A.B. CRITES
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An Analysis of the VSWR Characteristics of Amphenol Series 83 UHF R.F. Connectors

Introduction

Since the advent of solid dielectric coaxial cable, the UHF R.F. Connector has been extensively used in applications where ease of assembly, mechanical durability and economy are of primary importance and rigorous VSWR requirements are of secondary importance.

The familiar UHF connector with the mica-filled Bakelite bead has found a myriad of applications in the VHF Band and at lower frequencies. It has been and will continue to be the most utilitarian connector in applications where excellent VSWR characteristics are not of prime importance. The teflon bead UHF connector, while retaining the excellent mechanical properties of the mica-filled Bakelite bead UHF connector and to a large degree its attractive price, has the added usefulness of pushing the VSWR barrier well into the UHF Band. This analysis vividly shows that the teflon bead UHF connector is an effective bridge between the mica-filled Bakelite bead UHF connector and Types "N" and "C" R.F. connectors.

Within recent years, communications bands in the upper VHF and lower UHF ranges have found increasing use. The desirable price, assembly and mechanical characteristics of the UHF R.F. connector were ideally suited for these applications but the reflections introduced into an R.F. transmission system by the under-impedance mica-filled Bakelite beads of UHF connectors began to present a serious problem. Reflected power loss, due to the connectors, degraded the communications systems' power transfer characteristics in applications where such power losses must be rigidly controlled. For these applications, the teflon bead UHF connector will find increasing use.

The investigation of Amphenol's Series 83 UHF Connectors conducted by the Amphenol Engineering Department was motivated and performed in accordance with the following conditions:

A. It is well known that UHF connectors introduce substantial reflections into solid dielectric cable systems when frequencies in excess of 200 mc/s are encountered. The investigation should yield results which show the effect of these reflections (as indicated by the VSWR of the connectors) as a function of frequency.

B. VSWR measurements are to be performed with existing equipment which covers the frequency range of interest.

C. 20 mc/s will be the lowest test frequency since:

1. It is nearly impossible to construct an RF connector which would introduce a VSWR of more than 1.08 (Z_0 = 50 ohms) into a cable system at 20 mc/s or below unless good engineering practices are completely disregarded.
2. 20 mc/s is the lowest frequency at which existing equipment can be used.
3. Measuring system inaccuracy would completely "mask" the connector VSWR.

D. 500 mc/s will be the highest frequency since it is hard to visualize the use of the types of Bakelite or polystyrene bead structures which certain UHF connectors contain at higher frequencies and still exercise a degree of prudence when considering the economics of power transfer.

E. Basic theoretical considerations indicate that teflon bead structures are electrically superior to Bakelite beads in otherwise identical connectors. A comparative analysis should show this superiority as expressed by VSWR values.

F. Experimental accuracy of $\pm .1$ of a standing wave ratio will be considered satisfactory.

Abstract

This report covers the VSWR of Series 83 UHF Connectors for the frequency range 20 - 500 mc/s.

The mica-filled Bakelite beads of the 83-1SP and 83-1R connectors and the polystyrene bead of the 83-1J adapter are the principal causes for the high standing wave ratios introduced into solid dielectric coaxial cable R.F. systems when compared to similar connectors with bead structures of teflon (83-822, 83-798) or air (83-1J less polystyrene bead).

Experimental curves show the inferiority of the Bakelite and polystyrene beads, especially above 300 mc/s.

Measurement Technique

A General Radio Admittance Meter was used to measure the admittance of a GR 874-WM 50 ohm load which terminated a six inch length of RG-8/U (or RG-58A/U) cable. The cable was cut and the various mated Series 83 UHF Connector arrangements were assembled to the cable. The admittance of this new arrangement was measured.

The VSWR is obtained using the following relationships:

$$|K| = \frac{|Y_o - Y_m|}{|Y_o + Y_m|}$$

$$VSWR = \frac{1 + |K|}{1 - |K|}$$

where:

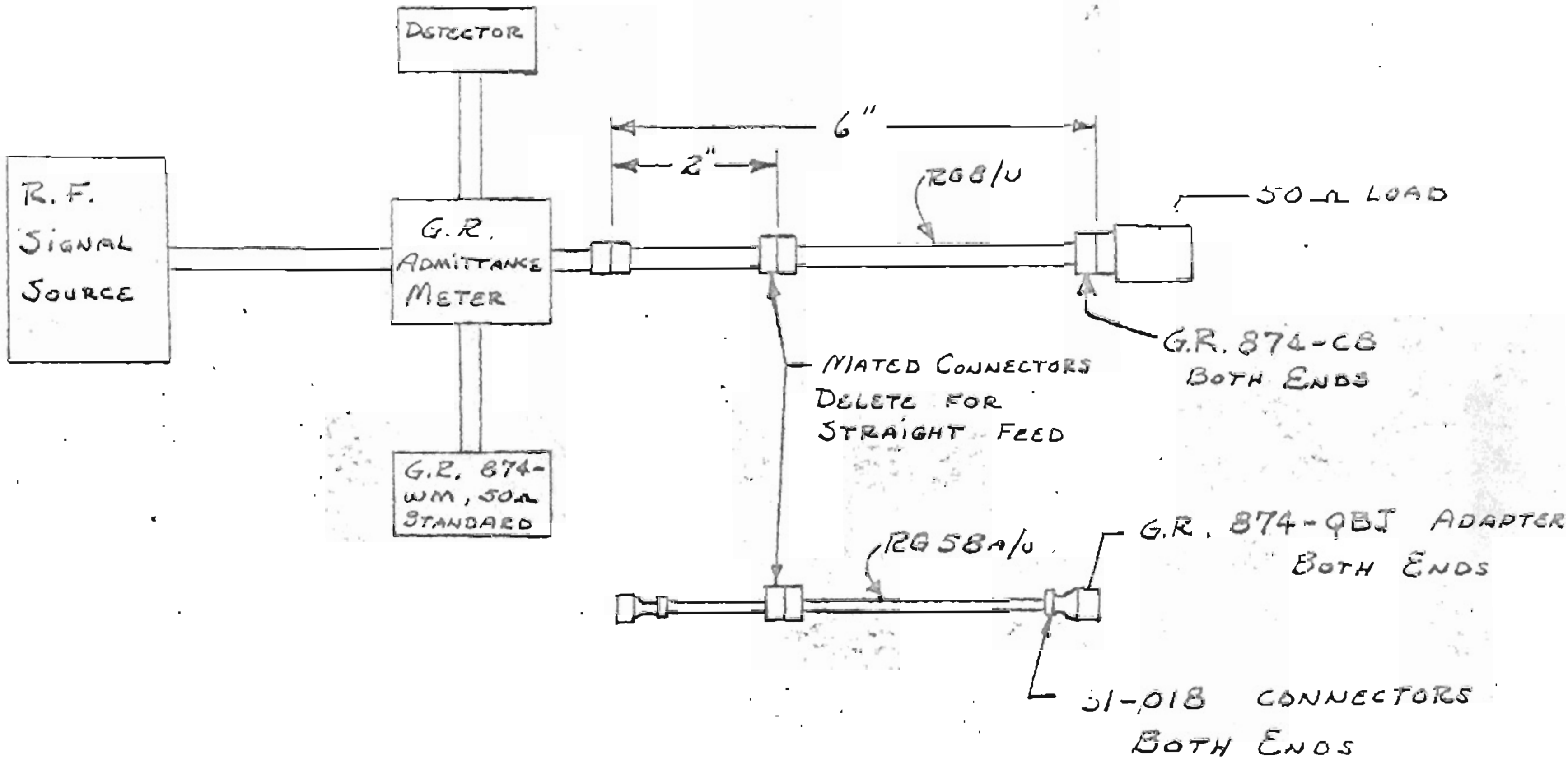
Y_o = Characteristic admittance, millimhos

Y_m = Measured admittance of load system or Series 83 Connectors and load, millimhos

$|K|$ = Absolute magnitude of reflection coefficient

VSWR = Voltage standing wave ratio with respect to Y_o.

Figure 1 depicts the measurement setup used.



EXPERIMENTAL SET-UP FOR MEASURING THE VSWR OF 83 SERIES CONNECTORS

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FIGURE 1

Accuracy of the Measurement Technique and General Considerations for the Proper Interpretation of VSWR Curves

The specifications on the accuracy of a Type 1602-B Admittance Meter are:

For both conductance and susceptance (up to 1000 mc/s):

From 0 to 20 millimhos ($3\% + 0.2$ millimho)

From 20 to ∞ millimhos ($3\sqrt{M}\% + 0.2$ millimho)

where M is the scale multiplying factor.

Translating these specifications into examples:

A. (1) Assume an unknown admittance of $20 \pm j0$ millimhos.

(2) Computation of error:

$\pm (.03)(20) + 0.2 = \pm .6 + 0.2$

using $+.6$, the error is: $+.8$ millimhos

(3) True VSWR $= 1.000$

(4) Apparent VSWR:

(Apparent admittance - 20.8)

$$K = \frac{Y_o - Y}{Y_o + Y} = \frac{20 - 20.8}{40} = \frac{.8}{40} = .02$$

$$VSWR = \frac{1 + K}{1 - K} = \frac{1 + .02}{1 - .02} = \frac{1.02}{.98} \approx 1.04$$

(5) Error is: .04 standing wave ratio.

B. (1) Assume an unknown admittance of $15.0 + j1.0$

(2) Computation of error:

Conductance:

$\pm(.03)(15) + 0.2 = \pm .45 + .2$

using $+ .45$; the error is: $+ .65$

B. (2) continued -

Susceptance:

$\pm(.03)(1) + 0.2 = \pm .03 + .2$

using + .03; the error is: + .23

(3) True VSWR:

$$K = \frac{Y_0 - Y}{Y_0 + Y} = \frac{5 - j1.}{35 + j1.} \approx \frac{5.1}{35} \approx .146$$

$$VSWR = \frac{1 + K}{1 - K} \approx \frac{1 + .146}{1 - .146} \approx \frac{1.146}{.854} \approx 1.34$$

(4) Apparent VSWR:

(Apparent admittance - 15.65 + j1.23)

$$K = \frac{Y_0 - Y_1}{Y_0 + Y_1} = \frac{4.35 - j1.23}{35.65 + j1.23} \approx \frac{4.83}{35.66} \approx .136$$

$$VSWR = \frac{1 + K}{1 - K} \approx \frac{1 + .136}{1 - .136} \approx \frac{1.136}{.864} \approx 1.31$$

(5) Error is: .03 standing wave ratio.

From the above examples it is evident that the accuracy of the Admittance Meter is approximately ± .05 standing wave ratio. Reading accuracy is estimated to be approximately ± .03 standing wave ratio.

The entire system accuracy is estimated to be in the ± .08 to ± .1 standing wave ratio range. When considering the following VSWR Curves, this basic inaccuracy must be kept in mind.

Whenever a mated connector VSWR curve approaches or is below the basic system curve without mated connectors, it is usually impossible to tell what the real VSWR of the mated connectors are because of the combined effects of reflections due to discontinuity capacitances and lower (or higher) impedance line sections. However, since the discontinuity capacitance effects of UHF connectors at or below 300 mc/s can be considered negligible, the major source of reflection is the "under impedance" bead structures used. A prima facie interpretation of the following curves would seem to indicate that the Bakelite bead connectors are superior to the teflon bead connectors below 250 mc/s. However, considering that the Bakelite bead connectors yield VSWR values lower than the basic system VSWR, it must be true that some reflection is being introduced in order to cancel out the basic system reflections.

Also, it must be true, as an engineering approximation, that the connector system which least upsets the basic system in these low frequency ranges truly has a lower VSWR than the measured value. Added to the validity of this assumption is the theoretical fact that the Bakelite beads with their higher dielectric constant yield a higher reflection at all frequencies where discontinuity capacitances can be neglected and the geometry being invariant.

Connector Type	Bead Material
83-1SP	Mica-filled Bakelite
83-1R	Mica-filled Bakelite
83-1J	Polystyrene
83-822	Teflon
83-798	Teflon

Conclusions

The general expression relating the impedance of a coaxial line to its physical parameters is:

$$Z = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where:

ϵ = dielectric constant of dielectric material between inner and outer conductors

D = inner diameter of outer conductor, linear units

d = outer diameter of inner conductor, linear units

It is easily seen that for a given geometry, $\log_{10}\frac{D}{d}$ is a constant and equation (1) can be written:

$$Z = \frac{138K}{\sqrt{\varepsilon}} \qquad \ldots\ldots\ldots\ldots\ldots\ (2)$$

Equation (2) shows that the impedance of a coaxial line is inversely proportional to the square root of the dielectric constant and when the geometry is invariant between several such lines the change of impedance is a function of the dielectric constant and nothing else. Or simply, as the dielectric constant is increased the impedance decreases.

A bead support in a coaxial line introduces two reflections, one at the front face of the bead caused by the sudden decrease in impedance and one at the back of the bead because of the sudden increase in impedance. The front end reflection coefficient may be expressed as:

$$K_{12} = \frac{Z_o - Z_1}{Z_o + Z_1}$$

where:

Z_o = the characteristic impedance of the coaxial line

Z_1 = the characteristic impedance of the bead

This reflection is noted to be real and positive. The reflection coefficient at the back face of the bead is:

$$K_{21} = \frac{Z_1 - Z_o}{Z_1 + Z_o} = -K_{12}$$

This reflection is noted to be real, negative and equal in magnitude to the front end reflection.

The total reflection coefficient may be expressed as:

$$K_T = K_{12}\varepsilon^{+j0} + K_{21}\varepsilon^{+j2\theta}$$

where:

θ = the length of the bead in electrical degrees.

Therefore, where θ is not negligibly small the front face reflection does not cancel the back face reflection and the total reflection coefficient may become substantial (reflection is maximum when $\theta = 90^\circ$).

The standing wave ratio may be calculated from the expression:

$$VSWR = \frac{1 + |K_T|}{1 - |K_T|}$$

The dielectric constants of bead materials used in Series 83 UHF Connectors are:

Material	Dielectric Constant
Mica-filled Bakelite	4.50
Polystyrene	2.55
Teflon	2.10

When R.F. coaxial connectors contain under impedance sections of line, reflections are set up in the system which are a function of frequency, bead length, impedance of the under impedance line sections, the number of such sections, the spacing between sections in terms of wavelength and the characteristic impedance of the coaxial line adjacent to the under impedance line sections (beads). The vector sum of the reflections in the system yield an overall reflection from which the VSWR of the system may be calculated. In simplified form, to minimize reflections and lower the VSWR of a Series 83 connector, the dielectric constant of the bead material must be lower with otherwise unchanging geometry.

Deleting the polystyrene bead of an 83-1J cable junction in a cable splice utilizing 83-822 connectors yields at 500 mc/s a VSWR of 1.15. A similar splice using the polystyrene bead at 500 mc/s has a VSWR of 1.55. When necessary, an 83-1J cable junction should be used without the polystyrene bead, to vastly improve the reflection properties of the cable splice.

The following interpretation of experimental data in this report is made to prevent unwarranted accuracies being assigned to the data presented which, in effect, do not exist.

A. Mated Connector Arrangements Assembled to RG-8/U Cable:

1. 83-1SP mated with 83-1R (hood 83-1H):

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.10
100 - 200	1.15
200 - 300	1.20
300 - 400	1.35
400 - 500	1.50

2. 83-1SP mated with 83-1J mated with 83-1SP:

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.10
100 - 200	1.25
200 - 300	1.40
300 - 400	1.60
400 - 500	1.80

3. 83-822 mated with 83-798 (hood 83-1H):

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.05
100 - 200	1.10
200 - 300	1.10
300 - 400	1.10
400 - 500	1.15
500 - 700	1.25
700 - 1000	1.30

4. 83-822 mated with 83-1J mated with 83-822:

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.10
100 - 200	1.15
200 - 300	1.25
300 - 400	1.40
400 - 500	1.60

B. Mated Connector Arrangements Assembled to RG-58A/U Cable:

1. 83-1SP (adapter 83-185) mated with 83-1R (hood 83-765):

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.10
100 - 200	1.15
200 - 300	1.20
300 - 400	1.35
400 - 500	1.55

2. 83-1SP (adapter 83-185) mated with 83-1J mated with 83-1SP (adapter 83-185):

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.10
100 - 200	1.15
200 - 300	1.30
300 - 400	1.55
400 - 500	1.75

3. 83-822 (adapter 83-185) mated with 83-798 (hood 83-765):

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.05
100 - 200	1.10
200 - 300	1.10
300 - 400	1.10
400 - 500	1.15
500 - 700	1.20
700 - 1000	1.15

4. 83-822 (adapter 83-185) mated with 83-1J mated with 83-822 (adapter 83-185):

Frequency range (mc/s)	Maximum VSWR (Z_o = 50 ohms)
20 - 100	1.10
100 - 200	1.15
200 - 300	1.20
300 - 400	1.35
400 - 500	1.50

Series 83 UHF Connectors with teflon beads are far superior to the Bakelite bead variety and should be preferred where connector VSWR must be kept within reasonable limits in the frequency range of 200 to 500 mc/s. Teflon dielectric Series 83 UHF Connectors can be used to 1000 mc/s when rigorous reflection requirements need not be met.

Sample Calculation of VSWR

83-1SP mated with 83-1R (hood 83-1H):

Frequency: 500 mc/s

Measured Admittance: (14.0 + j1.0)1

$$|K| = \frac{|Y_o - Y_L|}{|Y_o + Y_L|} = \frac{|20 - 14.0 - j1.0|}{|20 + 14.0 + j1.0|} = \frac{|6.0 - j1.0|}{|34.0 + j1.0|} \approx .179$$

$$VSWR = \frac{1 + |K|}{1 - |K|} \approx \frac{1 + .179}{1 - .179} \approx 1.44$$

Power Loss as a Function of VSWR

If an R.F. transmission line is not matched to its load, the energy delivered by the line to the load is less than if the impedances are properly adjusted. This effect is considered as due to reflection at the junction and makes its presence known by establishment of a reflected wave and a standing wave system.

The reflection loss expressed as a function of VSWR can be written as:

$$\text{Power loss (db)} = 10 \log_{10} \frac{4\rho}{(\rho + 1)^2} \quad *$$

where:

$$\rho = VSWR$$

Using this relationship, Table I was compiled relating reflection power loss and voltage standing wave ratio.

Figure 1 depicts the percent of power loss as a function of voltage standing wave ratio.

* Derivation in: Ryder, Networks, Lines and Fields, Chapter 6, Prentice-Hall, Inc., New York, 1949

Table I

Power Loss as a Function of VSWR

VSWR	Power Loss (db)	Power Loss (%)
1.000	0.0000	0.000
1.050	0.0026	0.060
1.100	0.0100	0.227
1.150	0.0213	0.488
1.200	0.0362	0.827
1.250	0.0537	1.235
1.300	0.0745	1.702
1.400	0.1224	2.778
1.500	0.1773	4.000
1.600	0.2443	5.474
1.700	0.3021	6.722
1.800	0.3697	8.164
1.900	0.4398	9.631
2.000	0.5164	11.111

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