The G5RV Multiband Antenna ... Up-to-Date#

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The G5RV antenna, with its special feeder arrangement, is a multiband center-fed antenna capable of efficient operation on all HF bands from 3.5 to 28 MHz. Its dimensions are specifically designed so it can be installed in areas of limited space, but which can accommodate a reasonably straight run of about 102 ft for the flat-top. Because the most useful radiation from a horizontal or inverted-V resonant antenna takes place from the center two-thirds of its total length, up to one-sixth of this total length at each end of the antenna may be dropped vertically, semi-vertically, or bent at a convenient angle to the main body of the antenna without significant loss of effective radiation efficiency. For installation in very limited areas, the dimensions of both the flat-top and the matching section can be divided by a factor of two to form the half-size G5RV, which is an efficient antenna from 7 to 28 MHz. The full-size G5RV will also function on the 1.8-MHz band if the station end of the feeder (either balanced or coaxial type) is strapped and fed by a suitable matching network using a good earth connection or a counterpoise wire. Similarly, the half-size version may be used on the 3.5- and 1.8-MHz bands.

In contradistinction to multiband antennas in general, the full-size G5RV antenna was **not** designed as a $\lambda/2$ dipole on the lowest frequency of operation, but as a $3\lambda/2$ center-fed long-wire antenna on 14 MHz, where the 34 ft open-wire matching section functions as a 1:1 impedance transformer. This enables the 75-ohm twin lead, or 50/80-ohm coaxial cable feeder, to see a close impedance match on that band with a consequently low SWR on the feeder. However, on all the other HF bands, the function of this section is to act as a "make-up" section to accommodate that part of the standing wave (current and voltage components) which, on certain operating frequencies, cannot be completely accommodated on the flat-top (or inverted-V) radiating portion. The design center frequency of the full-size version is 14.150 MHz, and the dimension of 102 ft is derived from the formula for long-wire antennas which is:

$$\text{Length (ft)} = \frac{492(n - 0.05)}{f_{MHz}} = \frac{492 \times 2.95}{14.15} = 102.57 \text{ ft } (31.27 \text{ m})$$

where n = the number of half wavelengths of the wire (flat-top)

Because the whole system will be brought to resonance by the use of a matching network in practice, the antenna is cut to 102 ft.

As the antenna does not make use of traps or ferrite beads, the dipole portion becomes progressively longer in electrical length with increasing frequency. This effect confers certain advantages over a trap or ferrite-bead loaded dipole because, with increasing electrical length, the major lobes of the vertical component of the polar diagram tend to be lowered as the operating frequency is increased. Thus, from 14 MHz up, most of the energy radiated in the vertical plane is at angles suitable for working DX. Furthermore, the polar diagram changes with increasing frequency from a typical $\lambda/2$ dipole pattern at 3.5 MHz and a two $\lambda/2$ in-phase pattern at 7 and 10 MHz to that of a long-wire antenna at 14, 18, 21, 24 and 28 MHz.

Although the impedance match for 75-ohm twin lead or 80-ohm coaxial cable at the base of the matching section is good on 14 MHz, and even the use of 50-ohm coaxial cable results in only about a 1.8:1 SWR on this band, the use of a suitable matching network is necessary on all the other HF bands. This is because the antenna plus the matching section will present a **reactive** load to the feeder on those bands. Thus, the use of the correct type of matching network is essential in order to ensure the maximum transfer of power to the antenna from a typical transceiver having a 50-ohm coaxial (unbalanced) output. This means unbalanced input to balanced output if twin-wire feeder is used, or unbalanced to unbalanced if coaxial feeder is used. A matching network is also employed to satisfy the stringent load conditions demanded by such modern equipment that has an automatic level control system. The system senses the SWR condition present at the solid state transmitter output stage to protect it from damage, which could be caused by a reactive load having an SWR of more than about 2:1.\1

The above reasoning does not apply to the use of the full-size G5RV antenna on 1.8 MHz, or to the use of the half-size version on 3.5 and 1.8 MHz. In these cases, the station end of the feeder conductors should be "strapped" and the system tuned to resonance by a suitable series-connected inductance and capacitance circuit connected to a good earth or counterpoise wire. Alternatively, an unbalanced-to-unbalanced type of matching network such as a T or L matching circuit can be used.\2 Under these conditions the flat-top (or inverted-V) portion of the antenna, plus the matching section and feeder, function as a Marconi or T antenna, with most of the effective radiation taking place from the vertical, or near vertical, portion of the system; the flat-top acts as a top-capacitance loading element. However, with the system fed as described above, very effective radiation on these two bands is obtainable even when the flat-top is as low as 25 ft above ground.

Theory of Operation

The general theory of operation has been explained above. The detailed theory of operation on each band from 3.5 to 28 MHz follows, aided by figures showing the current standing wave conditions on the flat-top, and the matching (or make-up) section. The relevant theoretical horizontal plane polar diagrams for each band may be found in any of the specialized antenna handbooks. However, it must be borne in mind that: (a) the polar diagrams generally shown in two dimensional form are, in fact, three dimensional (i.e., solid) figures around the plane of the antenna; and (b) all theoretical polar diagrams are modified by reflection and absorption effects of nearby conducting objects such as wire fences, metal house guttering, electric wiring systems, and even large trees. Also, the local earth conductivity will materially affect the actual polar radiation pattern produced by an antenna. Theoretical polar diagrams are based on the assumptions that an antenna is supported in "free space" above a perfectly conducting ground. Such conditions are obviously impossible of attainment in the case of typical amateur installations. What this means in practice is that the reader should not be surprised if **any** particular antenna in a typical amateur location produces contacts in directions where a null is indicated in the theoretical polar diagram, and perhaps not such effective radiation in the directions of the major lobes as theory would indicate.

3.5 MHz: On this band each half of the flat-top, plus about 17 ft of each leg of the matching section, forms a foreshortened or slightly folded up $\lambda/2$ dipole. The remainder of the matching section acts as an unwanted, but unavoidable reactance between the **electrical** center of the dipole and the feeder to the matching network. The polar diagram is effectively that of a $\lambda/2$ antenna. See Fig. 1.

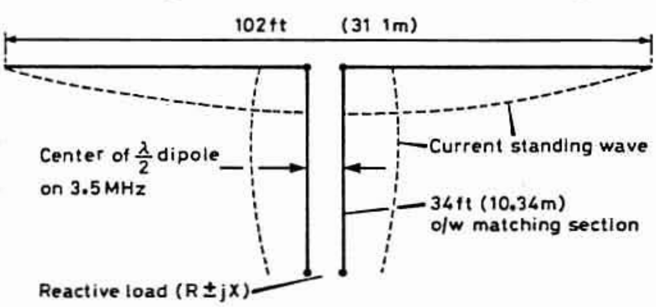

Fig. 1 — Current standing-wave distribution on the G5RV antenna and matching section at 3.5 MHz. The antenna functions as a $\lambda/2$ dipole partially folded up at the center.

7 MHz: The flat-top, plus 16 ft of the matching section, now functions as a partially folded up two half waves in phase antenna producing a polar diagram with a somewhat sharper lobe pattern than a $\lambda/2$ dipole because of its collinear characteristics. Again, the matching to a 75-ohm twin-lead or 50/80-ohm coaxial feeder at the base of the matching section is degraded somewhat by the unwanted reactance of the lower half of the matching section, but, despite this, by using a suitable matching network, the system loads well and radiates very effectively on this band. See Fig. 2.

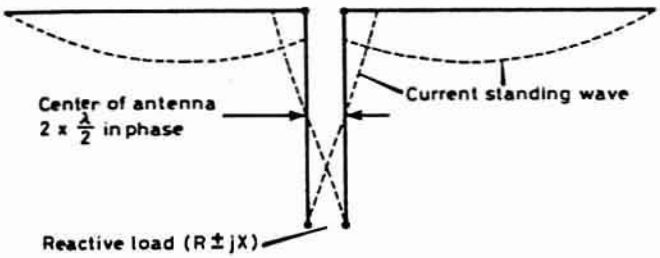

Fig. 2 — Current distribution on the antenna and matching section at 7 MHz. The antenna now functions as a collinear array with two half waves fed in phase.

10 MHz: On this band the antenna functions as a two half-wave in-phase collinear array, producing a polar diagram virtually the same as on 7 MHz. A reactive load is presented to the feeder at the base of the matching section but, as for 7 MHz, the performance is very effective. See Fig. 3.

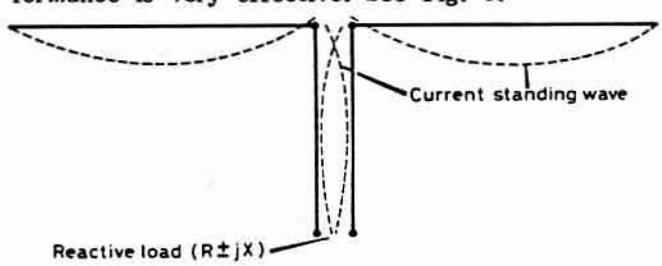

Fig. 3 — Current standing-wave distribution on the antenna and matching section at 10 MHz. The antenna functions as a collinear array with two half waves fed in phase.

14 MHz: At this frequency the conditions are ideal. The flat-top forms a $3\lambda/2$ long center-fed antenna which produces a multilobe polar diagram with most of its radiated energy in the vertical plane at an angle of about 14 degrees, which is effective for working DX. Since the radiation resistance at the center of a $3\lambda/2$ long-wire antenna supported at a height of $\lambda/2$ above ground of average conductivity is about 90 ohms, and the 34-ft matching section now functions as a 1:1 impedance transformer, a feeder of anything between 75 and 80 ohms characteristic impedance will see a nonreactive (i.e., resistive) load of about this value at the base of the matching section, so that the SWR on the feeder will be near 1:1. Even the use of 50-ohm coaxial feeder will result in an SWR of only about 1.8:1. It is assumed here that 34 ft is a reasonable average antenna height in amateur installations. See Fig. 4.

18 MHz: The antenna functions as two full-wave antennas fed in phase; it combines the broadside gain of a two-element collinear array with a somewhat lower zenithal angle radiation than a $\lambda/2$ dipole because of its long-wire characteristic. See Fig. 5.

21 MHz: On this band the antenna works as a long wire of five halfwaves, producing a multilobe polar diagram with effective low zenithal angle radiation. Although a high resistive load is presented to the feeder at the base of the make-up

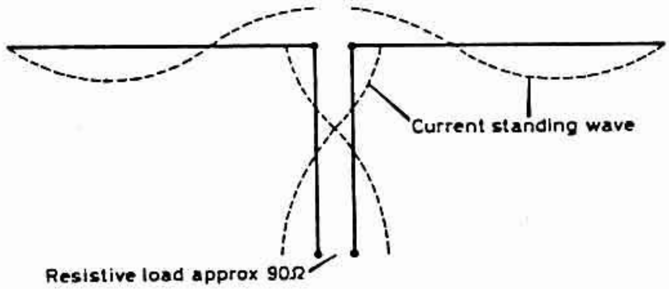

Fig. 4 — Current standing-wave distribution on the antenna and matching section at 14 MHz. In this case the antenna functions as a center-fed long wire of three half waves out of phase. The matching section now functions as a 1:1 impedance transformer, presenting a resistive load of approximately 90 ohms at the lower end.

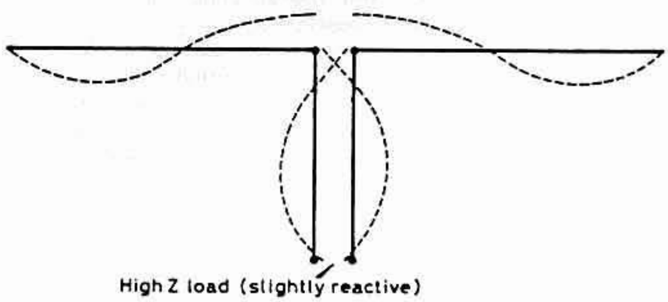

Fig. 5 — Current standing-wave distribution on the antenna and matching section at 18 MHz. The antenna functions as two full-wave antennas, slightly folded up at the center, fed in phase.

section, the system loads well when used in conjunction with a suitable matching network and radiates effectively for DX contacts. See Fig. 6.

24 MHz: The antenna again functions effectively as a $5\lambda/2$ long wire, but because of the shift in the positions of the current antinodes on the flat-top and the matching section (Fig. 7), the matching or make-up section now presents a much lower resistive load condition to the feeder connected to its lower end than it does on 21 MHz. Again, the polar diagram is multilobed with low zenithal angle radiation.

28 MHz: On this band, the antenna functions as two long-wire antennas, each of three half waves, fed in phase. The polar diagram is similar to that of a $3\lambda/2$ long-wire, but with even more gain over a $\lambda/2$ dipole because of the collinear effect obtained by feeding two $3\lambda/2$ antennas, in line and in close proximity, in phase. See Fig. 8.

Construction

The Antenna

The dimensions of the antenna and its matching section are shown in Fig. 9. If possible, the flat-top should be horizontal and run in a straight line, and should be erected as high as can be above ground. In describing the theory of operation, it has been assumed that it is generally possible to erect the antenna at an average height of about 34 ft, which happens to be the optimum height for the antenna at 14 MHz. Although this is too low for optimum radiation efficiency on 1.8, 3.5, and 7 MHz for **any** horizontal type of antenna, in practice few amateurs can install masts of the optimum height of half a wavelength at 3.5 or 7 MHz, and certainly not at 1.8 MHz.

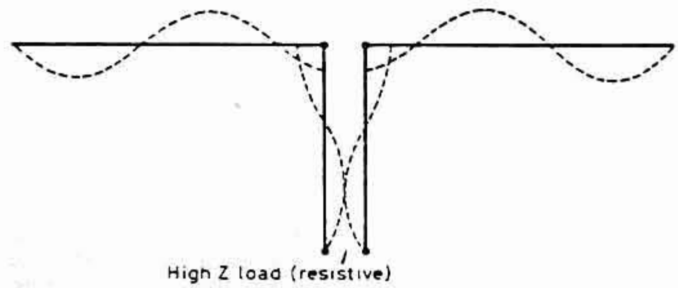

Fig. 6 —Current standing-wave distribution on the antenna and matching section at 21 MHz. On this band the antenna works as a long wire of five half waves. The base of the matching section presents a virtually nonreactive high impedance load to the feeder.

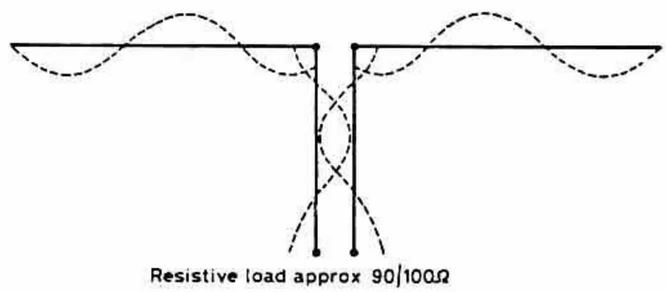

Fig. 7 — Current standing-wave distribution on the antenna and matching section at 24 MHz. The antenna functions as a long wire of five half waves.

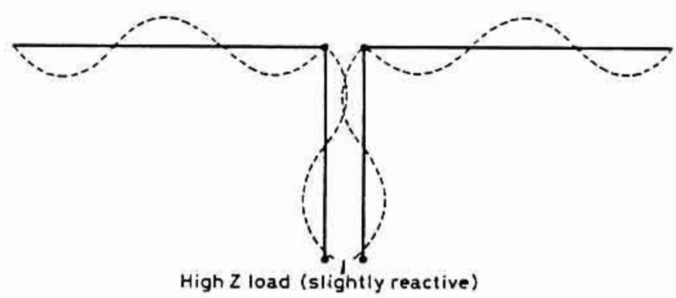

Fig. 8 — Current standing-wave distribution on the antenna and matching section at 28 MHz. The antenna functions as two long-wire antennas each of three half waves length, fed in phase. A very effective form of antenna giving good multilobe, low zenithal angle, radiation.

If it is not possible to accommodate the 102-ft top in a straight line because of space limitations, up to about 10 ft of the antenna wire at each end may be allowed to hang vertically or at some convenient angle, or be bent in the horizontal plane, with little practical effect on performance. This is because, for any resonant dipole antenna, most of the effective radiation takes place from the center two-thirds of its length where the current antinodes are situated. Near each end of such an antenna, the amplitude of the current standing wave falls rapidly to zero at the outer extremities; consequently, the effective radiation from these parts of the antenna is minimal.

The antenna may also be used in the form of an inverted V. However, it should be remembered that for such a configuration to radiate at maximum efficiency, the included angle at the apex of the V should not be less than 120 degrees.\3 The use of 14 AWG enameled copper wire is recommended for the flat-top or V, although thinner gauges such as 16 or even 18 AWG can be used.

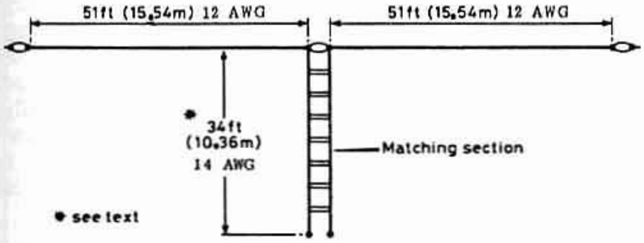

Fig. 9 — Construction dimensions of the G5RV antenna and matching section.

The Matching Section

This should be, preferably, of open-wire feeder construction for minimum loss. Since this section **always** carries a standing wave of current (and voltage), its actual impedance is unimportant. A typical, and satisfactory, form of construction is shown in Fig. 10. The feeder spreaders may be made of any high-grade plastic strips or tubing; the clear plastic tubing sold for beer or wine syphoning is ideal.

If you decide to use 300-ohm ribbon type feeder for this section, it is strongly recommended that the type with "windows" be used. It has lower loss than a feeder with solid insulation throughout its length, and it possesses relative freedom from the detuning effect caused by rain or snow. If this feeder is used for the matching section, allowance must be made for its velocity factor (VF) in calculating the mechanical length required to resonate as a half-wave section **electrically** at 14.15 MHz. Since the VF of standard 300-ohm ribbon feeder is 0.82, the **mechanical** length should be 28 ft. However, if 300-ohm ribbon with windows is used, its VF will be almost that of open-wire feeder, say 0.90, so its **mechanical** length should be 30.6 ft.

This section should hang vertically from the center of the antenna for at least 20 ft or more if possible. It can then be bent and tied off to a suitable post with a length of nylon or terylene cord at an above-head height. Supported by a second post, its lower end is connected to the feeder.

The Feeder

The antenna can be fed by any convenient type of feeder provided always that a suitable type of matching network is used. In the original article describing the G5RV antenna, published in the **RSGB Bulletin** for November 1966, it was suggested that if a coaxial cable feeder was used, a balun might be employed to provide the necessary unbalanced-to-balanced transformation at the base of the matching section. This was because the antenna and its matching section constitute a **balanced** system, whereas a coaxial cable is an **unbalanced** type of feeder. However, later experiments and a better understanding of the theory of operation of the balun indicated that such a device was unsuitable

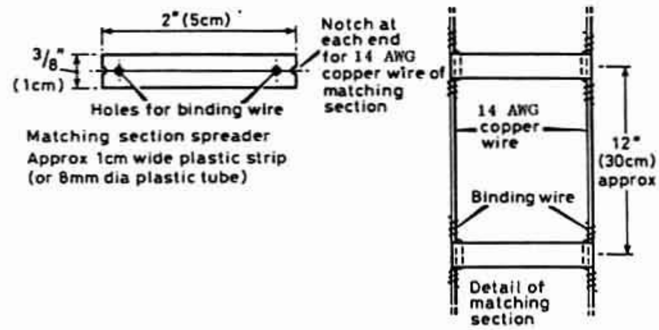

Fig. 10 — Constructional details of the matching section. Also suitable for open-wire feeder construction.

because of the highly reactive load it would see at the base of the matching or make-up section on most HF bands.

If a balun is connected to a reactive load with an SWR of more than 2:1, its internal losses increase. The result is heating of the windings and saturation of its core, if one is used. In extreme cases with relatively high power operation, the heat generated in the device can cause it to burn out. The main reason for not employing a balun in the G5RV antenna, however, is that unlike a matching network, which employs a **tuned circuit**, the balun cannot compensate for the reactive load condition presented to it by the antenna on most of the HF bands, whereas a suitable type of matching network can do this most effectively and efficiently.

Experiments were conducted to determine the importance, or otherwise, of unbalance effects caused by the direct connection of a coaxial feeder to the base of the matching section. There was a rather surprising result. The research showed that the HF currents measured at the junction of the inner conductor of the coaxial cable with one side of the (balanced) matching section, and at the junction of the outer coaxial conductor (the sheath) with the other side of this section, are virtually **identical** on all bands up to 28 MHz, where a slight, but inconsequential difference in these currents has been observed. There is, therfore, no need to provide an unbalanced-to-balanced device at this junction when using a coaxial feeder.

The use of an **unbalanced-to-unbalanced** type of matching network between the coaxial output of a modern transmitter (or transceiver) and the coaxial feeder is essential. This is because of the reactive condition presented at the station end of this feeder, which on all but the 14-MHz band, will have a fairly high to high SWR on it. The SWR, however, will result in insignificant losses on a good-quality coaxial feeder of reasonable length; say, up to about 70 ft. Either 50- or 80-ohm coaxial cable can be used. Because it will have standing waves on it, the actual characteristic impedance of the cable is unimportant.

Another convenient feeder type that can be employed is 75-ohm twin lead. It exhibits a relatively high loss at frequencies above 7 MHz, however, especially when a high SWR is present. I recommend that not more than 50 to 60 ft of this type be used between the base of the matching section and the matching network. The 75-ohm twin lead available in the United Kingdom is of the **receiver** type; less lossy **transmitter** type is available in the United States.

By far the most efficient feeder is the open wire type. A suitable length of such can be constructed in the same manner as that described for the open-wire matching section. If this form is employed, almost any length may be used from the center of the antenna to the matching network (balanced) output terminals. In this case, the matching section becomes an integral part of the feeder. A convenient length of open-wire feeder is 84 ft. It permits parallel tuning of the matching network circuit on all bands from 3.5 to 28 MHz, and with conveniently located coil taps in the matching network coils for each band, or where the alternative form of a matching network employing a three-gang 500 pF/section variable coupling capacitor is used, the optimum loading condition can be obtained for each band.\4 This is not a rigid feeder-length requirement, and almost any mechanically convenient length may be used. Since this type of feeder will always carry a standing wave, its characteristic impedance is unimportant. Sharp bends, if necessary, may be used without detriment to its efficiency. It is only when this type of feeder is correctly terminated by a resistive load equal to its characteristic impedance that such bends must be avoided.

Coaxial Cable HF Choke

Under certain conditions a current may flow on the **outside** of the coaxial **outer conductor.** This is because of inherent unbalanced-to-balanced effect caused by the direct connection of a coaxial feeder to the base of the (balanced) matching section, or to pickup of energy radiated by the antenna. It is an undesirable condition and may increase the chances of TVI [from fundamental overload, **if** the feeder is routed near a TV receiving antenna — Ed.]. This effect may be reduced or eliminated by winding the coaxial cable feeder into a coil of 8 to 10 turns about 6 inches in diameter immediately below the point of connection of the coaxial cable to the base of the matching section. The turns may be taped together or secured by nylon cord.

It is important that the junction of the coaxial cable to the matching section be made thoroughly waterproof by any of the accepted methods. Binding with several layers of plastic insulating tape or self-amalgamating tape and then applying two or three coats of polyurethane varnish, or totally enclosing the end of the coaxial cable and the connections to the base of the matching section in a sealant such as epoxy resin are a few methods used.

References

\1 Varney, L., "ATU or astu?," **Radio Communication,** August 1983.
\2 See Ref. 1.
\3 Varney, L., "HF Antennas in Theory and Practice — A Philosophical Approach," **Radio Communication,** Sept. 1981.
\4 See Ref. 1.