On Center-Fed Multiband Dipoles

Is the G5RV really an all-band antenna?

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Since the opening of the 30, 17 and 12-meter bands, interest in the center-fed dipole with tuned feeders has seen a revival. Particularly popular is the G5RV,[1] a multiband center-fed dipole with a particular feed-line arrangement. This dipole can be used on the amateur bands 3.5 MHz and above. Its arms are somewhat shorter than a quarter wavelength on 80 meters, which makes it an attractive antenna for some, since it will fit on many city lots. Many amateurs regard this antenna with its so-called *special feed-line arrangement* as a panacea, particularly when it is used in a drooping dipole (sometimes called *inverted V*) configuration. There is, however, nothing magical or superior about the antenna:[2] It is merely a center-fed dipole with a particular feed-line arrangement, which the newcomer to Amateur Radio may or may not want to duplicate. In fact, the performance of a multiband drooping dipole can be inferior to a dipole at the same apex height. In preparing this article, we conducted a critical analysis of center-fed multiband dipoles, and developed data on calculated radiation patterns for horizontal and drooping configurations.

Center-Fed Dipoles with Tuned Feeders

The center-fed dipole with tuned feeders was a simple and widely used multiband antenna in the 1930s and 1940s, and various versions of it are still in use today. Because each half of the "flat top" is the same length, the feeder currents are balanced at all frequencies, except for any imbalance introduced because one half of the antenna is closer to the ground than the other. Antenna length is not particularly critical, nor is the feed-line length; however, some combinations allow easier impedance matching to the transmitter over a wide frequency range.

The dipole was generally fed with an open-wire transmission line. Antenna lengths of 135 feet and 70 feet were typically used, with feed-line lengths ranging from 40 to 75 feet. In the years before affordable coaxial cable, the entire transmitting and radiating system was balanced. Because modern transceivers and antenna tuners are unbalanced devices, coaxial cable is now the preferred feed line. Whatever the feed-line arrangement, a balun is required, which can lead to difficulties, as the load may be a very reactive mismatch at some frequencies.

G5RV Version

In 1946, Louis Varney, G5RV, anxious to get on the air after the war, designed and erected a multiband antenna which would fit his average-sized backyard. The antenna consists of a 102-foot flat-top, split in the center and fed by tuned feeders. Two versions were tested: one using full length open-wire feeders (Figure 1A) and the other using a 34-foot open-wire *stub* fed at its base by either transmitting-grade 72-Ω twin lead or 72-Ω coax (Figure 1B). The length of the stub was designed to be a half wavelength at 14 MHz (the reason is discussed later). An alternative to using an open-wire stub was also tested, using 300-Ω ribbon. In this case, the stub was shortened by the velocity factor for the ribbon. The stub version, Figure 1B, has become known as the *G5RV Antenna*. It was first described in a note by him in the July 1958 RSGB *Bulletin*.

With a suitable tuner, this antenna can be used on all HF bands from 3.5 to 30 MHz. Varney referred to this stub as a *matching section*. (The italicization of *matching section* and other words to follow in this para-

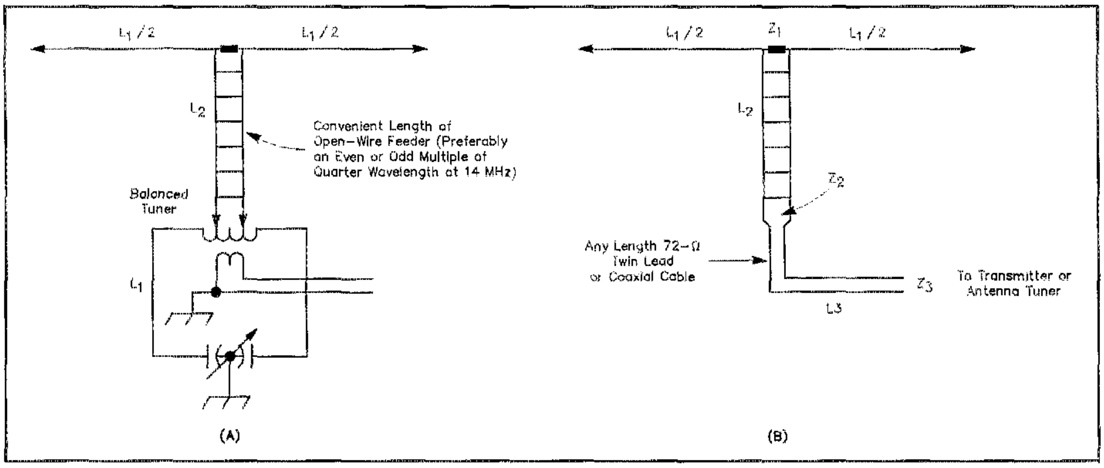

Figure 1—At A, a multiband dipole fed directly with open-wire line. The line is matched with a balanced tuner. At B, L3 is a length of 72-Ω twinlead or coaxial cable.

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[1] Notes appear on page 36.

graph is Varney's.) The statement *matching section* has led to considerable over-the-air discussion and confusion over the years. In retrospect, Varney concluded that it was probably a mistake to refer to this feeder arrangement as a *matching section* when it was only for the 20-meter band that it functions as one. (The dipole impedance of approximately 100 Ω at the center of the 3/2-λ flat-top was transformed by the λ/2 open-wire line (length, 34 feet) to the base of this section, thus providing an acceptable match for a suitable length of 72-Ω twin lead or coax *feeder* needed to reach the transmitter.[3]) More accurately, this *matching section* is a series-section impedance transformer. The *feeder* is also a series-section impedance transformer, a factor that in most cases is completely ignored. Varney recommended using open-wire tuned feeders to reduce losses due to the large-amplitude standing wave on this section of transmission line, and while he did not specify the impedance, the constructional details given correspond to a transmission-line impedance (Z_0) equal to 523 Ω.

Clearly, this feed-line arrangement is *special*, since multiband dipoles are more usually fed by means of a single feed line of constant characteristic impedance. The G5RV in effect uses a combination feed line: the open-wire line as described above in conjunction with the low-impedance *feeder*, which connects the antenna to the transmitter. This complicates discussion about the antenna. The confusion over the use of the words *special, matching section* and *feeder* persists today. Some antenna experimenters hold that the G5RV can be used without a tuner on all traditional amateur bands. It is curious how this idea came into the minds of the radio amateurs using this antenna, because Varney never said that it could be used without a tuner.

The G5RV antenna is typically not a perfect match on *any* amateur band, and since the SWR can be high on some bands, Varney recommended that no balun be used. This is another topic of controversy. A balun should be used to feed a balanced antenna by an unbalanced transmitter; however, the use of a balun can lead to difficulties when the SWR is too high. Without a balun there will be some feed-line radiation, which can be particularly severe on some frequency bands.

Dipole Orientation

Dipoles are often not installed in a horizontal straight line. Half-wave dipoles are generally tolerant of bending, sloping or drooping to fit the antenna site. But this is not always the case for multiband dipoles. We will consider here horizontal and drooping dipoles; we will not consider bent dipoles.

Louis Varney has always illustrated his multiband dipole mounted as a classical horizontal dipole. But radio amateurs frequently use multiband dipoles in a drooping configuration, since only one support mast is needed. In fact, this configuration is illustrated in *The ARRL Handbook*, which has for years given details for such a multiband dipole with 50-foot arms, fed by an open-wire transmission line. The caption under the sketch giving constructional details states that "the included angle (A) between the arms of the dipole for best efficiency should be between 90° to 110°."[4] The authors have not seen substantiating data to support this recommendation. In fact, as we see, the optimum angle for a multiband dipole is 180° (a horizontal dipole).

Measured Impedance Characteristics

The authors' G5RV (in spite of what was said previously) was installed as a drooping dipole. The included angle (A) between the arms of the dipole was about 127°; the apex height, about 30 feet. The dimensions for the authors' G5RV were those given by Louis Varney: L_1=102 ft; L_2=34 × 0.95=32.3 ft of 450-Ω transmission line. The factor 0.95 is the velocity factor for the 450-Ω ribbon. The antenna was resonant (reactance zero) on five frequencies in the 3- to 30-MHz range: 3.49, 7.52, 14.15, 19.5 and 24.6 MHz. It is interesting to note that the antenna was resonant in the 20-meter band, at 14.15 MHz, as G5RV intended. The antenna's resistance at these frequencies was 16, 31, 148, 48 and 162 Ω, respectively. This illustrates, in part, the problem in achieving a low SWR for harmonic-resonance frequencies of the antenna's impedance-versus-frequency response. For a 50-Ω feeder (see the following), the SWR at the corresponding resonant frequencies would be 3:1, 1.6, 3.0, 1.04 and 3.24.

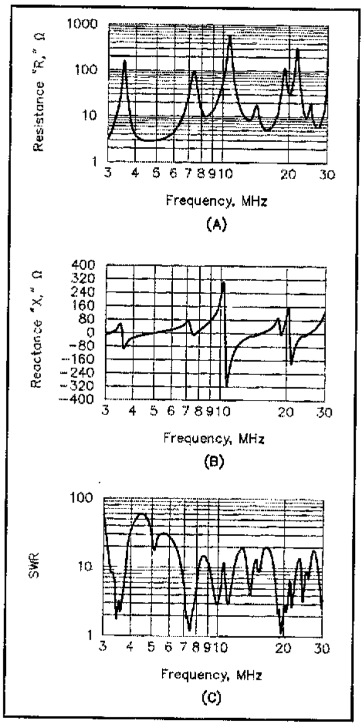

Figure 2—At A, input resistance versus frequency for the antenna tested by the authors; at B, input reactance versus frequency; at C, input SWR.

Our G5RV antenna was fed by an additional length of 50-Ω coax transmission line. We used a 31-foot length of mini-foam coax (the total length of which included the length of a 300-bead current balun; see below). The antenna-system impedance is changed by this feeder, depending on its length and characteristics (impedance and attenuation factor). In Figure 2A and B, the measured input resistance and reactance versus frequency is given for the antenna with a coaxial feeder and balun. Note in particular the anti-resonant responses in the 80-meter band, and just above the 40-meter band. The G5RV itself was resonant near these frequencies.

Figure 2C shows the SWR versus frequency. Although the SWR was low (less than 2:1) in three bands in the 3 to 30-MHz range, unfortunately it is high for most amateur bands. We should note that since a balun was used, there will be insignificant current on the outside surface of the feed-line coax, and therefore SWR should be independent of the length of the coax.

The G5RV antenna is clearly a multiband antenna. It is harmonically resonant on a number of frequencies in the 3 to 30-MHz range. Comparisons of measured SWRs we obtained with those reported by others showed low SWRs in different bands, though sometimes outside amateur bands.

Drooping versus Horizontal Dipoles

Drooping the arms of the λ/2 dipole has only a small effect on gain. When the length of the dipole is greater than λ/2, the place on the arms of the dipole where the current is a maximum is displaced from the center of the dipole. In this case, these current maxima occur at a lower height when the arms of the dipole are drooping. We might, therefore, expect that the effective height of the dipole would be decreased, and hence the launch angle increased. But the pattern and gain changes are more complicated than this. When the dipole is horizontal, the takeoff angle decreases continuously with increase in frequency (since the electrical height of the dipole increases with increase in frequency), and when the pattern becomes multi-lobed, the maximum takeoff value has the same value for all the lobes in the azimuthal plane. But this is not the case for the drooping dipole, and the differences become greater as the droop is increased.

A multiband dipole, if used at frequencies where its electrical length is appreciable (greater than λ/2) should be installed as a horizontal dipole, or as nearly horizontal as possible.

Conclusions and Recommendations

When reading about what has been written about the G5RV, or modified versions *based on the G5RV principle*, we must not think of the transmission-line segment L_2 as a *matching section*; more generally, it is a series-section transformer. This view is particularly important when considering the combined effect of the open-wire line and the coaxial feeder. Clearly the coaxial feeder of length L_1 is an add-on series-section impedance transformer, which may or may not include the impedance-transfer characteristics of the balun. The analysis approach (previously published) has considered only the impedance-transfer characteristics of the open-wire part, but has ignored the effect of the coaxial lead-in. This complication was avoided by considering only SWR rather than impedance. While there is nothing fundamentally wrong with this approach, in our view this confuses our understanding of the characteristics in the antenna system. Calling Figure 1A's antenna a dipole with tuned feeders, and Figure 1B's antenna a dipole with stub tuning, are also misnomers. Since an antenna tuner is used with the Figure 1B antenna, this antenna system is also a dipole with tuned feeders.

Despite several studies by those who have tried to optimize dimensions for the G5RV type of multiband dipole with its combination feeder arrangement, there is, in our opinion, little to be gained by this endeavor. Louis Varney, in correspondence with author Belrose said: "While I think that Brian Austin's ZS6BKW designs[5] of a multiband antenna are interesting, in view of the fact that whatever bands [on which] he manages to achieve an SWR less than 2:1, there will be other bands for which the SWR is greater than 2:1, and therefore the use of a suitable *antenna tuner* is *essential. I would prefer* more simply to use an antenna tuner." The authors agree with this view held. Attempts to optimize the antenna system are not worthwhile, except if operation on a particular band (or bands) for field use without a tuner is desired.

The length of the dipole depends on the frequency band of interest, and since the radiation pattern changes with frequency, the best length for the dipole as judged by a particular user should take this factor into account. The 102-foot length is a dimension that is approximately 3/8 λ long at the lowest frequency of operation, 3.5 MHz. This is a reasonable length. A dipole with shorter arm lengths quickly becomes impractical. The multi-lobed pattern for frequencies greater than 10 MHz is, in our view, undesirable. For communication in nonspecific directions a multiband dipole meets the requirements. If communication to a particular remote location is desired, however, it is important that the azimuthal pattern not have a null in the direction of interest. Dipole lengths greater than 1.25 λ generally do not meet this requirement. For operation on the higher bands, a scaled-down multiband dipole could be used, but other, quite different antenna types could be used instead. For example, a simple all-band antenna that avoids the difficulty of pattern change with frequency, for frequencies greater than 10 MHz, is a compact horizontal loop. Another simple antenna type, which the authors favor, is to use several dipoles in parallel (a so-called *fan* or *stagger-tuned* dipole).

Dipole orientation is rather unimportant at frequencies where the dipole arms are not appreciably greater than λ/2, whether the dipole is horizontal or drooping. When the dipole's arm length becomes greater than 1.25 λ, though, it should be mounted horizontally, or as horizontally as possible (A > 127°).

In our view, the correct feed-line length for a multiband dipole is that required to go from the output terminals of the antenna tuner to the antenna terminals, because—regardless of the length of the feed line—both the antenna and the feed line are made resonant by the tuner. Our recommendation, based on personal experience, is to use open-wire line for the *total length* of the required feeder. This will result in lower losses. An additional advantage in using a full-length feed line is that any necessary balun can be inside the station, easing evaluation of its performance, or you can use a balanced tuner.

It is interesting to note that the 100- to 150-Ω impedance of the 1.5-λ, 31.1-m-long dipole, when used for the 20-meter band, could be matched by employing two lengths of coaxial cable to form a balanced line. Varney designed his antenna to be resonant at 20 meters, so this arrangement would have suited him. This type of transmission line has been used by us in our studies of the performance of dipoles and baluns. The use of a low-impedance line limits the extremes of impedance variations, and such a line is easy to fabricate and feed into the station. In addition, its losses are not high (we recommend foam-dielectric coax) unless you need a very long feed line. (Our 300-bead 1:1 balun of Mix 73 ferrite on miniature Teflon-dielectric coax is the best balun we have found for use with HF multiband dipole antennas, where the mismatch impedance can be high.[7])

Notes

[1] P. Hawker, "More on the G5RV/ZS6BKW Antennas," Technical Topics, *Radio Communications*, Jan 1993, pp 43-45; Feb 1993, p 34; and Apr 1993, pp 53-54.

[2] W. Maxwell, *Reflections* (Newington: ARRL, 1990), pp 20-13 to 20-16.

[3] L. Varney, "An Effective Multi-Band Aerial of Simple Construction," RSGB *Bulletin*, Jul 1958.

[4] R. Schetgen, ed, *The ARRL Handbook for Radio Amateurs*, 1993 ed (Newington: ARRL, 1992), p 33-9, Figure 15.

[5] B. Austin, "Computer-Aided Design of Multi-Band Dipole Based on the G5RV Principle," *Radio Communication*, Aug 1985, pp 614-617, 624.

[6] J. Belrose, "An Update on Compact Transmitting Loops," *QST*, Nov 1993, pp 37-40.

[7] Small quantities of 50- and 100-Ω Teflon-dielectric cable, as well as 50-bead W2DU and VE2CV 1:1 and 4:1 baluns in ready-to-use or kit form, can be obtained from The Wire Man, 261 Pittman Rd, Landrum, SC 29356, tel 803-859-4195. We have noted that radio amateurs in North America and the UK have experienced difficulty in locating a source for Teflon-dielectric coax—particularly the 100-Ω type necessary for the VE2CV 4:1 balun.

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