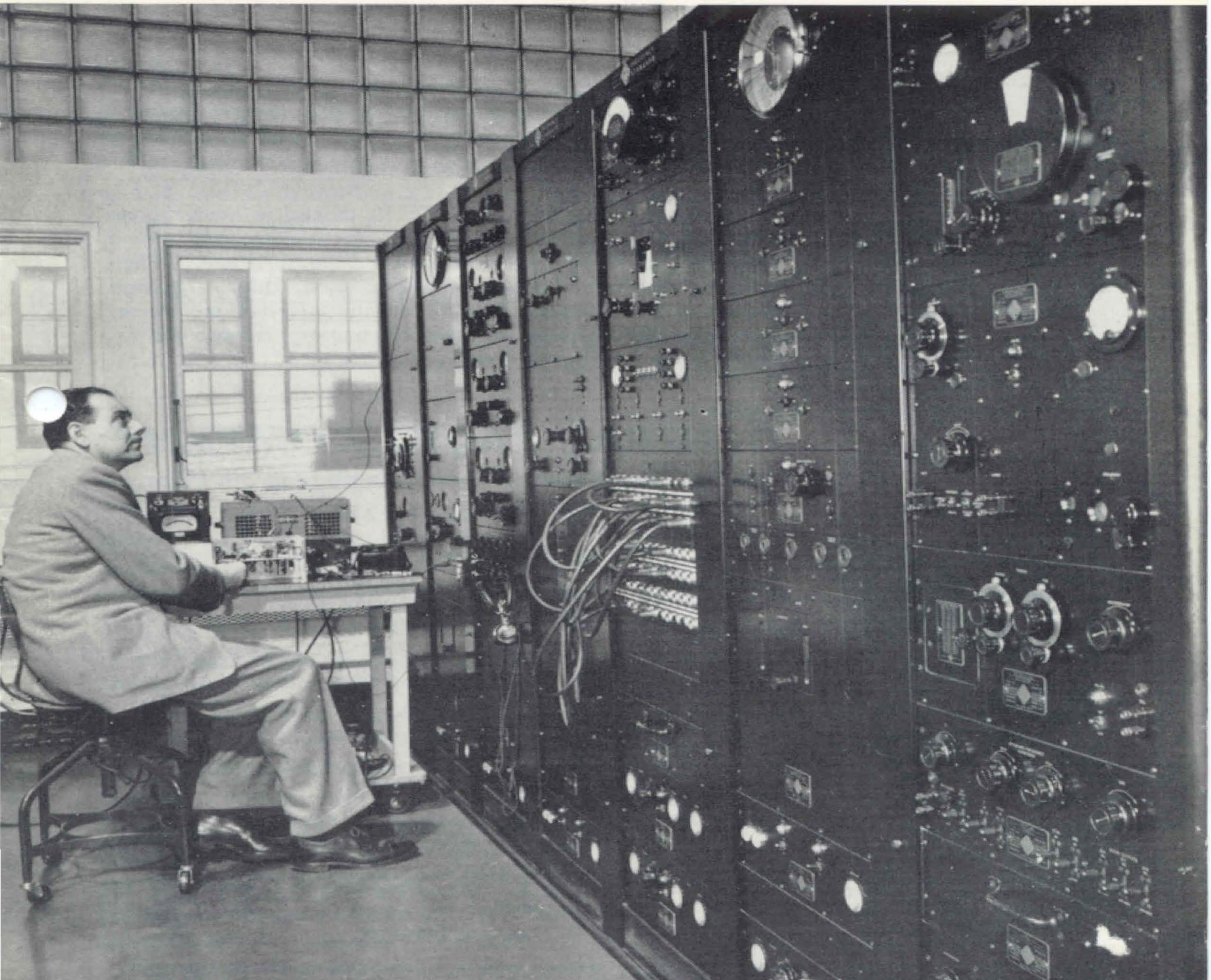
the GENERAL RADIO Experimenter

Since 1915 - Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 32 No. 1 JUNE, 1957



In This Issue

Measurement of Cable Characteristics, Part II

the GENERAL RADIO Experimenter

Published Monthly by the General Radio Company

VOLUME 32 • NUMBER 1 **JUNE, 1957**

CONTENTS

Page

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY

275 Massachusetts Avenue, Cambridge 39, Mass.

Telephone: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK: Broad Avenue at Linden, Ridgefield, New Jersey
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: 920 South Michigan Ave., Chicago 5, Illinois
Telephone — WAbash 2-3820

PHILADELPHIA: 1150 York Road, Abington, Pennsylvania
Telephone — HAncock 4-7419

WASHINGTON: 8055 13th St., Silver Spring, Maryland
Telephone — JUniper 5-1088

LOS ANGELES: 1000 North Seward St., Los Angeles 38, Calif.
Telephone — HOllywood 9-6201

SAN FRANCISCO: 1182 Los Altos Ave., Los Altos, Calif.
Telephone — WHitecliff 8-8233

REPAIR SERVICES

WEST COAST: Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.
Telephone — VIctoria 9-3013

CANADA: Bayly Engineering, Ltd., First St., Ajax, Ontario
Telephone — Toronto EMpire 8-6866

COVER

At General Radio we have been manufacturing frequency standards for the electronics industry since 1916. The frequency standard shown here includes four piezo-electric oscillators, with means for intercomparing their frequencies. It supplies standard frequencies and standard time throughout our Cambridge plant. The frequency is constant within five parts in 10^8 per month and is known at all times to 2 parts in 10^8.

THE MEASUREMENT OF CABLE CHARACTERISTICS (Part II)

MEASUREMENT OF ATTENUATION (α) OF COAXIAL CABLES AT 400 MC AND 3000 MC

Military specifications (MIL-C-17B) require that for quality control the attenuation of all high-frequency cables be measured at 400 Mc and, in most cases, also at 3000 Mc. Low-frequency cables are usually measured at 1 Mc. For both the 400-Mc and 3000-Mc measurements the insertion-loss method is recommended. This method can be used for all cable types. The insertion-loss method and its practical application using commercially available equipment are described in detail below.

METHOD OF MEASUREMENT

The measuring setup consists of a constant-output signal source, a cable sample to be measured, and a heterodyne-type detector having a step attenuator and an indicating meter that are accurately calibrated in decibels. The signal source and the detector are made up of the components shown within the dashed boxes of Figure 4. Changes in signal level into the detector are directly measured in terms of the corresponding changes in attenuator setting and meter reading.

To make a measurement, the signal source is first connected to the detector, the detector (attenuator plus meter) reading is noted; then the cable sample is inserted between the signal source and the detector, and the new detector reading is noted. The insertion loss of the sample in decibels equals the difference between the two detector readings.

The insertion loss measured as above is made up of the attenuation loss of the cable sample (which is the quantity to be determined) plus any reflection losses that may occur at the junctions between the signal source, cable, and detector. Pads are used at the signal source output and detector input, and if the impedance of the cable sample matches the impedance of the pads, the reflection losses are zero, and measured insertion loss equals attenuation loss of the sample. If the impedance of the cable sample does not match the impedance of the pads, then at each junction a reflection loss occurs, and their combined value is subtracted from measured insertion loss to obtain attenuation loss of the sample. A discussion of the nature of reflection losses and how to determine them will be found later in this paper.

DETAILS OF EQUIPMENT[6]

Signal Source: The signal source consists of a Unit Oscillator (TYPE 1208-B for 400 Mc or TYPE 1220-A2 for 3000 Mc), a TYPE 1201-A Unit Regulated Power Supply, a TYPE 874-G10 10-db Pad next to the oscillator, and a second 10-db pad next to the cable sample (see paragraph after next). At 400 Mc the use of a TYPE 874-F500 500-Mc Low-Pass Filter is recommended.

Detector: The heterodyne-type detector consists of a 20-db input pad (see next paragraph), a crystal mixer (TYPE 874-MR Mixer Rectifier), a local oscillator (TYPE 1209-B Unit Oscillator), and a 30-Mc i-f amplifier with step attenuator and meter, both accurately calibrated (TYPE 1216-A Unit I-F Amplifier). The mixer combines the signal input and the

[6] General Radio equipment required is listed briefly at the end of this article. For detailed specifications, see G. R. catalog, or write for them.

local-oscillator output (set to the proper frequency) to produce a beat at 30 Mc, which is amplified and measured by the i-f amplifier. With adequate level supplied by the local oscillator to the mixer, the amplitude of the 30-Mc beat is proportional to the signal input level, so that attenuation measurements can be made very accurately by means of the calibrated attenuator and meter in the i-f amplifier.

Pads: The type of pad used at the signal source output and detector input depends on frequency and on cable impedance. At 400 Mc for all cables up to 100-ohm impedance and at 3000 Mc for 50-ohm cables, Type 874-G10 10-db Pads are most conveniently used. At 400 Mc for cables above 100-ohm impedance and at 3000 Mc for cable impedances other than 50 ohms, use appropriate lengths (so as to obtain approximately 10 db attenuation in each) of the same type cable as that being measured.

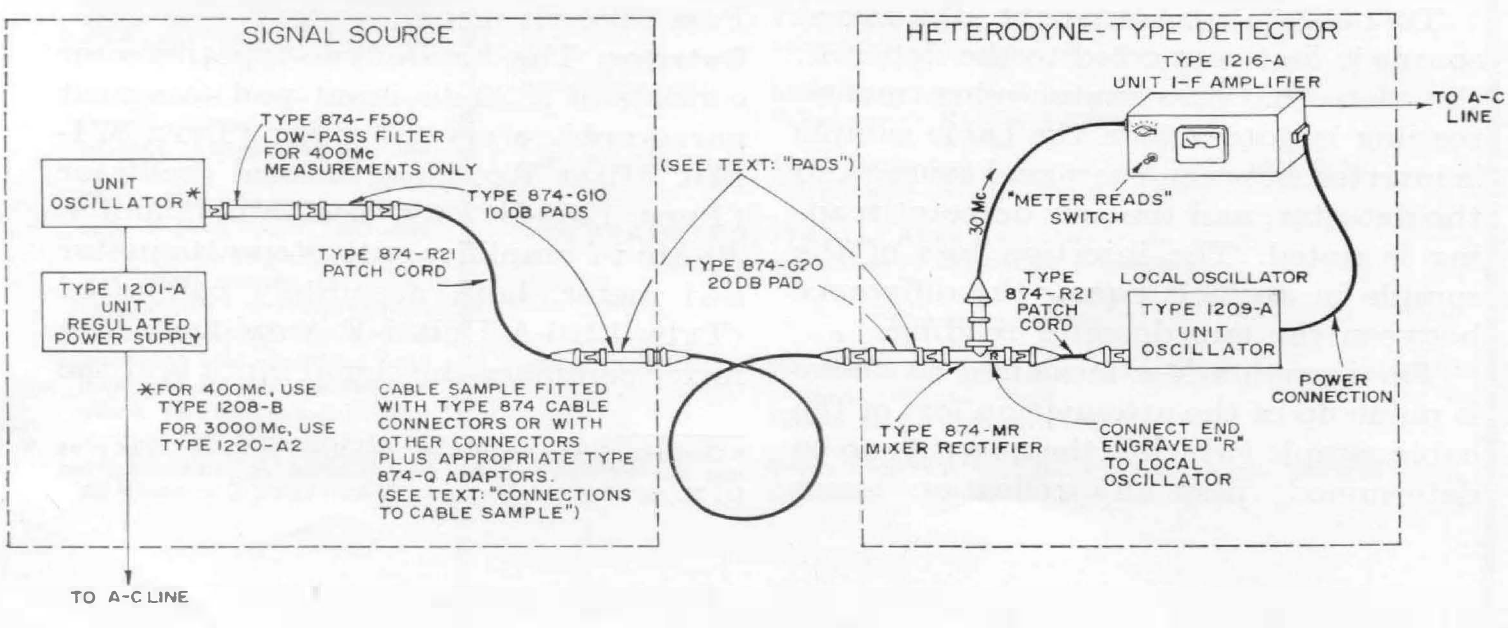
Connections to Cable Sample: The cable sample should be fitted with suitable connectors for making reliable connections to the measuring apparatus. Available Type 874 Cable Connectors can be used on many different standard cables,[7] or if standard military connectors are used, appropriate Type 874 Adaptors can be used to make the connections to the Type 874 Connectors at the signal source and detector. The use of Type 874 Connectors for attenuation measurement purposes is recommended where possible, because they can be installed on cables considerably more easily and quickly than other connectors and can be re-used many times.[8] Cables that cannot be fitted with Type 874 Connectors can be fitted with Type N, Type BNC, Type C, Type HN, Type LC, or Type UHF connectors, and adaptors

[7] For example, Type 874-C can be fitted to RG numbers 5, 6, 21, 126, and 143; Types 874-C8 and 874-C9 can interchangeably be fitted to RG numbers 8 through 13, 63, 79, 114, 115, 144, and 146; Type 874-C58 can be fitted to RG numbers 22, 55, 58, 111, 122, 141, and 142; and Type 874-C62 can be fitted to RG numbers 59, 62, and 140. Other combinations can probably be improvised. In many of these cases the fit to the cable will not be excellent mechanically, but it will be satisfactory as a temporary method of connection for measurement purposes. In installing these connectors, the rubber cable guard can be omitted, the armor of armored cables must be cut back, and the outer braid of double-shielded cables may not always fit under the braid-clamping ferrule, in which cases only the inner braid is used.

[8] The braid-clamping ferrules cannot usually be re-used, but they are available separately and inexpensively.

For cable connector type	*Ferrule type*	*Ferrule price*
874-C, C8	FEC-3	10 for $1.00
874-C58	FEC-2	10 for $1.00
874-C62	FEC-7	10 for $1.00
874-C9	FEC-9	10 for $1.00

Figure 4. Setup for the measurement of attenuation in coaxial cables at 400 and 3000 Mc.



from plug and jack versions of all of these to TYPE 874 are available.[9]

Length of Sample: The choice of sample length of a cable is usually a balance between measurement accuracy, which improves with longer samples, as will be discussed later, and practical considerations, which generally, though not always, make shorter lengths preferable. A maximum limit on the length is set by the sensitivity of the detector and power output of the oscillator. Expressed in terms of the attenuation of the sample, this limit is about 60 to 80 db.

The accuracy of the over-all measuring system can be checked at any time merely by measurements with the TYPE 874-G10 10-db signal source output pad in and out of the circuit. The change in reading when the pad is removed should equal the known attenuation of the pad.

ADJUSTING THE EQUIPMENT

Detector: The local-oscillator frequency is set to 370 Mc for a 400-Mc measurement or to 742.5 Mc for a 3000-Mc measurement. In the latter case, the 2970-Mc fourth harmonic of the local oscillator is generated by the mixer to produce a 30-Mc beat with the 3000-Mc signal frequency. In either case, tune the local oscillator for maximum i-f amplifier meter deflection after the signal source has been set to proper frequency of measurement as outlined below. The output coupling loop on the local oscillator should be adjusted to produce between 25% and 100% deflection of i-f amplifier meter when METER READS switch on amplifier is set to D-C MIXER CURRENT.

Signal Source: For 400-Mc measurements, the dial of the TYPE 1208-B Unit Oscillator is set to 400 and the output coupling loop adjusted to give a convenient level at the detector. For 3000-Mc measurements, the TYPE 1220-A2 Unit Klystron Oscillator must be set to 3000 Mc and its repeller voltage adjusted for maximum output.

When the oscillator is first turned on, allow a few minutes for warm-up. Since it does not have a frequency calibration, the klystron oscillator is set by using the local-oscillator frequency calibration as follows. (Once set, the frequency seldom needs to be readjusted.)

1. Connect detector to signal source, omitting the 20-db pad and the adjacent 10-db pad, disconnect local oscillator from mixer, set METER READS switch on i-f amplifier to D-C MIXER CURRENT, and adjust klystron oscillator REPELLER VOLTAGE control for maximum deflection of meter on i-f amplifier. This produces maximum output level from klystron oscillator for whatever frequency it happens to be set initially.

2. Set METER READS switch to I-F OUTPUT, reconnect local oscillator to mixer, and adjust local-oscillator frequency to produce two strong deflections of the i-f amplifier meter separated by 15 Mc on the local oscillator dial. If the klystron oscillator happens by luck to be set at 3000 Mc, then the two settings of the local oscillator dial will be at 742.5 Mc and 757.5 Mc respectively. If not, then use a screwdriver to readjust klystron-oscillator frequency, repeating steps 1 and 2 until these two frequency readings are obtained on local-oscillator dial. There also may be two very weak deflections in between the 15-Mc-spaced strong deflections, and these are beats

9

Military connector	*Adaptor Type* *with jack*	*with plug*
Type N	874-QNJ	874-QNP
Type BNC	874-QBJ	874-QBP
Type C	874-QCJ	874-QCP
Type HN	874-QHJ	874-QHP
Type UHF	874-QUJ	874-QUP
Type LC	874-QLJ	874-QLP

with harmonics of the klystron oscillator frequency, but they are so much lower in level that they cause no ambiguity.

ACCURACY

The accuracy of measurement is determined by the accuracy of the attenuator-meter combination in the i-f amplifier. The maximum error is 1 per cent of the attenuation value being measured plus a fixed error of 0.3 db. Since the measurement is always made at the intermediate frequency of 30 Mc, accuracy is independent of the measurement frequency. Because of the fixed error, the total error expressed in per cent of the attenuation value being measured is less for higher attenuation values; so it is desirable to use fairly long cable samples. For example, the maximum over-all error when measuring 6 db of attenuation is 6 per cent, while for 20 db it is 2.5 per cent, as shown in Figure 5.

The Type 1201-A Unit Regulated Power Supply prevents errors due to fluctuation of the signal source output during a measurement. The use of 50-ohm pads at the ends of the cable sample makes reflection losses at these junctions negligible for cables having characteristic impedance values near 50 ohms. When cables having other values of impedance are measured, the reflection losses are usually accurately known and can be subtracted from the measured insertion loss to obtain the true attenuation loss of the sample, as discussed in detail in the next section, or lengths of cable of the same type as being measured can be used as pads, thus eliminating reflection losses.

EFFECT OF IMPEDANCE MISMATCH

In general, the insertion loss of a network is made up of attenuation loss, representing essentially the power absorbed by the network, and reflection losses caused by impedance-level changes at the input and output junctions. Since, in the method previously described, the attenuation loss of a cable sample is for most cable types determined by measurement of its insertion loss in a 50-ohm measuring system, the reflection losses must be considered as possible sources of error when the cable characteristic impedance is not 50 ohms, and either their effects must be made negiligible or corrections must be made.

Reflection loss can be explained as follows. When energy traveling along a uniform system encounters an impedance discontinuity, a portion of the energy is reflected back to the source, so that the energy transmitted beyond the discontinuity is less than the incident energy by the amount of the reflected energy, thus resulting in a "reflection loss." The magnitude of this reflection loss for a single junction is:

$$10 \log_{10}\left(\frac{1}{1 - |\Gamma|^2}\right) \text{ decibels,}$$

in which $|\Gamma|$ is the absolute magnitude of the reflection coefficient of the junction and is directly related to the voltage-standing-wave ratio (VSWR)

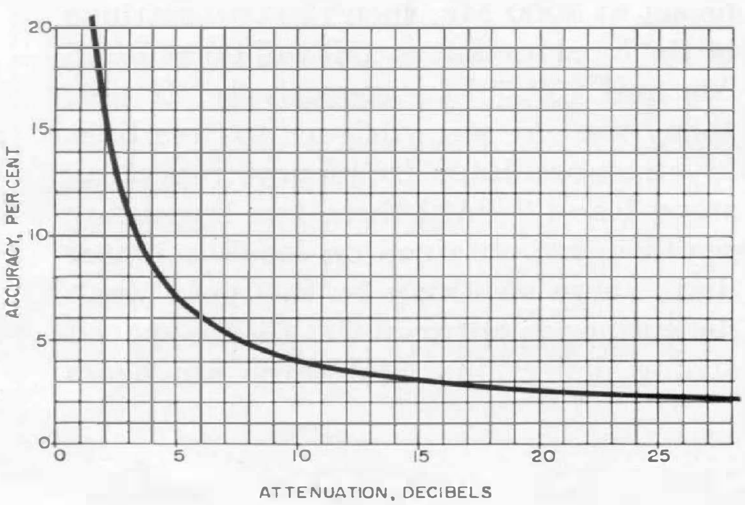


Figure 5. Variation of measurement accuracy with cable sample attenuation.

as follows:[10]

$$|\Gamma| = \frac{(VSWR) - 1}{(VSWR) + 1}$$

Fortunately, the VSWR must be fairly high before any significant amount of reflection loss is produced; for example, a VSWR of 1.25 corresponds to a reflection loss of only 0.05 db, while a VSWR of 2.00 corresponds to a loss of 0.5 db.

If the cable sample being measured in the 50-ohm system does not have a characteristic impedance of 50 ohms, two equal discontinuities exist, one at each end of the cable sample. As a result, there are two equal reflection losses, each of which can be calculated from the equations in the above paragraph. In addition, multiple reflections are set up in the cable sample between the junctions, and these can modify the reflection losses by an amount depending on the electrical length of the cable sample and on the frequency and thus cannot be corrected for by a simple calculation. The multiple reflections are rapidly attenuated in traveling through the cable sample and can be made negligible by the use of a long sample.

For example, to take an extreme case, suppose the VSWR of the junctions is 2.00, as it would be for a 100-ohm cable sample. Then, if the attenuation of the cable sample is about 10 db, the maximum possible error caused by multiple reflections is only ± 0.1 db. The normal calculated reflection loss at each junction is, as mentioned earlier, 0.5 db, so the total reflection loss for both junctions is 1.0 db. Suppose that the measured insertion loss of the 100-ohm cable sample in this example turns out to be 11.2 db. The desired attenuation loss is found by subtracting the calculated total reflection loss of 1.0 db from the measured insertion loss of 11.2 db, giving a final answer of 10.2 db with an uncertainty of ± 0.1 db, or ± 1%, owing to multiple reflections.

Figure 6 gives values of the total reflection loss of both junctions as a function of VSWR and also as a function of the characteristic impedance of the cable sample. (The references to twin-conductor cables and to the 200-ohm impedance level will be explained later.) It was pointed out in the previous paragraph that this loss is small, and the curve shows in addition that cable characteristic impedance need be known only approximately in order to obtain a sufficiently accurate value for the reflection-loss correction. For example, the correction is 0.36 db for 75-ohm cables and 0.28 db for 71-ohm cables; so it seems reasonable to use a rounded-off correction of 0.3 db for both types.

The maximum possible magnitude of the error caused by multiple reflections can be determined from Figure 6 and is equal to the number given for the reflection loss reduced by twice the cable attenuation; *e.g.*, if cable attenuation is 10 db, reduction is 20 db or 10 to 1.

[10] Γ is also related to the impedance levels on both sides of the junction as follows: $\Gamma = \frac{Z - Z_0}{Z + Z_0}$, in which Z_0 is the characteristic impedance of the uniform system up to the junction, and Z is the input impedance of the system beyond the junction. Also, the ratio of reflected power to incident power is equal to $|\Gamma|^2$. VSWR equals $\frac{Z}{Z_0}$ or $\frac{Z_0}{Z}$, whichever is greater than unity, if Z and Z_0 are both real.

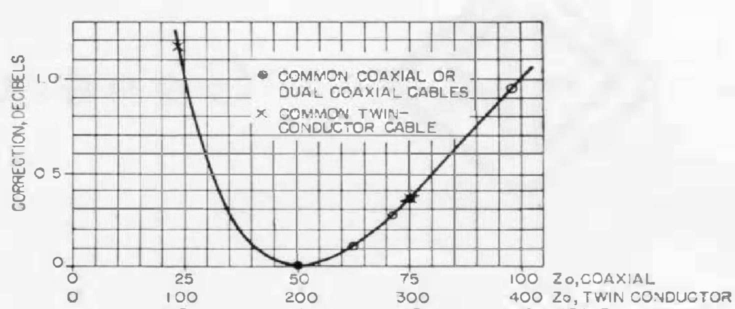


Figure 6. Reflection-loss correction (to be subtracted) vs. cable impedance and VSWR.

For a VSWR of 2.00, Figure 6 gives a reflection loss of 1.0 db, so the maximum possible error due to multiple reflections is one-tenth of this, or 0.1 db.

If the cable sample cannot be made long enough to attenuate the multiple reflections sufficiently when a high VSWR exists, steps should be taken to reduce the mismatch. Suitable resistance pads[11] can be used if available, or other means can be devised to fit the particular conditions.

If the impedance of the cable to be measured is greater than 100 ohms, the reflection-loss correction is too large to allow good accuracy; so for such cables the use of pads matching the cables is recommended.[11]

The military specification MIL-C-17B requires that at 3000 Mc the pads and connectors at the cable sample must match the sample impedance.[11]

In summary, the use of a Type 874-G10 10-db pad at each end of the cable sample provides a known impedance termination suitable for many types of cable. When cables having characteristic impedances in the vicinity of 50 ohms are measured, reflection losses are negligible, and the measured insertion loss is equal to the attenuation. When cables having impedances other than 50 ohms are measured, the reflection losses can, in most instances, be calculated, or determined directly from Figure 6, and subtracted from measured insertion loss to obtain the true attenuation. Thus a single measurement setup can be used for nearly all cable types.

For other cable types, appropriate lengths of the same type cable replace the 50-ohm pads.

— W. R. Thurston

(To be continued.)

[11] Lengths of cable having the same characteristic impedance as the cable under test can be used as pads.

LIST OF EQUIPMENT

Quantity	*Item*	*Price*
1	Type 1216-A Unit I-F Amplifier	$335.00
1	Type 1208-B Unit Oscillator	200.00
1	Type 1220-A2 Unit Klystron Oscillator	272.90
1	Type 1209-B Unit Oscillator	235.00
1	Type 874-F500 Low Pass Filter	16.00
2	Type 874-G10 10-db Pads	50.00
1	Type 874-G20 20-db Pad	25.00
1	Type 874-MR Mixer Rectifier	32.50
1	Type 1201-A Unit Regulated Power Supply	85.00
2	Type 874-R21 Patch Cords (one supplied with each Unit Oscillator)	
	Type 874 Adaptors and Cable Connectors as required	

Note: Much of this equipment is also used for other measurements to be described in later articles of this series.

NATIONAL CONVENTION ON MILITARY ELECTRONICS

SHERATON PARK HOTEL WASHINGTON, D. C. Booth 89 JUNE 17-19

General Radio Company

PRINTED IN U.S.A.