The Coaxial Resonator Match and the Broadband Dipole

It's easy to build a dipole with the coaxial resonator match. The SWR bandwidth of the antenna is almost *triple* that of a conventional dipole!

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Out of the search for a simple dipole with acceptable SWR over the entire 80-meter band has come a matching technique with broadbanding properties and potential for many applications. This antenna and matching technique are extensions of work described by the author in October 1986 *QST*.[1] A review of that article is recommended as background.

In the sections that follow, the complete description of an 80-meter broadband dipole is provided, including performance data and construction details. Then, for those who want a better understanding of how it works, an explanation of the theory behind the broadband dipole and the coaxial resonator match is provided. Some other applications are described, one of which will be of great interest to 80-meter DX hunters.

An 80-Meter Broadband Dipole

Fig 1 shows the detailed dimensions of the 80-meter coaxial-resonator-match broadband dipole. Notice that the total length of the coax is an electrical quarter wavelength, has a short at one end, an open at the other end, a strategically placed crossover and is fed at a T junction. (The crossover is made by connecting the shield of one coax segment to the center conductor of the adjacent segment and by connecting the remaining center conductor and shield in a similar way.) At AI1H, the antenna is constructed as an inverted-V dipole with a 110° included angle and an apex at 60 feet. The measured SWR v frequency is shown in Fig 2. Also in Fig 2 is the SWR characteristic for an uncompensated inverted-V dipole made from the same materials and positioned exactly as was the broadband version. SWR measurements were made with a Daiwa Model CN 520 cross-needle SWR/power meter. Corrections were made

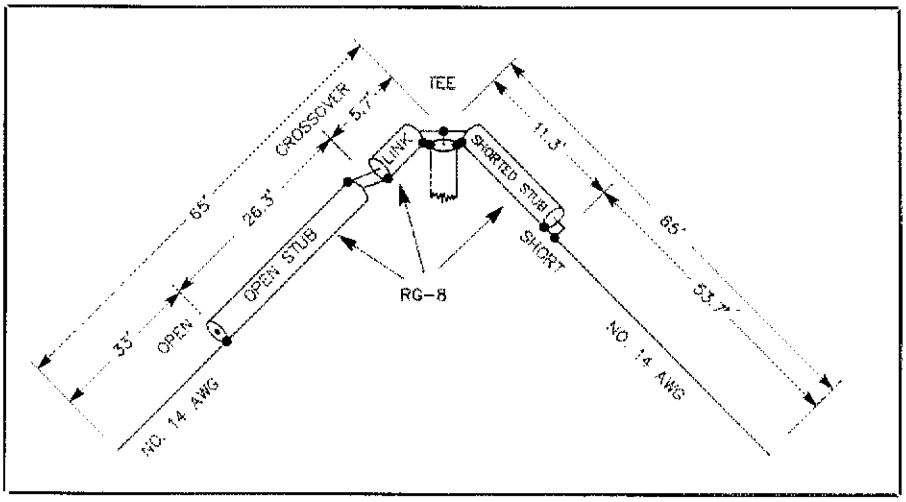

Fig 1—Coaxial-resonator-match broadband dipole for 80 meters. The coax segment lengths total ¼ wavelength. The overall antenna length is the same as that of a conventional inverted-V dipole.

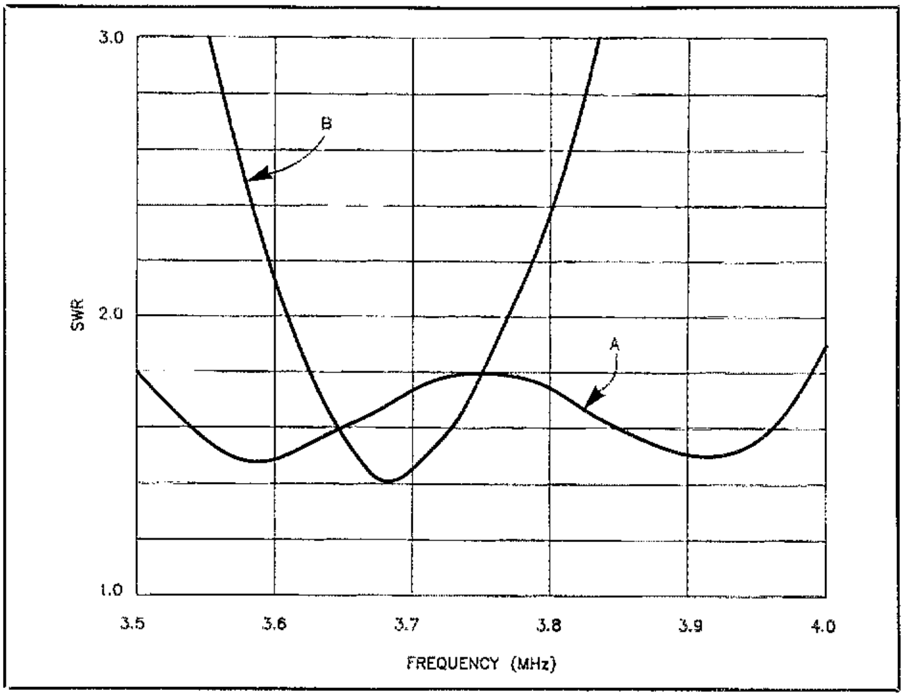

Fig 2—Curve A, the measured performance of the antenna of Fig 1. Also shown for comparison is the measured SWR of the same dipole without compensation, curve B.

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[1] Notes appear on p 27.

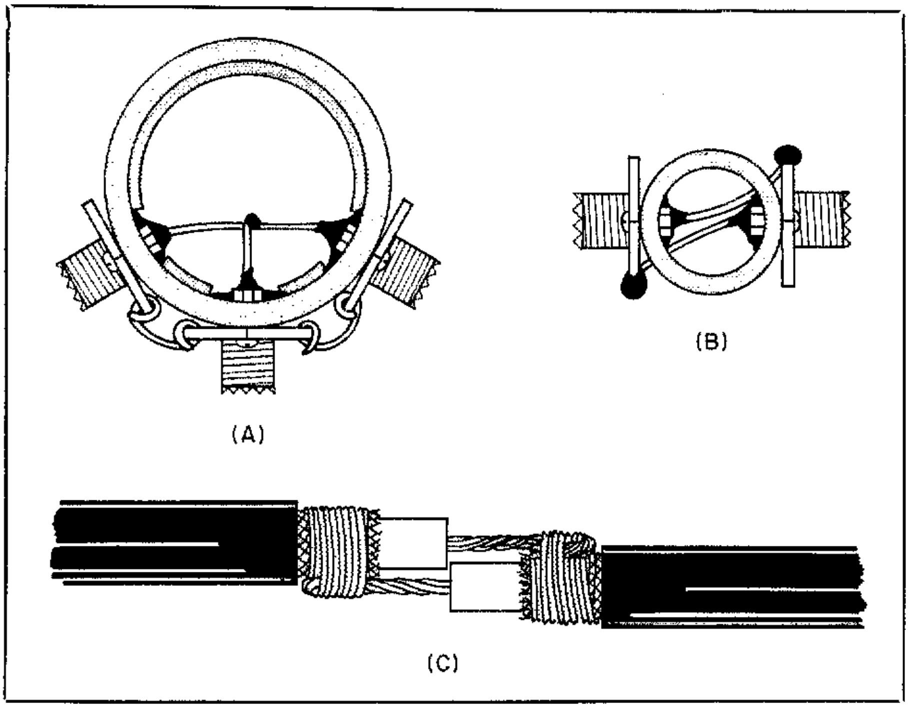

Fig 3—T and crossover construction. At A, a 2-inch PVC pipe coupling can be used for the T, and at B, a 1-inch coupling for the crossover. These sizes are the nominal inside diameters of PVC pipe that fits these couplings. The T could be standard UHF hardware (an M-358 T and a PL-258 coupler). An alternative construction for the crossover is shown at C, where a direct solder connection is made.

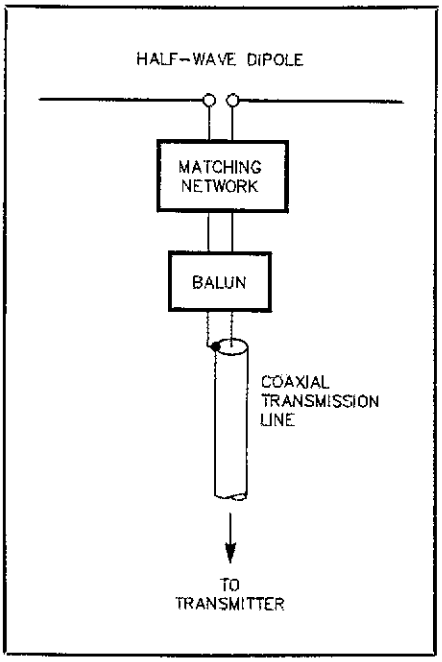

Fig 4—The broadband antenna system.

for the cable loss between the antenna and the meter.

The antenna, made from RG-8 coaxial cable and no. 14 AWG wire, is fed with 50-Ω coax. The coaxial cable should be cut so the stub lengths of Fig 1 are within ½ inch of the specified values. PVC plastic pipe couplings and SO-239 UHF chassis connectors can be used to make the T and crossover connections, as shown in Fig 3 at A and B. Alternatively, a standard UHF T connector and coupler can be used for the T, and the crossover can be a soldered connection (Fig 3C). I used RG-8 coax because of its ready availability, physical strength, power handling capability and moderate loss. An RG-58 model was also designed and built, and it performed well electrically. I don't recommend the RG-58 version, however, because it is too fragile. For example, the coaxial cable stretches enough from its own weight to affect the tuning. Also, RG-58 will have substantially lower power-handling capability than RG-8.

Cut the wire ends of the dipole about three feet longer than the lengths given in Fig 1. If there is a tilt in the SWR-v-frequency curve when the antenna is first built (a lopsided "W" shape), it can be flattened to look like the shape of curve A in Fig 2 by increasing or decreasing the wire length. Each end should be lengthened or shortened by the same amount. Try 6-inch changes at each end with each adjustment. Increasing the dipole length will lower the SWR at the low end of the band; decreasing the dipole length will lower the SWR at the high end of the band.

A word of caution: If the chosen coaxial cable is not RG-8 or equivalent, the dimensions will have to be modified. For example, RG-8X has a different insulation material than RG-8, and its use would dictate different segment lengths. The following cable types have about the same characteristic impedance, loss and velocity factor as RG-8 and could be substituted: RG-8A, RG-10, RG-10A, RG-213 and RG-215.

Important point: The calculated coaxial segment lengths were based on the assumption that the Q and radiation resistance at resonance of the uncompensated dipole were 11.5 and 70 Ω, respectively. If the Q and radiation resistance differ markedly from these numbers because of different ground characteristics, antenna height, surrounding objects and so on, then different segment lengths would be required. In fact, if the dipole Q is too high, broadbanding is possible, but an SWR under 2:1 over the whole band cannot be achieved. More is said on the practical limitations of the coaxial resonator match in a later section of this article.

What is the performance of this broadband antenna relative to that of a conventional inverted-V dipole? Aside from the slight loss (about 1 dB at band edges, less elsewhere) because of the nonideal matching network, the broadband version behaves essentially the same as a dipole cut for the frequency of interest. That is, the radiation patterns for the two cases are virtually the same. In reality, the dipole itself is not "broadband," but the coaxial resonator match provides a broadband match between the transmission line and the dipole antenna. This match is a remarkably simple way to broaden the SWR response of a dipole.

Broadbanding the Dipole

Fig 4 shows a broadband antenna system

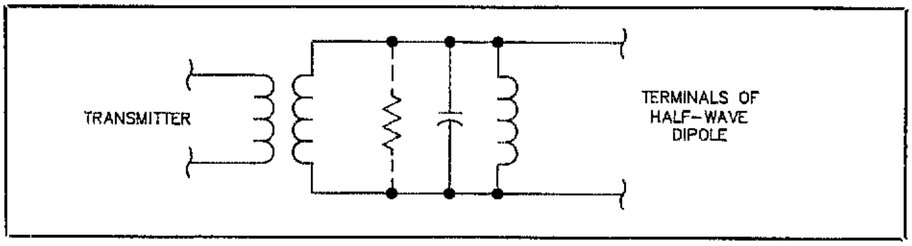

Fig 5—The matching network topology. The resonant circuit provides broadbanding by compensating for the reactance of the dipole, while the transformer adjusts the impedance level of the antenna feed to an optimum value.

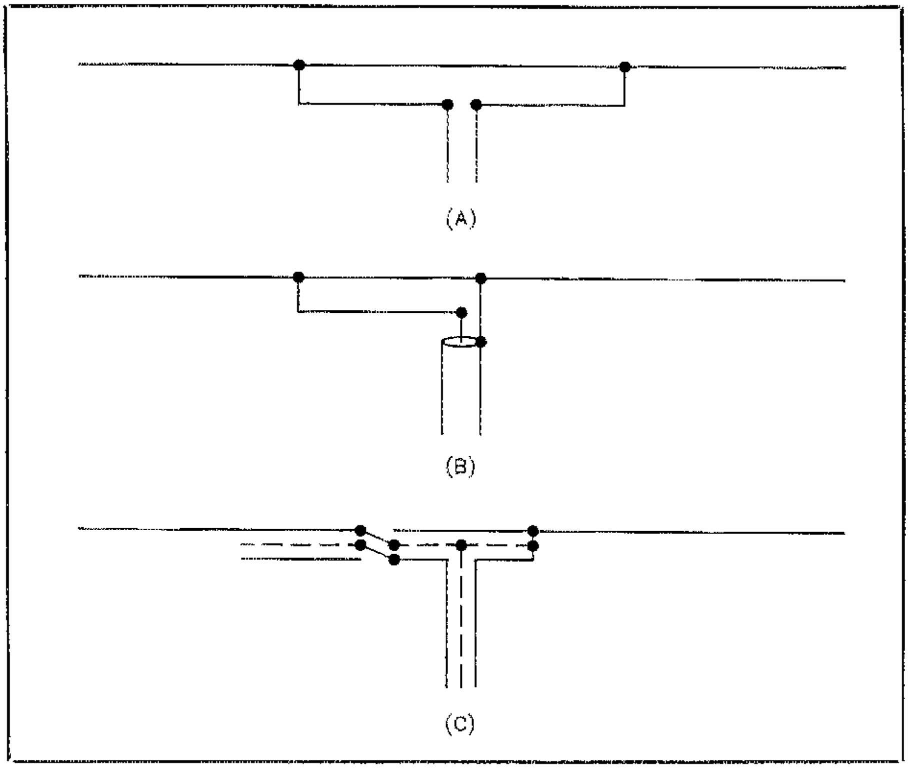

Fig 6—Dipole matching methods. At A, the T match; at B, the gamma match; at C, the coaxial resonator match.

containing a coaxial (unbalanced) transmission line, a balun, a matching network and the half-wave dipole antenna. Use of the balun is recommended in order to prevent radiation from the feed line.

The matching network is a transformer and a resonant circuit, as shown in Fig 5. Such an arrangement has been used in the past to achieve broadbanding.[2-4] The resonant circuit will have a finite Q, and this is the value of Q that determines the loss of efficiency caused by the matching network. The resonant circuit can be realized with LC components or with transmission-line segments. In fact, the transformer function can be performed with the same components. In the reference of note 1, it was shown how an LC resonator can act as the transformer as well. The transmission-line transformer can also be used to achieve the necessary impedance transformation, as is shown shortly.

The Coaxial Resonator Match

The coaxial resonator match performs the same functions as its predecessors, the T match and the gamma match, ie, that of matching a transmission line to a resonant dipole.[5] These familiar matching devices, as well as the coaxial resonator match, are shown in Fig 6. The coaxial resonator match has some similarity to the gamma match. It allows connection of the shield of the coaxial feed line to the center of the dipole and it feeds the dipole off-center, although center feed is also possible. The coaxial resonator match has a further advantage: It can be used to broadband the antenna system while it is providing an impedance match.

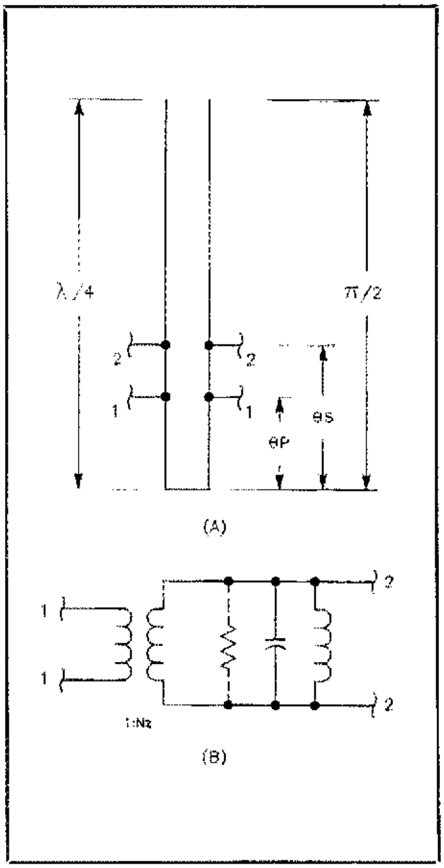

Fig 7—The quarter-wave resonator used as a transformer. Notice from the equivalent circuit of B that a simple piece of transmission line can provide the function of a tuned transformer.

The coaxial resonator match is a resonant transformer made from a quarter-wavelength piece of coaxial cable. It is based on a technique used at VHF and UHF to realize a low-loss impedance transformation.[6] Fig 7 shows how a quarter-wavelength transmission line with a short at one end and an open at the other end will provide transformer action over a limited band. Note that the equivalent circuit consists of a transformer with a parallel-tuned circuit connected across its secondary. The equivalent resonator has a Q, QN, which is related to the loss of the coax at the frequency of interest:

$$QN = \frac{2.774\ F0}{A \times VF} \qquad \text{(Eq 1)}$$

where

F0 = resonant frequency (MHz)
A = resonator transmission-line attenuation (decibels/100 ft)
VF = velocity factor of resonator coax

The approximate impedance transformation ratio is given by

$$NZ = \frac{\sin^2 \theta S}{\sin^2 \theta P} \qquad \text{(Eq 2)}$$

where θS and θP are the electrical angles (lengths) of the secondary and primary taps, respectively, measured from the shorted end of the resonator.

For example, if the secondary tap were 0.1 wavelength from the short and the primary tap were 0.06 wavelength from the short, then

$$NZ = \frac{\sin^2 (2\pi \times 0.1)}{\sin^2 (2\pi \times 0.06)} = 2.5$$

For the practical application of matching the coaxial cable to the broadband dipole, the desired impedance transformation ratio can be readily obtained. The resonator transformer impedance transformation ratio is analogous to a conventional transformer, where

$$NZ = \frac{NS^2}{NP^2} \qquad \text{(Eq 3)}$$

where NS and NP are the number of secondary and primary turns, respectively. The resonator impedance level (impedance of resonator inductance or capacitance at resonance) is given by

$$ZN = \frac{4\ ZR}{\pi} \sin^2 \theta S \qquad \text{(Eq 4)}$$

where ZR = characteristic impedance of line (ohms).

Off-Center Feed

The reason for the use of coaxial cable

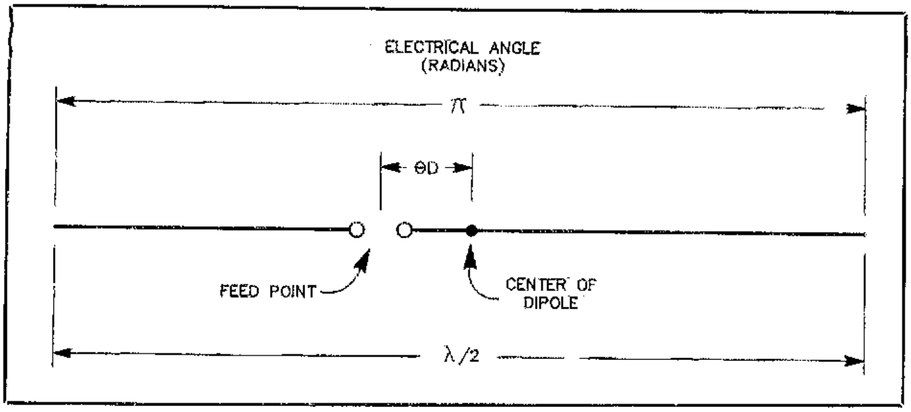

Fig 8—The dipole with off-center feed. See text regarding the feed-point impedance.

for the resonator will be seen later. But first, consider the concept of feeding the dipole off center. In most cases, half-wave dipoles are split and fed at the center. However, off-center feed is possible and has been used before. Two examples are the so-called Windom antenna and the dipole using the gamma match. Fig 8 shows a dipole with off-center feed. If you assume that the current distribution over the dipole is sinusoidal in shape, with zero current at the ends and maximum current at the center (and this is usually a very good assumption), then the radiation resistance at resonance is modified as follows.

$$\mathrm{RAF} = \frac{\mathrm{RA}}{\cos^2 \theta\mathrm{D}} \qquad \text{(Eq 5)}$$

where

RAF = the radiation resistance at the feed point (ohms)
RA = the radiation resistance at the center of the dipole (ohms)
θD = the electrical angular distance off of center

For example, if the radiation resistance of the dipole at its center were 72 Ω, then, if it were fed off center by 0.03 wavelength ($\theta\mathrm{D} = 2\pi \times 0.03 = 0.188$ radians), the radiation resistance at the feed point would be

$$\mathrm{RAF} = \frac{72}{\cos^2 0.188} = 74.6 \text{ ohms}$$

In the practical cases I considered, the change in antenna feed-point impedance arising from off-center feed is small, but it should be taken into account for best results.

The Coaxial Resonator Matched Broadband Dipole

All of the necessary elements of the broadband dipole have now been described. It remains to assemble them into an antenna system. If you compare Figs 5 and 7, you can see that the coaxial resonator match contains the necessary elements for matching and broadbanding. The off-center feed concept provides the finishing touch.

Fig 9 shows the evolution of the broad-

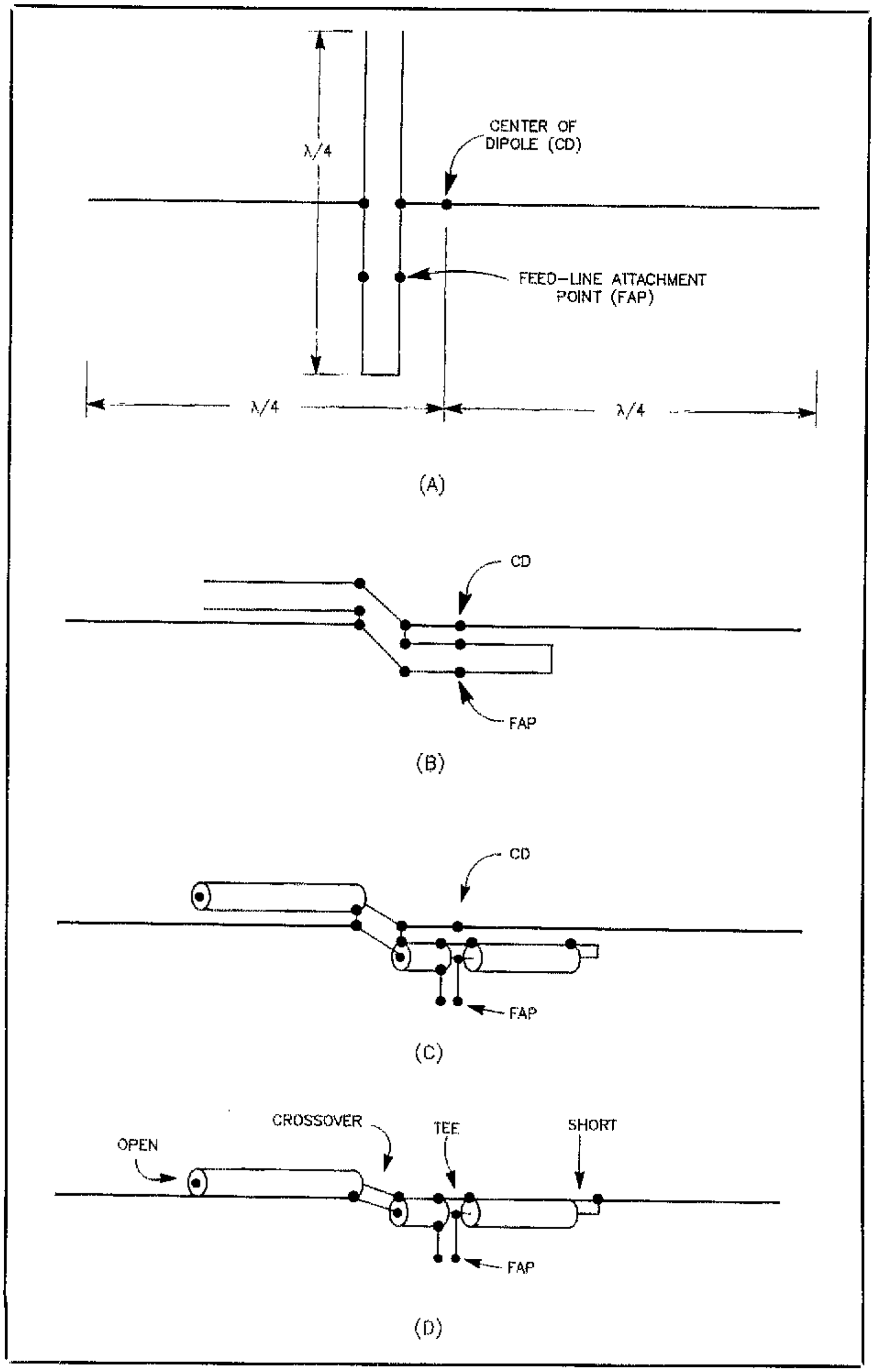

Fig 9—Evolution of the coaxial-resonator-match broadband dipole. At A, the resonant transformer is used to match the feed line to the off-center-fed dipole. The match and dipole are made collinear at B. At C, the balanced transmission-line resonator/transformer of A and B is replaced by a coaxial version. Since the shield of the coax can serve as part of the dipole radiator, the wire adjacent to the coax match can be eliminated, D.

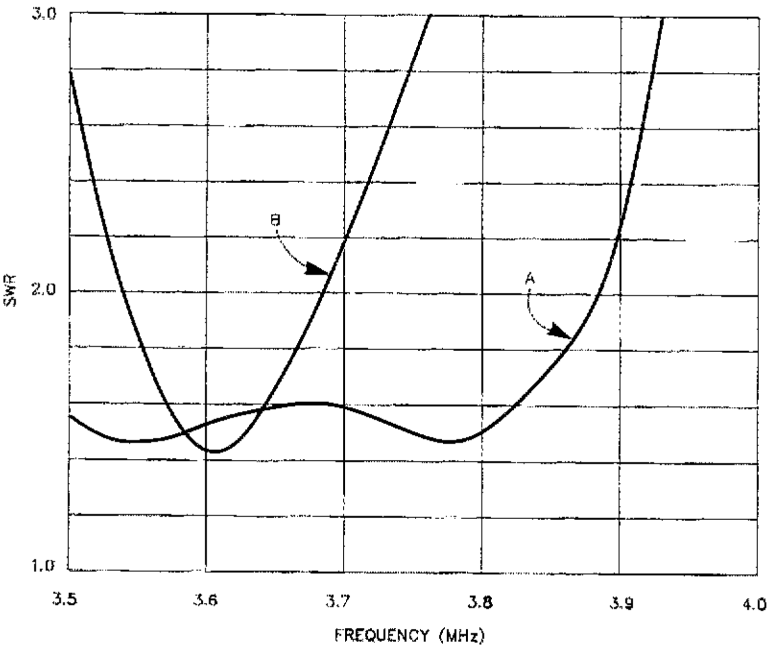

Fig 10—Measured SWR performance of the 80-Meter DX Special, curve A. Note the substantial broadbanding relative to a conventional uncompensated dipole, curve B.

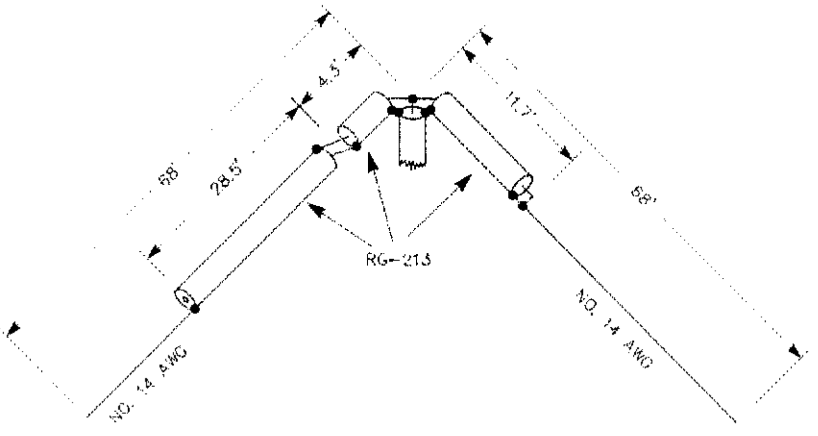

Fig 11—Dimensions for the 80-Meter DX Special, an antenna optimized for the phone and CW DX portions of the 80-meter band. Also see Fig 12.

band dipole. Now it becomes clear why coaxial cable is used for the quarter-wave resonator/transformer; interaction between the dipole and the matching network is minimized. The effective dipole feed point is located at the crossover. In effect, the match is physically located "inside" the dipole. Currents flowing on the inside of the shield of the coax are associated with the resonator; currents flowing on the outside of the shield of the coax are the usual dipole currents. Skin effect provides a degree of isolation and allows the coax to perform its dual function. The wire extensions at each end make up the remainder of the dipole, making the overall length equal to a half wavelength.

The coaxial resonator match, like the gamma match, allows you to connect the shield of the coaxial feed line to the center of the dipole. If the antenna were completely symmetrical, then the RF voltage would be zero (relative to ground) at the center and no balun would be required. In the real situation, some voltage (again referred to ground) does exist at the dipole midpoint (as it does with the gamma match), but in many practical cases no balun is required. If one is used, it should be of the "choke" or "current balun" variety.[7,8] A longitudinal choke can be made by threading several turns of coax through a ferrite toroid, or a commercial variety, such as the W2DU balun, is appropriate. I've used the coaxial resonator matched broadband dipole both with and without a balun with little difference in SWR characteristic. However, there are situations where the balun would be required. To be safe, use a balun.

A useful feature of an antenna using the coaxial resonator match is that the entire antenna is at the same dc potential as the feed-line potential, thereby avoiding charge buildup on the antenna. Hence, noise and the potential of lightning damage are reduced.

Other Applications

The design of Fig 1 can be modified to yield an "80-Meter DX Special." In this case the band extends from 3.5 MHz to 3.85 MHz. Over that band the SWR is better than 1.6:1 and the calculated matching network loss is less than 0.75 dB. See Fig 10 for measured performance of an 80-Meter DX Special built and used by Ed Parsons, K1TR.

Design dimensions for the 80-Meter DX Special are given in Fig 11. The coax segment lengths are based on the assumption that the dipole Q and radiation resistance at resonance are 13 and 60 ohms, respectively. The calculated SWR for the uncompensated dipole and the coaxial resonator matched broadband dipole are shown in Fig 12. Since most amateurs do not know what Q and radiation resistance would exist for their installation, it is desirable to know how sensitive the SWR characteristic is to those parameters. With the aid of a simulation program, a deviation study was made for Q over the range 10 to 16 and radiation resistance ranging from 50 to 70 ohms. In the analysis, the coax segment lengths were not changed from the values shown in Fig 11. The results, given in Fig 13, show that the coaxial-resonator-matched dipole is very robust. The SWR is less than 2:1 over virtually the entire 3.5- to 3.85-MHz band for the wide range of Q and radiation resistance values simulated. An obvious application of the coaxial resonator match is to broadband a 160-meter dipole to cover the entire 1.8- to 2.0-MHz band. A design similar to the 80-meter antenna described in this article would have an SWR better than 1.5:1 over the whole 160-meter band. The calculated matching network loss is less than 1.1 dB.

The same concept might be applied to broadband a Yagi array, where you must usually settle for a compromise among gain, front-to-back ratio and SWR bandwidth. By applying the coaxial resonator matching principle, the SWR bandwidth of the array might be made wide enough that the gain and front-to-back ratio could be better optimized. This conjecture was sug-

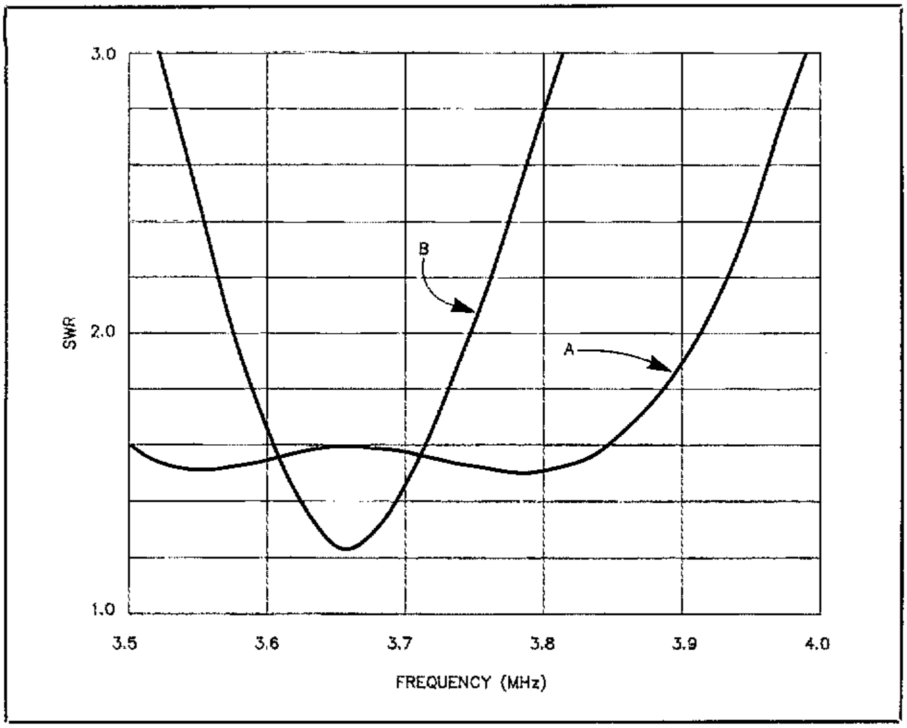

Fig 12—Calculated SWR response of the 80-Meter DX Special, curve A, and a conventional dipole, curve B.

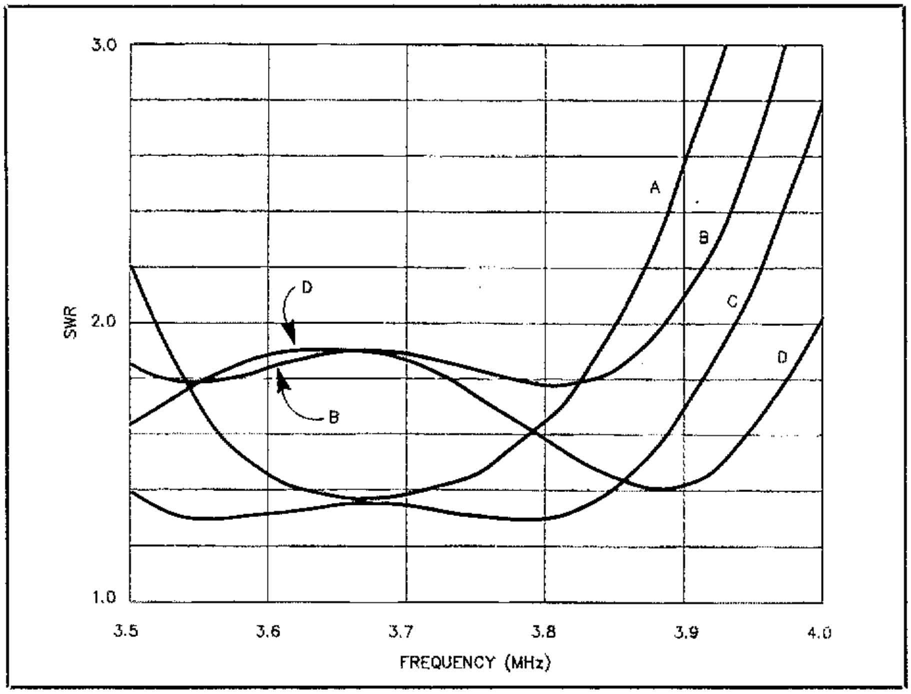

Fig 13—The results of a deviation study reveal the expected performance of the antenna of Fig 11 for a variety of conditions. The various curves were obtained with these parameters. Curve A: Q = 16, R = 70 Ω. Curve B: Q = 16, R = 50 Ω. Curve C: Q = 10, R = 70 Ω. Curve D: Q = 10, R = 50 Ω.

gested by John Kenny, W1RR.

The coaxial resonator match can be applied to monopoles as well. In this case, one of the coax segments could be located "inside" one of the radials. Other applications include full-wave loops and 3/2-wavelength center-fed antennas.

Summary and Acknowledgments

The coaxial resonator match is a form of matching network for use between the transmission line and the antenna. This match, which becomes an integral part of a dipole antenna, serves not only as a matching device, but also has inherent broadbanding properties. The 80-meter broadband dipoles presented as practical examples ably demonstrate the utility of the coaxial resonator match. This antenna achieves a long-sought-after goal of realizing a simple dipole that is well matched over the entire 80-meter band.

I am indebted to my wife, Barbara, N1DIS, for her encouragement throughout the course of this project. Also, several discussions with John Kenny, W1RR, provided inspiration during the course of the development of the coaxial resonator match. Further, an example of a broadband dipole shown to me by Reed Fisher, W2CQH, initiated my investigation which led to the relatively efficient design presented in this paper. I am grateful to Ed Parsons, K1TR, who first constructed and evaluated the 80-Meter DX Special.

A complete description of how one can use the coaxial resonator match in other applications is planned for presentation in *The ARRL Antenna Compendium, Volume 2.* [Appearance is scheduled for later in 1989—Ed.] That paper also contains design equations for computing the segment lengths of the coaxial resonator match.

Notes

[1] F. J. Witt, "Broadband Dipoles—Some New Insights," *QST*, Oct 1986, pp 27-37.

[2] J. Hall, "The Search for a Simple, Broadband 80-Meter Dipole," *QST*, Apr 1983, pp 22-27.

[3] R. D. Snyder, "Broadband Antennae Employing Coaxial Transmission Line Sections," United States Patent no. 4,479,130, issued Oct 23, 1984.

[4] R. C. Hansen, "Evaluation of the Snyder Dipole," *IEEE Transactions on Antennas and Propagation*, Vol. AP-35, No. 2, Feb 1987, pp 207-210.

[5] G. L. Hall, Ed, *The ARRL Antenna Book* (Newington: ARRL); 14th ed (1982), pp 5-13—5-14; 15th ed (1988), pp 26-16—26-18.

[6] *The Radio Amateur's Handbook*, 52nd ed (Newington: ARRL, 1975) pp 54-55.

[7] M. W. Maxwell, "Some Aspects of the Balun Problem," *QST*, Mar 1983, pp 38-40.

[8] R. W. Lewallen, "Baluns: What They Do and How They Do It," *The ARRL Antenna Compendium, Vol. 1* (Newington: ARRL, 1985), pp 157-164.

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Frank has a weekly schedule with W3OWN, VP9HK and WA2NVG on approximately 3.82 MHz on Thursdays at 9:30 PM Eastern Time. They welcome others interested in broadband antennas.