scale has a least count of one millimeter; accuracy of

TABLE 1-1
LIST OF EQUIPMENT SUPPLIED
TYPE 900-LB PRECISION SLOTTED LINE

Fig Ref	*Name*	*Function*	*Part No.*
1-4 (1)	Rf Probe Accessory	Probe for use with unmodulated rf signal source	0874-4670
(2)	Type 900-WO	Precision Open-Circuit Termination	0900-9981
(3)	Type 900-WN	Precision Short-Circuit Termination	0900-9971
(4)	Type 900-LB Precision Slotted Line (includes carriage)	Measuring instrument	0900-9651
(5)	Adjustable-Probe-Tuner Assembly	Mount adjustable pickup probe and tune it to resonance	0900-3070
(6)	Storage Case	Store slotted line and accessories	0900-2210
(7)	Type 1N21C Diode	Detector	6084-1005
	Type 1N23C Diode	Detector	6084-1007
(8)	Type 874-R22A	Coaxial patch cord	0874-9682
(9)	Micrometer Drive Assembly	Position carriage to 0.01-millimeter accuracy	0900-3100

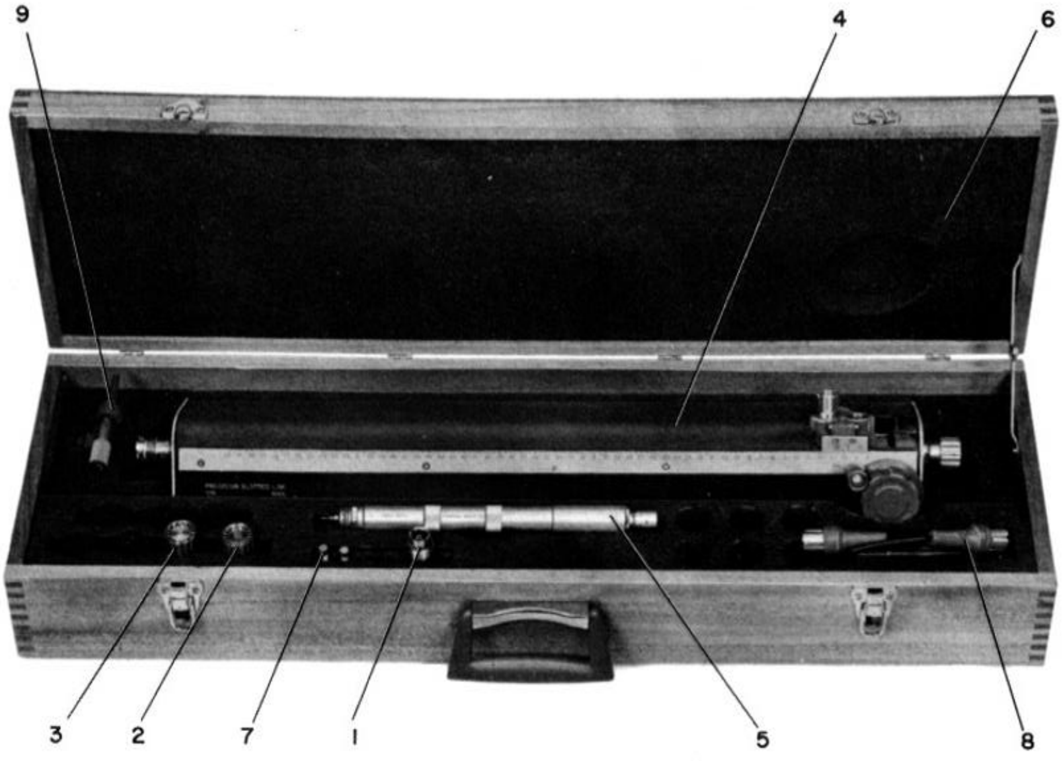


Figure 1-1. Type 900-LB Precision Slotted Line equipment supplied (refer to Table 1-1).

the probe-position indication is 0.1 mm ±0.05%. The reference plane is precisely located at the contact surfaces of the Type 900-BT connector inner and outer conductors.

The removable, barrel-type probe-tuner has a vernier drive for stability, smooth rotary action, and easy settability, and a tuning range of 300 Mc to 9 Gc. Probe penetration is adjustable by means of the knob (calibrated in thousandths of an inch) at the top of the assembly.

For precise measurement of carriage movement, the micrometer carriage drive, which can be read to 0.002 mm, is supplied. It mounts on the rear guide rod, to the right of the carriage. The drive can be positioned at any point along the rod and fixed in place by thumbscrew. It can be tipped back to clear the carriage for routine measurements.

The piano-hinged cover panel opens out at the back of the instrument to permit carriage movement. Closed, it completely covers the slot in the top of the line as well as the precision-ground bearing surfaces and the driving mechanism. Thus, it retards the accumulation of dust and otherwise protects the instrument.

Four rubber-tipped feet provide a stable mounting base for the slotted line.

1.3 ACCESSORIES SUPPLIED.

1.3.1 COAXIAL CALIBRATION ACCESSORIES.

For use as calibration standards with the slotted line, two precision coaxial terminations are supplied. They are a Type 900-WO Open-Circuit Termination and a Type 900-WN Short-Circuit Termination (see Figure 1-2). They are useful to establish reference planes in impedance measurements, as low-loss terminations for the measurement of networks with more than one port, and as coaxial-line reactance standards in combination with Type 900-L or -LZ Air Lines (refer to paragraph 2.3). Both mate directly with the Type 900-BT connector at the load end of the slotted line.

Type 900-WN Short-Circuit Termination. The Type 900-WN Precision Short-Circuit Termination is a silver-plated brass body (with the necessary GR900 external mounting hardware); the body is gold-plated for protection against tarnish. Ohmic losses are extremely small, as demonstrated by a reflection coefficient of 0.999. The shorting contact is achieved by pressure of the flat surface of the body against the Type 900-BT contact surfaces at the load-end connector of the slotted line. The reference plane of this termination is conveniently located at the reference plane of the Type 900-BT connector.

Type 900-WO Open-Circuit Termination. The Type 900-WO Precision Open-Circuit Termination presents a well-shielded open circuit 0.26 cm from the mating plane of the Type 900-BT connector. It is a closed-end outer conductor with GR900 external mounting hardware. The open-circuit reference plane cannot be made identical in position to the short-circuit reference plane because of end effect. This end effect can be represented closely by an additional length of line, in this case 0.26 cm, or a capacitance of 0.166 pf shunting the end of the line. The effective length is slightly frequency-dependent, as shown in Figure 6-21.

Figure 1-2. Coaxial calibration accessories supplied, Type 900-WO (left) and Type 900-WN (right).

1.3.2 OTHER ACCESSORIES SUPPLIED.

The coaxial patch cord supplied mates with the Type 874 connector found at the detector-output terminal of the slotted line, to permit direct connection to any instrument fitted with a General Radio Type 874 coaxial connector.

Two microwave diodes (type 1N21C and 1N23C) are furnished for use as detectors when the slotted line is operated with a 1-kc square-wave-modulated signal source. They mount interchangeably in a cylindrical holder at the rear of the probe carriage and are easily accessible inside the large, knurled, screw-type cover.

For applications requiring a direct rf output, the RF Probe Accessory is also provided. Terminated with a Type 874-BL connector, this unit replaces the probe-tuner.

Sample copies of Smith-chart paper, available from General Radio, are also included.

SECTION 2

INSTALLATION

2.1 GENERAL.

This section covers the setup of the slotted line, the assembly of removable components, and recommendations on accessory equipments.

2.2 PREPARATION FOR USE (See Figure 1-1).

Observe the following procedures to set up the Type 900-LB:

a. Grasp the slotted line (4) at each end, lift it out of the storage case, and place it on the bench.

b. Tip out the rear cover panel of the slotted line and bring it to rest on the bench behind the instrument.

c. If required, mount the Micrometer-Drive Assembly (9) on the slotted line.

d. Install the micrometer drive on the rear guide rod. Finger-tighten the knurled thumbscrew at the base and tip the assembly to a retracted position, so that it clears the carriage until ready for use.

e. *If 1-kc modulated rf is to be used,* continue with steps f through j below. If unmodulated rf is to be used, omit them.

f. Remove the probe-tuner (5) from the case. Remove the plastic tip protector.

g. Check that the probe-penetration indicator reads 0.100 or greater, then thread the tuner into the empty socket in the top of the carriage. Tighten it with a 13/16-inch open-end wrench; apply approximately 1 foot-pound torque.

CAUTION

The probe tip, if bent or scratched, can degrade instrument accuracy. The diode holder must be empty when probes are installed or removed.

h. Remove the knurled aluminum cover at the rear of the carriage to expose the diode holder.

i. Select the appropriate diode (7) (paragraph 3.2.2), remove it from the container, and plug it into the larger of the two openings in the holder. The small end goes in first and the diode bottoms in its holder. Type numbers are marked on the diodes.

NOTE

The diode must be removed before either the probe tuner or the rf probe is mounted.

j. Reattach the diode cover hand-tight.

k. *For unmodulated rf test signals,* take rf probe (1) from its nest in the storage case and remove the plastic-tip protector.

l. Thread the probe into the empty socket in the top of the carriage until the assembly bottoms.

NOTE

Use of a Type 874 Outer-Conductor Wrench, part no. 0874-2610, is recommended for convenience and best results (see Figure 7-4).

m. Take the Type 874-R22A Patch Cord (8) from the storage case and attach it to the Type 874 connector on the carriage.

NOTE

Remove the rf probe when replacing the line into its storage case.

Retain all plastic covers supplied to protect the precision-finished surfaces.

TABLE 2-1
RECOMMENDED INPUT EQUIPMENT* FOR USE WITH TYPE 900-LB

FREQ RANGE Gc	SOURCE		1 KC MODULATOR		VARIABLE ATTENUATOR TYPE	TERMINATION TYPE	FILTER TYPE	FIXED ATTENUATOR TYPE	FIG REF
	OSC TYPE	POWER SUPPLY TYPE	OSC TYPE	POWER SUPPLY TYPE					
0.18 - 0.60	1209-CL	1267	1210-C	1201	N.A.†	N.A.	874-F500L	874-G10L	2-1
0.25 - 0.96	1209-C	1267	1210-C	1201	N.A.	N.A.	874-F1000L	874-G10L	
0.90 - 2.00	1218	1267	1210-C	1201	N.A.	N.A.	874-F2000L	874-G10L	
1.70 - 4.10	1360-B	N.A.	N.A.	N.A.	N.A.	N.A.	874-F4000L	874-G10L	2-2
3.84 - 4.46	1220-A4	1201	N.A.	N.A.	874-GAL	874-W50L	874-F4000L	874-G10L	2-3
4.24 - 4.91	1220-A5	1201	N.A.	N.A.	874-GAL	874-W50L	—	874-G10L	
5.10 - 5.90	1220-A6	1201	N.A.	N.A.	874-GAL	874-W50L	—	874-G10L	
5.92 - 6.45	1220-A7	1201	N.A.	N.A.	874-GAL	874-W50L	—	874-G10L	
6.20 - 7.42	1220-A8	1201	N.A.	N.A.	874-GAL	874-W50L	—	874-G10L	

† N.A. -- Not applicable.

* Or equivalent

2.3 ACCESSORIES REQUIRED BUT NOT SUPPLIED.

2.3.1 GENERAL.

The Type 900-LB requires only a laboratory-quality rf signal source and an amplifying indicator to be ready for operation. The line is compatible with all commercial instruments available for these purposes. Tables 2-1 and 2-2 list recommended General Radio instruments to fulfill these functions; suggested hook-ups are shown in Figures 2-1 through 2-3.

Coaxial devices under test, equipped with the Type 900-BT Precision Coaxial Connector, may be attached directly to the slotted line. Adaptors are available to permit use of the slotted line for measurements on devices fitted with Type 874 and other popular 50-ohm coaxial connectors. In fact, the attachment of such adaptors readily converts the Type 900-LB to a slotted line with performance characteristics that equal or surpass most commercial equipment designed specifically for those line sizes (see paragraph 4.10). The adaptors and other coaxial devices in the GR900 series, suitable as accessories to the slotted line but not supplied, are listed and described in Table 2-3.

Type 874 coaxial accessories particularly useful at the input of the slotted line are covered in subsequent paragraphs. A complete table of Type 874 components is given at the back of the manual.

2.3.2 OSCILLATOR ISOLATION.

Slotted-line measurement errors can be caused by shifts in the oscillator frequency with changes in load impedance. Oscillators that are tightly coupled to the line can have relatively large frequency shifts. This effect can be greatly reduced by the insertion of a fixed attenuator, such as a Type 874-G10L 10-db coaxial attenuator, between the oscillator and the slotted line (refer to Table 2-1).

The attenuators are fitted with Type 874 connectors at both ends; locking versions are required for low leakage. They are single-section, T-type re-

TABLE 2-2
RECOMMENDED INDICATOR EQUIPMENT* FOR USE WITH TYPE 900-LB

MODE	TYPE	TEST FREQ RANGE - Gc	VSWR RANGE	FIG REF
1-kc Modulated — Automatic Recording	1521-SL Slotted Line Recorder	0.3 to 9.0	1.001 - 1.200	3-12
1-kc Modulated — Manual	Commercial VSWR Indicator	0.3 to 9.0	Direct 1.01 - 10 Width-of-minimum 10 - 1000	2-1 to 2-3
	1232-A Null Detector	0.3 to 9.0	Direct 1.0 - 1.8 Width-of-minimum 1.8 to 1000	3-5
RF Heterodyne	DNT-3	0.30 - 0.95 0.47 - 1.87**	1.0 - 1000	3-11
	DNT-4	0.87 - 2.03 1.77 - 4.03** 2.67 - 6.03**		

* Or equivalent.

** Harmonic Operation.

sistance pads, capable of improving the match of sources to 50 ohms, over the frequency range of the Type 900-LB.

2.3.3 CONTROL OF HARMONICS.

Another possible source of error in slotted-line measurements is the presence of harmonics generated by the driving oscillator. A small harmonic-voltage content in the signal may produce a harmonic signal many times that of the fundamental at a minimum point. Therefore, if the detector will respond at all to harmonics, difficulty may be encountered.

The General Radio Type DNT detector offers the best solution to harmonic problems, because of the high selectivity afforded by its tuned heterodyne circuit. Refer to Table 2-2.

The tuned diode detector may not have a large amount of rejection for various harmonics because the tuning stub has higher-order resonances. Insertion of a Type 874-F low-pass filter between the oscillator and the line can reduce the harmonics to an insignificant value.

The Type 874 filters called out in Table 2-1 are useful at frequencies up to 4.0 Gc. They are coaxial filters of the Tschebyscheff type, which produce a very steep cutoff characteristic and a stop-band typically 50 db down. They come with locking Type 874 connectors at both ends for minimal leakage.

2.3.4 FREQUENCY MODULATION PROBLEMS.

Square-wave modulation should be used to minimize frequency modulation of the signal source. The Type 1210-C Unit R-C Oscillator, with the Type 1201 Unit Regulated Power Supply, is recommended for use with those oscillators listed in Table 2-1 that require external modulators. The Type 1360-B and the Type 1220-A have internal modulators.

TABLE 2-3

GR900 COAXIAL ELEMENTS AND EQUIPMENT

ADAPTORS

Type	*Function*
900-Q874	Connects to GR874
900-QBJ	Connects to type-BNC Plug
900-QBP	Connects to type-BNC Jack
900-QCJ	Connects to type-C Plug
900-QCP	Connects to type-C Jack
900-QNJ	Connects to type-N Plug
900-QNP	Connects to type-N Jack
900-QTNJ	Connects to type-TNC Plug
900-QTNP	Connects to type-TNC Jack
900-QMMJ	Connects to type-OSM Plug
900-QMMP	Connects to type-OSM Jack
900-QSCJ	Connects to type-SC Plug
900-QSCP	Connects to type-SC Jack

AIR LINES — PRECISION

900-L10	Phase, Time-Delay & Impedance Standard — 10 cm
900-L15	Phase, Time-Delay & Impedance Standard — 15 cm
900-L30	Phase, Time-Delay & Impedance Standard — 30 cm

AIR LINES — REFERENCE

900-LZ5	Ultraprecise Impedance Standard — 5 cm
900-LZ6	Ultraprecise Impedance Standard — 6 cm
900-LZ7H	Ultraprecise Impedance Standard — 7.5 cm
900-LZ10	Ultraprecise Impedance Standard — 10 cm
900-LZ15	Ultraprecise Impedance Standard — 15 cm
900-LZ30	Ultraprecise Impedance Standard — 30 cm

CONNECTOR AND CONNECTOR KITS

Type	*Function*
900-BT	GR900 Precision Connector
900-AB	GR900 Coupling Hardware Kit
900-AC	GR900 Contact & Coupling Hardware Kit
900-AP	GR900 Coupling Hardware & Center Tip (for custom reference air line use)
900-PKM	GR900 Panel Mounting Kit

TERMINATIONS

900-W50	50-Ohm Standard
900-W100	100-Ohm Standard
900-W200	200-Ohm Standard
900-WO	Precision Open Circuit
900-WO4	Open Circuit (for standards)
900-WN	Precision Short Circuit
900-WNC	Reference Line Short Circuit
900-WNE	Short Circuit (Coplanar with Type 900-WO)
900-WN4	Short Circuit (for standards)
900-WR110	Standard Mismatch (VSWR = 1.1)
900-WR120	Standard Mismatch (VSWR = 1.2)
900-WR150	Standard Mismatch (VSWR = 1.5)

MISCELLANEOUS

900-TOK	GR900 Connector Tool Kit
900-TUA	Tuner (1.0 - 8.5 GHz)
900-TUB	Tuner (0.25 - 2.5 GHz)
0900-9508	Precision Inner-Conductor Rod
0900-9509	Precision Outer-Conductor Tube
0900-9782	Adaptor Flange

TYPE 900-LB	PRECISION SLOTTED LINE
TYPE 1640-A	SLOTTED LINE RECORDER SYSTEM

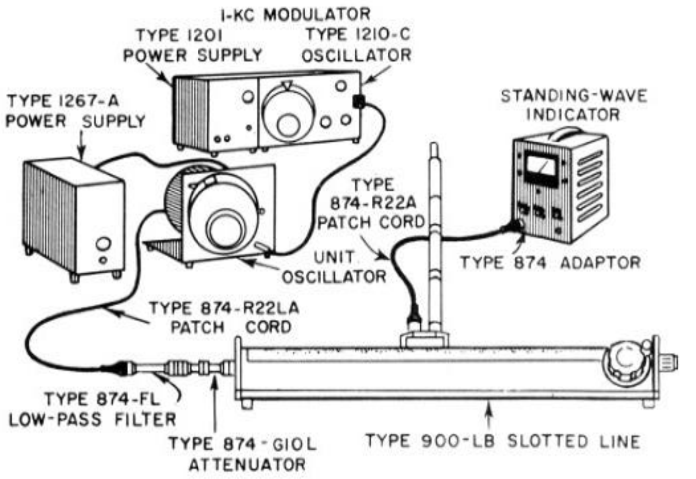


Figure 2-1. Type 900-LB setup for measurements below 2.0 Gc.

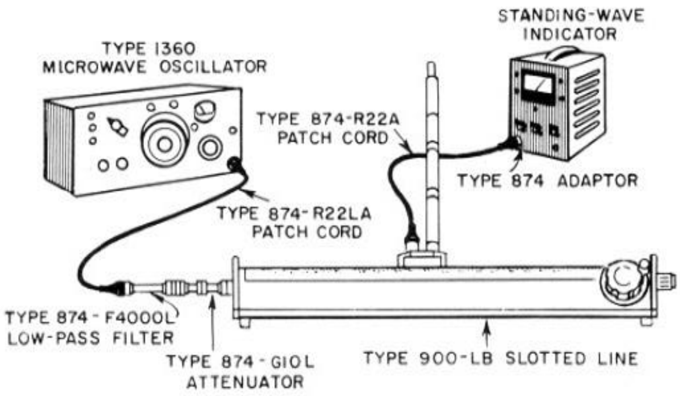


Figure 2-2. Type 900-LB equipment set-up for measurements 2-4 Gc.

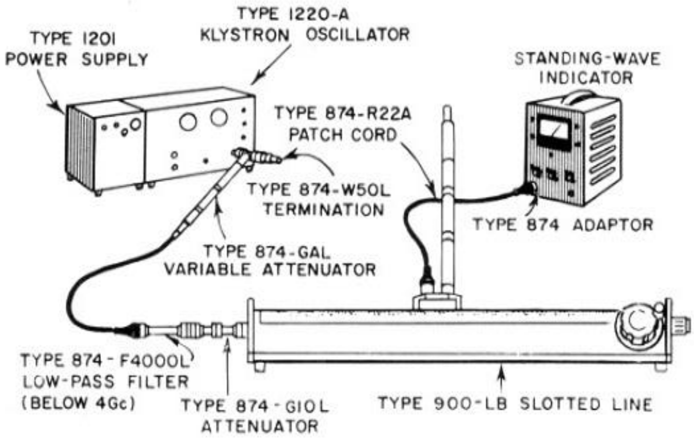


Figure 2-3. Type 900-LB equipment set-up for measurements above 4 Gc.

SECTION 3

OPERATION

3.1 GENERAL.

Upon completion of the appropriate equipment setup as indicated in paragraph 2.2, apply power to the source and indicator and allow for any warm-up time required. Detailed operating instructions for any of the General Radio equipments recommended are supplied with them.

3.2 PRELIMINARY ADJUSTMENTS. (See Figure 3-1.)

3.2.1 MATING OF TYPE 900-BT CONNECTORS.

Attach the unknown (fitted with a Type 900-BT connector) or a GR900 termination or adaptor as appropriate. Since only one Type 900-BT locking nut can be used at one time, one must be placed in the storage position.

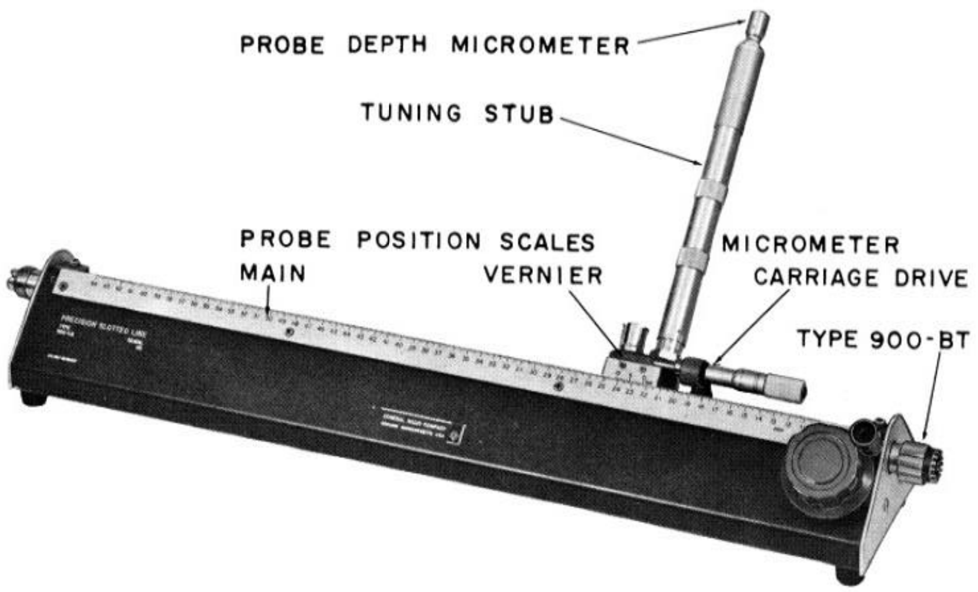


Figure 3-1. Controls and indicators, Type 900-LB.

a. To store the locking nut, slide it back until the threads engage. Then thread it back off the centering gear ring and slide it to the ridge at the rear of the coupling nut.

b. Move the locking nut of the other connector back. Align the connectors axially and engage the teeth of the centering-gear rings in any convenient orientation.

c. Hold the connectors in the joined position, thread the active locking nut over the centering gear ring of the mating connector, and hand-tighten.

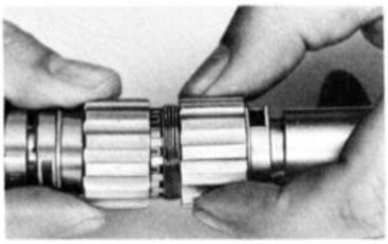


Figure 3-2. Mating of Type 900-BT connectors.

3.2.2 DIODE SELECTION.

The choice of microwave diode depends upon operating frequency, since such diodes have a self-resonant frequency which may reduce sensitivity slightly and broaden the tuning-stub resonance. Two diodes (types 1N21C and 1N23C) with different resonant frequencies are supplied. If the above condition is encountered, it can be eliminated by interchange of diodes.

NOTE

A diode is used only with a modulated signal source.

3.2.3 PROBE PENETRATION.

Both the main probe (mounted in the tuning stub) and the untuned accessory probe can be adjusted for depth of penetration. Penetration should be adjusted for adequate sensitivity with minimal effect on the standing-wave pattern. The presence of the probe affects the residual VSWR because it is a small admittance in shunt with the line. It has the greatest effect at a voltage maximum, where the line impedance is high.

Probe tuner. Adjust the probe tuner penetration by means of the small control knob at the top of the tuning stub. Set it at 0.100 for routine measurements. The adjustments scale is calibrated in thousandths of an inch and reads the distance between the tip of the probe and the center conductor of the slotted line. A stop, which prevents the probe from touching the center conductor, holds the minimum distance to about 0.005 inch; maximum is about 0.150 inch.

RF Probe. To adjust the penetration of the RF Probe Accessory, use the small screw inside the center conductor of the Type 874 connector. Clockwise rotation increases penetration.

CAUTION

Do not screw this probe down tight against the center conductor of the slotted line, as it will damage the probe or the center conductor.

The effect of the probe coupling is shown in Figures 6-10 and 6-11, or it can be determined by measurement of the VSWR at two different degrees of coupling. If the measured VSWR is the same in both, the probe coupling used has no significant effect on the measurement. If the measured VSWR's are different, additional measurement should be made with decreasing amounts of probe penetration until no difference occurs.

3.2.4 TUNING STUB.

Rotate the knurled barrel to adjust the tuning stub for maximum audio output as read on the indicator. Readjust the signal level as necessary to keep the audio output of the diode below 2 mv, which ensures operation in its square-law region.

NOTE

Tuning is preferably done with a Type 900-W50 50-ohm Termination on the line to minimize the possibility of tuning to a harmonic of the signal source.

The scale on the lower part of the tuning stub reads the position of the sliding short-circuit within the barrel. It is calibrated in centimeters, one per turn, with marks on the barrel every 0.1 cm. A family of resonance curves for the stub is given in Figure 3-3

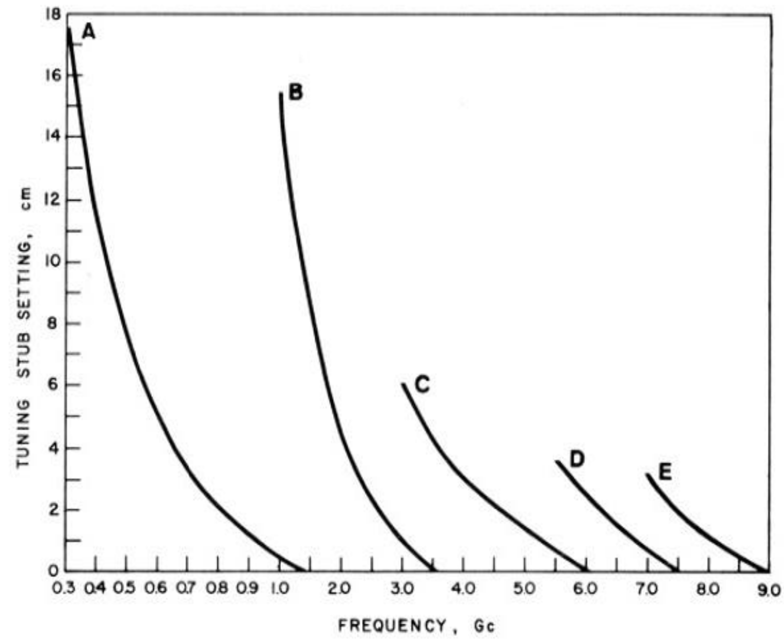


Figure 3-3. Adjustable probe-tuner resonance curves.

as a guide in choosing the approximate setting for any source frequency. When the slotted line is operated at 2.0 Gc, curve B indicates that the stub should be set approximately at 4.5 cm, initially, and adjusted slightly around this setting for peak output.

The curves overlap and the extent of overlap increases at higher frequencies; thus, multiple resonance points occur. For high-Q performance, use the curve corresponding to the lower setting on the cm scale. For example, when the slotted line is operated at 3.0 Gc, the 1.0-cm setting indicated by curve B, rather than the 6.0-cm setting indicated by curve C, should be used.

Above 1.5 Gc, to be sure that the tuning stub is not set to a harmonic of the source frequency, tune to two adjacent maxima on the ***tuning stub***. The difference (in cm) should equal one-half wavelength at the source frequency. Below 1.5 Gc, measure the distance between two adjacent minima on the *slotted line* with either the Type 900-WN or the Type 900-WO termination on the line. This distance should also be one-half wavelength; for convenience, use the nomograph of Figure 3-7 to determine this value.

NOTE

Maxima at harmonics will be of much lower magnitude than maxima at the fundamental frequency.

3.3 MEASUREMENT OF VSWR.

3.3.1 VSWR BELOW 10.

When the VSWR of the unknown is less than 10, it can be read directly on a standing-wave indicator. Set a maximum of the standing-wave pattern for full-scale deflection on the meter. Move the carriage to an adjacent minimum, and read the VSWR directly on the specially calibrated scales of the instrument (following the manufacturer's instructions).

VSWR below 10 can also be measured by the heterodyne detector method given in paragraph 3.10.

3.3.2 VSWR BELOW 1.8. (Refer to Table 3-1).

The Type 1232-A Tuned Amplifier and Null Detector is suitable as an indicator, when the db difference between a maximum and a minimum of the standing-wave pattern is measured, if the VSWR is less than 1.8. Divide this difference, Δdb, by 2, to take into account the square-law of the detector, and convert this number to VSWR as follows:

$$\text{VSWR} = \log^{-1} \frac{\Delta \text{db}}{20}$$

For example, set a maximum on the standing-wave pattern for a full-scale indication (0 db) on the Type 1232-A. If the adjacent minimum gives a reading 5 db down, substitute half that amount in the formula and calculate the VSWR as follows:

$$\text{VSWR} = \log^{-1} 2.5/20 = 1.33.$$

3.3.3 VSWR BELOW 1.2.

Accurate measurements of VSWR below 1.2 require special techniques. The use of the Type 1640-A Slotted Line Recorder System is recommended, for it directly plots, on an expanded strip-chart scale, the standing-wave pattern in the slotted line. Expansions from 1.008 to 1.200 full-scale make measurements of very low VSWR's as easy and accurate as the measurements of moderate VSWR's. Refer to paragraph 3.12 for details.

If the Type 1640-A system is not available, it is best to use an ordinary standing-wave indicator with an expanded-scale presentation (1.3 full scale is typical). Read the standing-wave indicator in the usual manner; if possible, average the readings from several maxima and minima along the line to minimize effect of the small variation in probe coupling along the line.

3.3.4 VSWR ABOVE 10—WIDTH-OF-MINIMUM.

Accurate measurements of VSWR's above 10 by the direct method place severe requirements on the dynamic range, noise level, and accuracy of the square-law characteristic of a diode detector. More satisfactory results are obtained by the "width-of-minimum" method, the theory of which is shown in Figure 3-4.

The micrometer carriage-drive assembly can be used to measure minute changes in probe position to 0.002 mm. It functions at any point in the probe travel and is capable of moving the carriage over 2.0 cm. The Type 1232-A is a sensitive indicator for this application (see Figure 3-5).

Proceed as follows:

a. Calibrate the indicator directly from a 1-kc signal generator to establish a reference of 1.0 mv full-scale (linear) deflection.

NOTE

The General Radio Type 1210-C Unit R-C Oscillator and a Type 546-C Audio Frequency Microvolter are recommended.

b. Reconnect the indicator to the slotted line.

c. Connect the unknown to the slotted line.

d. With the main control, carefully position the carriage at the voltage minimum nearest the load.

e. Adjust the rf input-signal level to produce an audio output of 0.5 mv from the diode detector if possible (if not, the maximum available output).

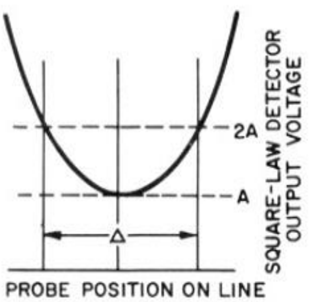


Figure 3-4. Method of measuring the width-of-minimum for determination of high VSWR.

f. Bring the Micrometer-Drive spindle (set at ≈1.00 cm) to bear on the button at the right-hand side of the carriage, directly behind the vernier plate.

g. Clamp the micrometer to the guide rod.

h. Move the carriage slightly to the right of the voltage minimum to increase the output to slightly more than 1 mv (twice the original level). Use the micrometer to bring it back to 1 mv exactly and observe the micrometer reading.

i. Rotate the micrometer-head to drive the carriage to the left, through the minimum, until the audio output is again exactly twice the minimum audio output. Again, observe the micrometer reading.

j. Subtract the second probe position from the first to determine the width-of-minimum; generally, this will be tenths of a millimeter.

k. Refer to Figure 3-6 to convert the width-of-minimum information so obtained to VSWR.

EXAMPLE: If the width-of-minimum measured at 1 Gc is 1.8 mm (0.18 cm on the nomograph), then a straightedge joining these two points on the left-hand and center scales intersects the VSWR scale at 53.

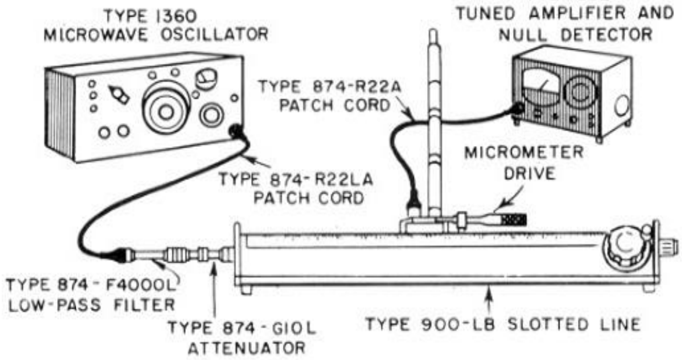


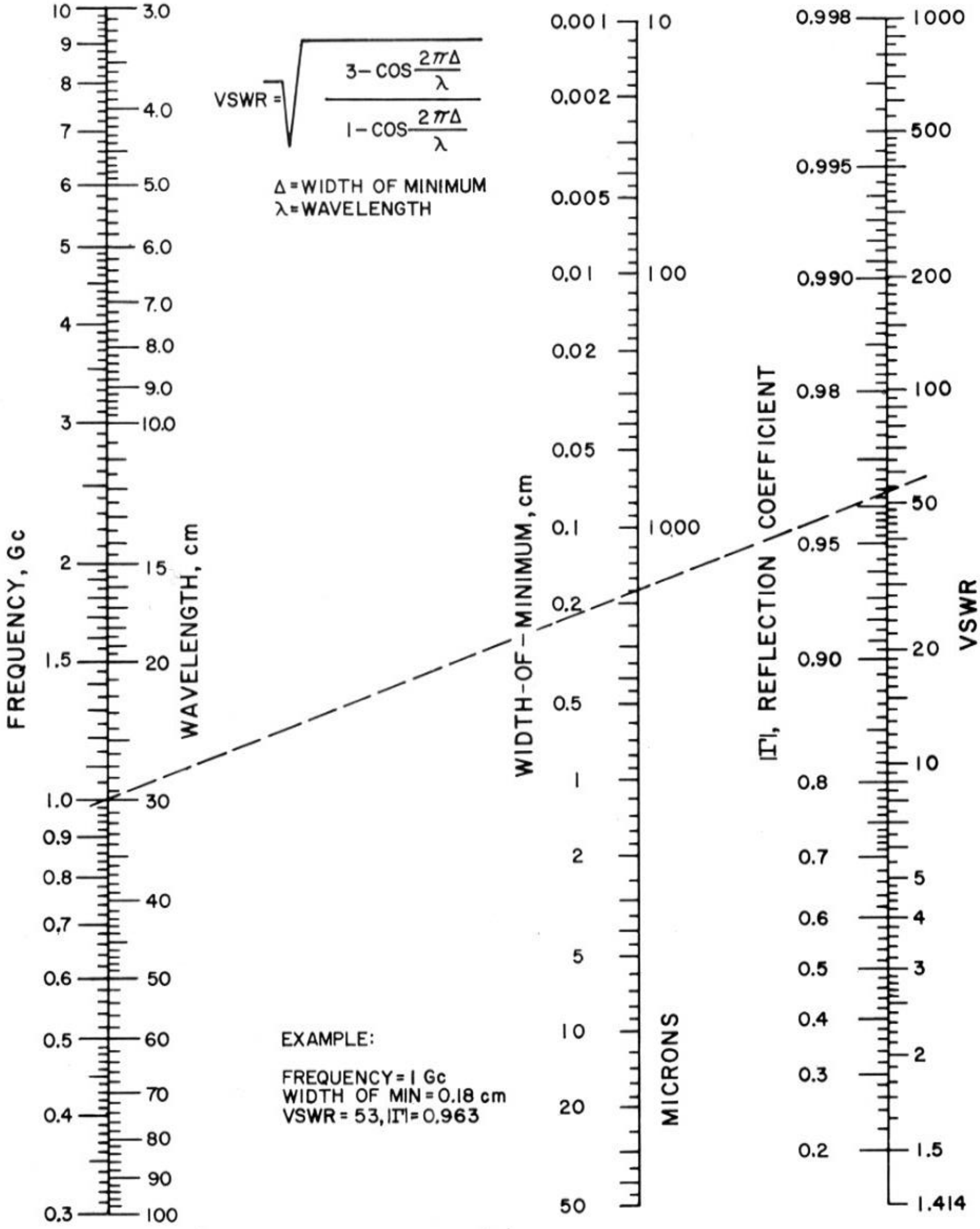
Figure 3-5. Set-up for width-of-minimum VSWR measurements with Type 900-LB.

At very high standing-wave ratios, the losses in the slotted line and connecting lines cause large errors in the measurement. For highest accuracy, correct for the line losses as described in paragraph 3.9.3. Also, take care to isolate the slotted line from signal-source vagaries, such as harmonics, as covered in paragraph 2.3.

3.4 MEASUREMENTS OF TWO-PORT DEVICES — INSERTION VSWR.

The VSWR of a two-port device, such as an attenuator, is the VSWR at the input to the device when the output is terminated in a perfect match.

The Type 900-W50 Termination is recommended for this application with the Type 900-LB. It is broad-



$$\text{VSWR} = \sqrt{\frac{3-\cos\frac{2\pi\Delta}{\lambda}}{1-\cos\frac{2\pi\Delta}{\lambda}}}$$

Δ = WIDTH OF MINIMUM
λ = WAVELENGTH

EXAMPLE:

FREQUENCY = 1 Gc
WIDTH OF MIN = 0.18 cm
VSWR = 53, $|\Gamma|$ = 0.963

Figure 3-6. VSWR and $|\Gamma|$ vs width-of-minimum.

band, with extremely low VSWR, useful to 8.5 Gc. It comprises an accurately derived, continuous transition, a precision cylindrical resistor, and a Type 900-BT connector. Its change of resistance and VSWR *vs* heating due to incident power is negligible up to 1-watt incident power.

To make this measurement:

a. Connect the termination to the output of the component under test, either directly or through an adaptor.

b. Connect the input of the component to the slotted line, either directly or through an adaptor.

c. Measure the VSWR on the slotted line. This equals the insertion VSWR of the component to within the accuracy of the slotted line, plus the termination, plus the adaptors (if any) at each end.

EXAMPLE: For a precision measurement at 2.0 Gc of the VSWR of a low-power, 3-db pad terminated with a type-N jack on one end and a type-N plug on the other, the procedure would be as follows:

(a) Connect the plug end of the pad to the slotted line through a Type 900-QNJ Adaptor.

(b) Connect the 50-ohm termination to the other end through a Type 900-QNP Adaptor.

(c) Measure the VSWR.

The combined VSWR of the slotted line (see specifications in Appendix A), plus the two adaptors plus the termination at 2.0 Gc would be less than:

Element	Type	VSWR at 2.0 Gc	Effect on Measurement
Slotted Line	900-LB	1.003	±0.003
Adaptor to N plug	900-QNJ	0.012	±0.012
Adaptor to N jack	900-QNP	0.012	±0.006
Termination	900-W50	0.015	±0.008
		Total	±0.029

This reading may increase or reduce the actual VSWR figure for the device under test. Thus, if the total measured VSWR in this example is 1.30 (with the pad in the circuit), the actual value may vary ±0.029, allowing for the measurement error of the slotted line and other elements. The net value depends on the interaction of discontinuities of all elements in the hook-up and varies with frequency and other factors. Note that the reflections caused by the adaptor at the load end of the pad, and those of the termination, are reduced to 0.006 and 0.008, respectively, since the 2-way trip through the 3-db pad cuts them in half.

3.5 REFLECTION-COEFFICIENT MEASUREMENTS.

The complete reflection coefficient of an unknown cannot be measured directly on a slotted line, since most indicators are calibrated only in terms of VSWR, although phase information can be directly determined from relative probe positions.

As the foregoing implies, reflection coefficient, Γ_x, is a complex quantity consisting of magnitude $|\Gamma_x|$ and phase ϕ_x. The complete expression is:

$$\Gamma_x = |\Gamma_x| e^{j\phi_x}$$

The magnitude can be calculated from

$$|\Gamma_x| = \frac{S-1}{S+1}$$

where S = VSWR,

or, approximately (for $S < 1.1$),

$$|\Gamma_x| = \frac{S-1}{2}.$$

For convenient conversion from VSWR to $|\Gamma_x|$, for values of VSWR from 1.414 to 1000, use the right-hand scale of the nomograph, Figure 3-6.

The angle of the reflection coefficient ϕ_x is given by

$$\phi_x = 180° \left(1 - \frac{2d}{\lambda}\right)$$

where

d = distance as measured in cm on the slotted line between a minimum for the unknown and the nearest minimum to the left for the Type 900-WN Short-Circuit Termination substituted for the unknown.

λ = wavelength of test frequency in cm.

3.6 SUBSTITUTION MEASUREMENTS OF VSWR.

The accuracy of the measurement can be improved for essentially lossless two-port unknowns (viz., a pair of GR900 adaptors to type-N, back-to-back), if the frequency is adjusted to make the electrical length of the unknown equal to a multiple of one-half wavelength. A substantial section of the unknown must consist of an air line of known 50-ohm characteristic impedance, which serves as the reference for the measurement. For information on precision materials and fabrication techniques, refer to paragraph 5.6. If necessary, add a section of Type 900-L Precision Air Line or Type 900-LZ Reference Air Line to meet this condition.

Set the frequency of measurement to satisfy the half-wavelength condition as follows:

a. Short-circuit the slotted line with the Type 900-WN.

b. Measure the position of minimum and remove the short circuit.

c. Place the unknown test section on the line, and short-circuit the end of it.

d. Measure the new position of minimum (it will be the same only if the electrical length of the unknown equals a multiple of one-half wavelength).

e. Readjust the frequency until positions of minima coincide.

f. Place a Type 900-W50 termination directly on the slotted line, measure the VSWR and calculate the complex reflection coefficient of this combination, as described in paragraph 3.5.

g. Insert the test section between the line and the termination and repeat the measurement of reflection coefficient.

The reflection coefficient of the unknown, Γ_x, is then equal to the vector difference between the two complex reflection coefficients measured above. Convert this to insertion VSWR as follows:

$$\text{Insertion VSWR} = \frac{1 + |\Gamma_x|}{1 - |\Gamma_x|}$$

The accuracy of the substitution method is much greater than that of the direct method, the error being, in effect, a small percentage of Γ, rather than a small percentage of the VSWR itself.

3.7 IMPEDANCE MEASUREMENTS.

The Smith-chart plot is the most convenient method for determination of the complex impedance of an unknown whose VSWR has been measured with a slotted line. It is necessary also to measure the phase of the standing-wave pattern to utilize the Smith chart. That is, the position of the voltage minimum with the unknown on the line must be found.

The procedure is as follows:

a. Observe the position of the minimum nearest the unknown on the slotted line.

NOTE

For best accuracy, find two points on each side of the minimum at which the voltage is the same and then average the readings.

b. Enter the nomograph (Figure 3-7) on the "DISTANCE, cm" scale. Connect the location of this position of minimum (by straightedge) with the test "FREQUENCY" scale.

c. Read the phase information from the intersection with the "WAVELENGTH" scale.

d. To plot the result on the Smith chart (see Figure 3-8), find the point on the peripheral "WAVELENGTHS TOWARD LOAD" scale determined above. A line through this point to the center of the chart fixes the phase of the reflection.

e. Lay off the previously measured VSWR on the "STANDING WAVE RATIO, E_{MAX}/E_{MIN}" scale, and transpose this distance as a radius along the phase line. The intersection of the radius and the arc so drawn can now be read, from the impedance coordinates of the Smith chart, as the impedance of the unknown.

EXAMPLE: If, in making measurements at 6 Gc, the VSWR of the unknown is found to be 4.0 and the position of minimum is 12 centimeters, use the lower left-hand quadrant of the nomograph (Figure 3-7) and, with a straightedge, connect 12 cm on the outside scale with 6 Gc on the diagonal scale. The point at which the straightedge cuts the center scale, 2.4, is the phase shift, in number of wavelengths towards the load, between the probe and the unknown. Since the Smith chart repeats every one-half wavelength, the 2 can be ignored.

To translate this information into the 50-ohm chart (Figure 3-8), it is necessary first to plot the phase information thus found by drawing a radial from 50 on the "RESISTIVE COMPONENT AXIS" (the center of the chart) through 0.40 on the "WAVELENGTHS TOWARD LOAD" scale. Then, on the horizontal scale at the bottom marked "STANDING WAVE RATIO - E_{MAX}/E_{MIN}," lay off 4.0. Transfer this distance to the radial and strike an intersecting arc. The value of impedance at the intersection, which is the impedance of the unknown at the GR900 reference plane, is 18 + j33 ohms.

NOTE

The same procedure can be used for admittance measurements, provided a Smith chart with admittance coordinates is substituted, and $\lambda/4$ is added to the wavelength scale.

3.8 MEASUREMENT OF WAVELENGTH.

Install either the Type 900-WN or the Type 900-WO termination on the slotted line. Determine the position of two adjacent voltage minima, as read on the probe-position scale; use the vernier scale to measure to 0.01 cm. The wavelength of the exciting wave is twice the distance measured above.

The nomograph of Figure 3-6 offers a convenient conversion to frequency in gigacycles from distance-between-minima (as distinct from width-of-minimum) over the operating range of the slotted line. On the left-hand scale, twice the distance between minima in cm determines a point on the "WAVELENGTH" scale which matches the "FREQUENCY - Gc" scale. Thus, if the minima are separated by 7.5 cm, the wavelength is 15 cm, which corresponds to 2.0 Gc. For greater accuracy, measure the distance over a span of several

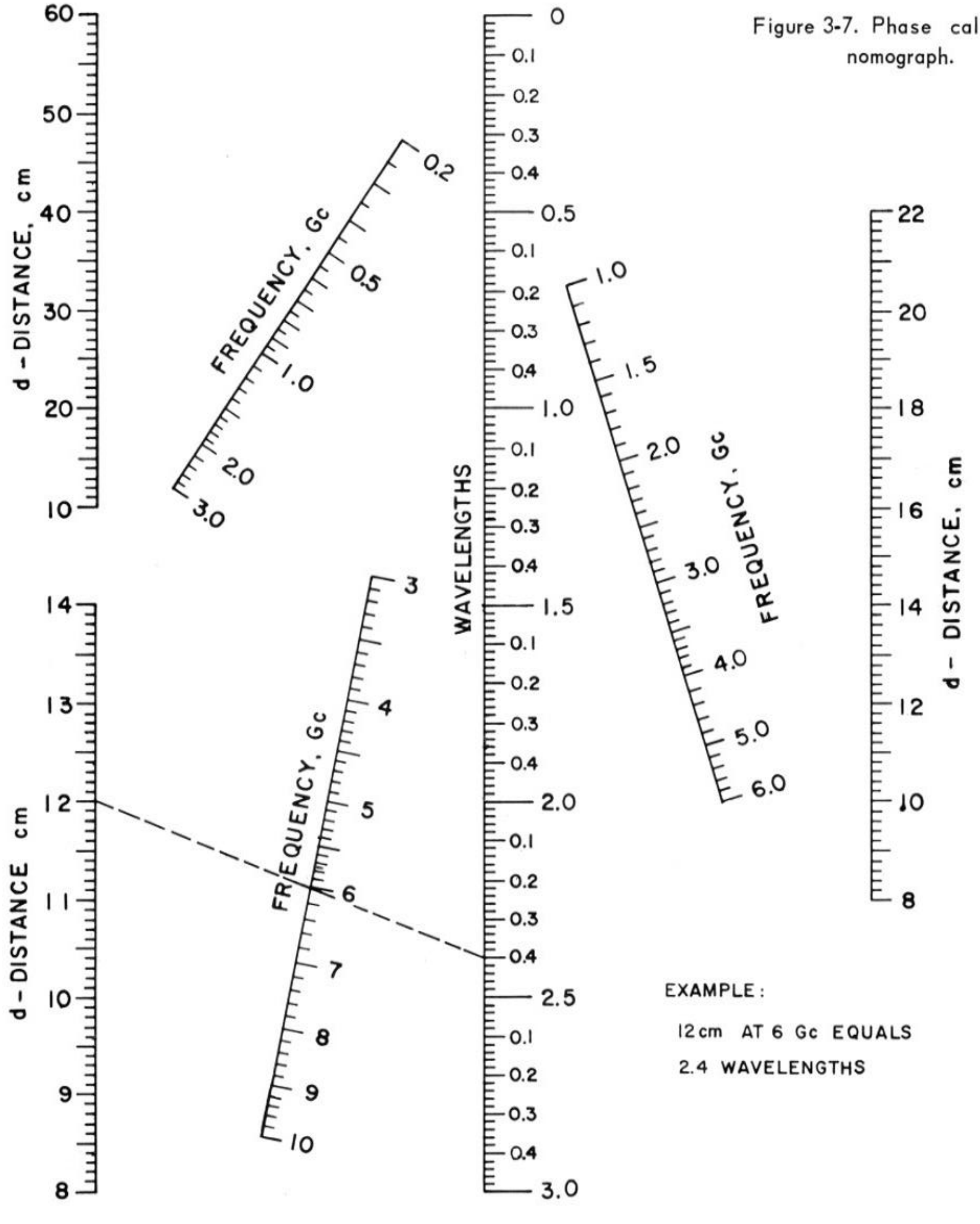


Figure 3-7. Phase calculation nomograph.

minima, and divide by half the number of minima (not counting the starting point) in the span covered. Frequency in Gc is also equal to 29.97 divided by the wavelength in cm.

The centimeter scale on the slotted line reads directly in distance from the reference plane, which is at the face of the Type 900-BT connector. Therefore, an alternative method is to place a short-circuit termination at the reference plane and measure the position of any single minimum. The scale reading at this point is some integral number of half wavelengths. Determine this number from a rough calculation based on the approximate wavelength, then divide the scale reading by half this number, as before.

3.9 MEASUREMENT OF ATTENUATION.

3.9.1 GENERAL.

A slotted line, when used with the width-of-minimum method (paragraph 3.3.4) is well suited for the measurement of small values of attenuation in two-port devices. For example, the loss in a pair of connectors, or of a short length of transmission line or coaxial cable, can thus be measured with a high degree of accuracy.

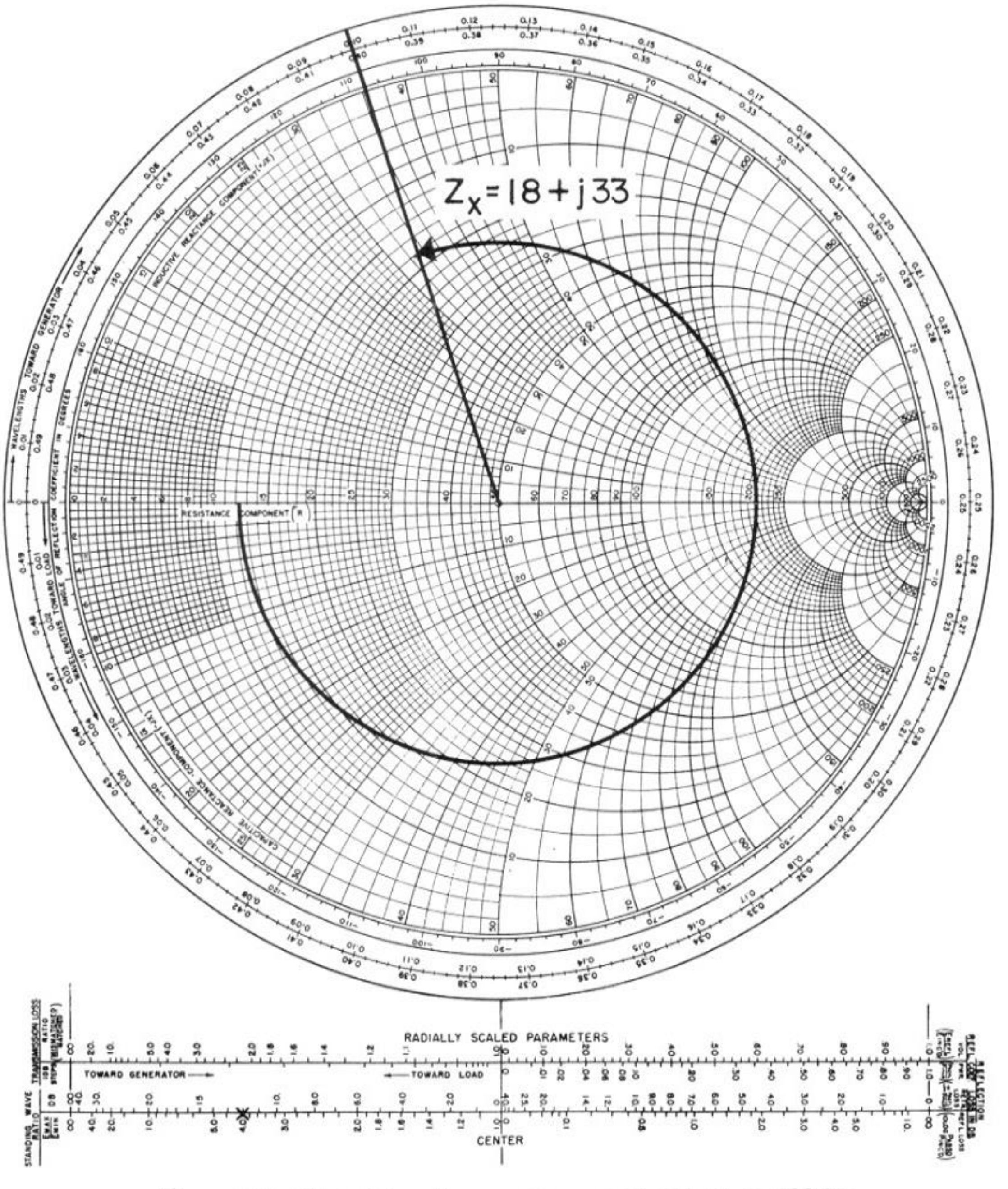


Figure 3-8. Plot of impedance measurement with Type 900-LB.

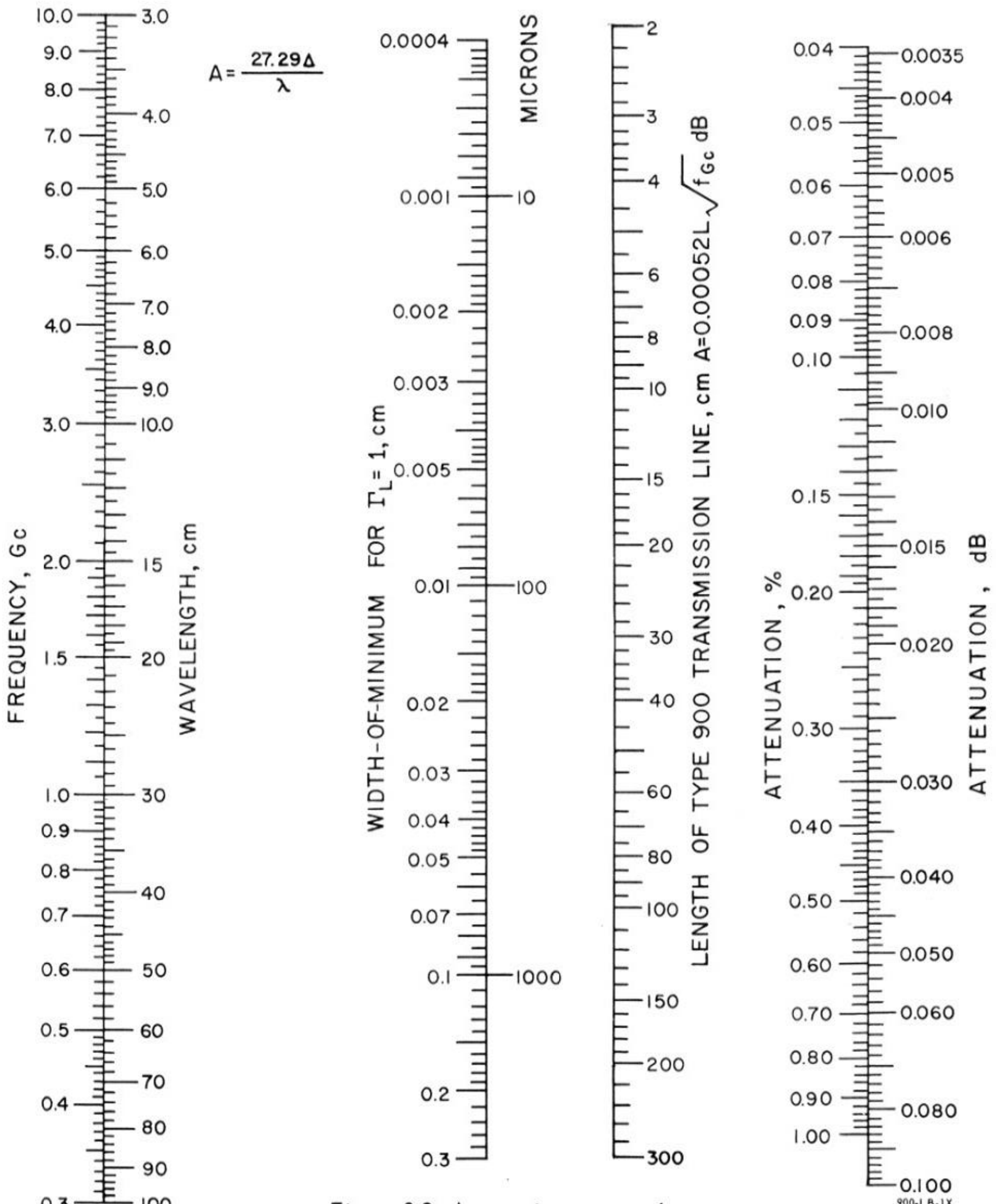


Figure 3-9. Attenuation nomograph.

NOTE: This nomograph was revised in May, 1966 to correspond with improvements in the silverplating of the air line and slotted line sections. This revised nomograph is based on the value 1.67 x 10^{-6} ohm-cm resistivity for the c ductors, typical of resistivity in the lines now being s plied.

The method is based upon the relation between the attenuation in a section of coaxial line and the input reflection coefficient of the line measured with a termination having a unity reflection coefficient, such as a short or open circuit. The attenuation reduces both the forward wave and the reflected wave, and reduces the input reflection coefficient by twice the amount of the attenuation. For example, if the attenuation of the line is 3 db, the forward wave will be reduced by 3 db, so that only 0.71 the forward wave will reach the termination and be total reflected. The reflected wave will also be reduced by db to 0.50 times the value of the forward wave. Cons quently, the input reflection coefficient is 0.50, or bel unity by an amount corresponding to the 6-db attenuat encountered in the round trip.

The relation between input reflection coefficient, $|\Gamma_m|$, and attenuation is, therefore

$$A = 10 \log_{10} |\Gamma_m|$$

For attenuation measurements below 0.1 db, two approximations can be made, first

$$|\Gamma| \doteq 1 - \frac{2\pi\Delta}{\lambda}$$

and

$$\ln (1 + x) \doteq x$$

Then,

$$A = 10 \times 0.4343 \ \log_e (1 - \frac{2\pi\Delta}{\lambda})$$
$$= 27.29 \, \Delta / \lambda, \text{ db}$$

where

Δ = width-of-minimum, cm

λ = wavelength, cm

The nomograph of Figure 3-9 is based on this latter equation.

Measurements with both short- and open-circuit terminations must be made because the losses in the unknown are not necessarily uniformly distributed. The geometric mean of the two answers will give the attenuation of the unknown in a matched 50-ohm system.

Two methods, selected on the basis of the amount of attenuation to be measured, are available.

3.9.2 ATTENUATION BETWEEN 0.1 AND 6 DB.

When the attenuation of the unknown two-port device is above 0.1 db, the attenuation of the slotted line may usually be neglected, and the following direct method is valid.

The procedure is as follows:

a. Attach the Micrometer Carriage Drive to the slotted line in preparation for width-of-minimum measurements.

b. Attach the unknown to the Type 900-BT end of the slotted line.

c. Short-circuit the output end of the unknown two-port device with the Type 900-WN termination.

d. Measure the width of the minimum closest to the unknown and remove the Type 900-WN.

e. Repeat the width-of-minimum measurement for a Type 900-WO open-circuit termination.

f. Use the nomograph of Figure 3-6 to determine the reflection coefficients corresponding to the above two measured width-of-minima. Call these Γ_{sc} and Γ_{oc}.

g. Calculate the geometric mean of these two reflection coefficients:

$$\Gamma_m = \sqrt{\Gamma_{sc} \times \Gamma_{oc}} \ .$$

h. Calculate the attenuation of the unknown, A, by

$$A = 10 \ \log_{10} |\Gamma_m|, \text{db.}$$

3.9.3 ATTENUATION BELOW 0.1 DB (FIGURE 3-9).

When the residual attenuation of the slotted line approaches that of the unknown and cannot be neglected, the substitution method should be used. This allows the attenuation of the measuring equipment to be subtracted from the total measured system attenuation and results in much higher accuracy than the direct method, for measurement of small values of attenuation.

The procedure is as follows:

a. Make a preliminary measurement of the loss in the measuring equipment, exclusive of the unknown. Connect all components except the unknown to the slotted line and short-circuit the output with a Type 900-WN termination. Measure the width of the second accessible minimum from the load by the procedure of

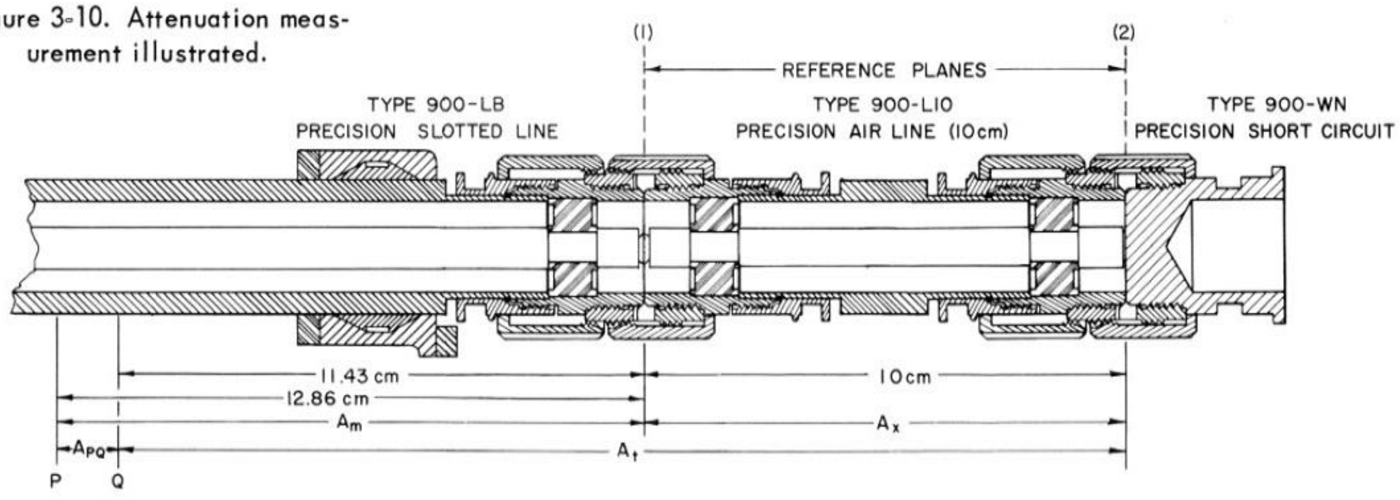


Figure 3-10. Attenuation measurement illustrated.

paragraph 3.9.2, record its position, and call this point P (see Figure 3-10).

b. Replace the short-circuit with the Type 900-WO open-circuit termination and measure the widths of the two minima which straddle point P. Average these two widths-of-minima.

c. Average the width-of-minimum from step a with that of step b, and use this value with the attenuation nomograph (Figure 3-9) to determine the residual attenuation of the measuring equipment (less the unknown) from the output reference plane (1) to point P. Call this attenuation A_m.

d. Insert the unknown two-port device between the slotted line and the Type 900-WN termination, and measure the width of the minimum closest to point P. Record the new position of the minimum, and let this be point Q.

e. Replace the short-circuit with the open-circuit termination, and measure the widths of the two minima that straddle point Q. Average these two widths-of-minima.

f. Average the width-of-minimum from step d with that of step e, and use this value with the attenuation nomograph to determine the total attenuation, A_t, of the unknown plus measuring equipment, i.e., from the output reference plane of the unknown (2) to point Q.

g. Determine a correction for the attenuation between points P and Q. Apply the values for frequency and for the distance in cm between points P and Q (from probe-position scale) to the "LENGTH OF TYPE 900 TRANSMISSION LINE, cm" scale of the attenuation nomograph, to determine the attenuation between the two points. Call this attenuation A_{PQ}, positive if P is to the left of Q, and vice versa.

h. Calculate the attenuation of the unknown, A_x, from:

$$A_x = A_t - A_m + A_{PQ}, \text{ db}$$

EXAMPLE: See Figure 3-10. Determine the attenuation of a Type 900-L10 Precision Air Line at 3.5 Gc (wavelength at 3.5 Gc is 8.57 cm).

(a) With short-circuit directly on slotted line, minima occur at 8.57 cm, 12.86 cm, 17.15 cm, etc. Width of second minimum (at point P, 12.86 cm), 0.0066 cm.

(b) With open-circuit on slotted line, minima occur at 10.45 cm, 14.75 cm, etc.

Width-of-minimum at 10.45 cm, 0.0050 cm.
Width-of-minimum at 14.75 cm, 0.0070 cm.

$$\text{Average, } \frac{0.0050 + 0.0070}{2} = 0.0060 \text{ cm.}$$

(c) Average of steps a and b,

$$\frac{0.0066 + 0.0060}{2} = 0.0063 \text{ cm.}$$

With a straightedge, connect 3.5 Gc on the "FREQUENCY" scale with the value calculated (0.0063) on the "WIDTH OF MINIMUM FOR $\Gamma_L = 1$ scale. Read the value in db where the straightedge intersects the "ATTENUATION, db" scale, which is 0.020.

Call this attenuation $A_m = 0.020$ db.

(d) With Type 900-L10 plus short-circuit on line, closest minimum to point P is at 11.43 cm.

Width-of-minimum, at point Q (11.43 cm), 0.0112 cm.

(e) With Type 900-L10 plus open circuit on line, minima at 9.02 cm and 13.32 cm.

Width-of-minimum at 9.02 cm, 0.0090 cm.
Width-of-minimum at 13.32 cm, 0.0110 cm.

$$\text{Average, } \frac{0.0090 + 0.0110}{2} = 0.0100 \text{ cm.}$$

(f) Average of steps d and e,

$$\frac{0.0112 + 0.0100}{2} = 0.0106 \text{ cm.}$$

From Figure 3-9, attenuation, $A_t = 0.034$ db.

(g) $P - Q = 12.86 - 11.43 = +1.43$ cm.

A_{PQ} = Attenuation of 1.43 cm of Type 900 line at 3.5 Gc
= 1/10 attenuation of 14.3 cm from "TYPE 900 TRANSMISSION LINE"
= 0.001 db.

(h) Answer: Attenuation of Type 900-L10 at 3.5 Gc is:

$$\begin{aligned} A_X &= A_t - A_m + A_{PQ} \\ &= 0.034 - 0.020 + 0.001 \\ &= 0.015 \text{ db.} \end{aligned}$$

3.10 USE WITH HETERODYNE DETECTOR.

NOTE

The diode detector and probe-tuner must be removed from the carriage and the RF Probe Accessory mounted in place of it.

For applications in which a linear detector is preferred to the square-law type, the Type 900-LB can be used with an rf heterodyne detector. The heterodyne detector is also more selective and more sensitive than the diode detector, and is therefore preferable where large amounts of harmonic discrimination or spurious-signal discrimination are required, or where minimum probe coupling is required to minimize probe reflections. A typical test setup using General Radio DNT-type equipment is shown in Figure 3-11 (refer also to Table 2-2).

When the DNT detector is used, the local oscillator must be carefully tuned to mix with the desired signal and not with one of its harmonics. Harmonics of the oscillator signal can mix with harmonics of the signal picked up from the slotted line and produce an output at the intermediate frequency, if the local oscillator is tuned to a wrong frequency. Proper settings of the local oscillator are given in the operating instructions supplied with the DNT equipment.

In general, spurious responses do not cause much difficulty, as the frequency to which the detector is tuned can be easily checked by measurement of the distance between two voltage minima on the line, which should be a half-wavelength at the operating frequency (refer to the left-hand scale of Figure 3-6). The use of an appropriate Type 874 low-pass filter is recommended.

At some frequencies it is necessary to insert a Type 874-L10L, 10-cm Air Line, or a Type 874-G3L attenuator between the connector on the carriage and the mixer rectifier in the DNT, in order to develop sufficient local-oscillator voltage across the diode in the Type 874-MRL Mixer.

Use Table 3-1 to convert to VSWR the db-difference reading observed at voltage maxima and minima on the Type 1216-A, the indicator portion of the DNT Detector. The usable range of Δdb is 20; for larger VSWR subtract multiples of 20 db before entering the Table.

3.11 BOLOMETER OPERATION.

A bolometer element of the same physical outline as the type 1N21C/1N23C may be substituted for the diode detector, provided an indicator with bolometer-input capabilities is used.

3.12 AUTOMATIC RECORDED SLOTTED-LINE MEASUREMENTS.

The General Radio Type 1640-A Slotted Line Recorder System shown in Figure 3-12 automatically produces precision plots of small standing-wave patterns and other slotted-line phenomena. The system consists basically of a chart recorder combined with the Type 900-LB. With such a system, VSWR's from 1.001 to 1.200 can be measured and recorded rapidly and accurately.

The Type 900-LB can be converted to automatic-recorder operation by connection to the Type 1521-SL Graphic Level Recorder via a mechanical-linkage unit, through which the recorder drives the carriage of the slotted line. No modification of the Type 900-LB is required, since it fits directly on the mounting plate of the linkage unit. Carriage drive is accomplished by means of a bevel gear supplied as standard equipment on the drive shaft of the slotted line. This gear meshes with a matching gear on the linkage unit.

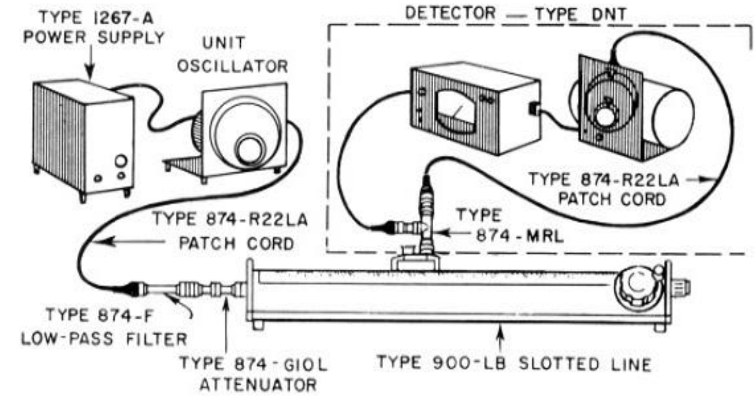


Figure 3-11. Set-up for heterodyne detector measurements with the Type 900-LB.

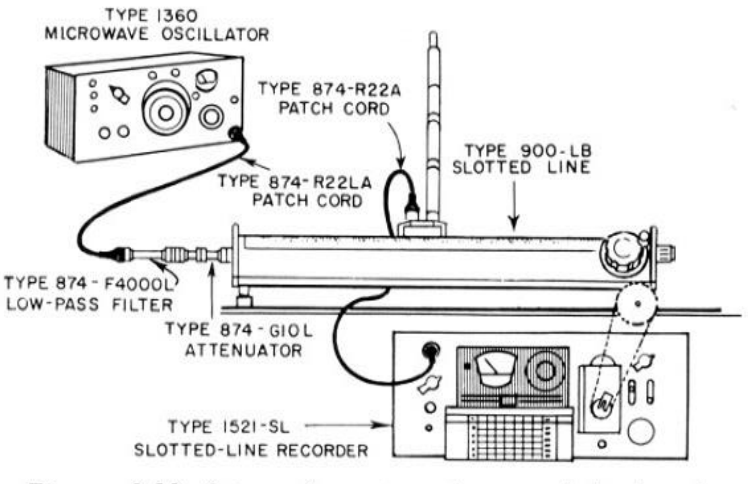


Figure 3-12. Set-up for automatic recorded slotted line measurements with Type 900-LB used as part of Type 1640-A.

TABLE 3-1
CONVERSION DB SCALES TO VSWR
GENERAL RADIO TYPE 1216-A

(Divide Δdb by 2 to use with Type 1232-A)

Δdb	VSWR	Δdb	VSWR	Δdb	VSWR	Δdb	VSWR
0	**1.000**	**5.0**	**1.778**	**10.0**	**3.162**	**15.0**	**5.623**
.1	1.012	5.1	1.799	10.1	3.199	15.1	5.689
.2	1.023	5.2	1.820	10.2	3.236	15.2	5.754
.3	1.035	5.3	1.841	10.3	3.273	15.3	5.821
.4	1.047	5.4	1.862	10.4	3.311	15.4	5.888
.5	1.059	5.5	1.884	10.5	3.350	15.5	5.957
.6	1.072	5.6	1.905	10.6	3.388	15.6	6.026
.7	1.084	5.7	1.928	10.7	3.428	15.7	6.095
.8	1.096	5.8	1.950	10.8	3.467	15.8	6.166
.9	1.109	5.9	1.972	10.9	3.508	15.9	6.237
1.0	**1.122**	**6.0**	**1.995**	**11.0**	**3.548**	**16.0**	**6.310**
1.1	1.135	6.1	2.018	11.1	3.589	16.1	6.383
1.2	1.148	6.2	2.042	11.2	3.631	16.2	6.457
1.3	1.161	6.3	2.065	11.3	3.673	16.3	6.531
1.4	1.175	6.4	2.089	11.4	3.715	16.4	6.607
1.5	1.189	6.5	2.113	11.5	3.758	16.5	6.683
1.6	1.202	6.6	2.138	11.6	3.802	16.6	6.761
1.7	1.216	6.7	2.163	11.7	3.846	16.7	6.839
1.8	1.230	6.8	2.188	11.8	3.890	16.8	6.918
1.9	1.245	6.9	2.213	11.9	3.936	16.9	6.998
2.0	**1.259**	**7.0**	**2.239**	**12.0**	**3.981**	**17.0**	**7.079**
2.1	1.274	7.1	2.265	12.1	4.027	17.1	7.161
2.2	1.288	7.2	2.291	12.2	4.074	17.2	7.244
2.3	1.303	7.3	2.317	12.3	4.121	17.3	7.328
2.4	1.318	7.4	2.344	12.4	4.169	17.4	7.413
2.5	1.334	7.5	2.371	12.5	4.217	17.5	7.499
2.6	1.349	7.6	2.399	12.6	4.266	17.6	7.586
2.7	1.365	7.7	2.427	12.7	4.315	17.7	7.674
2.8	1.380	7.8	2.455	12.8	4.365	17.8	7.762
2.9	1.396	7.9	2.483	12.9	4.416	17.9	7.852
3.0	**1.413**	**8.0**	**2.512**	**13.0**	**4.467**	**18.0**	**7.943**
3.1	1.429	8.1	2.541	13.1	4.519	18.1	8.035
3.2	1.445	8.2	2.570	13.2	4.571	18.2	8.128
3.3	1.462	8.3	2.600	13.3	4.624	18.3	8.222
3.4	1.479	8.4	2.630	13.4	4.677	18.4	8.318
3.5	1.496	8.5	2.661	13.5	4.732	18.5	8.414
3.6	1.514	8.6	2.692	13.6	4.786	18.6	8.511
3.7	1.531	8.7	2.723	13.7	4.842	18.7	8.610
3.8	1.549	8.8	2.754	13.8	4.898	18.8	8.710
3.9	1.567	8.9	2.786	13.9	4.955	18.9	8.811
4.0	**1.585**	**9.0**	**2.818**	**14.0**	**5.012**	**19.0**	**8.913**
4.1	1.603	9.1	2.851	14.1	5.070	19.1	9.016
4.2	1.622	9.2	2.884	14.2	5.129	19.2	9.120
4.3	1.641	9.3	2.917	14.3	5.188	19.3	9.226
4.4	1.660	9.4	2.951	14.4	5.248	19.4	9.333
4.5	1.679	9.5	2.985	14.5	5.309	19.5	9.441
4.6	1.698	9.6	3.020	14.6	5.370	19.6	9.550
4.7	1.718	9.7	3.055	14.7	5.433	19.7	9.661
4.8	1.738	9.8	3.090	14.8	5.495	19.8	9.772
4.9	1.758	9.9	3.126	14.9	5.559	19.9	9.886

Data applies when Type 1216-A used as part of DNT Heterodyne Detector with slotted line.
To extend range above 20 db, subtract multiples of 20.

The output of such a system produces a continuous and permanent measurement record (see Figure 3-13) which can be analyzed graphically for the most accurate determination of the magnitude and phase of the standing-wave pattern. Positions of minima, with a short circuit at the reference plane, can also be plotted automatically.

In substitution measurements, several curves can be plotted on the same record, to facilitate measurement of VSWR differences directly and cancel the effect of nonconstant probe pickup, as in Figure 3-14.

The Type 900-LB must be operated with a 1-kc square-wave-modulated input signal in this application. The audio output from the diode detector actuates the recorder for a variable expanded-scale VSWR presentation. Audio input levels, continuously variable from 0.05 to 2 millivolts, can be accommodated on-scale to permit operation at the level producing the best signal-to-noise ratio.

The presentation is produced on a strip chart with a 4-inch recording width, broken down into eight major divisions, each of which has five minor divisions. In the sample shown in Figure 3-13, the full scale is calibrated for a VSWR of 1.04, so that each of the 40 divisions represents a VSWR of 1.001. The recorder is accurate to within one such minor division at any setting.

The Type 1521-SL Graphic Level Recorder is a completely transistorized, single-channel, servo-type recorder. It produces an ink record on white paper, suitable for reproduction. The pen is attached to a coil which moves linearly (over a 4-inch span) in a uniform magnetic field. A contact attached to the coil rides on a potentiometer, which is the balancing element for the servo. The difference between the slotted-line detector output and an internal reference voltage is amplified and used to position the coil, which carries the potentiometer contact and pen. A velocity-feedback coil mounted on the drive-coil frame furnishes appropriate damping.

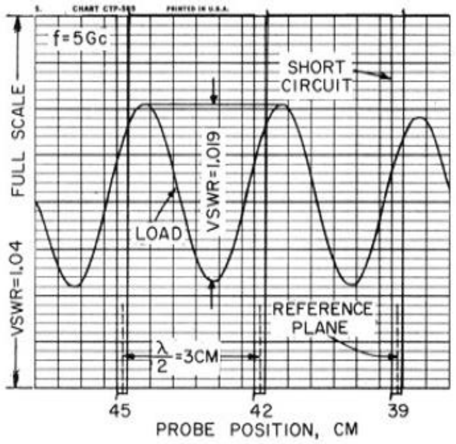


Figure 3-13. Typical readout of Type 1640-A Slotted Lin
Recorder System.

The recorder possesses both a high writing speed and a large servo bandwidth. The horizontal scale contains 1/4-inch divisions which can be calibrated in either 0.5- or 1.0-cm units, in terms of the main scale on the slotted line. A choice of drive sprockets supplied with the linkage unit determines the calibration. A manual-drive control on the recorder facilitates accurate pen positioning for comparison measurement of either standing-wave or wavelength measurements.

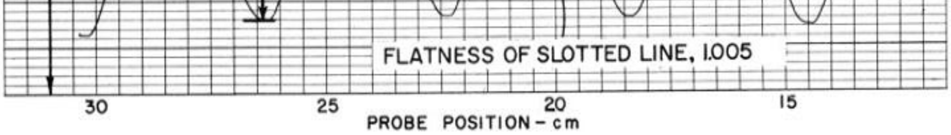


Figure 3-14. Representative Type 1640-A VSWR multiplot of standing-wave samples recorded at 3.8 Gc/s over 15 cm of slotted-line probe travel. Shown are the insertion VSWR of a mated pair of Type 900-Q874 Adaptors (sinusoid marked "UNKNOWN") and the curve made with a matched load ("ADJUSTED RESIDUAL VSWR = 1.001"). The slotted line was matched for the latter curve with a tunable composite termination (Type 900-TUA Tuner plus Type 900-W50 50-Ohm Termination) to show the flatness of the slotted line as well as the ability of the recorder to resolve low VSWR's. Note the cleanliness and low distortion of the recorded sinusoidal standing-wave pattern, even when it is expanded to 1.08 full scale, and the ease with which wavelength and the position of minimum can be measured.

SECTION 4

SPECIAL MEASUREMENTS

4.1 INTRODUCTION.

The slotted line has many applications in addition to the usual measurements described in Section 3. Various less well known but valuable applications (such as use as a precision phase shifter and use with generator and detector reversed to reduce voltage on a nonlinear unknown) are described in this section. Several substitution techniques are described which greatly increase the accuracy of measurement over that obtainable by direct methods. Techniques to adapt the slotted line for use in other coaxial line sizes are also covered.

4.2 CALIBRATION OF ONE-PORT UNKNOWNS.

4.2.1 GENERAL.

The calibration of a one-port device, such as a termination, requires a comparison against a standard with an accuracy of better than 0.1%, much higher than that of the slotted line itself. For coaxial measurements in the GR900 series, the reference standards of impedance are the Type 900-LZ Reference Air Lines (refer to paragraph 5.2.2).

One-port unknowns can be calibrated with reference lines that are an odd multiple of one-quarter wavelength long. The frequencies satisfying this condition for regular Type 900-LZ Reference Air Lines are given in Table 5-1. Reference air lines for special frequencies can be constructed, as discussed in paragraph 5.6. A matching tuner, Type 900-TUA (-TUB)* or equivalent, is also required (paragraph 5.2.3). The calibration principle is described in paragraph 5.3 and the general measurement technique in paragraph 3.3. If the unknown is not fitted with a Type 900-BT connector, it should be so equipped. Complete instructions are supplied with the connector for preperation and mounting.

4.2.2 LOW-VSWR UNKNOWNS.

If the VSWR of the unknown is within the matching range of the tuner (i.e., 1.000 + 0.012 × f_{Gc}), the short method of calibration below is most convenient.

The procedure is as follows:

a. Connect the Type 900-TUA (-TUB) Tuner to the slotted line, the reference air line to the tuner, and the unknown to the air line. Use the tuner to match the unknown to the slotted line, i.e., to tune out all standing waves on the slotted line (refer to paragraph 5.4.4 for procedures).

b. Break the connection between the tuner and the air line, remove the air line, and reconnect the unknown impedance to the tuner.

c. Measure the VSWR and divide the reading by two to obtain the actual magnitude of the VSWR of the unknown impedance. If desired, develop phase information from the VSWR pattern, as discussed in paragraph 3.7.

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*The Types 900-TUA and 900-TUB differ in their frequency range (refer to paragraph 5.2.3 and Appendix A).

4.2.3 INTERMEDIATE-VSWR UNKNOWNS.

When the VSWR of the unknown impedance exceeds the matching range of the tuner, use an alternate procedure. Match the slotted line to the reference air line with the tuner to reduce the effective residual VSWR of the slotted line to a very small value. The VSWR of the unknown can then be measured on the slotted-line-plus-tuner combination by any of the conventional means (Section 3). The accuracy will be that of the reference air line rather than that of the slotted line (see paragraph 5.3). A Type 900-W50 50-ohm Termination is required for this method, as well as the Type 900 Tuner and Type 900-LZ Reference Air Line. The procedure is as follows:

a. Connect the tuner to the slotted line and the termination to the tuner. Adjust the tuner to match the termination to the slotted line, and record the scale readings of the tuning knobs of the tuner.

b. Break the connection between the tuner and the termination, insert the reference air line, and rematch the slotted line. Again record the settings on the tuning knobs.

c. Compute the average of the two readings for each tuning knob, and set each knob to its average value. With these settings the residual VSWR of the slotted line is tuned out to within the accuracy of the reference air line.

d. As a check to see that the tuning has been properly done, measure the VSWR of the termination on the slotted-line-tuner combination, both with and without the reference air line. The two answers should be the same in magnitude, and opposite in phase. If not, repeat the above tuning adjustments.

e. Measure the VSWR of the unknown impedance.

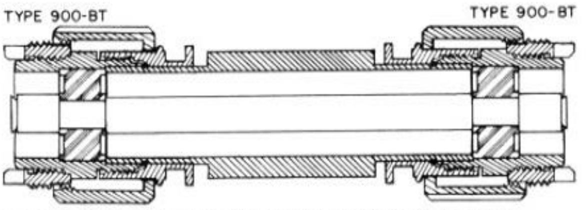
NOTE

For reference-plane purposes, apply the short-circuit termination to the output of the tuner, rather than to the end of the slotted line, as is usually done.

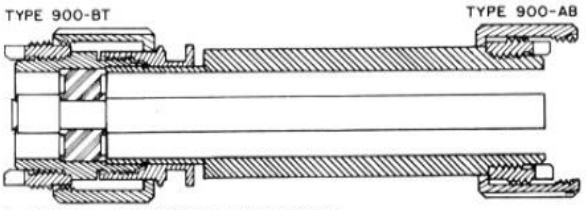
4.3 CALIBRATION OF TWO-PORT UNKNOWNS.

4.3.1 GENERAL.

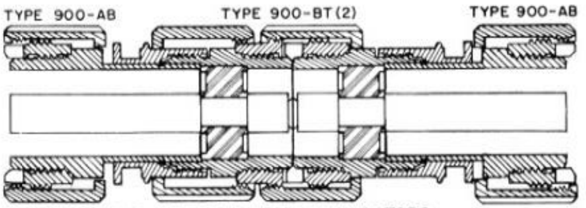
The methods of this section are most useful in the design of support beads, diameter transitions, adaptors, connectors, slotted lines, and in other design problems which can be cast in the form of two-port unknowns. Typical examples, based on the use of GR900 connectors, are shown in Figure 4-1. Since the



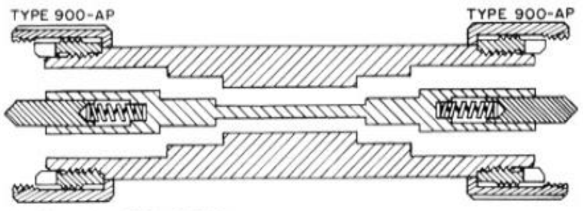
a. PRECISION AIR LINE WITH PRECISION CONNECTORS



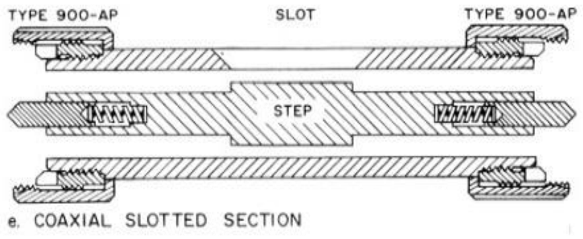
b. SINGLE PRECISION CONNECTOR



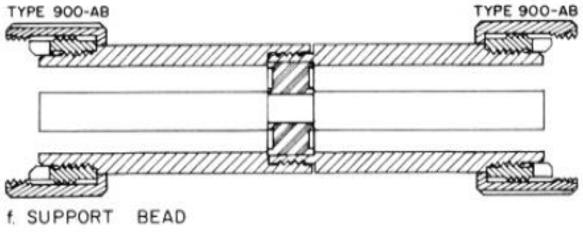
c. MATED PAIR OF PRECISION CONNECTORS



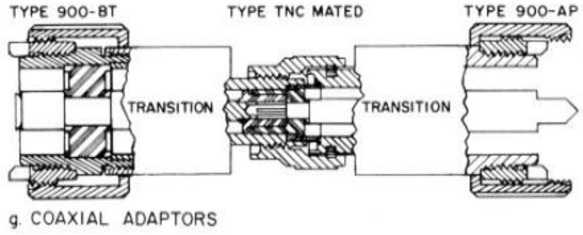
d. COAXIAL TRANSITION



e. COAXIAL SLOTTED SECTION



f. SUPPORT BEAD



g. COAXIAL ADAPTORS

Figure 4-1. Representative two-port unknowns suitable for precision measurement on Type 900-LB.

substitution method is utilized, the accuracy is not limited to that of the slotted line, but is equal to the much higher accuracy (0.1 - 0.3%) of the reference air line.

There are two basic methods of calibrating two-port unknowns with respect to a section of reference air line: the half-wave substitution method, and the reference-air-line substitution method (for continuous frequency coverage).

The half-wave substitution method is useful when the unknown two-port device contains a section of precision transmission line which can serve as the impedance reference standard. This is true, for example, in tests of precision coaxial connectors mounted at the ends of precision rod and tubing[1,2]. Test frequencies are limited to multiples of the frequency at which the test section is one-half-wavelength long.

When the unknown does not contain a section of precision 50-ohm transmission line, or when tests are required at many closely spaced or arbitrary frequencies, the reference-air-line substitution method is necessary. The electrical length of the test section must be duplicated in a section of reference air line, either by fabrication of an unknown equal in length to one of the Type 900-LZ Reference Air Lines, or by fabrication of a special length of reference air line (refer to paragraph 5.6). Connector kits, available from General Radio for use with reference air lines are listed in Table 4-1.

4.3.2 HALF-WAVE SUBSTITUTION METHOD.

The half-wave substitution method depends upon the fact that the input impedance of an ideal length of transmission line is equal to its terminating impedance, at a series of equally spaced frequencies at which its electrical length equals a multiple of one-half wavelength. Two measurements are made, one with a termination on the slotted line, and another with the unknown between the termination and the slotted line. The reflection coefficient of the ter-

TABLE 4-1
CONNECTOR KITS FOR CUSTOM FABRICATED GR900 COAXIAL AIR LINES

TYPE	CONTENTS	FUNCTION	REF FIG. 4-1
900-AP	Locking nut Centering-gear-ring nut Centering pin Contact spring	Used on beadless lines that take support from mating Type 900-BT connectors (such as Type 900-LZ air lines)	d, e, g
900-AB	Locking nut Centering-gear-ring nut	Used in beadless connector where inner conductor is supported at one end and contact is in mating connector	b, c, f
900-AC	Locking nut Centering-gear-ring nut Center contact	Used in beadless connector where inner conductor is supported at one end and contact is not in the mating connector	none

NOTE: Kits are intended principally for use with GR900 Precision Coaxial Rod and Tubing. Refer to paragraph 5.6.1 for fabrication techniques. Two are required per line.

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[1] A. E. Sanderson, "A New High-Precision Method for the Measurement of the VSWR of Coaxial Connectors," IRE Transactions on Microwave Theory and Techniques, Vol MTT-9, No. 6, November 1961, pp 524-528.

[2] A. E. Sanderson, "An Accurate Substitution Method of Measuring the VSWR of Coaxial Connectors," The Microwave Journal, Vol 5, No. 1, January 1962, pp 69-73. GR Reprint A-95.

mination, as seen by the slotted line, will be the same in magnitude and phase in both measurements and will cancel out when the difference is taken. The difference represents the reflection coefficient of the unknown with respect to its built-in standard of 50 ohms.

Proceed as follows:

a. Choose an initial test frequency at which the unknown is approximately equal to a multiple of one-half wavelength (see Figure 3-7). Short-circuit the slotted line at the reference plane with the Type 900-WN and measure the position of the first minimum; use the Micrometer Carriage Drive accessory to read the probe position in thousandths of a centimeter.

b. Add the unknown between the short-circuit and the slotted line, and remeasure the position of the minimum. If it has not changed, the electrical length of the unknown is equal to a multiple of one-half wavelength and no adjustment is necessary. If the second minimum is farther from the reference plane than the first, raise the frequency and repeat the measurement; the converse also obtains. To estimate the amount of the correction, multiply the test frequency by the discrepancy in the positions of minima, and divide the product by the approximate electrical length of the unknown.

NOTE

A Type 900-WNC is required if the terminated end is fitted with a Type 900-AP Connector. Also, omit step d below.

EXAMPLE:

Position of initial minimum	9.3 cm
Position of second minimum	9.7 cm
Approximate electrical length of the unknown	15.0 cm
Test frequency	6000 Mc
Correction, $\frac{6000 \times (9.7 - 9.3)}{15.0} =$	160 Mc
New test frequency	6160 Mc

c. Repeat steps a and b until the two positions of minima agree (within the accuracy of the measurement).

d. Repeat steps a and b for the Type 900-WO Open-Circuit Termination. If there is a difference between the electrical lengths measured with the two types of termination, the true electrical length is equal to the average of the two values. Reset the test frequency to the average of the two values determined for the short- and open-circuits.

e. Connect the Type 900-TUA (-TUB) Tuner to the slotted line, and the Type 900-W50 termination to the tuner. Match the termination to the slotted line so that no standing waves remain.

f. Break the connection between the tuner and the slotted line and insert the unknown two-port device. The resulting VSWR on the slotted line is the insertion VSWR of the unknown (in both phase and magnitude) referred to the built-in characteristic impedance of the section of reference air line.

4.3.3 REFERENCE-AIR-LINE SUBSTITUTION METHOD.

The reference-air-line substitution method is simply the comparison of the unknown with a section of transmission line of the same electrical length known to have excellent electrical characteristics. The vector difference between the two can be measured at any frequency and represents the reflection coefficient of the unknown with respect to the characteristic impedance of the reference air line.

The measurement consists of two parts: determination of the electrical length of the unknown and measurement of the vector difference between the unknown and the reference air line.

It is necessary to have a reference air line of the same length as the unknown. Either adjust the electrical length of the unknown by trimming it to a length equal to that of one of the Type 900-LZ's, or fabricate a reference air line of the required length (refer to paragraph 5.6).

Proceed as follows:

a. Determine the frequency at which the electrical length of the unknown is exactly equal to an integral multiple of one-half wavelength, following steps a, b, and c of paragraph 4.3.2.

b. Measure the distance between the first minimum and the last minimum on the slotted line, with the main scale and vernier. Count the number of half-wavelengths between the minima and divide the total distance by this number to obtain the exact half-wavelength interval.

c. Multiply the half wavelength thus determined by the appropriate integer to obtain the electrical length of the unknown. Use a reference air line of equal length in the following steps.

d. Set the test frequency to any desired value; there is no frequency restriction.

e. Connect the reference air line between the slotted line and the tuner, and connect the 50-ohm termination to the tuner. Use the tuner to eliminate standing waves on the slotted line.

f. Remove the reference air line, and substitute the unknown.

g. Measure the resulting VSWR on the slotted line. This value equals the insertion VSWR of the unknown (in both phase and magnitude) referred to the characteristic impedance of the reference air line.

4.4 MEASUREMENT OF DIELECTRICS[3,4].

4.4.1 GENERAL.

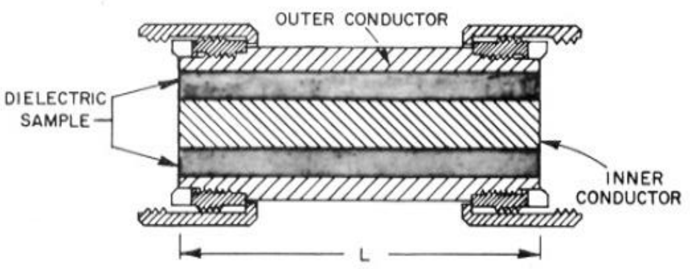
The Type 900-LB Precision Slotted Line can be used to measure the dielectric constant and dielectric loss of materials which can be fabricated into cylindrical samples, with a hole through the center (see Figure 4-2). Measurements can be conveniently made over the entire frequency range of the slotted line and over the entire range of dielectric constants and losses normally encountered. Because of the low and uniformly distributed losses of the slotted line and the reference air lines, accurate measurements can be made of the loss in the lowest-loss materials presently available, i.e., $\tan \delta = 0.0003$.

The shape of the sample is dictated by the use of the Type 900-LZ Reference Air Line as the sample holder. The tolerances on diameters should be held as tight as possible to prevent air gaps between the dielectric material and the inner and outer conductors. In fact, a light press fit is most desirable.

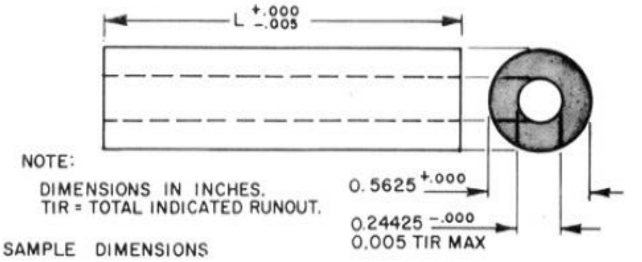
CAUTION

Rigid material may scratch or warp the reference air line if force-loaded.

The length of the dielectric sample must be equal to, or slightly less than, the length of the air line. If it is not convenient to make the sample in one piece the full length of the air line, several shorter segments may be stacked to achieve the required total length. There must be no air gap between segments, however, which means that the butting surfaces must be flat and perpendicular to the axis.



a. SAMPLE IN TYPE 900-LZ



b. SAMPLE DIMENSIONS

Figure 4-2. Dielectric sample fabrication for measurement inside Type 900-LZ.

Measurements are most conveniently made at frequencies at which the electrical length of the dielectric sample is a multiple of one-half wavelength, because of the resultant simplicity of the equations for dielectric constant and loss. This condition is usually achieved by adjustment of the frequency for a given test specimen, but it may sometimes be desirable to adjust the length of the test specimen in order to make measurements at a particular test frequency.

The measurement techniques employed are given in detail in Section 3, particularly in paragraph 3.3.4.

4.4.2 DIELECTRIC-CONSTANT MEASUREMENT.

The accessories required are the Micrometer Carriage Drive, the Type 900-WN Short-Circuit Termination, and one of the Type 900-LZ Reference Air Lines. After the dielectric sample has been inserted in the reference air line, proceed as follows:

a. Set the frequency according to a preliminary calculation so that the electrical length of the dielectric-filled sample holder will be approximately equal to an integral multiple of one-half wavelength. Short-circuit the slotted line and measure the position of the first minimum with the Micrometer Carriage Drive.

b. Insert the sample holder between the slotted line and the short-circuit and measure the shift, if any, in the position of the first minimum.

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[3] C. G. Montgomery, (ed.), "Techniques of Microwave Measurements," MIT Radiation Laboratory Series, McGraw-Hill, New York, Vol. 11, 1947, pp 561-676.

[4] A. R. Von Hippel (ed.), "Dielectric Materials and Applications," Technology Press of MIT, Cambridge, Mass, and Wiley, New York (1954).

c. Correct the test frequency by the following amount:

$$\Delta f = \frac{\Delta x \cdot f}{L_p\sqrt{\epsilon_r}}$$

where Δf = frequency correction, Gc,
Δx = shift in position of minimum, cm,
f = initial test frequency, Gc,
ϵ_r = relative dielectric constant,
L_p = physical length of sample holder, cm.

Lower the test frequency if the minimum shifted toward the load, and vice versa.

d. Repeat steps a, b, and c until the position of minimum is the same with and without the test sample.

e. Measure the distance between the first and last minima on the slotted line, with the main scale and the vernier. Count the number of half wavelengths between them and divide the total distance by this integer to determine the half-wavelength interval.

f. Multiply the half wavelength by the appropriate integer to obtain the exact electrical length of the dielectric-filled sample holder. The relative dielectric constant, ϵ_r, of the sample is then given by the equation:

$$\epsilon_r = \left(\frac{L_e}{L_p}\right)^2$$

where L_e = electrical length of sample holder, cm,
L_p = physical length of sample holder, cm.

EXAMPLE: Measure the dielectric constant of Teflon in the region of 6 Gc with the Type 900-LZ5 (5-cm) Reference Air Line as the sample holder; the approximate dielectric constant of the sample is 2.0. The approximate electrical length of the sample holder is:

$$L_e = L_p\sqrt{\epsilon_r} = 5\sqrt{2} = 7.07 \text{ cm.}$$

Since the half-wavelength in the region of the desired frequency is about 2.5 cm, and the electrical length of the sample must be a multiple of this figure, possible lengths for the sample are 2.5 cm, 5 cm, 7.5 cm, 10 cm, etc. The multiple closest to 7.07 cm is the third one; therefore, the measurement will be made with the sample exactly 3 half wavelengths long. This exact frequency is determined during the measurement, but is approximately 6.37 Gc.

Following the steps of the above procedure, we have:

(a) Initial test frequency, 6.37 Gc.

Position of first minimum, 9.42 cm (on main scale).

Position of minimum, 1.431 cm (on micrometer).

(b) Position of minimum after addition of sample holder, 1.377 cm (on micrometer), a shift of minimum, 0.054 cm toward load (negative).

(c) Frequency correction:

$$\Delta f = \frac{0.054 \times 6.37}{\sqrt{2} \times 5} \doteq 0.05 \text{ Gc.}$$

Second test frequency, 6.37 - 0.05 = 6.32 Gc.

(d) At the second test frequency, the position of minimum shifts 0.004 cm toward the load (negative) with the addition of the sample holder.

Frequency correction:

$$\Delta f = \frac{0.004 \times 6.32}{\sqrt{2} \times 5} \doteq 0.0036 \text{ Gc.}$$

Third test frequency, 6.3200 - 0.0036 = 6.3164 Gc. At the third test frequency, no shift is noted in the position of the minimum with the addition of the sample.

(e) The first minimum occurs at 9.50 cm on the main scale, and the last at 57.00 cm; there are 20 half-wavelengths between. The half-wavelength equals (57.00 - 9.50) /20 = 2.375 cm.

(f) The test sample is three half wavelengths long, therefore, 7.125 cm in electrical length.

The dielectric constant of the Teflon sample at 6.3 Gc is:

$$\epsilon_r = \left(\frac{7.125}{5.000}\right)^2 = 2.031$$

Note that the dielectric constant can be measured to four significant figures by this method. The accuracy of the measurement is ±0.3% in dielectric constant, limited by the accuracy of the main scale in measurement of the wavelength.

Standard centimetric-length rods may be used to increase the accuracy considerably. These rods, inserted between the micrometer drive and the carriage, move the carriage in accurate increments between which the micrometer drive is used for interpolation.

4.4.3 DIELECTRIC-LOSS MEASUREMENT.

After the dielectric constant has been determined by the method of paragraph 4.4.2, the dielectric loss can easily be obtained as follows:

a. Measure the width of the first minimum on the slotted line, with the sample holder in place and terminated in the short circuit.

b. To the nomograph of Figure 3-9, apply the test-frequency and width-of-minimum information to determine the total attenuation between the first minimum and the short-circuit termination. This is read from the "ATTENUATION, db" scale.

c. Add the main-scale reading of the slotted line at the first minimum to the physical length of the sample holder. Enter the nomograph with this number on the "LENGTH OF TYPE 900 TRANSMISSION LINE" scale, connect this point to the test frequency, and read the attenuation on the ATTENUATION, db scale. This is the attenuation due to the silver losses in the slotted line and in the reference air line.

d. Subtract the silver-loss-attenuation figure from the total-attenuation figure to determine the part of the attenuation due to the dielectric losses in the dielectric material alone. Calculate the loss tangent, tan δ, of the dielectric material from the following formula:

$$\tan\delta = \frac{0.0366\,\frac{A\lambda}{L_e}}{1-0.0183\,\frac{A\lambda}{L_e}}$$

where A = attenuation from dielectric losses, db,
λ = wavelength, cm,
L_e = electrical length of sample holder, cm.

For low-loss materials the formula simplifies to:

$$\tan\delta = \frac{0.0366\,A\lambda}{L_e}$$

High-Loss Dielectrics. With high-loss dielectrics, the width-of-minimum determined in step a above may be off scale on the nomograph. In that event, use the nomograph of Figure 3-6 to determine the reflection coefficient corresponding to the measured width-of-minimum and the frequency. Calculate the attenuation required in step b above from the following formula:

$$A = 10\log_{10}|\Gamma|$$

Then proceed as before with steps c and d.

The effect of loss on the value of dielectric constant is negligible for tan δ less than 0.05.

Low-Loss Dielectrics. With very low-loss dielectrics, the loss in the slotted line should be obtained by measurement rather than from the nomograph. Measure the width of the first minimum with the Micrometer Drive, with the short-circuit termination on the slotted line. Use the attenuation nomograph (Figure 3-9) with the values for width-of-minimum and frequency, to determine the actual attenuation of the slotted line as read from the ATTENUATION, db scale. The attenuation owing to the silver losses in the sample holder can be determined by the same method as before. Enter the nomograph with the values for frequency and length of reference air line, and read the attenuation on the ATTENUATION, db scale. Use the sum of these two values, the attenuation of the slotted line plus the attenuation of the reference air line, then proceed as in step d above.

4.5 MEASUREMENT OF THE PHASE SHIFT OF TWO-PORT UNKNOWNS.

4.5.1 GENERAL.

The rf phase shift of reasonably low-loss, two-port unknowns fitted with GR900 connectors can be measured to a high degree of accuracy on the slotted line by an indirect method. The electrical length of the unknown is measured both with the short- and with the open-circuit terminations. The average of these two values is simply related to the rf phase shift of the unknown in a matched 50-ohm system. The detailed technique involved is covered in Section 3.

4.5.2 OVER-ALL PHASE SHIFT.

Accessories required for the measurement are Type 900-WN and -WO short- and open-circuit terminations. Set the signal source to the desired test frequency and proceed as follows:

a. Connect the unknown to the slotted line and the short-circuit to the output of the unknown. Measure the position of the first minimum on the slotted line with the main scale and vernier.

b. Remove the unknown, short-circuit the end of the slotted line, and measure the new position of the minimum, which will have shifted to the left by an amount equal to the electrical length of the unknown. At the higher frequencies, the shift may be several wavelengths, so that the minimum in question will no longer be the first one. To resolve the ambiguity, calculate a rough figure for the electrical length. To the over-all physical length of the unknown, add the physical length of any dielectric-filled sections of line times $(1 - \sqrt{\epsilon_r})$. Look for a minimum at this approximate distance to the left of the original minimum.

c. Reinstall the unknown, and terminate it with the open-circuit termination. Measure the position of the first minimum of the slotted line.

d. Remove the unknown, place the open-circuit on the end of the slotted line, and measure the new position of the minimum. It will have shifted to the left by approximately the same amount as in the short-circuit case.

e. Subtract the scale reading of step a from that of step b to determine the short-circuit electrical length of the unknown, L_{sc}. Similarly determine the open-circuit electrical length, L_{oc}.

f. Average the short- and open-circuit electrical lengths to obtain the electrical length for a matched 50-ohm system, L_m.

$$L_m = \frac{L_{sc} + L_{oc}}{2}$$

g. Calculate the rf phase shift of the unknown from the electrical length by the following formula:

$$\phi = \frac{2\,\pi\,L_m}{\lambda} \text{ radians}$$

$$\phi = \frac{360\ L_m}{\lambda} \text{ degrees,}$$

where λ = wavelength of the test frequency
ϕ = rf phase shift.

4.5.3 INCREMENTAL PHASE SHIFT.

The accuracy of measurement of phase-shift increments is much greater than that of over-all phase shift, because of the greater accuracy of the Micrometer Carriage Drive for measurement of positions of minima. The increment to be measured must not exceed 2.2 cm in equivalent electrical length, which is the maximum usable micrometer travel.

Sections of Type 900-L Precision Air Line and Type 900-LZ Reference Air Lines make excellent phase-shift standards because of their very low VSWR and accurate electrical length. With various combinations of lengths, a phase-shift standard can be made (within the micrometer travel limit) of an unknown of any electrical length. The incremental-phase-shift method can be used to compare the unknown to the standard, with much greater accuracy than that possible in the direct method of paragraph 4.5.2.

Another use for the incremental-phase-shift measurement is in phase-repeatability measurements. For example, phase repeatability of a connector pair as it is broken and reconnected, phase repeatability between different units of a production run, and phase repeatability of coaxial cable, as it is flexed, can all be measured.

The Types 900-L10, 900-L15, and 900-L30 are precision coaxial air-line sections fitted with standard Type 900-BT connectors (see Figure 4-3). The terminal digits in the type designation refer to the electrical length in centimeters, ±0.02 cm. The precise lengths restrict electrical-phase-shift uncertainty to ±0.24° at 1 Gc.

The air-line sections are held to extremely close dimensional tolerances. These tolerances maintain the characteristic impedance at 50 ohms ±0.065%. The basic material is brass with a layer of silver at the conducting surfaces plus a protective gold plating. Typical VSWR characteristics are shown in Figure 4-4.

Other accessories required are Types 900-WN and -WO short- and open-circuit terminations.

The procedure is as follows:

a. Connect the unknown to the slotted line, and the Type 900-WN termination to the output of the unknown. Measure the position of the first minimum with the micrometer.

b. Make the change in the test setup for which the incremental phase shift is desired, and remeasure the position of the minimum.

c. Subtract the two micrometer readings to determine the incremental change in the short-circuit electrical length, ΔL_{sc}.

d. Repeat steps a, b, and c above with the Type 900-WO termination to determine the incremental change in open-circuit electrical length, ΔL_{oc}.

e. Average ΔL_{sc} and ΔL_{oc} to obtain the incremental change in electrical length for the matched condition, ΔL_m.

Figure 4-3. Type 900-L Precision Air Lines.

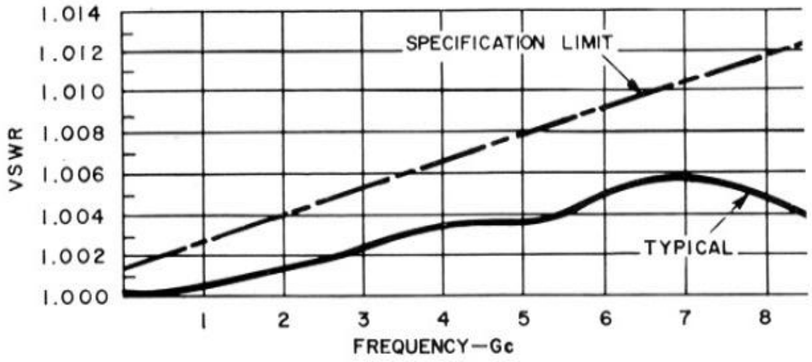


Figure 4-4. VSWR Performance for Type 900-L10, -L15, -L30 Air Lines.

f. Convert this length to equivalent phase shift with the following formula:

$$\phi = \frac{2\pi \Delta L_m}{\lambda} \text{ radians,}$$

$$\text{or } \phi = \frac{360 \Delta L_m}{\lambda} \text{ degrees.}$$

4.6 OPERATION AS A PRECISION PHASE SHIFTER.

4.6.1 GENERAL.

The slotted line with the RF Probe Accessory and a well-matched load may be used as a precision phase shifter. Accuracy of well under one degree, with no output-amplitude variation, is possible; neither the input nor the output impedance changes as the phase is being shifted.

Rf power is fed into the source-end of the line, and is extracted from the RF Probe Accessory installed on the carriage. The slotted line is terminated in a 50-ohm load and matched, if necessary, to eliminate standing waves on the line. Under these conditions, the phase of the rf output at the probe will vary linearly with the position of the carriage at the rate of 360° (or 2π radians) per wavelength at the frequency of operation. The magnitude of the output voltage will be practically independent of carriage position. Large changes in phase may be measured on the main scale of the slotted line, while more-accurate measurements of small changes may be made with the Micrometer Carriage Drive.

4.6.2 THEORY.

The output at the probe for a perfectly matched slotted line represents a sampling of the incident wave in the line, as a function of distance along the line. The incident wave has a phase which changes linearly as a function of distance, but the amplitude of the incident wave in independent of distance. Thus, the matched slotted line approaches the ideal as a precision phase shifter.

The presence of a reflected wave in the line modifies these conditions somewhat, causing not only the amplitude variations known as standing waves, but phase variations as well. The resultant rf voltage at any point on the line is the vector sum of the incident and the reflected waves. Assuming the reflected wave to be of much smaller amplitude than the incident wave, the maximum phase error occurs when the reflected wave is at an angle of 90° with respect to the forward wave. The formula for the maximum phase error is:

$$\theta_{max} = \sin^{-1} \frac{S - 1}{S + 1}$$

where θ_{max} = maximum phase error
S = standing-wave ratio in the slotted line.

For example, a standing-wave ratio of 1.01 will cause a maximum phase error of

$$\theta_{max} = \sin^{-1} \frac{0.01}{2.01} = 0.3^\circ$$

This error cycles from plus to minus (with carriage position), with a period of one-half wavelength.

This error formula demonstrates the importance of matching the line for best results and can be used to determine the degree of match necessary to satisfy the requirement at hand. Probe coupling can be increased, by clockwise rotation of the screwhead in the center conductor of the RF Probe Accessory, to reduce the insertion loss of the phase shifter. As probe coupling is increased, however, the probe reflection itself will cause standing waves on the line, and this will necessitate rematching of the line. Refer to Figures 6-10 and 6-11 for plots of this relationship. As long as this rematching is carried out, operation as a phase shifter is unaffected by the degree of probe coupling.

4.6.3 OPERATION.

The equipment configuration is shown in Figure 4-5, and the procedures are as follows:

a. Remove the crystal diode and the probe-tuner assembly from the carriage, and insert the RF Probe Accessory. Replace the crystal cover and tighten it.

b. Terminate the load end of the slotted line with a Type 900-W50 50-ohm Termination.

c. Connect the signal source to the input end of the slotted line.

d. Connect the rf output from the RF Probe Accessory to whatever detector is to be used in the system.

NOTE

The rf output may be padded with a Type 874-G attenuator if a matched rf output is necessary.

e. Use the line as a conventional slotted line to determine the standing-wave magnitude on the line (refer to Section 3). If the VSWR is within acceptable limits, according to the above formula, the phase shifter is ready for use.

f. If the VSWR exceeds the value necessary to achieve the desired phase accuracy, insert a Type 900-TUA (-TUB) Tuner between the slotted line and the termination. Adjust the tuner to eliminate the standing waves from the line; refer to paragraph 5.2.3. The phase shifter is then ready for use.

4.7 OPERATION WITH GENERATOR AND DETECTOR REVERSED.

4.7.1 GENERAL.

In the measurement of nonlinear devices such as transistors, crystal diodes, etc., it is necessary to keep the signal level on the device as small as possible for several reasons:

(1) to avoid damage to delicate devices, such as semiconductors;

(2) to measure accurately the small-signal parameters of a device;

(3) to avoid generation of harmonics of the input signal by the unknown.

In normal operation of the slotted line, full signal power is applied to the unknown. If this is likely to cause any of the above difficulties, the signal source and the detector can be interchanged, to reduce the signal power on the unknown by an amount equal to the probe isolation, which can be 20 to 50 db, depending on the probe penetration.

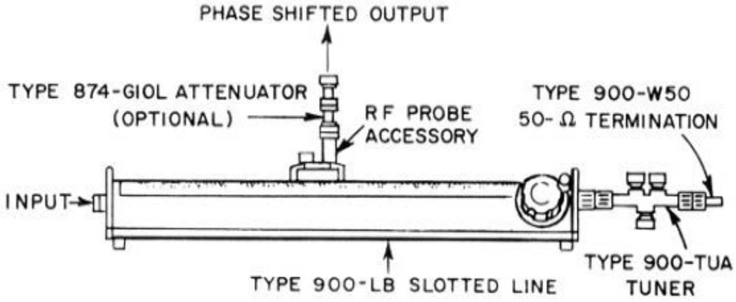


Figure 4-5. Operation of the Type 900-LB as a precision phase shifter.

The apparent indication of standing waves on the line is unchanged by the reversal of the generator and the detector, as can be proved by the reciprocity theorem. Therefore, all the procedures described for normal operation of the line (refer to Section 3) apply equally well to the reversed operation described below.

The detector may be either a crystal detector, such as the Type 874-VQL (see Figure 4-6) for use with a modulated source, or a heterodyne detector, such as the Type 874-DNT setup (refer to paragraph 3.10), for greater sensitivity and for use with an unmodulated source. Suitable oscillators for both signal sources and local oscillator are shown in Table 2-1.

4.7.2 OPERATION.

To prepare for operation in this mode:

a. Remove the crystal diode and the probe-tuner assembly from the carriage of the slotted line, and replace them with the RF Probe Accessory.

b. Remount the crystal cover and screw it down tightly by hand, to prevent rf leakage.

c. Connect the signal source to the Type 874 connector on the RF Probe.

NOTE

A Type 874-G attenuator may be necessary to reduce the mismatch seen by the signal source.

d. Connect the detector to the left-hand end of the slotted line (normally the input end).

e. Resonate the crystal detector with a Type 874-D20L Adjustable Stub connected to its output.

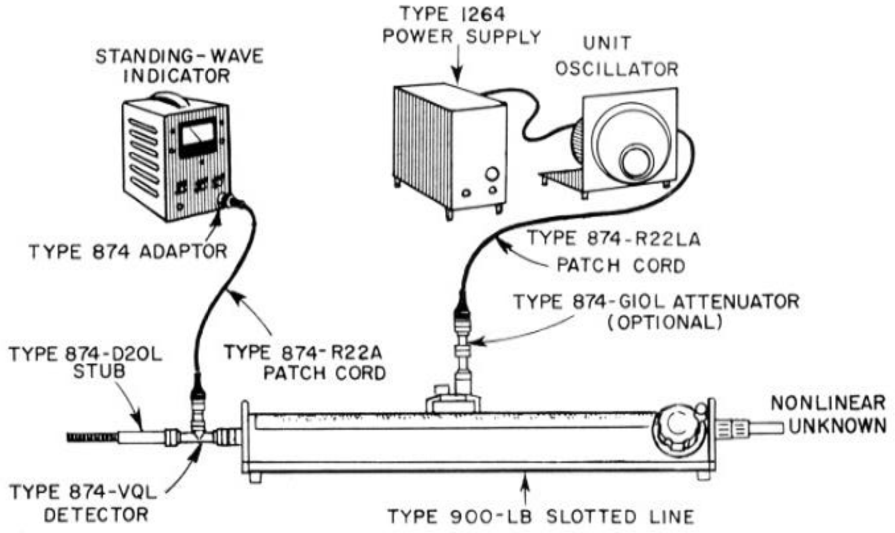


Figure 4-6. Operation with generator and detector reversed.

f. Make the desired measurement on the nonlinear unknown, following the appropriate procedure in Section 3.

4.8 MEASUREMENT OF SOURCE IMPEDANCE.

4.8.1 GENERAL.

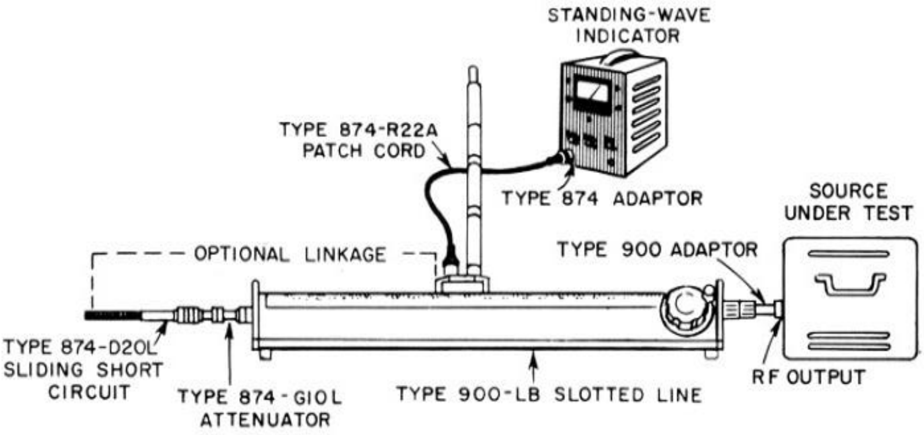
The slotted line can be used to measure the source impedance of an active source of rf power, such as a signal generator or a transmitter, by measurement of the signal provided by the source itself. The source under test is connected to the load (right-hand) end of the slotted line through an appropriate adaptor, as shown in Figure 4-7; refer to paragraph 4.10 for a detailed discussion of adaptors.

The opposite end of the line is terminated in a sliding short-circuit, such as a Type 874-D20L stub. For maximum measuring convenience, the sliding short-circuit should be linked to the probe carriage, so that the position of the short circuit remains fixed (with respect to the carriage) as the carriage is moved along the slotted line. The linkage must allow the distance between the short-circuit and the carriage to be set, and locked, at an odd multiple of one-quarter wavelength.

The signal generator under test is set to the desired test frequency, and the probe tuner and the sliding short-circuit are both adjusted for maximum detected output, with the probe positioned near 30 cm on the line. Then, the linkage, if any, is locked. As the carriage and the short-circuit are moved in synchronism, the detected output will vary in accordance with the VSWR of the *signal generator.* That is, the detected output will vary not at all if the generator is a perfect match, will vary 2:1 if the VSWR of the generator is 2, etc.

It is not possible to place a short-circuit termination at the reference plane, for this would disconnect the signal source. However, the phase of the mismatch can be determined from the position of mini-

Figure 4-7. Measurement of source impedance.



mum on the slotted line and the frequency, with the phase nomograph of Figure 3-7. Then, the measurement may be plotted on the Smith chart, if desired.

4.8.2 GENERAL THEORY.

The incident wave and the first reflected wave normally cause the standing-wave pattern observed on a slotted line, as the probe moves along the slot. However, if the probe and a sliding load are moved in synchronism, as they are in this method, the standing-wave pattern resulting from the first reflected wave moves along with the carriage, and results in no variation in the probe output. Consequently, the VSWR of the load is apparently suppressed.

A second reflected wave, one that has traveled to the load, been reflected, traveled back to the source, and been re-reflected, also affects the system. The distance from the probe to the second reflection is not constant, so that it causes probe output to vary with changes in probe position. It can be shown that this variation corresponds to the VSWR pattern of a load impedance, on the right-hand end of the slotted line, identical to the source impedance of the generator.

4.8.3 REDUCTION OF MISMATCH EFFECTS ON SOURCE.

Care is necessary with some inadequately isolated signal sources. During the measurement, the source "sees" a purely reactive impedance of every possible value, yet it is required to change neither frequency nor impedance as a result. If the source cannot satisfy this requirement, an attenuator (such as the Type 874-G) may be inserted between the slotted line and the sliding short circuit. Insertion of the pad requires a correction in the measurement, however. Since it is much easier to correct for reflection-coefficient measurements than for those of VSWR, the reflection-coefficient procedures (refer to paragraph 3.5) are recommended. The reflection coefficient of the short circuit will be reduced by twice the attenuation of the pad, and the measured reflection coefficient must be divided by the reflection coefficient of the padded short circuit to find the actual reflection coefficient of the source. The reflection coefficient of the source can then be converted back to VSWR, if desired, by use of the nomograph of Figure 3-6.

For greater accuracy with the padded short circuit, measure its reflection coefficient (with the linkage disconnected) for four positions of the short circuit, at one-eighth-wavelength intervals, and average the readings. Divide the measured reflection coefficient of the source by the average reflection coefficient of the padded short circuit, before converting to VSWR.

EXAMPLE: Measure the source impedance of a Type 1218-A Unit Oscillator at 1.5 Gc. The test setup is shown in Figure 4-7.

(a) The unit-oscillator output is directly coupled, and with tight coupling it is possible for the slotted line to pull the frequency or alter the rf amplitude. Therefore, a 3-db pad (Type 874-G3L) must be inserted between the slotted line and the short circuit to reduce the mismatch, as seen by the source, to 3:1.

(b) The reflection coefficients of the short-circuited attenuator, measured at 4 positions of the short circuit 2.5 cm apart, are 0.50, 0.49, 0.50, and 0.51 (average 0.50).

(c) With the linkage connected between the short circuit and the carriage, the VSWR on the line is 2.5. The corresponding reflection coefficient is 0.43.

(d) Divide this by the above-determined 0.50 to obtain 0.86, the reflection coefficient of the source. The VSWR of the source is, therefore, 13.3.

4.9 OPERATION AT FREQUENCIES BELOW 300 MC.

Since the maximum probe travel of the Type 900-LB is 50 cm, it will not always be possible to measure both a voltage minimum and a voltage maximum on the line at frequencies below 300 Mc, as the range of travel of the probe is one-half wavelength at 300 Mc. If both a minimum and maximum do not appear on the the line, additional lengths of Type 900-L or -LZ air lines can be inserted between the line and the load until both a minimum and a maximum do appear (refer to paragraphs 4.5.2 and 5.2.2). Of course, if the VSWR is greater than 4, only the minimum need appear on the slotted section of line, because the measurement can conveniently be made by the width-of-minimum method (paragraph 3.3.4).

The tuner supplied with the Type 900-LB will not function below 300 Mc. However, the Type 874-D50L Adjustable Stub (not supplied), connected to the RF Probe Accessory, will tune the diode down to 150 Mc satisfactorily.

4.10 CONVERSION TO OTHER COAXIAL SERIES.

The Type 900-LB readily converts to General Radio Type 874 and to other leading coaxial-connector

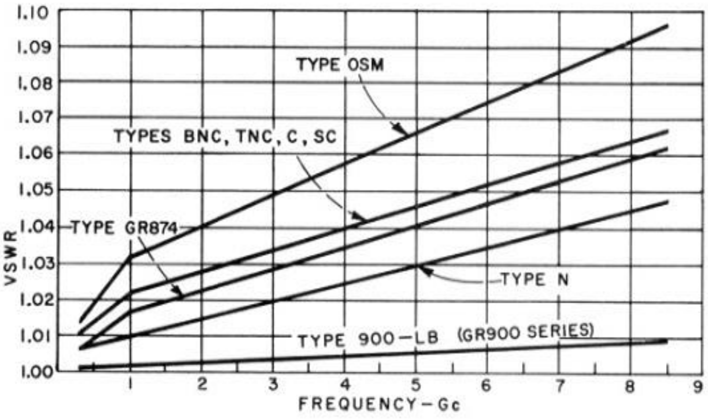


Figure 4-8. Residual VSWR specifications for Type 900-LB terminated in different GR900 adaptors.

series and gives superior performance in those line sizes. The conversion is performed quickly and inexpensively by the installation of an appropriate Type 900 adaptor on the Type 900-BT connector of the slotted line. Most performance specifications are unchanged by the conversion except for residual VSWR, which increases due to the inevitable discontinuities introduced by the nonprecision coaxial connector. The VSWR of the adaptor is minimized by the specially designed connectors which retain standard military connector mating dimensions.

4.10.1 TYPE 874.

The Type 900-Q874 adaptor transforms the Type 900-LB into a Type 874 slotted line with a residual VSWR of $1.001 + 0.016 \times f_{Gc}$ up to 1 Gc and of $1.011 + 0.006 \times f_{Gc}$ from 1 to 8.5 Gc, (the Type 874 connector is included).

The Type 900-Q874 Coaxial Adaptor comprises a Type 900-BT Precision Coaxial Connector and a Type 874-BBL Locking Coaxial Connector mounted on a short section of precision air line. This adaptor is intended to introduce minimum reflections, and, to this end, the Type 874-BL connector contains a fully compensated Type 874 support bead. The adaptor mates with both locking and nonlocking Type 874 connectors.

The residual VSWR characteristics for the Type 900-LB with the Type 900-Q874 adaptor is given in Figure 4-8. The electrical length of the adaptor is 6.50 ±0.04 cm, extending from the face of the Type 900-BT connector to the face of the bead in a *mating* Type 874-B (nonlocking) connector; see Figure 4-9. This is the same position at which the short circuit is applied when a Type 874-WN Short-Circuit Termination is employed to obtain a reference.

4.10.2 TYPE-N.

The Type 900-QNJ or -QNP Adaptors transform the Type 900-LB into a type-N male or female slotted line with a residual VSWR of $1.005 + 0.005 \times f_{Gc}$, including the type-N connector, as shown in Figure 4-8. The possible adverse effects on VSWR of the joining of standard type-N connectors to the converted slotted line should be borne in mind by those interested in precision measurements.

Each adaptor comprises a Type 900-BT Precision Coaxial Connector, specially designed continuous transition from the GR900 line size to the type-N line size, and a low-VSWR version of a type-N connector. The absence of any discrete discontinuities in the transition between the two line sizes is a unique feature of these adaptors.

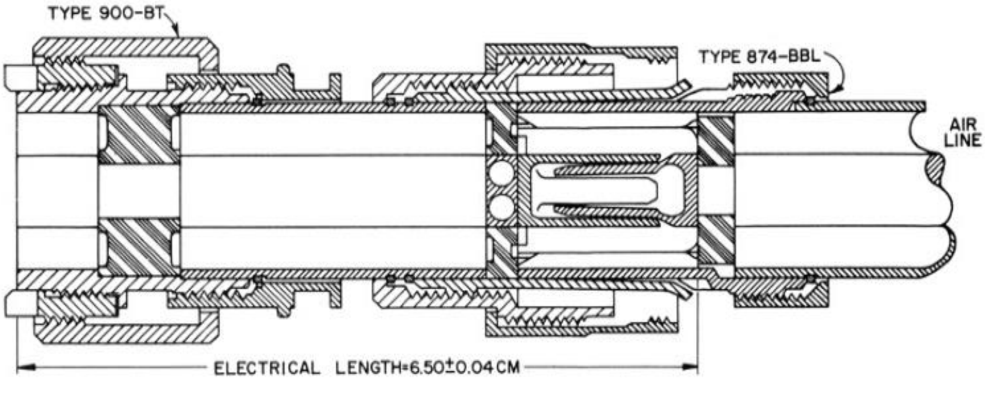


Figure 4-9. Electrical length of Type 900-Q874.

The low-VSWR version of the type-N connector is compatible with standard, military type-N connectors, and is recommended for measurements on components so equipped. However, in order to obtain minimum reflections from the type-N junction, it is recommended that the mating connector also be a low-VSWR version.

Both inner and outer contacts of the type-N connectors are made of hardened beryllium-copper (gold-plated) to provide good spring action, long wear, and good contact.

Low-VSWR Type-N Connectors. The General Radio low-VSWR type-N connectors are designed so that a mated pair introduces a minimum VSWR into a 50.0-ohm transmission line when a butt joint is achieved at both outer- and inner-conductor contacts. Since damage to the adaptor inner conductor or bead (or to some other adjacent part) could result if the type-N inner-conductor junction were to butt before the outer-conductor junction, a minimum gap of 0.002 inch is recommended at the inner-conductor junction, as shown in Figure 4-10. The inductance introduced by the gap in many instances can be neglected, or, by determination of gap size, the inductive effect can be taken into account in measurements made through the connector junction. The inductive effect normalized to 50.0 ohms is given approximately by

$$X_L = 0.070 \cdot f \cdot g \%$$

where X_L is the effect in percent, f is the frequency in Gc, and g is the gap in mils.

The effect of this gap in terms of VSWR is approximately 1.001 at 1 Gc, 1.004 at 3 Gc, and 1.013 at 9 Gc. A gap of less than 0.002 inch can be used if sufficient care is taken.

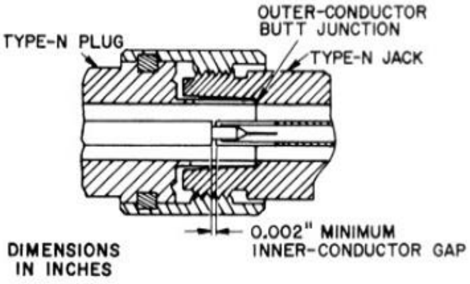


Figure 4-10. Recommended inner-conductor gap for a mated pair of low-VSWR version type-N connectors.

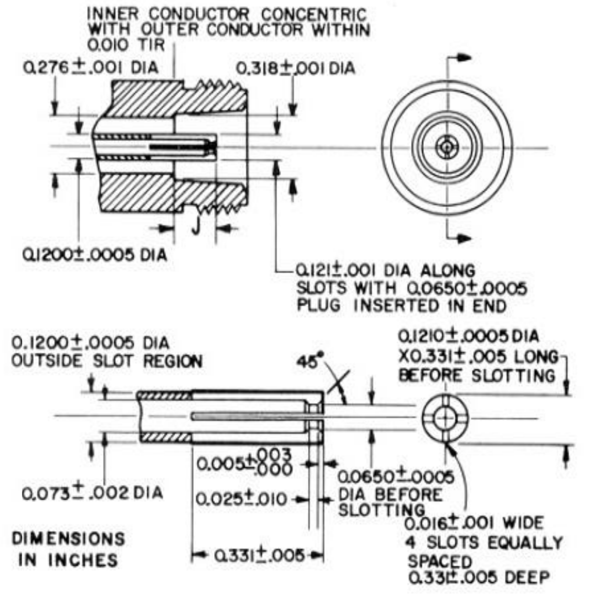


Figure 4-11. Recommended dimensions to mate Type 900-QNP Adaptor.

The specified VSWR of the adaptors is based on use with a mating, low-VSWR, type-N connector, and includes any residual reflections introduced by the Type 900-BT connector, the transition section, and the type-N section, up to the center of the gap.

To achieve a low-VSWR connection, both connectors that make up the type-N junction should be of optimum design. Recommended dimensions for a mating connector to be used with the Type 900-QNP Adaptor appear in Figure 4-11.

If the mating connector is made so that dimension "J" is $0.206^{+0.000}_{-0.003}$ inch, the gap at the inner-con-

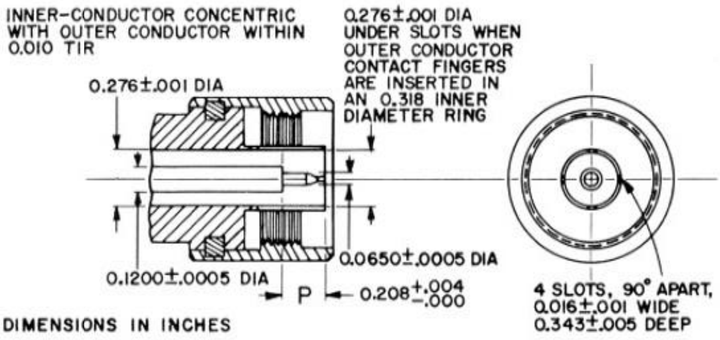


Figure 4-12. Recommended dimensions to mate Type 900-QNJ Adaptor.

Figure 4-13. Flange Adaptor for Type 900-BT.

ductor junction, when such a connector is mated with a Type 900-QNP Adaptor, should be between 0.002 and 0.009 inch.

Recommended dimensions for a mating connector to be used with the Type 900-QNJ Adaptor appear in Figure 4-12. If the mating connector is made so that dimension "P" is $0.208^{+0.004}_{-0.000}$ inch, the gap at the inner-conductor junction, when such a connector is mated with a Type 900-QNJ Adaptor, should be between 0.002 and 0.009 inch.

CAUTION

Dimension "J" must not be greater than 0.206 inch and dimension "P" must not be less than 0.208 inch, or excessive longitudinal forces can be exerted on the connector inner conductors.

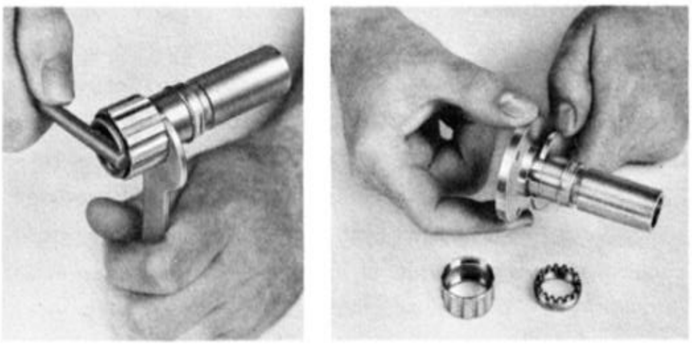


Figure 4-14. Adaption of Type 900-BT connector.

4.10.3 ADAPTATION TO FLANGE SYSTEMS.

To connect the Type 900-LB directly to a coaxial unknown that terminates in a flat, flush surface, such as a ground-plane antenna, the Adaptor Flange shown in Figure 4-13 (P/N 0900-9782) is recommended.

This general-purpose device converts the Type 900-BT connector on the slotted line to a flange connector by making use of the fact that the inner contact of the Type 900-BT works suitably against any flat surface, with no requirement for special, additional contacting devices or "bullets."

The adaptor consists of a gold-plated, circular, brass flange with three (no. 6 clearance) mounting holes. The mounting holes have a diameter of 0.157 inch, ±0.005 inch, and are set 120° ±0.5° apart on a radius of 0.812 inch, ±0.003 inch. The holes are arranged around a raised hub, which is threaded to mesh with the Type 900-BT outer conductor. The centering-gear-ring-and-locking-nut coupling system of the connector must be removed before the adaptor can be in-

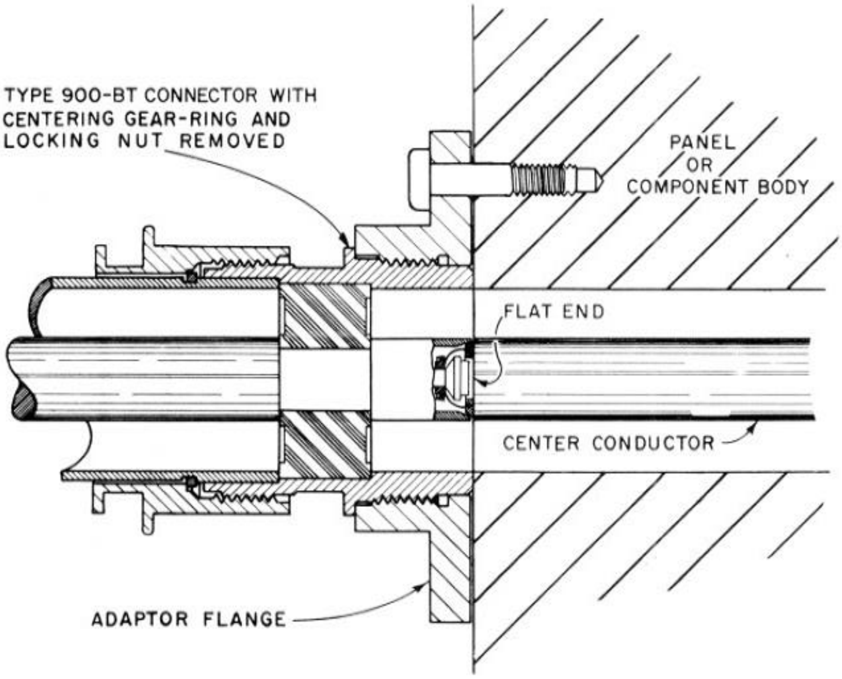


Figure 4-15. Flange adaptor on Type 900-BT connector.

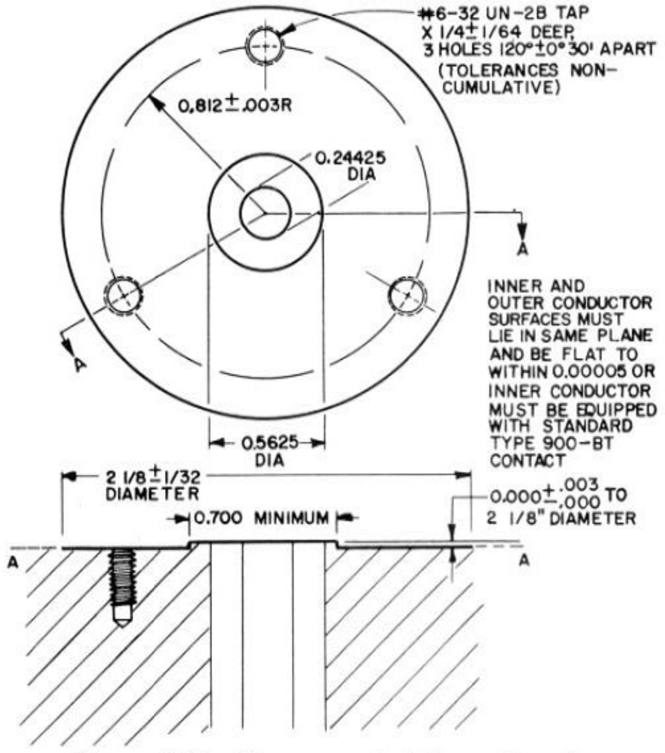


Figure 4-16. Recommended dimensions for surface to mate with Adaptor Flange.

stalled. Because of the unique design of the Type 900-BT, such a change can be made without altering the structural integrity or electrical characteristics of the connector, both of which are independent of the mechanical coupling method used.

To modify the Type 900-BT connector, use the Type 900-TOK Tool Kit, described in paragraph 7.11.1, and proceed as follows (see Figure 4-14):

a. Engage the gear-ring wrench in the centering-gear ring and slide the locking nut forward to expose the wrench flats on the connector outer conductor. Hold the outer conductor with the 11/16-inch open-end wrench and unscrew the gear ring from the connector. Remove the tools and slide the locking nut off.

b. Thread the Adaptor Flange on the connector, hub end first; tighten, while holding the outer conductor stationary with the open-end wrench. The outer conductor will protrude 0.002 inch beyond the flange surface.

The completed connection between the modified Type 900-BT representative flat-surfaced termination is shown in cross section in Figure 4-15. In such a junction, the mating outer conductors must be concentric within 0.002 inch TIR or performance will be significantly degraded. The inner conductors must be concentric within 0.005 inch, TIR (total indicated runout).

Dimensional information on the preparation of the mating surface to permit proper attachment of the Adaptor Flange is given in Figure 4-16.

4.10.4 OTHER ADAPTORS.

Plug- and jack-fitted GR900 adaptors to five other 50-ohm coaxial systems are also available which offer performance comparable to the adaptors to GR874 and type-N. They are listed in Table 4-2 and shown in Figure 4-17. The residual VSWR specifications of the Type 900-LBB terminated in these adaptors is shown in Figure 4-8. All possess uniquely designed, continuous, diametral transitions and are entirely free of step discontinuities. The plugs and jacks are special low-VSWR versions of the other-series connector, yet they are fully compatible with standard military designs when used for routine measurements not requiring the full precision capability of the Type 900-LB. The residual VSWR of most of the adaptors is less than 1.005 +0.015 × f_{Gc} to 1 Gc, and 1.015 +0.005 × f_{Gc} from 1 to 8.5 Gc. Refer to paragraph 3.4 for an indication of the effect on Type 900-LB measurement accuracy that a typical adaptor would have.

TABLE 4-2
ADDITIONAL GR900 ADAPTORS

Type	Contains GR900 and . .	Connects GR900 and . .
900-QBJ	BNC Jack	BNC Plug
900-QBP	BNC Plug	BNC Jack
900-QCJ	C Jack	C Plug
900-QCP	C Plug	C Jack
900-QTNJ	TNC Jack	TNC Plug
900-QTNP	TNC Plug	TNC Jack
900-QSCJ	SC Jack	SC Plug
900-QSCP	SC Plug	SC Jack
900-QMMJ	OSC Jack	OSC Plug
900-QMMP	OSC Plug	OSC Jack

Figure 4-17. Additional GR900 adaptors.

SECTION 5

CALIBRATION

5.1 INTRODUCTION.

The single electrical-performance characteristic of the Type 900-LB slotted line that may require exact determination by users interested in ultra-precise measurements is the "residual VSWR." Since each line typically has a residual VSWR of a few tenths of 1%, this must be taken into account and applied as a correction to VSWR measurements. Due to the ruggedness of construction and the nature of the built-in dimensional standards, the calibration of the instrument should remain stable indefinitely, unless the line is damaged or improperly disassembled.

This section describes special test equipment and accessories, available from General Radio, needed for this calibration. The procedures necessary for proper calibration of the slotted line in terms of residual VSWR are also given, along with a dicussion of the theory behind the technique.

5.2 CALIBRATION EQUIPMENT.

5.2.1 GENERAL.

The test setup required to perform the residual-VSWR calibration of the Type 900-LB is shown in Figure 5-1. All instruments and accessories have been described in Section 2, and appropriate operating procedures are given in Section 3. The parts peculiar to the calibration procedures will be described in subsequent paragraphs. They are the Type 900-LZ Refer-

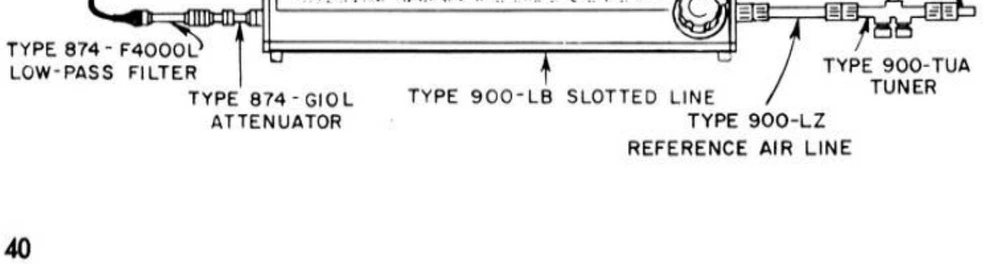


Figure 5-1. Typical calibration set-up for Type 900-LB.

ence Air Lines, the Type 900-TUA Tuner, and the Type 900-W50 Precision 50-Ohm Termination. All transmission-line elements are the same line size as the Type 900-LB and mate with Type 900-BT connectors.

5.2.2 REFERENCE AIR LINES (Figures 5-2 and 5-3).

A group of six reference air lines, Type 900-LZ5, LZ6, -LZ7H, -LZ10, -LZ15, and -LZ30, is available. These are beadless coaxial air lines, of the same inner- and outer-conductor diameters as the slotted line, equipped with GR900 coupling hardware. They are essentially reflectionless and possess a specified residual VSWR lower than that of the slotted line. Since bead supports are not used in these lines, even the minor discontinuities inevitably introduced by well-designed beads have been eliminated. By means of spring-loaded inserts at each end, the free inner conductor centers itself on the center-conductor contacts of the Type 900-BT connectors with which the line mates and takes its support from the beads in those connectors.

The Reference Air Lines come in six lengths ranging from 5 to 30 centimeters, as indicated in the digit suffix of each type-number designation (except Type 900-LZ7H, 7.5 cm). The lengths, measured between the contact surfaces of the outer conductors, are accurate to ±0.002 cm. The outer conductor ends are precisely finished so that they make a smooth butting contact with their counterparts on the Type 900-BT connectors.

The inner conductor is held to a tolerance of +0.000, -0.0006 inch of the outer-conductor length. Inner-conductor insert tips, although they project, are fully retractile, so that direct contact is made with the Type 900-BT center conductor. Except for the Type 900-BT coupling hardware, which threads directly on the outer conductor, there are no "connector" parts as such on these air lines, hence no discontinuities.

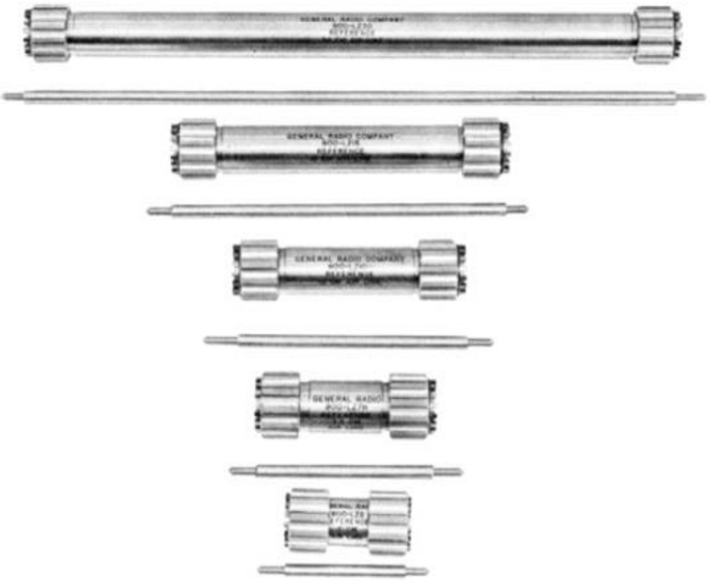


Figure 5-2. Type 900-LZ Reference Air Lines.

In this slotted-line application, the sole purpose of the air line is to obtain a precise odd-quarter-wave displacement for the termination, in order to invert the phase component of the load. Thus, as the physical lengths of the various lines are fixed, the calibration frequencies available with this technique are limited to 30 discrete values within the operating range of the slotted line. Table 5-1 provides a complete breakdown of these frequencies and shows the interrelationship of the entire group of Reference Air Lines. For users who require calibration at frequencies other than those appearing in Table 5-1, two courses of action are open. First, a beadless air line of appropriate length can be constructed from parts available from General Radio, which are described fully in paragraph 5.6. Or, the Reference Air Lines may be used to calibrate the line at the two closest frequencies on either side of the desired frequency and the desired calibration can then be interpolated.

In the Type 900-LZ series, the characteristic impedance of the air line, at frequencies where skin

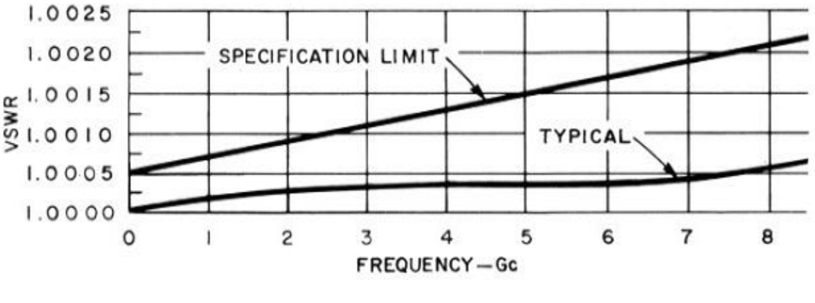


Figure 5-3. VSWR performance of Type 900-LZ Reference Air Lines.

FREQ Gc/s	ODD-QUARTERWAVE MULTIPLES					
	LZ5 (5 cm)	LZ6 (6 cm)	LZ7H (7.5 cm)	LZ10 (10 cm)	LZ15 (15 cm)	LZ30 (30 cm)
0.25						1
0.50					1	
0.75				1		3
1.00			1			
1.25		1				5
1.50	1				3	
1.75						7
2.25				3		9
2.50					5	
2.75						11
3.00			3			
3.25						13
3.50					7	
3.75		3		5		15
4.25						17
4.50	3				9	
4.75						19
5.00			5			
5.25				7		21
5.50					11	
5.75						23
6.25		5				25
6.50					13	
6.75				9		27
7.00			7			
7.25						29
7.50	5				15	
7.75						31
8.25				11		33
8.50					17	

depth is negligible, is 50 ± 0.0325 ohms, or ±0.065%. The skin-depth deviation in characteristic impedance as a function of frequency is shown in Figure 6-2.

The inner conductor, brass with a layer of silver approximately 0.001-inch thick, is ground to a finished diameter of 0.24425 inch, ±65 microinches. The outer conductor, also brass with a layer of silver on the inside approximately 0.002-inch thick, has an 0.830-inch outer diameter; the inner diameter is finished to 0.5625 inch, ±140 microinches. Both conductors are stress-relieved (to minimize diameter changes due to machining) and straightened.

In coaxial transmission-line systems, a section of uniform transmission line is ordinarily used as the impedance standard, since the absolute accuracy of the line's characteristic impedance is determined directly by the conductor diameters. In this application, the Type 900-LZ air line is used to calibrate the Type 900-LB with respect to the 50-ohm standard of impedance provided by the air line.

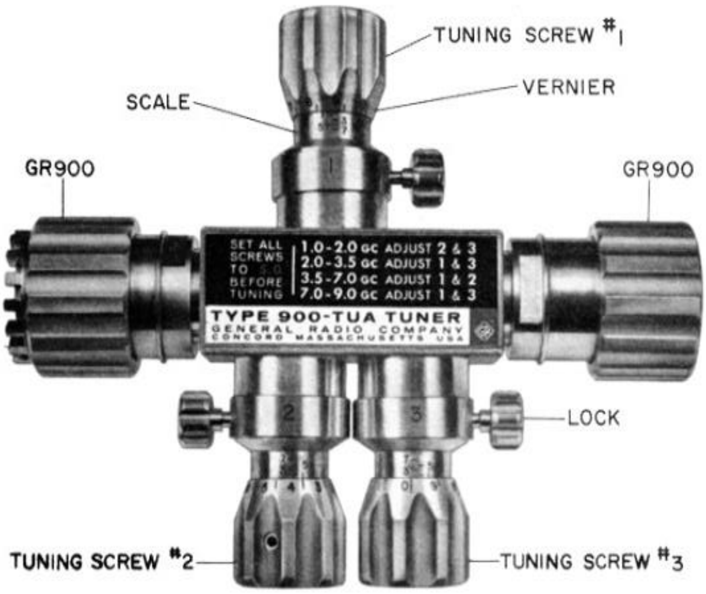


Figure 5-4. Type 900-TUA Precision Coaxial Tuner.

5.2.3 TUNERS.

Type 900-TUA. The Type 900-TUA Tuner is useful to match out residual reflections of rf terminations at frequencies between 1 and 8.5 Gc. This tuner comprises a section of nominally 50-ohm coaxial transmission line with three adjustable tuning screws, located asymmetrically along the line. The screws can be adjusted in and out with respect to a nominal position. Input and output connectors are Type 900-BT.

The tuning range of the Type 900-TUA Tuner is dependent on the phase of the reflection to be tuned out, relative to the location of the tuner in the test transmission line, and on the frequency of operation. The maximum VSWR that can be tuned out under all conditions of mismatch, phase, and frequency is given by:

$$\text{VSWR} = 1.00 + 0.012 \times f_{Gc} \qquad (5\text{-}1)$$

Only two screws are adjusted at any given frequency. The third screw is left in the nominal position, which is 5.00 on the scales.

The locations of the tuning screws and their locks are shown in Figure 5-4; the screws to be adjusted as a function of frequency are tabulated on the tuner. The locks, if partially made, permit friction driving of the tuning screws. If fully made, the locks provide long-term stability of adjustment and protection against accidental movement. The tuning screws have engraved scales reading from 1 to 8.

Type 900-TUB. The Type 900-TUB Tuner differs from the Type 900-TUA only in its frequency range: 0.25 to 2.5 Gc (refer to Appendix A for the specifications of both tuners).

5.2.4 TERMINATIONS.

Type 900-W50. The Type 900-W50 Precision 50-Ohm Termination (Figure 5-5) is a broadband device with low VSWR, useful from dc to 8.5 Gc. It comprises an accurately derived, continuous transition and a precision cylindrical 50-ohm resistor. The connector is a Type 900-BT. Typical VSWR characteristics are given in Figure 5-6. The change of resistance and VSWR vs heating due to incident power is negligible up to 1 watt.

Figure 5-5.
Type 900-W50 Termination.

Other terminations. The Types 900-W100 and -W200 are 100 Ω and 200 Ω standard terminations. The Types 900-WR110, -WR120, -WR150 standards mismatch introduce reflections of known VSWR (1.1, 1.2, 1.5) into a 50-Ω transmission line. (Refer to Appendix A.)

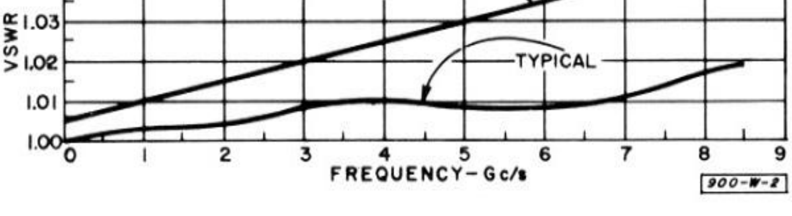


Figure 5-6. VSWR performance for Type 900-W50.

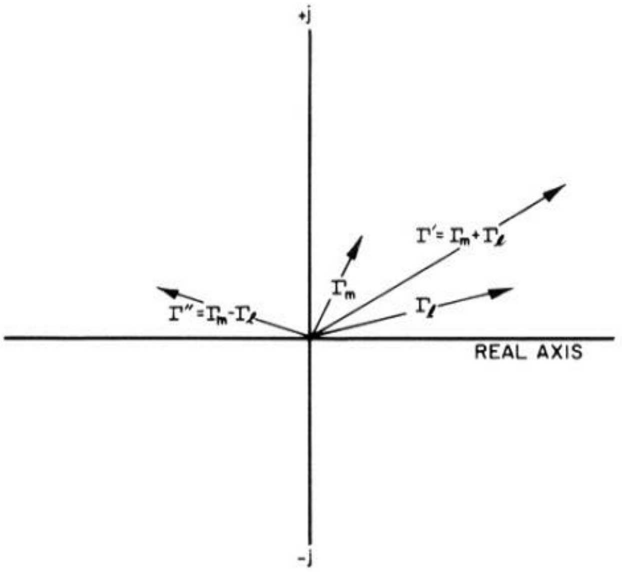


Figure 5-7. Vector relationships in the calibration of a slotted line and termination.

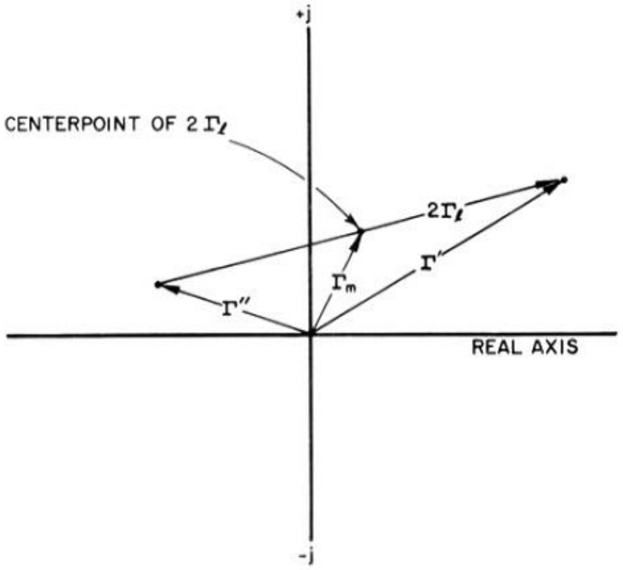


Figure 5-8. Smith-chart determination of Γ_m and Γ_ℓ from measured values of Γ' and Γ''.

5.3 CALIBRATION THEORY.

This calibration theory supports the technique for measurement of the residual VSWR of the slotted line. Residual VSWR is defined as the VSWR which the slotted line would indicate (falsely) if it could be terminated in a perfect 50-ohm match. This must not be confused with "flatness," described in paragraph 6.5.6. Residual VSWR is a vector quantity, and must be measured in both magnitude *and* phase, if the calibration is to be used to correct measurements. The residual VSWR as a function of frequency is usually plotted on the Smith chart, to facilitate its use in the correction of measured Smith-chart data.

In order to carry out the calibration of an instrument, it is always necessary to have something of much higher accuracy than the instrument as a reference standard for comparison. In the calibration of the Type 900-LB Precision Slotted Line, this function is served by the Type 900-LZ Reference Air Lines.

The technique used to compare the slotted line with the reference air line is most easily explained with the reflection-coefficient vectors, as plotted on the Smith chart of Figure 5-7. All measured points are so plotted and the reflection coefficients of the slotted line and the termination can then be deduced from simple graphical constructions on the Smith chart. Explanation in terms of residual VSWR directly is not possible because VSWR is a <u>scalar</u> quantity and the explanation involves <u>vector</u> relationships between slotted-line and termination errors.

Assume a slotted line with a residual reflection coefficient of Γ_m, terminated in a nominal 50-ohm termination with a reflection coefficient of Γ_ℓ. A direct measurement of the termination on this measuring instrument will yield a reflection coefficient, Γ', equal to the sum of these two vectors.

$$\Gamma' = \Gamma_m + \Gamma_\ell \tag{5-2}$$

Now, assume that a section of reference air line, an odd quarter-wavelength long, is inserted between the measuring instrument and the termination. The reflection coefficient of the termination is inverted on the Smith chart by the action of the reference air line. This is equivalent to changing the sign of Γ_ℓ from plus to minus. The measuring instrument will now indicate a reflection coefficient, Γ'':

$$\Gamma'' = \Gamma_m - \Gamma_\ell \tag{5-3}$$

The two equations for Γ' and Γ'' can be solved as simultaneous equations for Γ_m and Γ_ℓ as follows:

$$\Gamma_m = \frac{\Gamma' + \Gamma''}{2} \tag{5-4}$$

$$\Gamma_\ell = \frac{\Gamma' - \Gamma''}{2} \tag{5-5}$$

Thus, the error in the measuring instrument, Γ_m, and the error in the termination, Γ_ℓ, can be calculated from two measurements made with an odd-quarter-wavelength reference air line, even though neither can be measured explicitly.

The indicated operations are most easily carried out on the Smith chart as shown in Figure 5-8.

The measured vectors, Γ' and Γ'', are plotted in the Smith chart. The vector from the tip of Γ'' to the tip of Γ' equals $2\Gamma_\ell$ (equation 5-5) while a vector from the center of the Smith chart to the center of the $2\Gamma_\ell$ vector equals Γ_m (equation 5-4).

The addition of the Type 900 two-port tuner simplifies these measurements considerably and increases the accuracy of the calibration, especially the calibration of a small Γ_m in the presence of a relatively large Γ_ℓ. The tuner is inserted between the measuring instrument and the termination and is adjusted to make Γ' equal to zero. The reference air line is then inserted between the measuring instrument and the tuner, and the measurement of Γ'' is made. Substituting $\Gamma' = 0$ in the equation for Γ_m we have:

$$\Gamma_m = \frac{\Gamma''}{2} \qquad (5\text{-}6)$$

Note that no calculation is necessary with the composite termination, and the quantity to be measured, Γ_m, is effectively doubled, increasing the resolution by a factor of two.

A similar technique can be used to calibrate terminations. After setting $\Gamma' = 0$ with the tuner, insert the reference air line between the tuner and the termination. Then we have:

$$\Gamma_\ell = -\frac{\Gamma''}{2} \qquad (5\text{-}7)$$

A typical calibration curve of a Type 900-LB slotted line, taken with a Type 900-LZ15, 15-cm Reference Air Line, is shown in Figure 5-10. The 15-cm reference air line is one-quarter wavelength long at 0.5 Gc, etc., so that the calibration can be made at intervals of 1.0 Gc from 0.5 Gc to 8.5 Gc (refer to Table 5-1). With a slowly changing function such as this, interpolation between measured calibration points is valid. However, calibration at other frequencies can be made if desired, with the other Type 900-LZ Reference Air Lines, or a special-length of reference air line made from the rod and tubing, as described in paragraph 5.6.

5.4 CALIBRATION PROCEDURE.

5.4.1 GENERAL.

The calibration system shown in Figure 5-1 should be assembled. The VSWR meter must be stable and must present an expanded scale that can be resolved to at least 1.005.

5.4.2 TYPE 1640-A SLOTTED LINE RECORDER SYSTEM.

The most convenient system available for such a calibration procedure is the Type 1640-A Slotted Line Recorder System described fully in paragraph 3.12. This system is capable of resolution to 1.0005, or approximately ten times better than a VSWR meter. Furthermore, calibration corrections of measured data (including phase information) can be very accurately and easily applied on the strip-chart record of the system.

5.4.3 PRELIMINARY ADJUSTMENTS.

The signal source used must be stable, and its dial accuracy must be reliable within ±1%. Refer to Section 2 for suggested General Radio oscillators and coaxial accessories.

5.4.4 PROCEDURES.

The calibration procedures are as follows:

a. Make a composite termination (which will be the final matched termination) by connection of a Type 900-TUA (-TUB) Tuner to the Type 900-W50.

b. Attach this composite termination directly to the slotted line's Type 900-BT connector.

NOTE

Position the tuner so that all three scales can be read and all three tuning screws adjusted easily. Adjust the tuning-screw locks so that an easy but firm drive of the tuning screws results.

c. Set all three tuning screws of the Type 900-TUA (-TUB) to 5.00.

d. Lock the tuning screw that is to remain stationary at the calibration frequency, according to the table printed on the device.

e. Alternately adjust the remaining two tuning screws to eliminate all standing waves on the slotted line, as the probe carriage is moved over two or more wavelengths.

f. Remove the tuner-termination assembly and install the appropriate Type 900-LZ (see Table 5-1) between it and the slotted line.

g. Observe the new reading of the VSWR meter; call this S.

h. Calculate the residual VSWR of the slotted line, S_m, from

$$S_m = 1 + \frac{S-1}{2}$$

i. Measure the position of the first minimum on the slotted line. Use the phase nomograph (Figure 3-7), with this position-of-minimum and frequency data, to determine the phase of the residual VSWR for the Smith-chart plot.

NOTE

For greater phase accuracy, remove the composite termination, short-circuit the line with the Type 900-WN and measure the position of the nearest minimum to the left of the "unknown" minimum. Divide the distance (in cm) between minima by the wavelength (in cm), to find the position on the "WAVELENGTHS TOWARD GENERATOR" scale.

5.5 CORRECTION OF MEASURED DATA FOR SLOTTED-LINE ERROR.

5.5.1 GENERAL.

The calibration data obtained in paragraph 5.4 can be used to correct measured data for the effect of the slotted-line residual reflection coefficient (or residual VSWR) by the procedures described below. The slotted-line calibration and the measurement are both vector quantities, and the correction procedure is more than a simple addition or subtraction of the correction data. In general, the correction requires the solution of vector relationships involving the residual reflection coefficient of the slotted line, plus the measured and the true reflection coefficients of the unknown. However, the residual reflection coefficient of the Type 900-LB Precision Slotted Line is so small that important simplifications of the equations are possible, which lead to relatively simple forms of the correction equations. In special cases of very low or very high unknown reflection coefficients, further simplifications can be made and these special cases are treated separately.

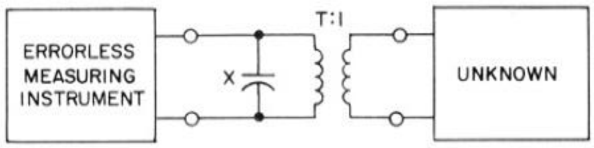


Figure 5-9. Equivalent circuit for slotted-line error.

In the following, the error of the slotted line will be expressed as the residual reflection coefficient, Γ, and the unknown will also be expressed in terms of reflection coefficient. This notation leads to the most straightforward correction procedures, and the results can be converted to VSWR, impedance or admittance if desired, with the following formulas,

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (5\text{-}8)$$

$$Z = 50\,\frac{1+\Gamma}{1-\Gamma}\ \text{ohms.} \qquad (5\text{-}9)$$

$$Y = 0.020\,\frac{1-\Gamma}{1+\Gamma}\ \text{mhos.} \qquad (5\text{-}10)$$

5.5.2 THEORY.

Equivalent Circuit. It has been shown that a slotted line with error can be represented by an errorless slotted line plus an equivalent circuit[1], which is assumed to be of zero electrical length and placed at the reference plane of the slotted line, as shown in Figure 5-9. The turns ratio of the equivalent transformer is called T and X is a positive or negative equivalent reactance in shunt with the primary of the equivalent transformer.

This equivalent circuit is chosen because the short-circuit termination is used to calibrate the slotted line, and this particular equivalent circuit has a short-circuit input impedance for a short-circuited output. The turns ratio of the equivalent transformer and the equivalent shunt reactance can both be determined from a single measurement of the input impedance of the circuit as seen terminated with a matched load. Therefore, the equivalent circuit of the slotted line is completely specified by the calibration procedures of paragraph 5.4, which yield the reflection coefficient for a perfectly matched load with a short-circuit termination as the phase reference.

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[1] H. V. Shurmer, "Transformation on the Smith Chart of Lossless Junctions," Proc. IEE, Vol 105, Part C No. 7, March 1958, pp 172-182.

Both T and X can be expressed simply in terms of the residual reflection coefficient of the slotted line:

$$\Gamma_m = \rho e^{j\theta} \tag{5-11}$$

$$T = 1 + \rho\cos\theta \tag{5-12}$$

$$X = \frac{Z_o}{2\rho\sin\theta} = \frac{25}{\rho\sin\theta} \text{ ohms} \tag{5-13}$$

where ρ = magnitude of the reflection coefficient of the slotted line

θ = phase angle of reflection coefficient of the slotted line

Scattering Coefficients. The relation between the true reflection coefficient of the unknown, Γ_x, and the reflection coefficient measured on the slotted line, Γ'_x, can be expressed in terms of the scattering coefficients:[2]

$$\Gamma'_x = s_{11} + \frac{s_{12}{}^2\,\Gamma_x}{1 - s_{22}\,\Gamma_x} \tag{5-14}$$

where s_{11}, s_{12}, and s_{22} are the scattering coefficients of the equivalent circuit and, owing to reciprocity, $s_{21} = s_{12}$. The definitions of the scattering coefficients are

s_{11} = input reflection coefficient with output matched

s_{22} = output reflection coefficient with input matched

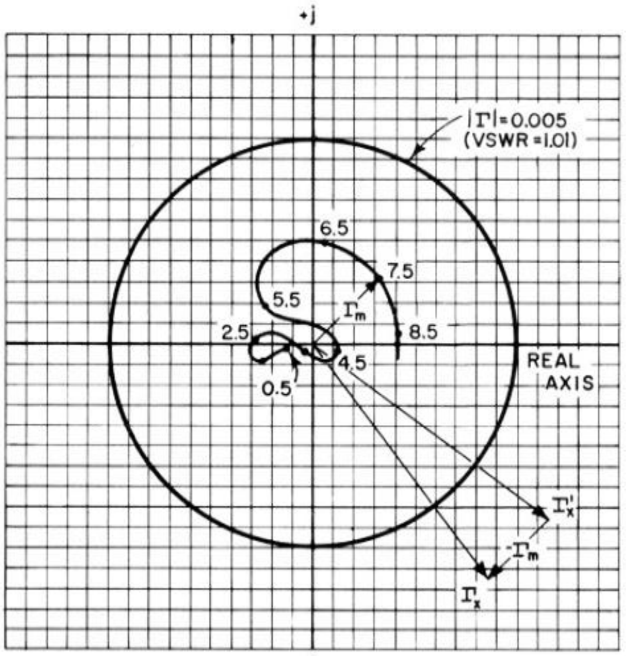

Figure 5-10. Calibration data typical of a Type 900-LB as a function of frequency from 0.5 to 8.5 Gc, calibrated with a Type 900-LZ15 Reference Air Line.

s_{12} = transmission coefficient between matched source and matched load.

The above relation can be solved for Γ in terms of Γ_x, to obtain the relation required for the correction of measured values:

$$\Gamma_x = \frac{\Gamma'_x - s_{11}}{s_{12}{}^2 - s_{22}\,\Gamma'_x - s_{11}s_{22}} \tag{5-15}$$

The scattering coefficients of the equivalent circuit can be written with the aid of the above definitions. Terms in ρ^2 can be neglected since $\rho < 0.005$ with the slotted line.

$$s_{11} = \rho e^{j\theta} \tag{5-16}$$

$$s_{22} = -\rho e^{-j\theta} \tag{5-17}$$

$$s_{12} = e^{j\rho\sin\theta} \tag{5-18}$$

Correction Formulas. The desired correction formulas can now be derived by insertion of the scattering coefficient into the equation for Γ_x, and elimination of all terms in ρ^2.

In Cartesian coordinates:

$$\Gamma_x = \frac{\sigma\cos\phi - \rho\cos\theta + j(\sigma\sin\phi - \rho\sin\theta)}{1 - \sigma\rho\cos(\phi - \theta) + j\left[2\rho\sin\theta - \sigma\rho\sin(\phi - \theta)\right]} \tag{5-19}$$

where

σ = magnitude of Γ'_x

ϕ = phase of Γ'_x

ρ = magnitude of Γ_m

θ = phase of Γ_m

This equation is the general formula for correction of measured reflection coefficients to true reflection coefficients, under the condition that ρ^2 is negligible.

The general equation can be simplified considerably for certain special cases.

Case 1 $|\Gamma'_x| < 0.05$ (VSWR < 1.1)

When the magnitude of the unknown reflection coefficient is small, terms in $\sigma\rho$ became negligible, and the equation for Γ_x becomes:

$$\Gamma_x = \sigma\cos\phi - \rho\cos\theta - j(\sigma\sin\phi - \rho\sin\theta) \tag{5-20}$$

$$= \Gamma'_x - \Gamma_m \tag{5-21}$$

The correction reduces to the simple vector subtraction of the slotted-line error from the measured reflection coefficient. This is the most important case requiring correction with the Type 900-LB because the correction is usually not trivial. The calibration curve for the slotted line is shown in Figure 5-10.

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[2] G. A. Deschamps, "Determination of the Reflection Coefficients and Insertion Loss of a Waveguide Junction," Journal of Applied Physics, Vol 24, August 1953, pp 1046-1050.

A typical measurement at 7.5 Gc, and its correction for slotted-line error, are shown in the lower right-hand quadrant. The slotted-line residual reflection coefficient, Γ_m, is 0.0016 + j 0.0015, and the measured reflection coefficient of the unknown, Γ'_x, is 0.0058 - j 0.0043. The true reflection coefficient of the unknown, Γ_x, is therefore the difference, 0.0042 - j 0.0058.

Case 2 $|\Gamma'_x| > 0.95$ (VSWR > 40)

When the magnitude of the unknown reflection coefficient approaches 1, as in most dielectric-constant measurements, we can rewrite equation 5-19, ignoring terms in $\rho(1 - \sigma)$.

$$\Gamma_x = \Gamma'_x \; e^{j2\rho[\sin(\phi - \theta) - \sin\theta]} \qquad (5\text{-}22)$$

The main effect of the correction is to change the phase of the unknown reflection coefficient; the change in amplitude is negligible. The amount of the phase shift depends upon the phase angles of the reflection coefficients of both the slotted line and the unknown, as would be expected. The value of the exponent in equation 5-22 won't exceed 0.02 radian with the Type 900-LB Precision Slotted Line; thus, the angular correction can never exceed 1.2°.

5.5.3 EXAMPLES.

EXAMPLE 1 - General Case.

At 4 Gc, the residual reflection coefficient of the slotted line is $0.002 \angle +30°$, and the measured reflection coefficient of the unknown is $0.50 \angle +60°$ as in paragraph 3.6. What is the true reflection coefficient of the unknown?

Solution. Use equation 5-19 of the preceding section.

$$\sigma = 0.50, \quad \phi = +60°$$
$$\rho = 0.002, \quad \theta = +30°$$

$$\Gamma_x = \frac{0.5 \times 0.5 - 0.002 \times 0.8660 + j(0.5 \times 0.8660 - 0.002 \times 0.5)}{1 - 0.001 \times 0.8660 + j(0.004 \times 0.5 - 0.001 \times 0.5)}$$

$$\Gamma_x = 0.4987 \angle +60°$$

In this particular case, the correction happens to be in magnitude only, but of course both phase and magnitude corrections usually occur. It is obvious from the small size of the above correction that an extremely accurate measurement of Γ'_x is necessary, in order for the correction to be worthwhile.

EXAMPLE 2 - Small Γ'_x.

At 4 Gc, the residual reflection coefficient of the slotted line is $0.002 \angle +30°$. The measured reflection coefficient of a Type 900-W50 50-Ohm Standard Termination is $0.010 \angle +120°$. What is the true reflection coefficient of this termination?

Solution. Use equation 5-20 of the preceding section.

$$\sigma = 0.010, \quad \phi = +120°$$
$$\rho = 0.002, \quad \theta = +30°$$

$$\Gamma_x = 0.010(-0.5) - 0.002 \times 0.8660 + j(0.010 \times 0.8660 - 0.002 \times 0.5)$$
$$= 0.0102 \angle +131°$$

Note that the correction can have a substantial effect on both the magnitude and phase of the measured reflection coefficient for small unknowns.

EXAMPLE 3 - Large Γ'_x.

At 4 Gc, the residual reflection coefficient of the slotted line is $0.002 \angle +30°$. The uncorrected reflection coefficient of the unknown is $0.99 \angle -60°$. What is the true reflection coefficient of the unknown?

Solution. Use equation 5-22 of the preceding section.

$$\sigma = 0.99, \quad \phi = -60°$$
$$\rho = 0.002, \quad \theta = +30°$$

$$\Gamma_x = \Gamma'_x \; e^{j2 \times 0.002[\sin(-60° - 30°) - \sin 30°]}$$
$$= 0.99 \angle -60° + (-0.34°)$$
$$= 0.99 \angle -60.34°$$

It is apparent again that a very accurate measurement of the phase of the initial reflection coefficient is necessary, in order for the correction to have practical value. The Micrometer Drive Assembly is recommended for this measurement, with commercially available length standards as necessary to increase the range of the micrometer travel.

5.6 CALIBRATION AT SPECIFIC FREQUENCIES.

5.6.1 CUSTOM AIR-LINE CONSTRUCTION.

If it is necessary to calibrate the slotted line at frequencies other than those compatible with the Type 900-LZ Reference Air Lines (refer to Table 5-1), an appropriate reference air line can be constructed from parts available from General Radio.

The principal elements will be the Precision Rod (P/N 0900-9508) and Precision Tubing (P/N 0900-9509), which form the basic coaxial inner and outer conductors, respectively. These items are intended for use with GR900 connectors in the fabrication of custom air lines which require precise diameter, excellent surface finish, and low-loss characteristic in material of appreciable length. Rod and tubing, supplied in 27-inch lengths specially packed to retard tarnish, offer the same critical surface dimensions and finish as the Reference Air Line (paragraph 5.2.2).

The characteristic impedance of a transmission line made of this material, at frequencies where skin depth is negligible, is 50 ±0.0325 ohms, or ±0.065%. The skin-depth deviation in characteristic impedance as a function of frequency is shown in Figure 6-2.

There is a practical limit (11.8 in. or 30 cm) to the length of the precision air line that can be made of this material, because of inner-conductor sag. For instance, the characteristic-impedance error for an incremental section whose center conductor is 0.005 inch off center is 0.046%, and the error increases exponentially as the length increases (refer to the graph of Figure 5-11).

To determine the finished length of air line, calculate the quarter wavelength at the desired test frequency. Multiply this distance by an odd integer to obtain a figure greater than 5.0 cm. Cut and trim the rod and tubing to this length. Strict adherence to dimensional tolerances is important to high-precision performance.

5.6.2 RECOMMENDED MACHINING TECHNIQUES.

NOTE

In trimming the rod, bear in mind that the front face must lie in the same plane as the tubing, +0.0000, -0.0005, when they are mounted in the coaxial device.

Inner-Conductor Rod. In order to minimize diameter changes due to machining, the following procedures should be employed:

a. Trim to length. Make all cuts from the outside surface towards the center of the rod, never in the reverse direction, or the surface plating may lift at the cut edge and significantly degrade electrical performance in precision applications. The cut edge should be sharp and true.

b. Machine the insert hole (see Figure 5-12).

(1) Drill a hole, $0.110^{+0.002}_{-0.000}$ inch in diameter, $31/32^{+0}_{-1/64}$ inch deep.

(2) Bore $0.140^{+0.001}_{-0.000}$ inch diameter, 29/32

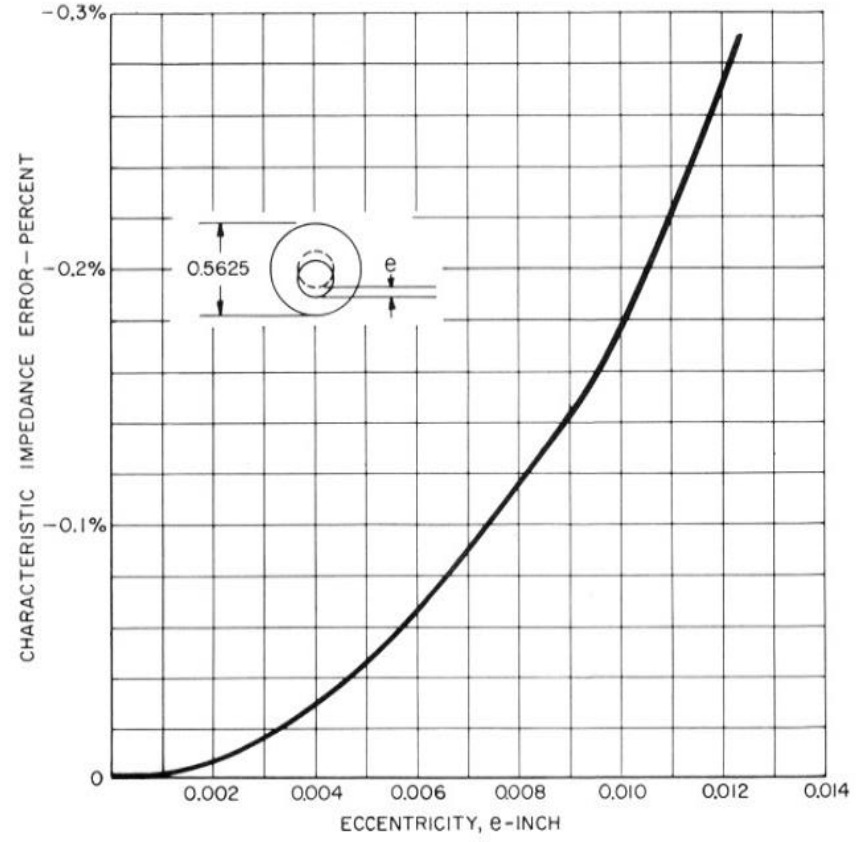


Figure 5-11. Characteristic-impedance error vs sag in inner conductor.

±1/64 inch deep, and observe concentricity with OD to within 0.001 TIR (Total Indicated Runout).

Outer-Conductor. In order to minimize diameter changes, the following machining procedures should be employed:

a. Trim to length. Make all final cuts from the inside diameter outwards, never in the reverse direction, or the plating on the inner diameter may lift at the cut edge and significantly degrade electrical performance in precision applications. The cut edge should be sharp and true.

b. Turn down the outer diameter to the dimensions shown in Figure 5-12, as follows:

(1) Set the lathe to turn at approximately 2000 rpm.

(2) Limit the cut to 6 mils.

(3) Use a light cutting pressure and no lubrication.

(4) Chase the 3/4-27NS-2A threads with a single-point tool.

5.6.3 SURFACE PROTECTION.

The silver lining on the inner conductor and on the inner surface of the outer conductor may tarnish and increase loss at microwave frequencies. To retard this effect, it is recommended that a gold flashing of from 4 to 10 microinches in thickness be applied. However, precautions must be taken to prevent excessive buildup.

5.6.4 ASSEMBLY.

Use the Type 900-AP Air Line Connector Kit to complete the test section. The kit consists of the following parts (sufficient for one end):

1. GR900 locking nut - P/N 0900-6030
2. GR900 centering-gear-ring nut - P/N 0900-2090
3. Centering pin - P/N 0900-6565
4. Inner-contact spring - P/N 0900-6560

The procedure is as follows:

a. Slide the locking nut (unthreaded end first) over the end of the outer conductor, back far enough to expose the threads.

b. Screw the centering-gear-ring nut on the exposed threads.

c. Tighten the gear ring to 3 foot pounds; the special wrench of the Type 900-TOK Tool Kit (P/N 0900-1035) is recommended.

d. Thread the locking nut out over the gear-ring nut.

e. Insert the spring and centering pin and bottom the assembly to seat it.

CAUTION

Do not scratch the inner surface of the outer conductor or the outer surface of the inner conductor, or there is danger of introducing electrical reflections which would degrade performance.

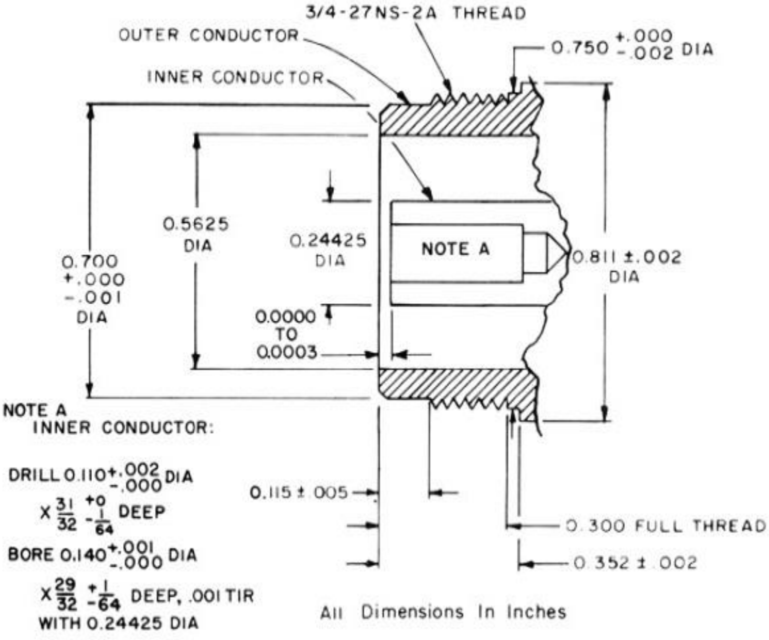


Figure 5-12. Machining dimensions.

SECTION **6**

PRINCIPLES OF OPERATION

6.1 TRANSMISSION LINE CHARACTERISTICS.

6.1.1 CHARACTERISTIC IMPEDANCE.

A coaxial transmission line has uniformly distributed inductance and capacitance, as shown in Figure 6-1. The series resistance due to conductor losses and the shunt resistance due to dielectric losses are also uniformly distributed. The square root of the ratio of the inductance-per-unit-length, L, to the capacitance-per-unit-length, C, is defined as the characteristic impedance, Z_o, of the line.

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \sqrt{\frac{L}{C} \times \frac{1 - j\frac{R}{\omega L}}{1 - j\frac{G}{\omega C}}}$$

where:

L = the inductance-per-unit-length in henrys,
C = the capacitance-per-unit-length in farads,
R = the series-resistance-per-unit-length in ohms, and
G = the shunt-conductance-per-unit-length in mhos.

When line losses are low (or when $\frac{R}{L} = \frac{G}{C}$) and the rf skin effect depth is much smaller than the diameter tolerances, the following approximation is valid:

$$Z_o \cong \sqrt{\frac{L}{C}}$$

As frequency decreases, the path of the average current flow tends to move away from the surfaces of the conductors. It moves toward the center of the inner conductor and away from the inner surface of the outer conductor. Thus, the effective diameters are shifted (in opposite directions), thereby causing a slight increase in the ratio which determines the characteristic impedance. The extent of this shift varies with the material used for the conductors and is least with a

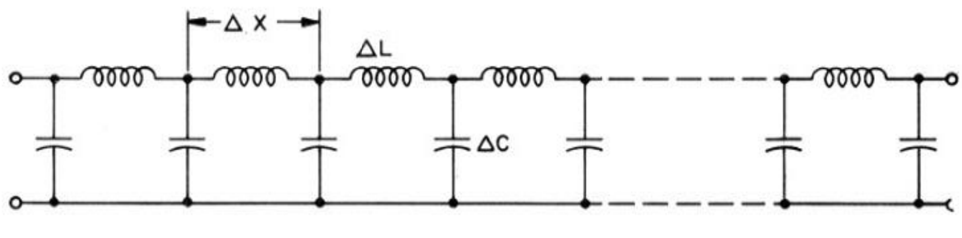


Figure 6-1. Distribution of inductance and capacitance along a transmission line.

conductor such as silver. In silver this effect is enough to cause a change of 0.1% at 100 Mc; see Figure 6-2.

The characteristic impedance of a coaxial line derives directly from the diameters of the conductors, the ratio that these diameters bear to one another, their respective concentricity, and the dielectric constant of the medium separating them. Thus, for concentric coaxial lines in general, the expression is:

$$Z = \frac{A}{\sqrt{\epsilon}} \log_e \frac{a}{b}$$

where:

a = inner diameter of outer conductor

b = outer diameter of inner conductor

ϵ = dielectric constant

$A = \frac{2c}{10^9} = 59.9585$

c = velocity of light, cm/sec

The dielectric constant of air under standard laboratory conditions is 1.0007.

The General Radio Type 900 precision coaxial line is built around a standard-diameter rigid air line with a characteristic impedance of 50 ohms (±0.1%), in which:

a = 0.5625 ±0.0002 inch.

b = 0.24425 ±0.0001 inch.

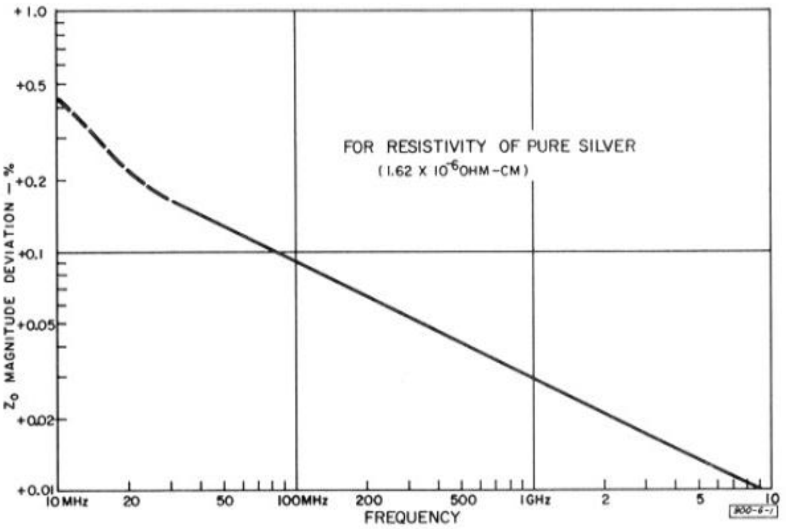


Figure 6-2. Skin-effect error as a function of frequency.

The accuracy of the characteristic impedance, therefore, is controlled by the precision with which the inner and outer conductors can be machined. Furthermore, the constancy of impedance depends in turn upon the ability of the fabrication process to maintain uniform size and to preserve straightness throughout, since deviations result in impedance variations.

The uniformity of the impedance along the line is also dependent upon the concentricity of the conductors. An important factor bearing upon this consideration is sag occurring in the center conductor. The characteristic impedance of a coaxial transmission line with an eccentric inner conductor is given by the following:

$$Z_o = \frac{A}{\sqrt{\epsilon}} \cosh^{-1}\left[\frac{b}{2a}\left(1 - 4\frac{e^2}{b^2}\right) + \frac{a}{2b}\right],$$

where:

e = amount of eccentricity of the center conductor.

Control of eccentricity within a few thousandths is required to keep the Z_o error below 0.1% (see Figure 5-11).

6.1.2 WAVE PROPAGATION.

As with all transmission-line types, the purpose of coaxial line is to carry energy from a source to a load. The efficiency with which it performs this function at uhf and above is dependent upon (among other things) the mode in which it propagates electromagnetic-wave energy. Such modes of propagation can best be described in terms of their electrical and magnetic field patterns within the line.

A coaxial transmission line may provide the means for more than a single mode of propagation. Commonly, the dominant mode is that in which both electrical and magnetic field components of the wave lie entirely in planes transverse to the direction of propagation (see Figure 6-3). The wave is therefore called a transverse electromagnetic (TEM) wave. There is no longitudinal component of the field in this mode, as in rectangular waveguide. Thus, this mode is broadband and has no cutoff frequency.

6.1.3 VELOCITY OF PROPAGATION.

In subsequent paragraphs, transmission-line behavior will be discussed in terms of electromagnetic waves propagating along the line. The waves travel with a velocity, v, which depends on L and C in the following manner:

$$v = \frac{1}{\sqrt{LC}}$$

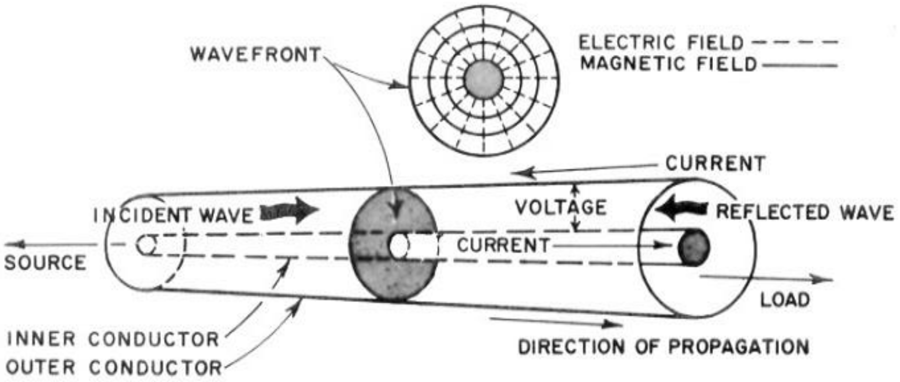


Figure 6-3. TEM-mode field pattern in coaxial transmission line.

In an evacuated line, the dielectric constant is unity and the velocity of propagation is equal to the velocity of light, c, (2.997925×10^{10} cm/sec). If the effective dielectric constant, ϵ, is greater than unity, the velocity of propagation will be the velocity of light divided by the square root of the effective dielectric constant.

$$v = \frac{c}{\sqrt{\epsilon}}$$

The relationship between frequency, f, and wavelength, λ, in the transmission line, if the dielectric is air, is

$$\lambda = \frac{2.99687 \times 10^{10}}{f} \text{ cm/sec}$$

if λ is in centimeters and f is in cycles per second.

6.1.4 TRAVELING AND STANDING WAVES.

The performance of a transmission line having a uniform characteristic impedance can be explained in terms of the behavior of the electromagnetic wave that travels along the line from the generator to the load, where all or a portion of it may be reflected, with or without a change in phase, as shown in Figure 6-4. The reflected wave travels in the opposite direction along the line, back toward the generator. The phases of these waves are retarded linearly 360° for each wavelength traveled.

The wave traveling from the generator is called the incident wave, and the wave traveling toward the generator is called the reflected wave. The combination of these two traveling waves produces a stationary interference pattern which is called a standing wave. The maximum amplitude of the standing wave occurs when the incident and reflected waves are in phase or when they are an integral multiple of 360° out of phase. The minimum amplitude occurs when the two

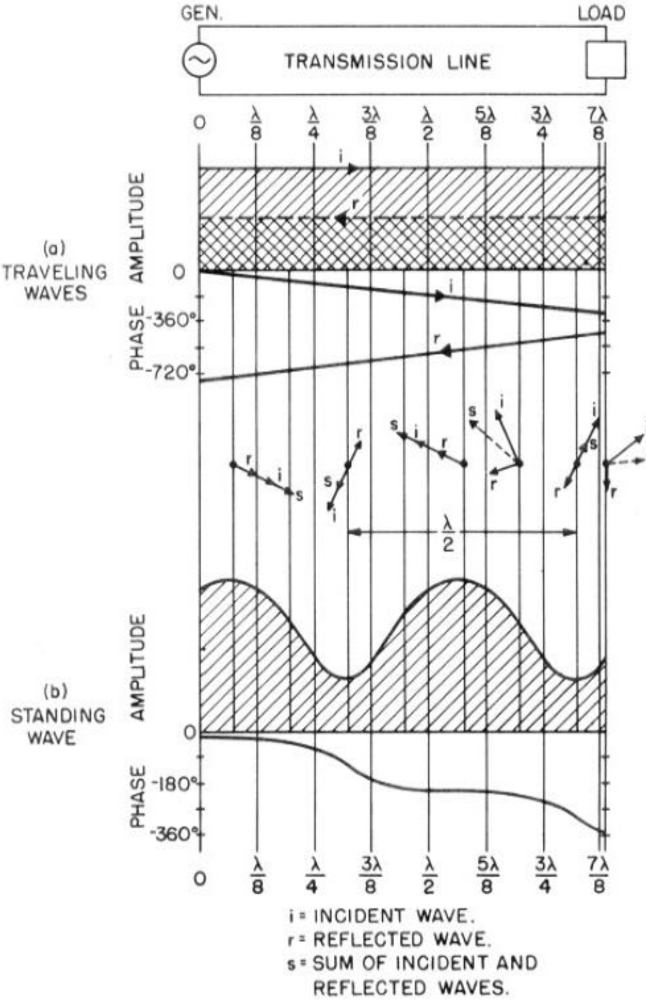


Figure 6-4. Variations in the amplitude and phase of incident and reflected waves along a transmission line with a 3:1 mismatch condition. Vector combination of incident and reflected waves at various points along the line and resultant standing wave are shown.

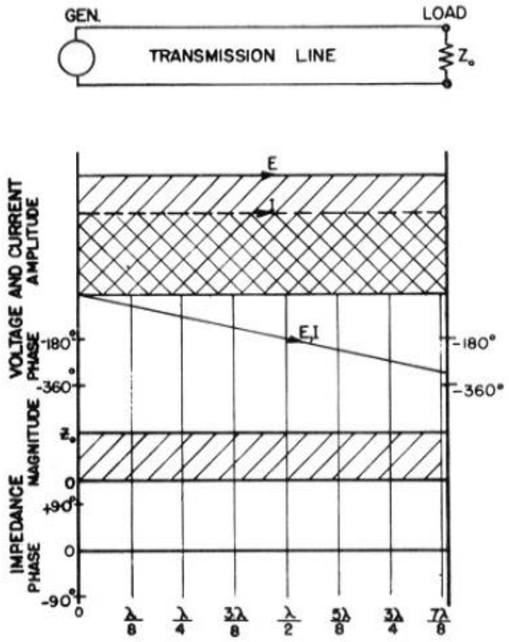


Figure 6-5. Voltage and current waves along a transmission line terminated in its characteristic impedance. Note the absence of reflected waves and that the impedance is constant and equal to the characteristic impedance at all points along the line.

waves are 180°, or an odd integral multiple thereof, out of phase. The amplitude of the standing wave at other points along the line is the vector sum of incident and reflected waves. Successive minima and maxima are spaced, respectively, a half wavelength along the line.

The magnitude and phase of the reflected wave at the load, relative to the incident wave, are functions of the load impedance. For instance, if the load impedance is the same as the characteristic impedance of the transmission line, the incident wave is totally absorbed in the load and there is no reflected wave. On the other hand, if the load is lossless, the incident wave is always completely reflected, with no change in amplitude but with a change in phase.

A traveling electromagnetic wave actually consists of two component waves: a voltage wave and a current wave. The ratio of the magnitude and phase of the incident voltage wave, E_i, to the magnitude and phase of the incident current wave, I_i, is always equal to the characterisitc impedance, Z_o. The reflected waves travel in the opposite direction from the incident waves, and consequently the ratio of the reflected voltage wave, E_r, to the reflected current wave, I_r, is $-Z_o$. Since the characteristic impedance in most cases is practically a pure resistance, the incident voltage and current waves are in phase with each other, and the reflected voltage and current waves are 180° out of phase.

$$\frac{E_i}{I_i} = Z_o$$

$$\frac{E_r}{I_r} = -Z_o$$

These equations are valid at all points along the line.

The magnitude and phase of the reflected voltage wave, E_r, relative to the incident wave, E_i, at the load is called the reflection coefficient, Γ, which can be calculated from the expression

$$\Gamma = \frac{Z_x - Z_o}{Z_x + Z_o} = \frac{Y_o - Y_x}{Y_o + Y_x}$$

$$E_r = E_i\Gamma \quad \text{at the load}$$
$$I_r = -I_i\Gamma \quad \text{at the load}$$

where Z_x and Y_x are the complex load impedance and admittance, and Z_o and Y_o are the characteristic impedance and admittance of the line. $(Y_o = \frac{1}{Z_o})$.

6.2 VOLTAGE AND CURRENT DISTRIBUTION.

If the line is terminated in an impedance equal to the characteristic impedance of the line, there will be no reflected wave, and $\Gamma = 0$. The voltage and current distributions along the line for this case are shown in Figure 6-5.

If the line is open-circuited at the load, the voltage wave will be completely reflected and will undergo no phase shift on reflection, $(Z_x = \infty)$, while the current wave will also be completely reflected but will undergo a 180° phase shift on reflection, as shown in Figure 6-6. If the line is short-circuited, the current and voltage roles are interchanged, and the impedance pattern is shifted $\lambda/4$ along the line. The phase shifts of the voltage and current waves on reflection always differ by 180°, as the reflected wave travels in the opposite direction from the incident wave. A current maximum, therefore, always occurs at a voltage minimum, and vice versa.

The voltage at a maximum of the standing-wave pattern, E_{max}, is $|E_i| + |E_r|$ or $|E_i|\,(1 + |\Gamma|)$ and at a minimum, E_{min}, is $|E_i| - |E_r|$ or $|E_i| \times (1 - |\Gamma|)$.The ratio of the maximum to minimum voltages, which is called the voltage standing-wave ratio, VSWR, is

$$VSWR = \frac{E_{max}}{E_{min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

The standing-wave ratio is frequently expressed in decibels or percent

$$VSWR \text{ in db} = 20 \log_{10} \frac{E_{max}}{E_{min}}$$

$$VSWR \text{ in } \% = 100\left(\frac{E_{max}}{E_{min}} - 1\right)$$

6.3 LINE IMPEDANCES.

At any point along a uniform lossless line, the impedance seen looking towards the load, Z_p, is the ratio of the complex voltage to the complex current at that point. It varies along the line in a cyclical manner, repeating each half wavelength of the line, as shown in Figure 6-6.

At a voltage maximum on the line, the incident and reflected voltage waves are in phase, and the incident and reflected current waves are 180° out of phase with each other. Since the incident voltage and incident current waves are always in phase (assuming Z_o is a pure resistance), the effective voltage and current at the voltage maximum are in phase and Z_p at that point is pure resistance. At a voltage maximum, Z_p is equal to the characteristic impedance multiplied by the standing-wave ratio.

$$Z_p = Z_o \times VSWR$$

At a voltage minimum, the two voltage waves are opposing and the two current waves are aiding. Again the effective impedance is a pure resistance and is equal to the characteristic impedance of the line divided by the standing-wave ratio.

$$Z_p = \frac{Z_o}{VSWR}$$

The impedance, Z_p, at any point along the line is related to the load impedance by the expression

$$Z_p = Z_o\left(\frac{Z_x + jZ_o \tan\theta}{Z_o + jZ_x \tan\theta}\right)$$

where

Z_o = characteristic impedance,
Z_x = complex load impedance,
$\theta = \frac{2\pi \ell_e}{\lambda}$,
ℓ_e = electrical length of line between point p and load, $\ell\sqrt{\epsilon}$
ℓ = physical length.

Thus, if ℓ_e is in cm,

$\theta = 12 \times f_{Gc} \times \ell_e$, degrees.

In Figure 6-7, point p is shown at a voltage minimum. However, the expressions above are valid for any location of point p on the line.

Conversely, the load impedance, Z_x, can be determined if the impedance, Z_p, at any point along a lossless line is known..The expressions relating the impedances are:

$$Z_x = Z_o\left(\frac{Z_p - jZ_o \tan\theta}{Z_o - jZ_p \tan\theta}\right)$$

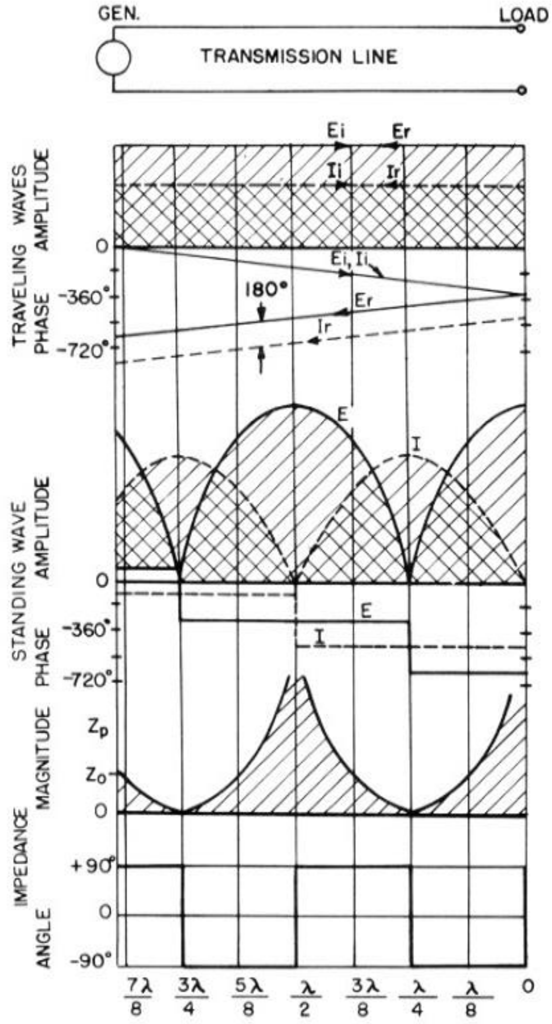


Figure 6-6. Voltage and current waves along a transmission line terminated in an open-circuit. Note that the minima of the voltage waves occur at the maxima of the current waves, and vice versa, and that the separation of adjacent minima for each wave is a half wavelength. The variation in the magnitude and phase angle of the impedance is also shown.

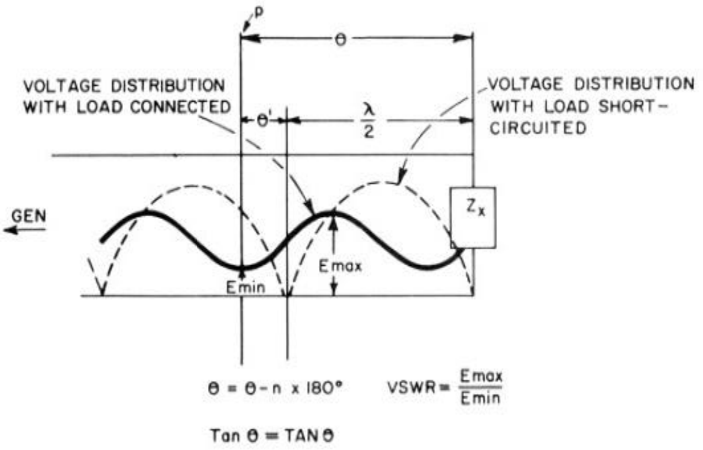


Figure 6-7. Voltage variation along a transmission line with a load connected, and with the line short-circuited at the load end.

The load impedance can be calculated from a knowledge of the VSWR present on the line and the position of a voltage minimum with respect to the load, since the impedance at a voltage minimum is related to the VSWR. The expression for the load impedance in terms of the VSWR, S, and the electrical distance, θ, between the voltage minimum and the load, is:

$$Z_x = Z_o\left(\frac{1 - jS\tan\theta}{S - j\tan\theta}\right)$$

$$= Z_o\left(\frac{2S - j\left[S^2 - 1\right]\sin 2\theta}{\left[S^2 + 1\right] + \left[S^2 - 1\right]\cos 2\theta}\right)$$

Since in a lossless line the impedance is the same at half-wavelength intervals along the line, θ' can be the electrical distance between a voltage minimum and any multiple of a half-wavelength from the load (see Figure 6-7). Of course, if the half-wavelength point used is on the generator side of the voltage minimum located with the load connected, θ' will be negative. The points corresponding to half-wavelength distances from the load can be determined, with the line short-circuited at the load, from the positions of the voltage minima on the line. The minima will occur at multiples of a half-wavelength from the load.

If the VSWR is greater than 10 tan θ, the following approximation gives good results:

$$R_x \cong \frac{Z_o}{S\cos^2\theta}$$

$$X_x \cong -Z_o\tan\theta$$

Corresponding general equations in admittance terms are:

$$Y_p = Y_o\left(\frac{Y_x + jY_o\tan\theta}{Y_o + jY_x\tan\theta}\right)$$

$$Y_x = Y_o\left(\frac{Y_p - jY_o\tan\theta}{Y_o - jY_p\tan\theta}\right)$$

6.4 SLOTTED LINES.

6.4.1 GENERAL.

The most accessible property of a transmission line, in measurement terms, is VSWR. A common method of measuring VSWR amplitude and phase is by observation of the standing-wave pattern in the line. This is accomplished by means of a narrow, longitudinal slot cut in the outer conductor of a standardized section of coaxial line, so that interior rf fields can be sampled with a movable probe inserted through the slot. The probe is part of an assembly mounted on a carriage capable of moving over the entire length of the slot on an accurately calibrated track. Within the probe assembly is an adjustable, thin rod that penetrates the line to extract the rf sample. Ideally, the probe is part of a tuned structure, so that it will provide a maximum pickup, which is detected by a microwave diode, an integral part of the assembly. The output of the diode is an audio voltage directly proportional to the rf power sampled, provided that the diode is operated in the square-law region of its response characteristic.

The output of the probe assembly must then be fed to a calibrated amplifier-indicator to measure VSWR magnitude. In addition, phase information (with respect to a fixed reference plane) can be determined from the position of the probe, when it is in a minimum of the standing-wave pattern. The reflection coefficient can be calculated from VSWR measurements, as can impedance. Impedance or admittance data can also be plotted by use of the Smith chart.

Desirable characteristics of a precision slotted line include the following:

1. The coaxial line must be uniform, with straight and concentric conductors, so that it does not itself introduce reflections.

2. It should possess a true coaxial cross section, free of step discontinuities.

3. It should be terminated at the measurement end with a precision coaxial connector possessing dimensional and electrical uniformity nearly identical to that of the line.

4. The line of motion of the tip of the probe and the axis of the line must all be accurately parallel.

5. The instrument must have mechanical rigidity.

6. Wear of moving parts in the carriage must be low.

6.4.2 SLOTTED-LINE ERRORS.

There are certain inherent errors in a slotted line which must be considered. The instrument errors may be neglected in many applications, but they must be taken into account when accuracies of a few percent or less are desired.

Certain rather obvious operational precautions are required, even for less-stringent accuracies. For example, the signal source must be stable in both amplitude and frequency and present a low harmonic level, all connectors must be tight and properly mated, and the response law of the detector must be accurately known.

Some of the more common sources of inherent instrument error are:

1. Residual VSWR.
2. Probe effects.
3. Losses.

The design of the Type 900-LB Precision Slotted Line, to a very great degree, either compensates directly for these errors or provides operator adjustments to overcome them. Still further reductions can be achieved by the precision calibration procedures given in Section 5.

Residual VSWR. The residual VSWR of a slotted line is that measured when the line is terminated in a perfect impedance match. It can have several causes.

1. Characteristic Impedance Under the Slot.

The slot in the outer conductor reduces the capacity per-unit-length of the line and causes a small increase in the characteristic impedance in the area under the slot. The fractional change in impedance can be calculated from the dimensions of the coaxial line, as follows:

$$\Delta Z_o = \frac{Z_o w^2}{4\pi^2 (x^2 - y^2)}$$

where

x = the radius of the inner conductor,
y = the radius of the outer conductor,
w = the width of the slot.

The minute change in impedance introduces a discontinuity which must be compensated for by a small increase in the diameter of the inner conductor under the slotted region. The slot should be accurately centered and free from burrs and dimensional defects.

2. Step Discontinuities.

Changes in diameter, such as occur in transitions from coaxial to a slab-type cross-section, cause severe reflections which cannot be compensated for completely enough for precision measurements over a frequency band. The Type 900-LB avoids this difficulty by maintaining a true coaxial cross-section in both the slotted and unslotted sections of the line. The sole exception to this is a small step, to compensate for the slot effect, which causes only negligible VSWR. No dielectric support bead other than the one in the Type 900-BT connector is necessary.

3. Connector Reflections.

A primary source of residual VSWR is reduced radically by use of the Type 900-BT connector. However, although small, the reflections within the connector are the most important cause of residual VSWR in the Type 900-LB slotted line, and lead directly to the test limit identical to that for the Type 900-BT connector.

Probe Effects.

1. Constancy of Probe Pickup.

Small irregularities in either the inner or the outer conductor of a slotted line lead to variations in probe penetration along the line. This variable is usually called "flatness" and is expressed in terms of equivalent VSWR. These variations cause corresponding changes in probe output even with a perfect termination and are easily confused with true VSWR, when the measured VSWR approaches the size of the flatness curve. For this reason the flatness specification determines the minimum VSWR measurable by conventional standing-wave indicators. (Use of the Type 1640-A Slotted Line Recorder System, however, enables VSWR's as small as 1.001 to be measured.)

2. Probe Reflection.

Some of the incident wave in the slotted line is reflected by the probe and travels back toward the generator. If the generator is well matched, all is well, but a mismatched generator will re-reflect some of the energy and the probe will detect and respond to its own reflection, as well as to that of the termination. The magnitude of the erroneous VSWR thus detected is:

$$\mathrm{VSWR}_e = \frac{1 + \Gamma_P \Gamma_G}{1 - \Gamma_P \Gamma_G}$$

where

Γ_P = the reflection coefficient of the probe

Γ_G = reflection coefficient of the generator.

The probe reflection depends upon frequency, probe penetration, probe tuning, and diode-detector characteristics. See Figures 6-10 and 6-11.

Losses. Measurements of high VSWR (>10) can be seriously affected by line losses. To minimize this effect, both inner and outer conductors of the Type 900-LB are made with an overlay of pure silver. The loss in the Type 900-BT connector is virtually the same as the loss in an equivalent length of air line, and the contact loss is negligible for most measurements; thus, the correction of measurements for the line loss is greatly simplified. This correction can be obtained either from the nomograph (Figure 3-9), orby direct measurement of the line loss with either a Type 900-WN or a 900-WO as the termination.

6.5 TYPE 900-LB PRECISION SLOTTED LINE.

6.5.1 GENERAL.

The Type 900-LB Precision Coaxial Slotted Line comprises a slotted section mounted in a calibrated carriage structure, which also mounts an adjustable probe and tuner. A particular feature of the slotted line is the Type 900-BT Precision Coaxial Connector at its load, or unknown, end. It permits measurements, on devices also fitted with Type 900-BT connectors, equal to those possible with the flanged connectors common to rectangular waveguide.

The Type 900-LB has a nominal frequency range of 300 Mc to8.5Gc, but measurements can be made as low as 150 Mc by addition of appropriate Type 900 Precision Air Lines as line extenders. The residual VSWR of the line, including the Type 900-BT Precision Coaxial Connector, is less than $1.001 + 0.001 \times f_{Gc}$.

The line is based on a single slotted section 26 inches long and is a true coaxial type, with precision-machined, concentric inner and outer conductors. A 50-cm slot cut longitudinally in the top of the outer conductor permits insertion of the pickup probe. Thus, the *single* slotted section, accurately positioned at the time of factory installation, provides up to five octaves of coverage from UHF through X-band. The probe can travel a half-wavelength at the lowest normal test frequency (i.e., 50 centimeters at 300 Mc) with a residual slope that is very small (±0.5%).

The slotted section is an air-dielectric coaxial line, with inner and outer conductors made to extremely close dimensional tolerances to ensure a characteristic impedance of 50.0 ohms, accurate to ±0.1%.

The chrome-plated outer conductor is precision-forged brass tubing lined with a 0.0005-inch-thick layer of pure silver for low loss. The finished inner diameter is 0.5625 inch, ±100 microinches. The inner conductor, a steel tube with a layer of silver approximately 0.0005-inch thick, is centerless-ground to a finished diameter tolerance of ±50 microinches.

Both tubing and rod are stress-relieved, to minimize diameter changes due to machining. The wall thickness of the outer conductor is 0.217 inch (except at connector shoulders) and the exterior surface (adjacent to the slot under the probe carriage) is honed to a ±0.0002-inch tolerance.

Dimensional irregularity in the slotted line and discontinuities at slot ends and at the load connector are the principal sources of error in this type of instrument. Such imperfections and discontinuities in the coaxial-line section have been virtually eliminated in the Type 900-LB. Moreover, there is no connector transition problem because there is no transition; the connection between the slotted section and the connector at the "unknown" end is a continuous, uniform, coaxial transmission line with very close control of diameters, as in the slotted section. The Type 900-BT connector has effectively reduced connector errors by an order of magnitude (refer to paragraph 6.5.7 for a more detailed treatment)..

Other connectors on the slotted line are Type 874, low-VSWR, quick-change coaxials. There is a locking type for low-leakage performance at the input end, and a nonlocking type built into the carriage for detector output. Adaptors from Type 874 to most commercial coaxial-connector types are available (see Appendix C).

Owing to the connection repeatability of the Type 900-BT connector, the slotted line can be calibrated to an accuracy of 0.1%, much higher than with any other connector type (refer to Section 5).

6.5.2 PROBE CARRIAGE DRIVE.

Two electrostatic-pickup-probe assemblies with external depth adjustment are furnished. The assemblies mount interchangeably in the rigid cast carriage which transports the probe throughout the entire length of the slot. The mechanism for driving the carriage offers nearly constant probe coupling along the line, with negligible backlash.

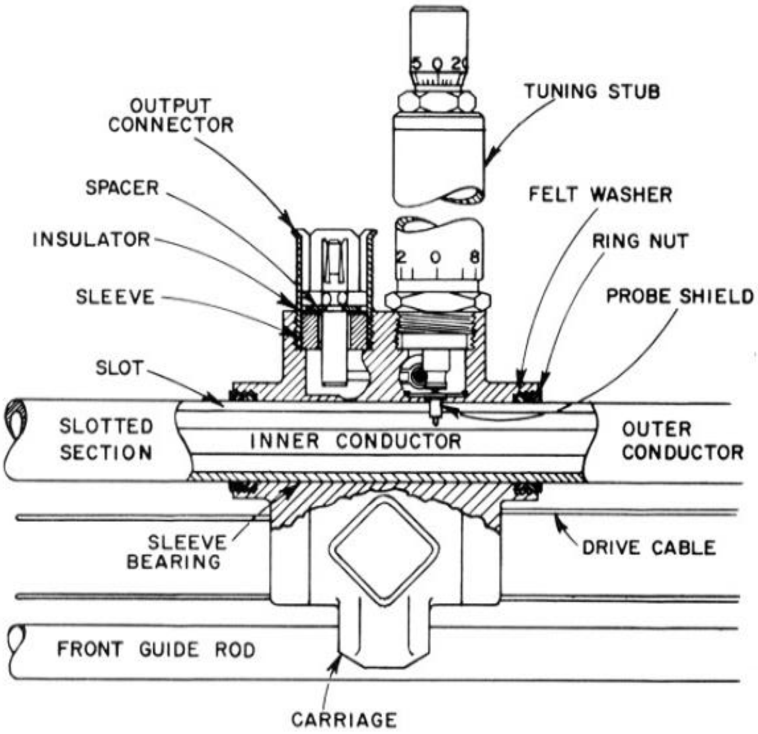


Figure 6-8. Type 900-LB construction details; carriage shown with probe-tuner assembly.

In order to minimize the effects of any slight distortion in the line and the changes in effective probe coupling resulting from forces applied to the carriage, the driving knob is mounted in a fixed position of the right-hand-end casting and the carriage is driven by means of a nylon cord. The cord forms a complete loop, which is attached to the carriage at one point, and passes over an idler pulley on one end of the line and around a drum attached to the knob shaft on the other. The connection between the cord and the driving drum is obtained by means of friction, and one and a half turns of the cord around the drum have been found sufficient for positive drive without slippage. Since there are no teeth or grooves involved in the drive mechanism, a very smooth adjustment is obtained. Ball bearings are used on the drum and pulley shafts to reduce the driving force required and to minimize wear. A small ratchet-type take-up reel is mounted on the back of the carriage to permit adjustment of the tension in the nylon cord.

The fixed position of the driving knob, the use of ball bearings, and the durability of the nylon cord make the line easily adapted to motor drive i.e., as part of the Type 1640-A Slotted Line Recorder System. A bevel gear is attached to engage the motor drive.

6.5.3 PROBE CARRIAGE CONSTRUCTION (See Figures 6-8 and 6-9).

The probe carriage is made of cast brass and its honed sleeve bearing slides on the finely ground, chrome-plated surface of the outer conductor. Play in the carriage, which can cause rocking and consequent changes in probe coupling when the direction of travel is reversed, is negligible, since the tolerance of the bearing surface is 0.0001 inch. Probe travel is further stabilized by a second sleeve-type bearing machined in the carriage body. This consists of a semicircular bearing surface in the lower end of the casting which rides along the polished stainless-steel guide rod at the front of the instrument. This bearing surface prevents rotation of the carriage about its axis.

Rubber washers at each end of the slotted section, just inside the guide-rod supports, serve as bumpers to protect the mechanism in the event of carriage overdrive.

A felt washer, held in place by a metal ring nut, is mounted at each end of the carriage to prevent dirt and other foreign material, which may collect on the surface of the outer conductor, from entering the bearing. Oil holes in the top of the carriage permit these washers to be filled with oil for long-lasting lubrication of the bearing surfaces.

A 3/4-inch-diameter hole in the top of the carriage, beside the output connector, is tapped to receive either of two threaded probe assemblies. The small hole, in the center of the base of this opening, is the access for the pickup probe. A probe-shield assembly, consisting of a brass disk with a two-stepped hub on its underside, shields the probe from undesirable variation in its capacity to ground as it travels the slot. The hub is lined with clear polystyrene to in-

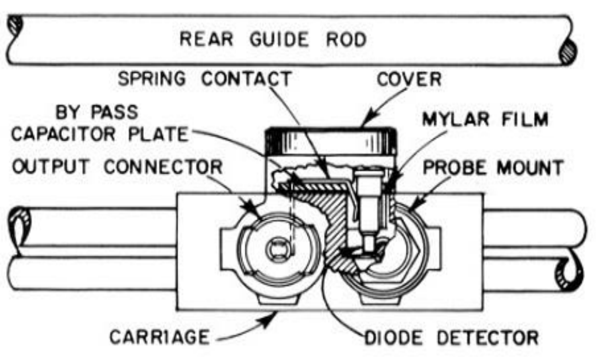


Figure 6-9. Type 900-LB. Top view, diode holder details.

sulate the probe from the rest of the carriage. The shield assembly is held in place by a retaining ring which seats in a groove at the base of the opening.

Beneath the probe mount, at the rear of the carriage, is a shallow, cylindrical cavity which houses the diode detector and a built-in by-pass capacitor. One of two symmetrically spaced holes in the inner wall of the cavity is the diode holder and the other provides access for a spring contact, which connects the diode output to the center conductor of the output connector.

The diode holder will also accept bolometers of a similar outline. The diode mounts small-end-first and bottoms in the holder; the small end fits snugly in a concave ridge in the chuck holding the probe tip. The spring contact makes the connection at the large end of the diode and also clamps the diode securely in position.

The two interchangeable microwave diodes supplied, types 1N21C and 1N23C, furnish adequately overlapping coverage for the frequency range of the instrument. For low-noise applications, types 1N21F and 1N23F are suggested.

The flange at the wide end of the diode rests against a brass plate, which is insulated from the carriage body by a Mylar disk of the same shape as the plate, but with smaller-diameter holes. The plate and the opposing surface of the carriage body constitute a diode by-pass capacitor, with the Mylar disk as the dielectric. Plate, disk, and contact are fastened by a threaded stud that also secures the knurl-rimmed aluminum cover. The stud is insulated from plate and contact.

6.5.4 PROBE ASSEMBLIES.

Of the interchangeable probe assemblies, one is mounted in an adjustable tuner and is intended for use with the diode to pick up modulated rf signals. The other is untuned, designed for use with unmodulated rf signals (without the diode).

The signal energy picked up by the tunable probe is detected by the diode and is available from the adjacent Type 874 connector. However, the energy picked up by the untuned probe assembly is available directly at the Type 874 connector at its exposed end; in this configuration, the other connector on the carriage is not used. The connector on the untuned probe is a locking type to minimize leakage; when another Type 874 connector is locked in place, leakage is typically better than 100 db below signal, through 8 Gc. Compatible GR874 coaxial devices, such as the Type 874-MRL Mixer Rectifier, are available to detect the output from this probe.

The probe penetrates the slot and couples into the electrostatic fields present between the conductors when the coaxial line is energized. As a result, it samples fields whose strength varies periodically along the line. The probe interferes with the fields and introduces reflections in the line in proportion to the amount of penetration. Therefore, penetration should be kept at a minimum.

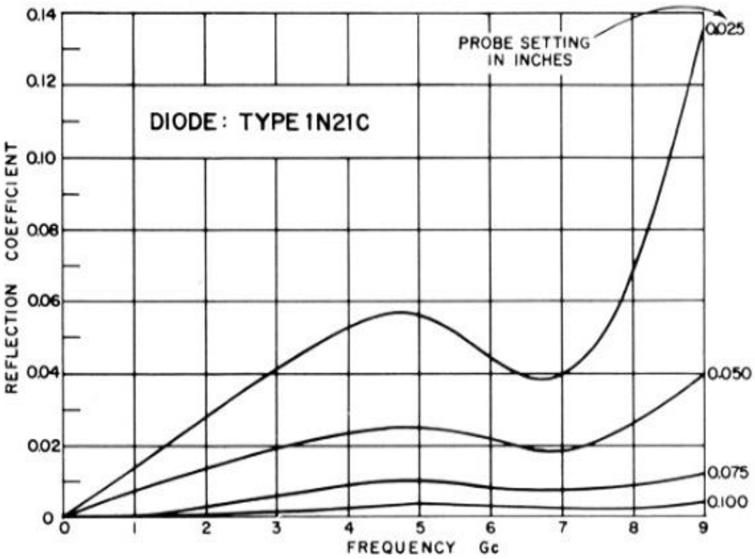


Figure 6-10. Probe reflections at four penetrations, with type 1N21C.

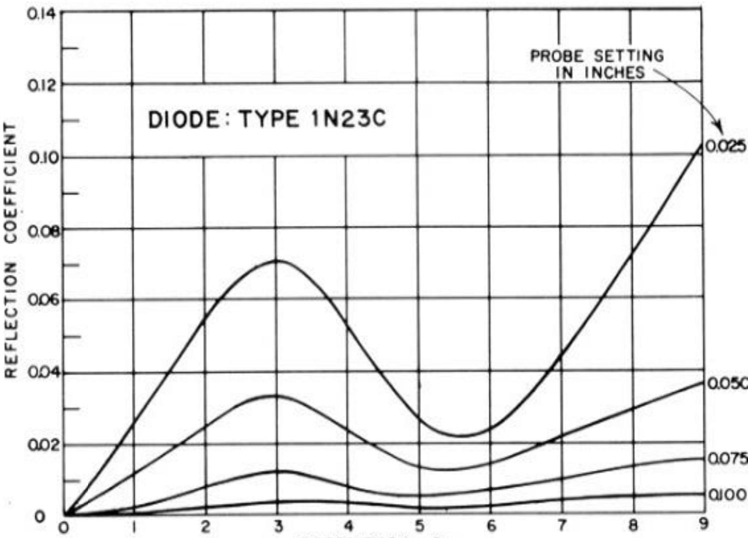


Figure 6-11. Probe reflections at four penetrations, with type 1N23C.

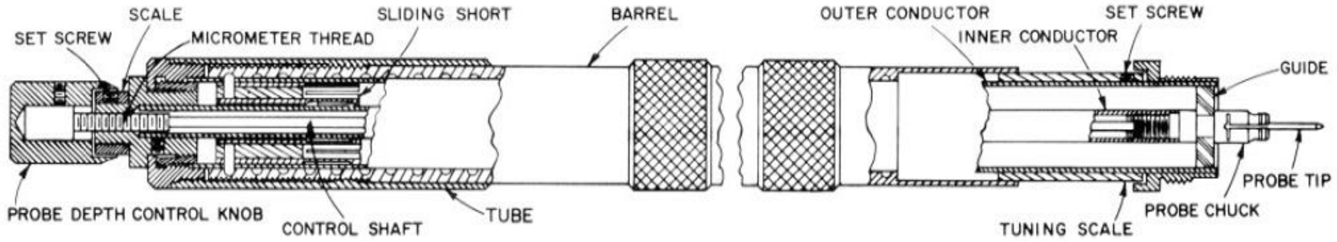


Figure 6-12. Adjustable Probe-Tuner Assembly.

Since probe reflection varies with frequency and with other factors, there is no single penetration depth suitable for all situations; both probes are therefore adjustable. In general, greater probe penetration is necessary at the low end of the frequency range. Figures 6-10 and 6-11 show plots of reflections from the tunable probe in the Type 900-LB at four representative penetration settings. Note the variations at shallow depths that depend upon the diode in use.

The output from the detector is greatly enhanced if a tunable stub is used to resonate the diode-probe assembly at the frequency of operation. This also provides rf selectivity; the resonant condition maximizes the voltage at the diode and cancels the shunt susceptance which the probe would otherwise place across the transmission line.

The adjustable probe-tuner assembly supplied (see Figure 6-12) is a probe mount combining both capabilities. It is an air-dielectric, coaxial device, terminated in a sliding short circuit, that forms a tuned structure to maximize the power transfer from the probe to the detector. The system makes it possible to resonate the probe over the range from 300 Mc to 8.5 Gc, and to hold probe reflections to a minimum by adjustment of depth of penetration.

Adjustment of probe depth is effected by a micrometer control at the top of the tuning stub. Vertical-scale calibration on the hub of the control extends from 0 to 0.140 inch. The beveled edge of the control thimble is divided into 25 equal parts and in one revolution the probe travels 0.025 inch; thus, the least count is 0.001 inch. Maximum reading indicates minimum probe penetration. The scale is preset to indicate directly the distance in inches between the probe tip and the center conductor. A positive stop prevents the probe from touching the center conductor.

The control shaft is supported by a micrometer thread, at the top end, and passes through the center conductor of the tuner to a chuck near the probe end. There, it is centered by a Teflon guide, which supports the chuck through which the probe slides. In operating position, the chuck remains directly above, but not touching, the probe-shield assembly and directs the probe descent, through shield and slot, into the line.

The sliding short in the tuner is an assembly consisting of two heat-treated beryllium-copper sleeves of different diameter joined concentrically at the top by a tubular-brass spacer. Both sleeves contain several finger contacts; one sleeve slides along the inner wall of the outer conductor, while the other slides along the inner conductor. Both are rhodium flashed for long contact life.

Movement of the sliding short is accomplished by a rotary control consisting of a knurled aluminum barrel in the center portion of the tuner. Rotation of this barrel tuner moves the sliding short along a screw thread on the inside wall of the tube, in a mechanical-pencil-type action.

A scale near the base of the tuner gives the approximate position of the short circuit in centimeters, relative to the bottom of the barrel. The radial scale on the barrel gives the control a least count of 1.0 millimeter.

6.5.5 PROBE POSITION.

Probe position along the 50-centimeter slot is accurately indicated, relative to the reference plane located at the contact surfaces of the Type 900-BT connector, by the coincidence of two metric scales. The long fixed scale calibrated in centimeters (8 to 62), with minimum interval markings in millimeters, is the principal indicator. The reference plane corresponds to 0 on this scale. The scale is complemented by a vernier, attached to the carriage, which consists of a 1.9-centimeter scale divided in ten equal parts. The probe centerline corresponds to the 0 marking on the vernier. Juxtaposition of the scales permits probe-position determination accurate to a least count of 0.1 millimeter.

Main scale and vernier are made of stainless steel, with markings accurate to ±(0.1 mm + 0.5%). A satin finish is used for low glare, and all markings are black for good contrast. Both scale and vernier are angle mounted for optimum visibility.

To extend probe-position measurements to fractional-millimeter accuracy, the micrometer-carriage-drive assembly (Figure 6-13) is supplied. It is useful in width-of-minimum measurements for large VSWR and also for precise phase and wavelength measurement. It consists of a metric micrometer head mounted in an adjustable holder.

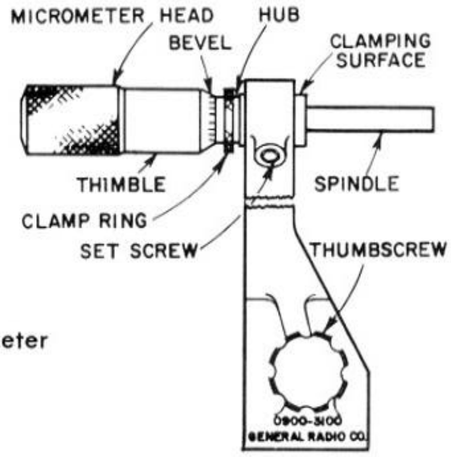


Figure 6-13. Micrometer Drive Assembly.

The micrometer drive, which has a 25-mm calibrated movement with a least count of 0.01 millimeter, can be used for the precise examination of any consecutive 2.2 cm over the entire travel of the carriage. The hub is calibrated in millimeters, 0 through 25, in 0.5-mm minimum intervals. The thimble is graduated in 50 equal parts and requires two complete revolutions to move 1 mm on the hub scale.

The assembly clamps on the rear guide rod of the slotted line, where the base of the heavy cast holder forms a 1-1/4-inch long cylindrical bearing surface. The holder can be clamped anywhere along the rod by means of the large screw at the rear of the base. The assembly is also free to swivel on the rod, so that it can be retracted to clear the probe carriage.

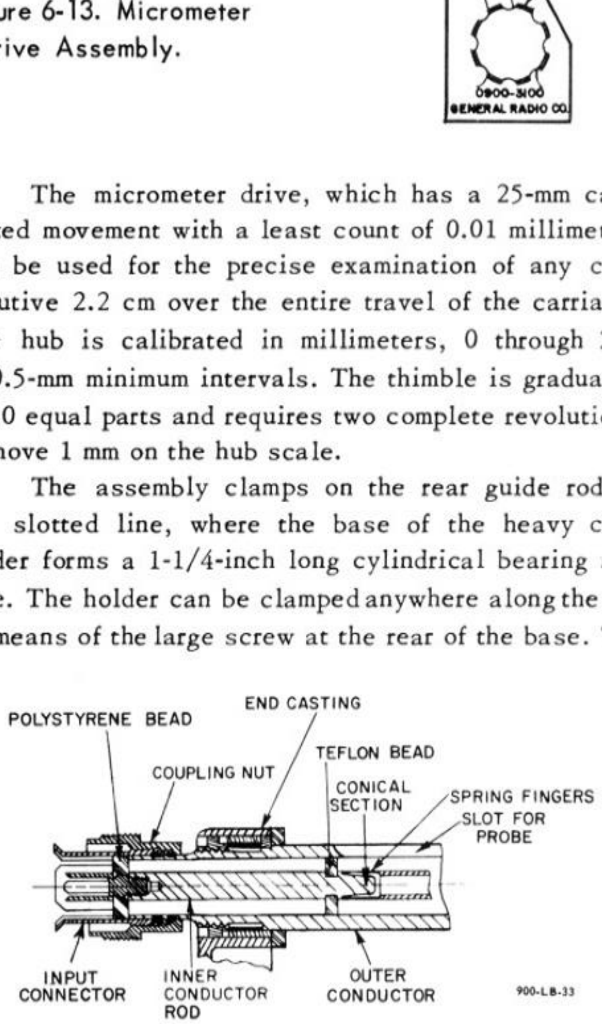


Figure 6-14. Input-end detail for Type 900-LB.

In operation, the micrometer-drive assembly is positioned so that the spindle rides against the contact button of the probe carriage, immediately above the vernier scale. The drive is used at the right of the carriage and moves it upscale, relative to the main probe-position indicator.

When the slotted line is not in use, the probe carriage stores at the far-right end, with the micrometer drive in its normal measurement position. A cutaway in the rear cover permits the protective panel to clear the carriage and micrometer drive when closed.

Carriage motion with respect to the line is such that the probe tip moves accurately parallel to the longitudinal axis of the coaxial line. The over-all construction ensures permanent accuracy and freedom from slope errors without tedious adjustment or the possibility of misalignment. The precision bearings of the carriage provide firm, symmetrical support and smooth action over the entire travel.

6.5.6 LINE CONSTRUCTION.

The outer conductor of the line itself is rigidly clamped in heavy brass castings at both ends, and the structure is stiffened by the two half-inch-diameter, stainless-steel guide rods and further reinforced by the heavy-gauge cover panels, so that distortion of the line as a result of mechanical forces is very small.

The inner conductor is made of seamless, cold-rolled steel tubing to minimize sagging. Since it is relatively easy to maintain eccentricity within 0.005 inch in fabrication, it is consequently possible to hold Z_0 error to 0.05% on a line of the GR900 dimensions. A heavy silver plating is applied for low electrical losses as well as minimum skin-depth effect over the frequency range of the instrument (see Figure 6-2). It is centerless-ground to its final dimension, then gold-flashed to retard tarnish.

The inner conductor connects to the Type 900-BT connector at the load end and terminates just beyond the slot at the other end. There, it is extended to the Type 874 connector through a short rod of the same diameter and finish (see Figure 6-14). The rod and inner conductor meet in a slip joint near the input end to minimize the transmission of forces from elements connected there which might tend to deflect the inner conductor. The slip joint consists of a conical taper in the end of the rod and mating spring fingers on the end of the inner conductor. There is no deflection problem possible at the Type 900-BT end.

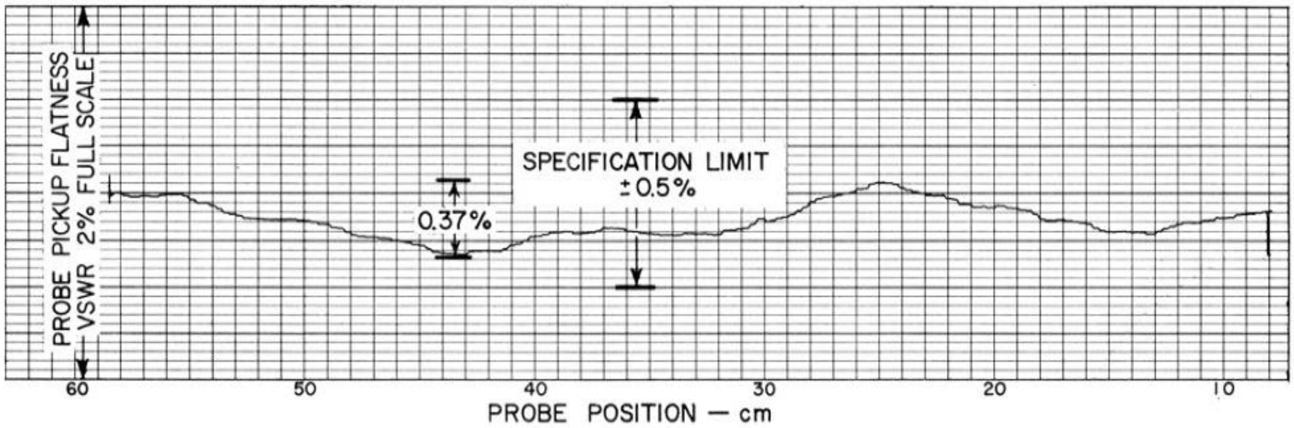


Figure 6-15. Typical "flatness" performance of Type 900-LB as plotted on Type 1640-A recording system. Taken at rf with residual VSWR tuned to 1.000.

Over all, the inner conductor is supported by the beads in the connectors and by an eccentric Teflon bead at the slipjoint. All insulator beads are located outside the slotted section of the line to preclude irregularities in probe coupling from that source.

The end castings permit attachment of the line to a mounting plate, as in the case of the Type 1640-A recording system configuration.

The high degree of constancy of probe coupling (flatness) over the 50-cm length of probe travel, as shown in Figure 6-15, is achieved from the inherent straightness of the centerless-ground inner conductor and the forged outer conductor. A further reduction in the variation in probe coupling is obtained by adjustment of the inner-conductor position, after assembly, until the highest degree of constancy is obtained. The resultant variation in probe coupling is always less than ±0.5%.

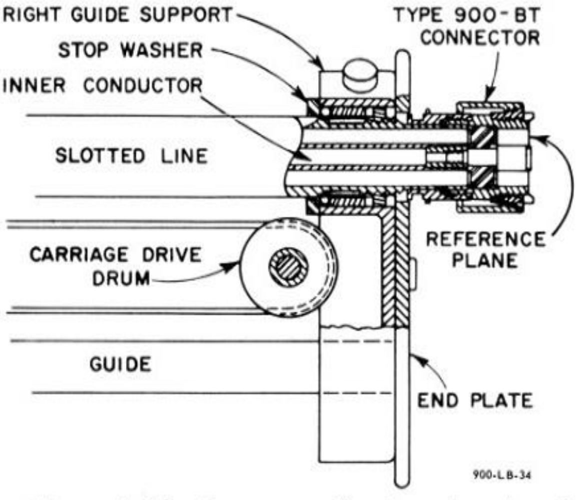


Figure 6-16. Connector-line junction detail at unknown (load) end of Type 900-LB.

6.5.7 TYPE 900-BT CONNECTOR.

The Type 900-BT Precision Connector on the line (see Figure 6-16) provides a smooth, transitionless connection between the slotted line and the circuit under test. The most important characteristic of a precision connector for slotted-line use is the extent to which it introduces reflections into an otherwise matched transmission line. Figure 6-17 shows the VSWR test specification for a *pair* of these connectors ($1.001 + 0.001 \times f_{Gc}$), as well as typical VSWR for a production lot. Since it is impossible to say how much each connector contributes to the VSWR of the pair, the test limits for the pair are used as the guaranteed specification for a single connector.

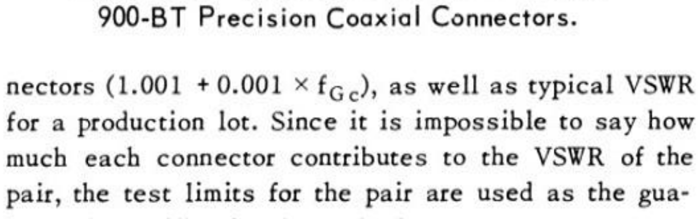


Figure 6-17. VSWR of a mated pair of Type 900-BT Precision Coaxial Connectors.

Another important characteristic of a precision connector is repeatability, that is, the consistency of measured value as the connection is broken and remade in different orientations. The connection of a pair of Type 900-BT connectors under these conditions typically repeats to within 0.03% up to 8.5 Gc.

The insertion loss, or attenuation, of the Type 900-BT connector is extremely small. It has been minimized by the use of Teflon for the bead and solid-silver alloys for both the inner and outer conductors, and by use of a special contact design.

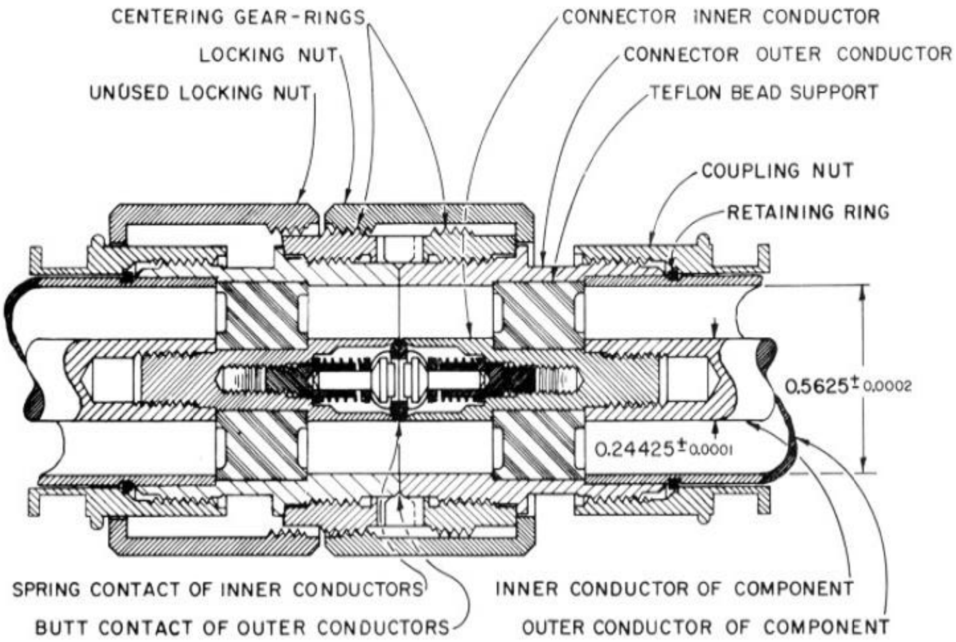


Figure 6-18. Mated pair of Type 900-BT Precision Coaxial Connectors.

The electrical length of a pair of Type 900-BT connectors is 3.50 cm and is virtually independent of frequency. The dc resistance of a mated pair is typically less than 0.5 milliohm for the inner conductors, and 0.07 milliohm for the outer conductors.

The Type 900-BT is a sexless connector intended for use on rigid, air-dielectric, 9/16-inch, 50-ohm, coaxial transmission line (principal dimensions: 0.5625 inch and 0.24425 inch). The connector (see Figure 6-18) consists of a solid silver-alloy inner conductor and spring contact, a solid coin-silver outer conductor, stainless-steel centering-gear ring, chrome-plated brass locking nut, and a solid Teflon bead support. The connector is attached to the slotted line by a coupling nut and retaining ring on the line's outer conductor; the inner conductor is threaded into the center conductor of the slotted line and has no loose parts, such as "bullets." All silver parts are plated with a few microinches of gold to retard tarnish.

When two of these connectors are mated, the centering-gear rings interlock and overlap, in order to center each of the connectors with respect to the other, and also to provide indexing in one of 16 possible positions. The outer conductors have flange-type surfaces butted tightly together by the pressure of the locking nut. Only one of the locking nuts is necessary for a connection; the unused nut is backed off into a storage position. The over-all diameter of the mated pair is only 1 $^{1}/_{16}$ inch.

The front surfaces of the inner conductors are recessed 0.001 inch, with respect to the surfaces of the outer conductors. Inner-conductor contact is made by a spring-contact assembly, which projects slightly beyond the surface of the outer conductor until the connector is mated. The spring-contact assembly consists of six solid silver-alloy segments, independently sprung. Upon mating, these contacts are forced back and spread, making wiping contact both with one another and with the inside surface of the inner conductor. This method avoids the reflections caused by slots in the inner and outer conductors, and eliminates changes in the electrical diameter due to wear. Only one spring contact is necessary for a good electrical connection; the spring contact will mate just as well with any flat surface.

When two connectors are mated, the conductors meet in the center of the connection, and this feature very conveniently provides the electrical reference plane.

An important practical requirement of a precision connector is that it be adaptable to other connector types without having its performance degraded significantly below that of the other series. To satisfy this requirement, low-reflection adaptors to connect the GR900 connector to GR874 and other commonly used 50-ohm connector series are available. As a result, measurements in other coaxial series are limited only by the accuracy of the lower-precision connectors themselves.

Moreover, instruments such as the slotted line, equipped with GR900 connectors, may be calibrated at the Type 900-BT connector reference plane to 0.1-percent accuracy with Type 900-LZ Reference Air Lines.

6.6 COAXIAL ACCESSORIES.

6.6.1 TYPE 900-WN PRECISION SHORT-CIRCUIT TERMINATION.

The Type 900-WN Precision Short-Circuit Termination is a very low-loss device which effectively short circuits a transmission line, such as the Type 900-LB, equipped with a Type 900-BT Precision Coaxial Connector. The reference plane of the short circuit is conveniently located at the mating plane of the connector. Extremely small ohmic losses, demonstrated by a reflection coefficient of 0.999 (or greater) to 8.5 Gc, occur when the short-circuit termination is mated with the Type 900-BT connector.

The Type 900-WN Short Circuit comprises a precision-machined, silver-plated, brass slug, gold-plated for tarnish protection, with the necessary Type 900-BT connector external hardware. The short circuit makes a butt joint with the Type 900-BT outer conductor. The flat surface of the short circuit, pressed against the inner-conductor contact of the Type 900-BT, achieves the inner-conductor junction; see the cross-section view of the mated junction (Figure 6-19). The excellent performance of this short circuit is inherent from the basic design of the Type 900-BT connector.

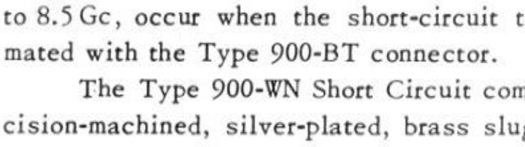
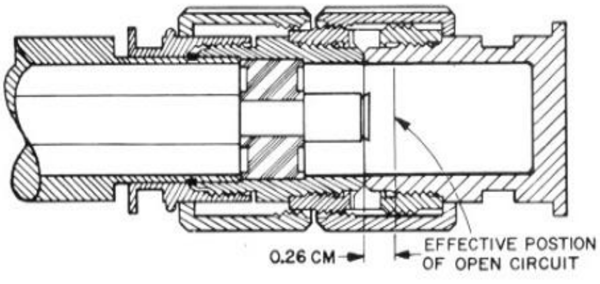


Figure 6-19. Cross section of a Type 900-WN Short-Circuit Termination (right) mated with a Type 900-BT connector on the slotted line.

Figure 6-20. Cross section of a Type 900-WO Open-Circuit Termination (right) mated with Type 900-BT connector on the slotted line.



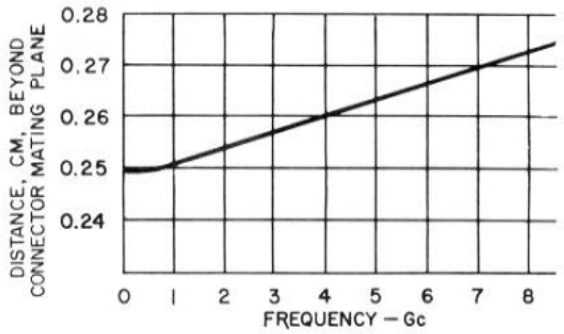


Figure 6-21. Typical effective open-circuit position for the Type 900-WO.

The Type 900-WN Precision Short-Circuit Termination is used to establish reference planes for impedance measurements. It is also used as a low-loss short-circuit termination in measurements, including loss measurements, of networks with more than one port.

6.6.2 TYPE 900-WO PRECISION OPEN-CIRCUIT TERMINATION.

The Type 900-WO Precision Open-Circuit Termination is a low-loss open-circuit termination which mates with a Type 900-BT Precision Coaxial Connector. This termination presents a well-shielded open circuit 0.26 centimeter beyond the reference plane of the Type 900-LB and has a reflection coefficient of 0.999, or greater, to 8.5 Gc.

The Type 900-WO Open-Circuit Termination comprises a closed-end, standard-diameter outer conductor with Type 900-BT connector external mounting hardware. A cross-section view of the Type 900-WO mated with the Type 900-BT connector on the slotted line is shown in Figure 6-20.

The open circuit cannot be established exactly at the mating plane of the Type 900-BT connector because of the end effect involved. This end effect can be represented closely by an additional length of line, or by a 0.166-pf capacitance shunting the end of the line. The representation is not exact, however, and a small increase in effective electrical length occurs with an increase in frequency as shown by representative measured data in Figure 6-21.

The Type 900-WO Precision Open-Circuit Termination can be used to establish reference planes for impedance measurements. It can also be used as a low-loss open-circuit termination in measurements, including loss measurements, of networks with more than one port.

SECTION 7

SERVICE AND MAINTENANCE

7.1 WARRANTY.

We warrant that each new instrument manufactured and sold by us is free from defects in material and workmanship, and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, Sales Engineering Office, or authorized repair agency personnel, will be repaired, or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

7.2 SERVICE.

The two-year warranty stated above attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see rear cover), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument. Always use the storage case supplied as part of the shipping container.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest Sales Engineering Office, requesting a Returned Material Tag. Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

7.3 DIODE CHECK (Figure 6-9).

To remove the detector diode, unscrew the cover on the back of the carriage and pull the diode from its socket.

The diode can be checked with a VOM (Simpson 260, or equivalent). Measure the resistance with both polarities of applied dc voltage. The resistance should be below 700 ohms in one direction and above 50,000 ohms in the other.

Occasionally, a diode that passes the above test may be noisy, as demonstrated by erratic output indication. Such a diode must be replaced.

7.4 CLEANING AND LUBRICATION.

7.4.1 SLOTTED LINE EXTERIOR.

The slotted line should be kept with the cover closed when not in use, and preferably in its storage case, to prevent dirt accumulation on the outside surface of the outer conductor. This surface serves as the carriage track and should be cleaned and lubricated at least every three months for best performance.

The felt washers in the carriage are lubricated through the oil holes provided. Use a light oil and keep the oil ports filled so that there is a thin film on the outer conductor. It may occasionally be necessary to tighten the retaining-ring nuts to keep the felt washers in contact with the line.

NOTE

Do not tighten them too much, or they will make carriage movement difficult and cause slippage of the drive cord.

When the carriage track needs cleaning:

a. Spread a coat of a very light instrument oil (Anderol L-401-D*, or equivalent) over the entire outside of the outer conductor; use a saturated cloth. Don't get oil in the slot.

b. Then, slide the carriage back and forth several times to dislodge any dirt.

c. Finally, wipe the track dry with a soft, lint-free cloth.

d. Repeat this procedure until the cloth no longer picks up dirt; if more comprehensive cleaning is required, refer to paragraph 7.4.2 for procedures.

7.4.2 CARRIAGE (Figure 6-8).

If the line is very dirty, remove and clean the felt washers. The procedure is as follows:

a. Insert a scribe or a small screw-driver blade in either vertical recess in the ring nuts (holding the felts in the ends of the carriage) and use it to start the nut. Turn the nut in a counterclockwise direction.

CAUTION

The honed surface of the outer conductor, if scratched slightly, will cause a troublesome high spot in the carriage bearing surface. Perform this operation so that the tool, if it slips, will not strike the line.

b. Unscrew the ring nut and slide it clear; remove the felt.

c. Wash the felt thoroughly in a commercial solvent (Vythene**, or equivalent), then flatten it out on a paper towel to dry.

d. Saturate the felt washers with instrument oil.

e. Reinstall the felt so that the gap straddles the slot.

f. Thread the ring nut back in place and tighten it.

g. Lubricate the front guide rod with a thin film of oil.

The slot in the outer conductor can be cleaned with a pipe cleaner saturated with solvent.

7.4.3 PRECISION CONNECTOR.

Inspect the Type 900-BT connector for accumulation of dust or grime, which could degrade performance. Use a solvent to degrease the butt surface of the outer conductor. This is easy to do if the centering-gear ring and locking nut are first removed with the Type 900-TOK Tool Kit (paragraph 7.10).

If the contact looks dirty, carefully remove it with a 1/16-inch Allen wrench, wash it in solvent, and reinstall it.

CAUTION

The contact is vulnerable when out of the connector; do not bend or twist the segments. Do not disassemble the connector beyond this point.

If electrical operation is erratic, look for nicks or protrusions (however minor) on the butting surface of the outer conductor and for damage to the inner-conductor contact. The spring contact in the center conductor should be inspected to ascertain that the segments have not been accidentally deformed.

7.4.4 SLOTTED-LINE INTERIOR.

If visual inspection (through the slot) of the interior surfaces of the line reveals dust or grime accumulations, the performance of the line in precision applications may be impaired. If so, RETURN THE INSTRUMENT TO GENERAL RADIO FOR CLEANING. UNDER NO CIRCUMSTANCES SHOULD THE INTERIOR OF THE SLOTTED LINE BE TAMPERED WITH.

7.5 FLATNESS CHECK.

The fastest and most accurate method of determining line flatness is to install the slotted line in a Type 1640-A Slotted Line Recorder System and use the following procedures. However, if such a system is not at hand, these procedures can be performed with a VSWR meter, although it will be more time-consuming and give less accurate results.

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* Lehigh Chemical Co., Chesterton, Md.

** Mancor Chemical Co., Pawtucket, R. I.

a. Connect a stable 1-kc oscillator (Type 1210-C Unit R-C Oscillator with Type 1201 Unit Regulated Power Supply) to the input end. Set for maximum voltage output. No termination is required on the line.

b. Mount the RF Probe Accessory on the carriage (diode detector removed), connect an expanded-scale-presentation VSWR meter to the rf probe, and tune the oscillator for peak reading.

c. Move the carriage to the extreme left and connect an ohmmeter (highest R scale) between the GR 874-connector inner conductor (at the left) and the RF Probe Accessory inner conductor.

d. Very carefully thread in the probe until it touches the inner conductor, as indicated by the ohmmeter, then back the probe out 5½ turns.

CAUTION

Use care because of the danger of bending the slotted-line inner conductor with the probe.

e. Set the indicator for expanded-VSWR measurement and adjust for mid-scale deflection.

f. With the main probe-position control, drive the carriage from one end of the line to the other and observe the variation on the meter. If the meter moves more than 0.005 total (outside one-half of one small division on the usual expanded scale), it requires adjustment.

NOTE

This is one-half the ±0.5% specification, because both the Type 1640-A and standing-wave meters are calibrated for use with square-law detectors, and when used direct the readings must be multiplied by two to obtain the correct value. If the Type 900-LB performs outside its flatness specification, service procedures to restore it to proper operation can be accomplished only by the General Radio Company.

7.6 PROBE-TUNER ASSEMBLY.

7.6.1 GENERAL.

The probe-tuner assembly (part number 0900-3070) is a sealed unit and normally should require no lubrication or internal cleaning. Refer to paragraph 6.5.4 and Figure 6-12 for interior details. The probe tip should be kept clean and straight. If the adjustment scales become loose, they can be reset and locked in place.

7.6.2 PROBE TIP.

If the probe tip should accidentally be snapped off or badly kinked as a result of rough handling, it can be replaced and recalibrated easily in the field. The replacement tip is General Radio part number 0900-1005. The procedure is as follows:

a. If the tip is bent, drive it out to get maximum exposure (0.010 inch on the penetration scale).

b. Cut it off cleanly as close as possible to the chuck.

c. Back off on the penetration adjustment beyond the scale maximum until the threads disengage completely.

d. Draw the probe up through the center of the stub and remove it.

e. Remove and retain the probe adjustment knob.

f. Attach the knob to the replacement probe structure; reinsert the assembly in the stub. Recalibrate it according to the procedure of paragraph 7.6.3.

7.6.3 PROBE PENETRATION CALIBRATION.

If the drive knob works loose, or if probe-structure replacement is necessary, the penetration control can be recalibrated according to the following procedure, which also provides a safety-stop setting to prevent the probe from being driven against the center conductor of the slotted line.

a. Mount the adjustable tuning stub in the carriage in the normal manner with probe penetration set at minimum (i.e., 0.150).

b. With a size-2 Bristol wrench remove the drive knob attached to the probe structure. Check that the fixed penetration scale faces front. If not, loosen its setscrew with the Bristol wrench, center it, and retighten the setscrews.

c. Connect the leads of a VOM (set to read ohms) to the inner and outer conductors of the Type 874 connector at the input end of the slotted line.

d. Carefully finger-turn the probe structure clockwise until it gently touches the center conductor of the line, as indicated by 0 ohms on the VOM.

e. Reattach the control knob, set it in the 0-penetration position, and lock it there.

f. Back it off to a penetration reading of 0.010 inch. The VOM should indicate an open circuit.

g. Release the knob set screw, push the knob down so that it presses against the top guide nut, and once again lock it in place. This ensures against overpenetration, since the knob will now bottom before the probe hits the inner conductor.

7.6.4 STUB SCALE SETTING.

If the fixed scale (which indicates stub shorting-finger position) becomes loose, it can be readjusted as follows:

a. With the probe-tuner assembly in position in the carriage, loosen the two set screws with a size-2 Bristol wrench.

b. Rotate the barrel to its fully closed position (bottomed).

c. Back off on the barrel as required to center its 0 marking with respect to 0 on the carriage vernier scale.

d. Slide the fixed scale up or down as required to align the 0 mark with the base of the scale on the barrel. Center the fixed scale with respect to the 0 mark on the carriage vernier.

e. Lock the set screws on the fixed scale.

7.7 PROBE POSITION SCALES.

The scales indicating probe position with respect to the reference plane can be reset and accurately calibrated.

7.7.1 VERNIER SCALE.

The vernier scale is attached to the carriage by two Phillips-head screws which pass through dragged holes in the scale to provide flexibility for minor adjustment. Follow the procedures set forth in paragraph 3.8 to determine precise half wavelength points along the main scale. Loosen the Phillips-head screws, set 0 on the vernier to correspond to the exact position in centimeters on the main scale, and tighten the screws.

7.7.2 MAIN SCALE.

The main scale can be adjusted in height and depth at four points along its length to make its surface flush with that of the vernier scale on the carriage and to set the gap between it and the vernier. (This gap should be approximately 0.005- to 0.010-inch.) The adjustment procedure is as follows:

a. Look between the scale and the front cover panel for the hex-shaped lock nuts behind the scale-attachment screws. Loosen these nuts with a thin, 1/4-inch, open-end wrench.

b. Adjust the four screws until the main scale is flush with the vernier at these four points.

c. Insert a shim (two thicknesses of scratch-pad paper) between the main and vernier scales at one of the four screw-adjustment points.

d. Press the main scale up to touch the shim and hold it there.

e. Tighten the main-scale locknut nearest the carriage position, release the scale, and remove the shim.

f. Repeat the above at the other adjustment points, until a uniform scale-to-vernier spacing is achieved for the full length of probe travel.

7.8 ADJUSTMENT OF DRIVE-CORD TENSION.

The nylon drive cord will stretch slightly with time and cause slippage on the drum. A take-up reel on the back of the carriage can be used to adjust the cord tension. The inner flange of the reel has a number of holes around its outer edge; a pin, on the carriage body, enters one of the holes to provide a lock. To turn the reel, first pull it out about 1/16 inch to withdraw the pin from the hole in the flange. Then, rotate the reel to produce the desired cord tension, and push it in so that the pin enters one of the holes.

7.9 REPLACEMENT OF DRIVE CORD
(See Figure 7-1).

The Nylon drive cord should last indefinitely unless accidentally cut. Replacement cords can be obtained from General Radio Company. The cord is 74 inches long; the part number is 0874-0490.

The procedure for restringing is as follows:

a. Prestretch the cord with a 15-pound load for several hours.

b. Place the slotted line on a padded bench, front panel down with the cover open, underside up.

c. Pass one end of the cord through the 5/64-inch-diameter hole in the anchor post on the carriage and form a knot at the end.

d. Pass the free end around the top of the idler pulley one-half turn.

e. Continue the cord over to the drive drum and pass it one-half turn from the underside.

f. Pass it around once more in the same direction with a turn toward the front of the slotted line for 1½ total turns on the drum.

g. Pass the end one-half turn around the top of the anchor post outside the start, then around the shaft of the reel, at least one turn from the underside.

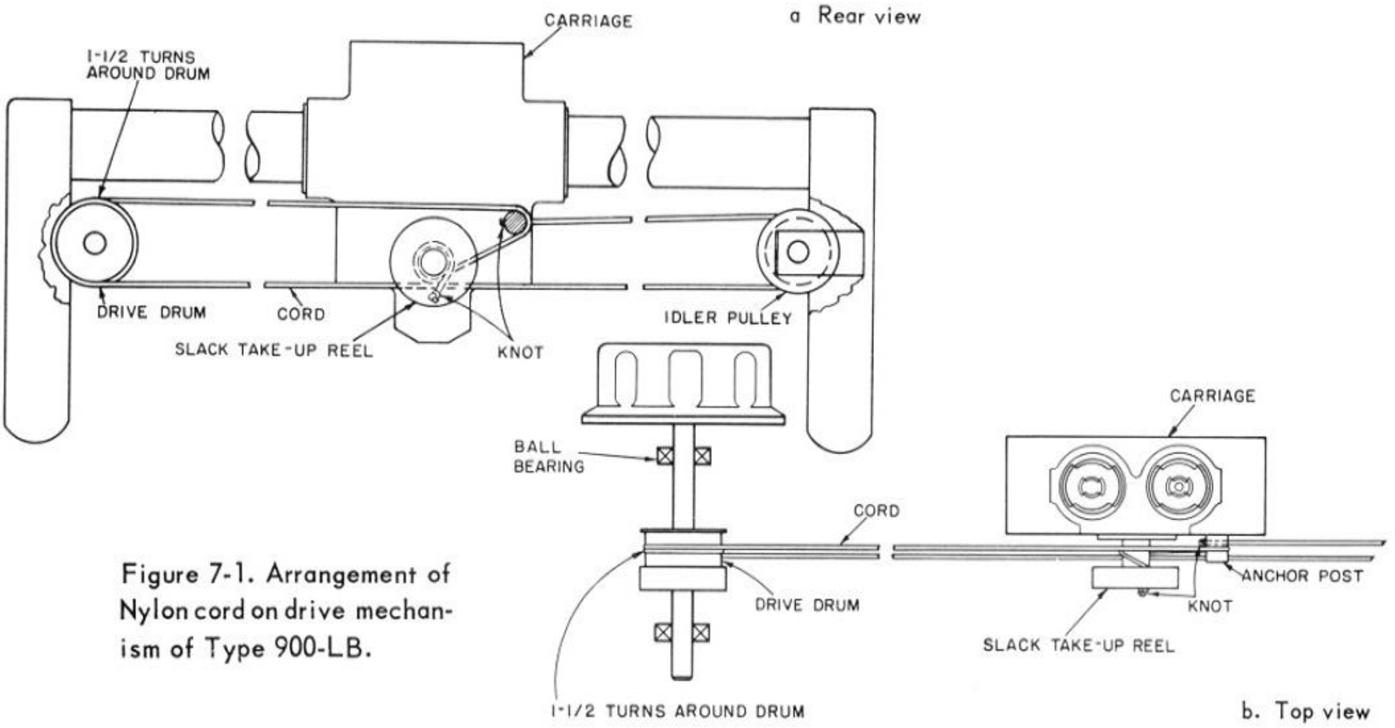
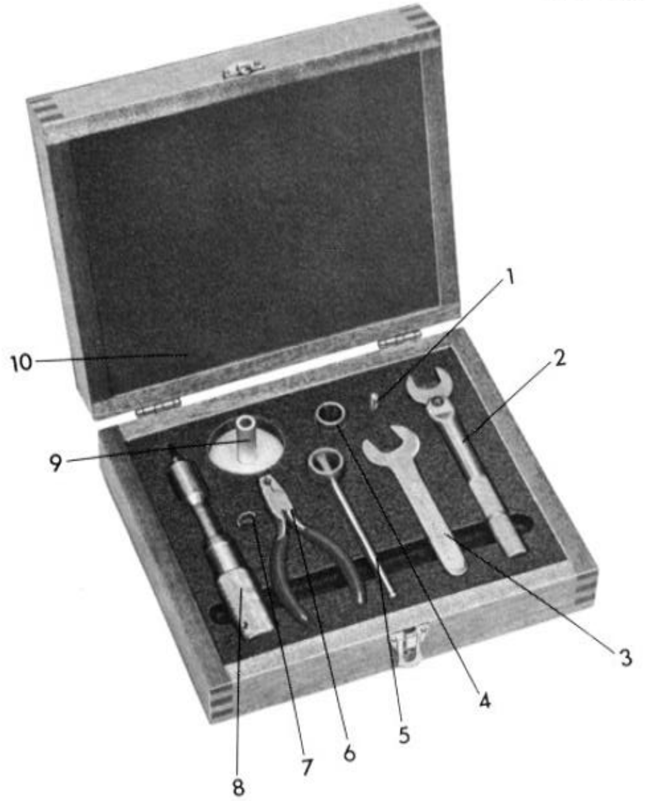


Figure 7-1. Arrangement of Nylon cord on drive mechanism of Type 900-LB.

h. Thread it through the 5/64-inch hole in the reel from the inside and knot it approximately two inches away. Cut off any surplus.

i. Release the lock and turn the reel clockwise to take up the slack in the cord, and adjust for proper tension.

j. Check the alignment of the idler pulley and cord; adjust the idler if necessary.



1. Inner-Conductor Injector
2. Coupling-Nut Torque Wrench
3. Open-End Wrench
4. Bead Compressor Sleeve
5. Gear-Ring Wrench
6. Inner-Conductor Plier
7. Spring-Contact Wrench
8. Bead Pusher
9. Inner-Conductor Torque Wrench
10. Case

Figure 7-2. Type 900-TOK Tool Kit.

7.10 CONNECTOR TOOLS.

7.10.1 TYPE 900-TOK TOOL KIT.

The Type 900-TOK Tool Kit includes the tools required to remove the gear-ring nut, coupling nut and spring contact from the GR900 connector. From a service standpoint, they should require removal only if the contact surfaces need to be cleaned to preserve a high-performance connector junction. The tool kit contains the items shown in Figure 7-2. Use the open-end wrench (tool 3) to offset rotational stress on the connector outer conductor when the gear-ring nut is removed with tool 5.

CAUTION

Further connector disassembly can permanently damage the slotted line.

APPENDIX A

GR900 ADAPTORS

The availability of precision adaptors from the GR900 series to other popular coaxial connectors means that the user of GR900-equipped instruments can convert to other series and still retain precision performance. For example, a Type 900-LB Precision Slotted Line equipped with a Type 900-QBJ or −QBP Adaptor becomes a type BNC slotted line with an over-all residual VSWR (line plus adaptor) of only 1.022 at 1 Gc/s. Conversely, users of instruments equipped with BNC, TNC, N, C, and GR874 Connectors can, by means of adaptors, take advantage of the precision offered by GR900 tuners, air-line standards, terminations, and other elements.

Each GR900 Adaptor includes a Type 900-BT Precision Coaxial Connector and an optimally designed connector of the other series. When ordering, note that the suffix letter "J" or "P" denotes the type of other-series connector (jack or plug) *included* in the adaptor. To obtain an adaptor to mate with a BNC plug, therefore, one would order a Type 900-QBJ Adaptor.

The Adaptor Flange (Catalog No. 0900-9782) listed in the table below threads onto a Type 900-BT Connector in place of the gear ring and locking nut to connect GR900 components to bridges and other instruments that terminate in a flat-plane surface or to other flange-type connectors.

SPECIFICATIONS

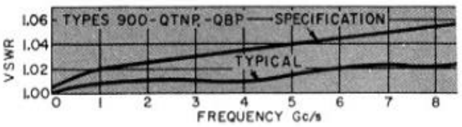
Frequency Range: Dc to 8.5 Gc/s.

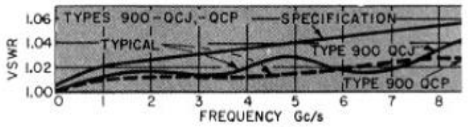
Characteristic Impedance: 50 Ω.

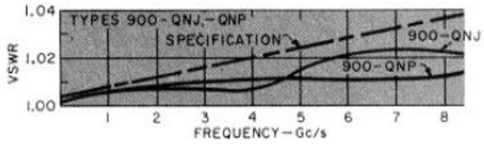
VSWR: See curves.

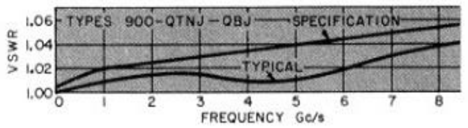
Maximum Voltage: Types 900-QBJ, -QBP, -QTNJ, -QTNP, 500 V; Types 900-QCJ, -QCP, -QNJ, -QNP, 1000 V; Type 900-Q874, 1500 V.

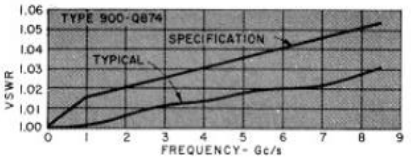
Maximum Power: Types 900-QBJ, -QBP, -QTNJ, -QTNP, 3 kW; Types 900-QCJ, -QCP, -QNJ, -QNP, 7 kW; Type 900-Q874, 10 kW. These values apply at 1 Mc/s; at higher frequencies maximum power varies inversely with the square root of frequency.











Adaptor to	*Type*	*Contains GR900 and*	*Connects GR900 to*	*Net Weight*	*Length*	*Catalog Number*
Type BNC	**900-QBJ** 	BNC Jack	**BNC Plug**	3½ oz (100 g)	2¹⁄₁₆ in (53 mm)	0900-9701
	900-QBP 	BNC Plug	**BNC Jack**	4 oz (115 g)	2⅛ in (54 mm)	0900-9801
Type C	**900-QCJ** 	C Jack	**C Plug**	3½ oz (100 g)	1⅞ in (48 mm)	0900-9703
	900-QCP 	C Plug	**C Jack**	4 oz (115 g)	2¹⁄₁₆ in (53 mm)	0900-9803
Type N	**900-QNJ** 	N Jack	**N Plug**	3½ oz (100 g)	2¼ in (58 mm)	0900-9711
	900-QNP 	N Plug	**N Jack**	4 oz (115 g)	2⁵⁄₁₆ in (59 mm)	0900-9811
Type TNC	**900-QTNJ** 	TNC Jack	**TNC Plug**	3½ oz (100 g)	2¹⁄₁₆ in (53 mm)	0900-9717
	900-QTNP 	TNC Plug	**TNC Jack**	4 oz (115 g)	2¹⁄₁₆ in (53 mm)	0900-9817
GR874	**900-Q874** 	GR874	**GR874**	3½ oz (100 g)	2⁹⁄₁₆ in (65 mm)	0900-9883
Flat Surface		Flange adaptor; converts any GR900 connector to a flange connector.		3 oz (85 g)		0900-9782

GR900 CONNECTORS

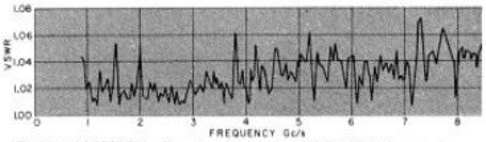
Type 900-C9 PRECISION COAXIAL CABLE CONNECTOR

Cable-connector counterpart of the Type 900-BT. The VSWR of this connector is much lower than that of even the best-made cables.

The braid-retention system does not compress the cable, yet has good torque resistance. The usual distortion and flow of cable dielectric during inner-conductor soldering have been virtually eliminated by means of a Teflon spacer and a special, low-temperature solder supplied with every connector. All inner-conductor parts are firmly captured in place.

Although designed for RG-9B/U and RG-214/U cable, the Precision Cable Connector can be used with the following other cables with some sacrifice in performance or mechanical reliability: RG-8/U, RG-8A/U, RG-10A/U, RG-87A/U, RG-116/U, RG-156/U, RG-165/U, RG-166/U, RG-213/U, RG-215/U, RG-225/U, and RG-227/U.

The Type 900-TOK Tool Kit is recommended for assembling this connector.



Typical VSWR of a single Type 900-C9 Connector on an "infinite" length of RG-214/U Cable.

Frequency Range: Dc to 8.5 Gc/s. **Characteristic Impedance:** 50 Ω.
Leakage: Better than 130 dB below signal.
Insertion Loss: $<0.006\sqrt{f_{Gc}}$ dB per pair. **Max Voltage:** 1500 V peak.
Dimensions: Length of one connector, $2\frac{1}{8}$ in (54 mm); maximum diameter, $1\frac{1}{16}$ in (27 mm). **Net Weight:** $2\frac{1}{2}$ oz (75 g).

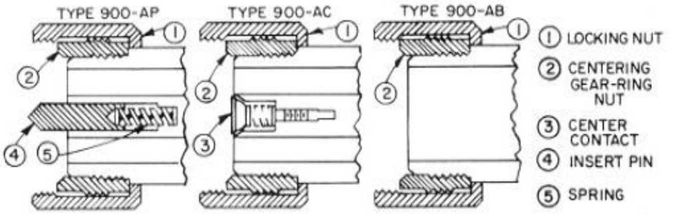
Catalog No.	*Description*
0900-9421	**Type 900-C9 Precision Coaxial Cable Connector**

GR900 LABORATORY PRECISION CONNECTOR KITS

Three kits are available for custom fabrication of air lines and terminations compatible with the GR900 Connector.

TYPE 900-AP LABORATORY PRECISION CONNECTOR KIT is for use on elements having unsupported inner conductors. A reference air line can be assembled from a pair of these kits and appropriate lengths of precision rod and tube. The kit consists of GR900 coupling nut, centering gear ring, and a spring-loaded centering pin, which allows the inner conductor of a beadless air line to derive its support from the mating Type 900-BT Connector. Air lines from 5 to 30 cm long can be machined from the GR precision rod and tube described below.

TYPE 900-AC LABORATORY PRECISION CONNECTOR KIT contains the locking nut, centering gear ring, and center contact of a standard GR900 Connector. It can be used in place of the Type 900-BT on any component whose inner conductor is supported within the component itself. Since it includes only those parts necessary in such applications, this kit offers the user superior electrical performance at a considerable saving in cost.



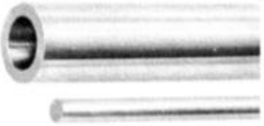
TYPE 900-AB LABORATORY PRECISION CONNECTOR KIT is like the Type 900-AC Kit in appearance and function, except that it does not contain the GR900 center contact. Thus it can be used to fabricate an air line to be mated with a Type 900-BT Connector, but it cannot mate with a Type 900-LZ Reference Air Line or with another Type 900-AB Connector.

TYPE 900-PKM PANEL MOUNTING KIT is used to equip standard Types 900-BT and 900-C9 Connectors for panel mounting. The kit includes a threaded flange, which accepts the outer conductor and mounting hardware.

Catalog Number	*Description*	*Net Weight (oz - g)*	*Length (in - mm)*
0900-9402	**Type 900-AB Laboratory Precision Connector Kit**	1 - 30	$1\frac{3}{16}$ - 31
0900-9404	**Type 900-AC Laboratory Precision Connector Kit**	1 - 30	$1\frac{3}{16}$ - 31
0900-9406	**Type 900-AP Laboratory Precision Connector Kit**	$1\frac{1}{4}$ - 35	$1\frac{1}{4}$ - 32
0900-9498	**Type 900-PKM Panel Mounting Kit**	1 - 30	$1\frac{3}{16}$ - 31

Type 900-PKM

PRECISION ROD AND TUBE



Used in fabrication of custom-length air lines and components, in conjunction with GR900 Connectors and Connector Kits. Diameters are specified at 23°C. Both rod and tube have been stress-relieved to minimize dimensional changes during machining.

PRECISION INNER-CONDUCTOR ROD Centerless-ground, silver-layered brass rod stock with a nominal 0.24425-in diameter.
Length: 26 in (660 mm). **Straightness:** 0.002 in/foot.
Diameter Accuracy: ±65 microinches. **Uniformity:** ±25 microinches.
Surface Finish: 20 microinches, maximum.

PRECISION OUTER-CONDUCTOR TUBE Precision-forged, silver-lined brass tubing with a nominal OD of 0.830 in and a nominal ID of 0.5625 ($\frac{9}{16}$) in. Nominal wall thickness is 0.134 in.
Length: 26 in (660 mm). **Straightness of ID:** 0.005 in/foot.
Inner-Diameter Accuracy: ±140 microinches.
Inner-Surface Finish: 30 microinches, maximum.

Catalog No.	*Description*	*Net Weight*
0900-9508	**Precision Inner-Conductor Rod**	7 oz (200 g)
0900-9509	**Precision Outer-Conductor Tube**	$2\frac{1}{2}$ lb (1.2 kg)

Type 900-TOK
TOOL KIT

Nine-piece tool kit in fitted case for convenient installation of Types 900-BT and 900-C9 Precision Coaxial Connectors on suitable air line or component. Complete instructions for use of tools are supplied with each connector to simplify assembly and to ensure precision results.

Catalog No.	*Description*	*Net Weight*
0900-9902	**Type 900-TOK Tool Kit**	2 lb (1 kg)