The G5RV Antenna System Re-Visited
Part 1: The G5RV on 20 meters

L. B. Cebik, W4RNL

Louis Varney's "G5RV" was and is not an antenna, that is, an array of elements. It is an antenna system including a radiating element and a length of transmission line designed to present a "correct" impedance at a design frequency.

The 1984 *RADCOM* Version of the Antenna System

The most familiar part of the system is the wire: a center-fed doublet 102' long. Actually, Varney calculated the length to be 3/2 wavelengths long at 14.15 MHz using a long standing equation:

$$L_{feet} = \frac{492(n-0.05)}{f_{MHz}} \qquad (1)$$

The letter 'n' is the number of half wavelengths in the antenna. The result is 102.57' or 31.27 m. It is interesting that Varney notes in his 1984 article in *RADCOM* that he can shorten the wire to 102' or 31.1 m, since the entire system will be handled by an antenna tuning unit (or ASTU--antenna system tuning unit--as Varney preferred).

(The entire 1984 article has been reprinted in Erwin David, G4LQI, *HF Antenna Collection*, published by RSGB in 1991. In the G5RV article, the author makes reference to his initial 1966 presentation of the basic idea. An adapted version appears in *The ARRL Antenna Compendium*, Vol. 1, 1985.)

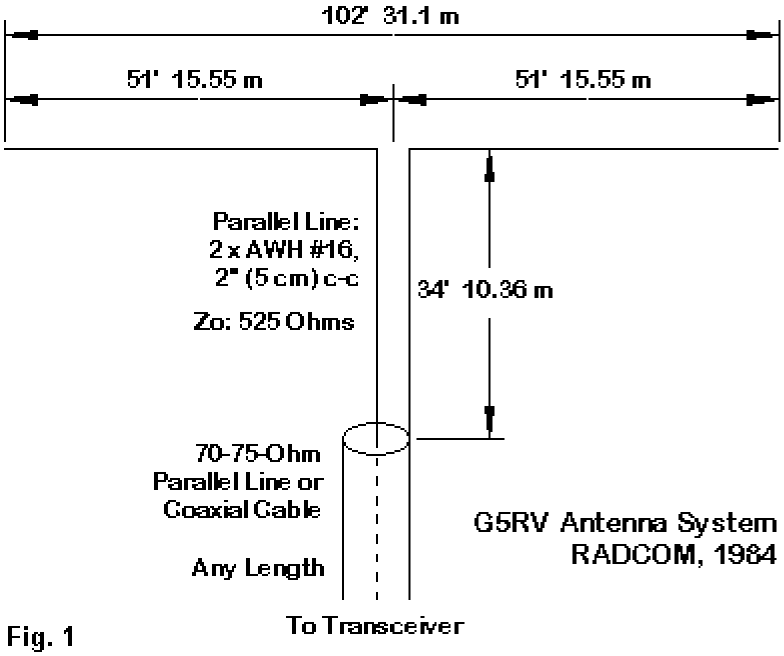

Fig. 1

However, we conventionally sketch the G5RV antenna system as in **Fig. 1**. The center-fed doublet has a section of parallel transmission line extending from the radiating wire feedpoint to a junction with the "main" feedline.

Curiously, Varney specifies the length of the matching section as 34.0' or 10.36 m. Using the same constant for a half-wavelength (492), the section is a half wavelength at 14.47 MHz. The prescribed length assumed a velocity factor (VF) in the line section of 0.98--hence the final length.

Many folks presume that the original impedance of the matching section line used in the G5RV is 450 Ohms. However, Varney specifies home-made open wire feeder composed of AWG #16 copper wire spaced 2" (5 cm) apart. The characteristic impedance of such line by standard calculations is closer to 525 Ohms. At 14.15 MHz, the line is 1/2-wavelength long, thus replicating the feedpoint impedance. Hence, the line Zo is--at 20 meters--of little consequence.

A 3/2-wavelength wire--if properly cut--should present a feedpoint impedance slightly higher than a 1/2-wavelength resonant dipole: about 90 Ohms. Hence, the impedance at 14.15 MHz at the base of the matching section should also be about 90 Ohms. Thus did Varney design the G5RV antenna system for a 75-Ohm "twinlead" or coaxial feeder.

There seemed to be an instant misunderstanding of the 1/2-wavelength line used by Varney in his antenna system, since recommendations immediately began to appear for the use of twinleads other than the home-made open- wire feeder used in the original. At 14.15 MHz, 300-Ohm solid ribbon twinlead with a VF of 0.82 (using numbers from the *RADCOM* article) requires 28.5' or 8.69 m of line for the matching section. However, the recommended length is 28' or 8.5 m. This latter value is closer to but not identical with applying the ribbon VF value to

Varney's 34' length--which already has a VF of 0.98 built into its length. Likewise 300-Ohm ribbon with windows has a VF (in the article) of 0.90. Calculating its length using the 492 constant yields 31.29' or 9.54 m. However, the recommended length of such line is 30.6' or 9.3 m, the values one would arrive at by applying the 0.90 VF value to Varney's 34' length.

With so much confusion built into the basic accounts of the G5RV, there can be little wonder that the antenna has become the subject of endless variations, some being serious attempts to arrive at an ideal antenna of its type, others being generated simply to sell commercial versions of the antenna.

We have not yet tried to place the antenna on bands other than 20 meters. It is in pursuit of this goal that the G5RV has been taken well past its original intent. Remember that, even though Varney thought the G5RV would provide a good match on 20 meters for a 75-Ohm main feedline, he believed in using an ATU at the rig end of the line.

Some Small Facts About Wire Antennas

Before we take the plunge into other bands, we should pause to review the methods by which the G5RV antenna system emerged and how well they play in the 21st century. The review will not be simple, because many of the notes are partially accounted for by the developer of the system. However, those same notes may be at odds with common but erroneous interpretations of the antenna. This feature will hold true without ever leaving 20 meters or straying very far from the design frequency, 14.15 MHz.

The equation for calculating the length of an antenna consisting of multiple half-wavelengths has a long and honored history when well used. In fact, it is very well used when calculating non-resonant antennas or antennas for which resonance is not at all crucial. Where we require some degree of precision in determining the length of a resonant antenna, the equation turns out to be quite off the mark.

Since Louis Varney stated that he intended to use the antenna system with an antenna tuner, he effectively implied that the equation used to determine the 102' length was sufficiently accurate for that method of operation. As well, his estimate of the feedpoint impedance, repeated at the end of the 34' matching section of parallel transmission line, was also within the limits of accuracy necessary for using the system with an ATU. However, 102' is not a resonant length of wire at 14.15 MHz, and its resistive impedance component is not 90 Ohms.

These latter facts, which we shall embellish shortly, would be not problem if the general conception of the G5RV antenna system included the use of an antenna tuner. However, the antenna has acquired a reputation for being able to provide under 2:1 SWR on more than one band--without qualifications needed to confine the claim to a reasonably clear arena of truth. So the following notes are more applicable to understanding why the general conception--rather than Varney's--is off base.

We should note two facts about wire antennas. First, in the HF region, we have tended to blithely ignore the fact that changes of wire diameter have an effect upon the resonant length of a wire antenna and upon the feedpoint impedance. We tend to use "cutting" formulas as if they were wholly unrestricted in scope and always accurate, regardless of the wire we select. For HF wire antennas in the U.S., we tend to use wires as small as AWG #18 (0.0403" diameter)--such as copperweld--and as large as AWG #12 (0.0808" diameter) hard drawn copper, not to mention the common sizes in between. The wire diameter is small compared to a wavelength (about 834.5" at 14.15 MHz); nevertheless, a 2:1 change of wire diameter will have a recordable affect on the wire's resonant length and feedpoint impedance.

Second, as we move a horizontal wire antenna to varying heights below about 1 wavelength, we shall find a second source of variation in the resonant length and feedpoint impedance of a wire antenna. Unlike variations due to wire diameter, which are quite regular, the variations due to height tend to follow cyclical patterns that repeat every half-wavelength.

We can sample some of these variations from the tables that follow. In each case, I modeled 102' copper wires from AWG #18 through AWG #12, using NEC-4, which is more than adequate to provide accurate data. The models used 101 segments with a source centered on the wire. The test models were initially modeled in free space and then at two different heights above average ground (conductivity: 0.005 s/m; permittivity: 13). The upper height was 65.62' or 20 m, close to 1 wavelength above ground. The lower height was 32.81' or 10 m above ground. Let's see what the models report.

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Source Impedance of a 102' Wire at 14.15 MHz

Free Space

Wire Dia. AWG	**Feedpoint Impedance R +/- j X Ohms**	**75-Ohm SWR**
#12	**102 - j 48**	**1.869**
#14	**103 - j 51**	**1.914**
#16	**104 - j 53**	**1.958**
#18	**105 - j 55**	**1.999**

65.62'/20m

Wire Dia. AWG	**Feedpoint Impedance R +/- j X Ohms**	**75-Ohm SWR**
#12	**104 - j 49**	**1.883**
#14	**104 - j 51**	**1.928**
#16	**105 - j 54**	**1.972**
#18	**106 - j 56**	**2.012**

32.81'/10m

Wire Dia. AWG	**Feedpoint Impedance R +/- j X Ohms**	**75-Ohm SWR**
#12	**111 - j 56**	**2.048**
#14	**112 - j 59**	**2.093**
#16	**112 - j 61**	**2.136**
#18	**113 - j 63**	**2.177**

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The SWR numbers are overly precise relative to the rounded impedance values. The intent is to show clearly the general trends. The thinner the copper wire, the higher the resistive component of the impedance, despite the fact that the wire is ever shorter of resonance. As well, although the impedance values at a 1-wavelength antenna height are very close to the free-space values, the impedance figures at a 1/2-wavelength height show some departure from the free-space values.

Finally, the wire is well short of resonance at the design frequency. Otherwise put, for precision of resonant length, the traditional equation simply will not do.

I replicated the exercise when I added in a 34' or 10.36-m length of 525-Ohm feedline with a velocity factor of 0.98. This provides an electrical half-wavelength of line, that is, the equivalent of 34.77' or 10.60 m at 14.15 MHz. Remember that the intent of this line section on the design frequency is to replicate the wire feedpoint impedance at the end of the so-called matching section.

For this exercise, it is unnecessary to model the parallel transmission line with physical wires. One may use the TL facility within NEC-4 software to provide a non-radiating mathematical model of a perfect (lossless) transmission line. Since Varney's writings anticipate that the antenna builder will respect the requirement of parallel transmission line to sustain its balance, the non-radiating aspect of the NEC TL facility is within the bounds of the exercise. Because the line is relatively short, the difference between a lossless line and a real line constructed according to Varney's specifications will almost too small to notice. On the other hand, because we are using a physical length that is only close to but not exactly a half-wavelength at the design frequency, we should expect to see small variations in the resulting impedance and SWR values. The following table records the results of this exercise.

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Source Impedance of a 102' Wire and 34' Line at 14.15 MHz

Free Space

Wire Dia. AWG	Feedpoint Impedance R +/- j X Ohms	75-Ohm SWR
#12	102 - j 52	1.933
#14	103 - j 54	1.979
#16	104 - j 57	2.024
#18	105 - j 59	2.066

65.62'/20m

Wire Dia. AWG	Feedpoint Impedance R +/- j X Ohms	75-Ohm SWR
#12	104 - j 52	1.946
#14	104 - j 55	1.993
#16	105 - j 57	2.037
#18	106 - j 59	2.079

32.81'/10m

Wire Dia. AWG	Feedpoint Impedance R +/- j X Ohms	75-Ohm SWR
#12	111 - j 60	2.111
#14	111 - j 62	2.158
#16	112 - j 64	2.203
#18	113 - j 66	2.245

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There are only slight differences between the two tables, and the bulk of those differences result from the fact of choosing a physical approximation of a 1/2-wavelength line rather than using an exact 1/2-wavelength line. However, it is likely that the modeled line is closer to 1/2 wavelength than will be most lines cut for a physical implementation of the G5RV antenna system.

At the design frequency, we need not explore the consequences of using something other than the line specified for the antenna. The use of 300-, 400-, and 450-Ohm lines--if each is an electrical half-wavelength--will result in virtually identical tables for 14.15 MHz.

A more important question concerns the antenna length. As initially specified, the wire is too short to be resonant at 14.15 MHz. But what length might seem more resonant? The spread of impedance figures suggests that we might use a compromise between the resonance at a 20-m height and resonance at a 10-m height. In fact, I used this compromise to arrive at a length of 103.35' or 31.5 m.

The compromise does not represent an ideal situation, only a convenient one. The change of impedance and resonant length does not follow a simple progression with decreases in height. Instead, the values change cyclically in half-wavelength increments (ignoring height below about 0.2 wavelengths above ground). The sample heights used here do not necessarily represent the extremes that might appear at other heights.

With these qualifications, we can examine the data reported by NEC-4 for the revise wire length with the 34' line attached. Since the free-space values and the 20-m height values are so similar, I have omitted the free-space portion of the exercise.

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Source Impedance of a 103.35' Wire and 34' Line at 14.15 MHz

65.62'/20m

Wire Dia. AWG	Feedpoint Impedance R +/- j X Ohms	75-Ohm SWR
#12	111 + j 7	1.494
#14	112 + j 7	1.497
#16	112 + j 6	1.504
#18	113 + j 6	1.515

32.81'/10m

Wire Dia. AWG	Feedpoint Impedance R +/- j X Ohms	75-Ohm SWR
#12	119 - j 1	1.586
#14	119 - j 2	1.592
#16	120 - j 2	1.601
#18	120 - j 3	1.613

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Increasing the length of the wire toward resonance, of course, increases the resistive component of the source impedance. Hence, there is a limit as to how low the 75-Ohm SWR can go by this strategy. As well, as the wire thins, the resistive component goes up.

We seem to have gained a usable 75-Ohm SWR at the design frequency, but obviously the 50-Ohm SWR would be well above 2:1. In the days before fixed-tuned output circuits in transmitters, the old pi-network amplifier output circuits--with variable "tune" and "load" controls--would have easily provided a match to these impedance values in 20 meters. As well, they fall well within the range of almost any ATU, even the limited range versions incorporated into some modern transceivers.

However, an SWR value at a spot frequency does not tell the entire story about antenna performance. We are as interested in the SWR bandwidth as we are in the particular value at some given frequency. So I ran frequency sweeps of the two versions of the G5RV antenna, both with the 34' line attached.

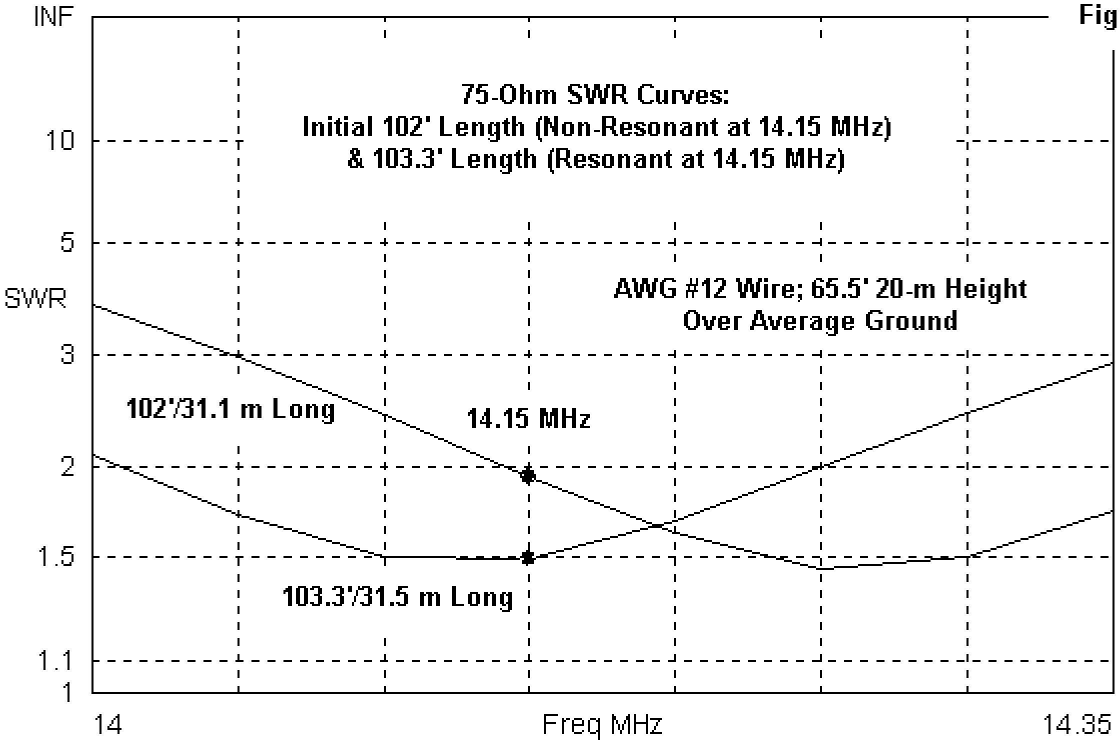


Fig. 2

Fig. 2 shows the curves for the short and the long antennas. Clearly, the longer length favors the lower end of 20 meters, while the 102' length favors the upper end of the band. The impedance level of a G5RV is high enough that we cannot obtain full band coverage from the wire and line combinations. In addition, the 1/2-wavelength line section is 1/2 wavelength only at the design frequency. Hence, it contributes to a narrowing of the SWR bandwidth.

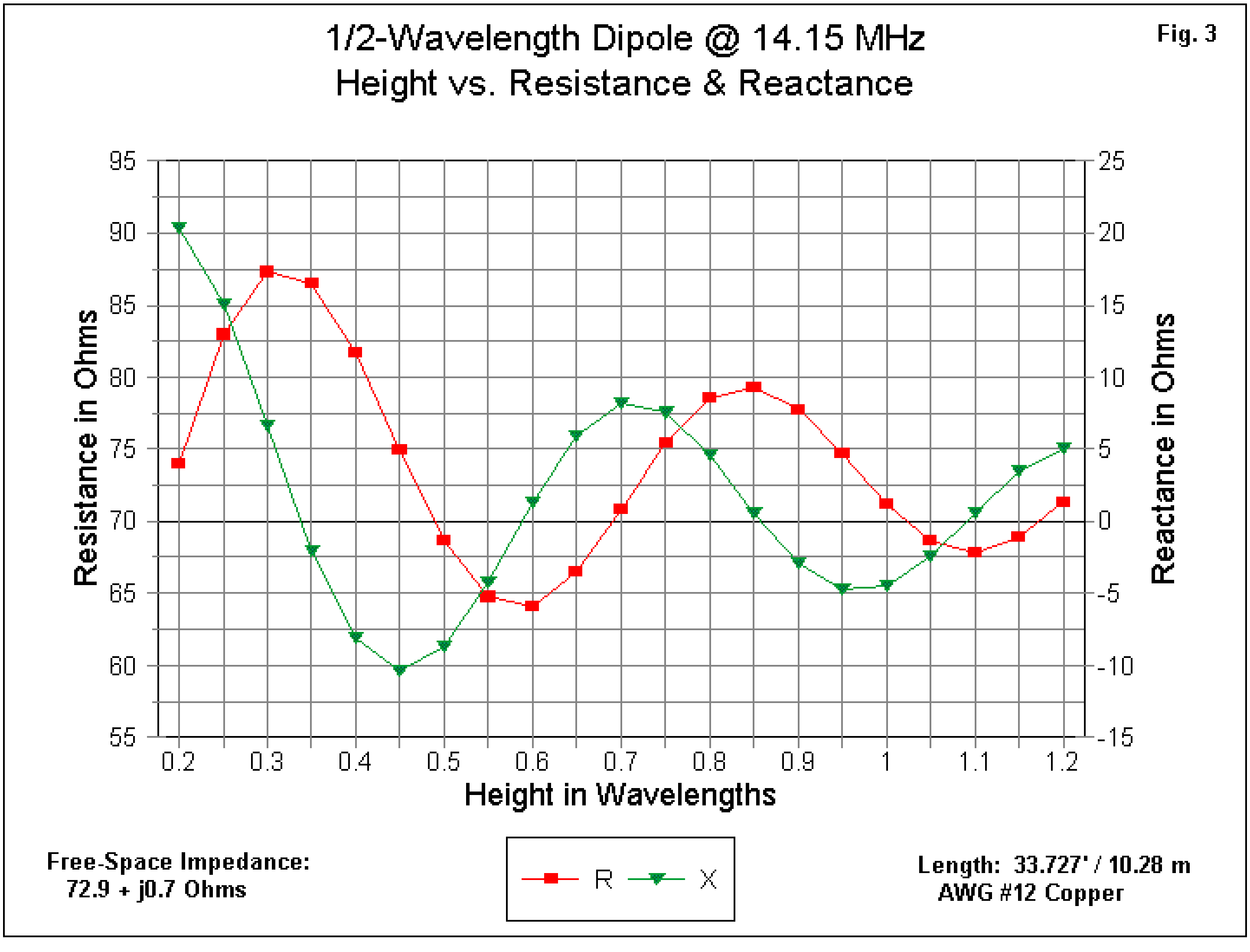
We may note in passing that a common resonant 1/2-wavelength dipole of any of the wire sizes sampled in this exercise would easily cover the 20-meter band with under 2:1 SWR. Moreover, an ATU would free us from concern about the 2:1 SWR that marks the limit of full output from most modern transceiver designs. Nonetheless, it is interesting to note that the 3/2-wavelength wire tends to show a narrower SWR bandwidth than the shorter half-wavelength dipole. The narrower operating bandwidth will, of course, be a matter of concern for anyone who tries to use a G5RV antenna system without an intervening ATU. Unfortunately, this latter mode of operation seems to be the rule rather than the exception--at least until one experiences first hand the limitations of the system.

A Side-Note on Height vs. Feedpoint Impedance

I have noted that for any single-wire doublet, the source impedance varies with the height above ground. The variation is most significant in the region below a 1-wavelength height. The differences in the G5RV feedpoint impedance reflected this variation, but perhaps not as convincingly as it ought to do.

Let's begin with a common center-fed dipole at 14.15 MHz. We shall make it from AWG #12 copper wire. Our model will be resonant in free-space. A length of 33.727' or 10.28 m satisfies this requirement within +/-j 1 Ohm reactance. The wire's impedance in free space is 72.9 + j 0.7 Ohms.

I then set the antenna over real average ground, beginning at 0.2 wavelength and continuing in 0.05-wavelength increments to 1.2 wavelengths. The effects of the height changes on the feedpoint resistance and reactance appear in **Fig. 3**.



As noted earlier, the resistance and reactance cycles peak at 0.5-wavelength intervals of height. However, the resistance and reactance curves are not synchronized. The reactance peaks occur about 0.15-wavelength higher than their closest resistance peaks.

The reactance swings allow us to re-interpret the data in this way: The resonant length of a 1/2-wavelength dipole changes with height, especially within the range of heights shown in **Fig. 3**. But, even if we resonate the dipole at each height, the feedpoint impedance will still show cyclical changes as we increase the height throughout the range that we have sampled.

A 3/2-wavelength doublet exhibits the same sort of impedance swing. Let's construct a 14.15-MHz resonant 3/2-wavelength doublet from the same AWG #12 copper wire. If we resonate it in free space, it will be 103.117' or 31.43-m long. Its free-space feedpoint impedance will be 108.1 + j 0.2 Ohms. Now we are ready to perform the same set of exercises that we performed on the dipole.

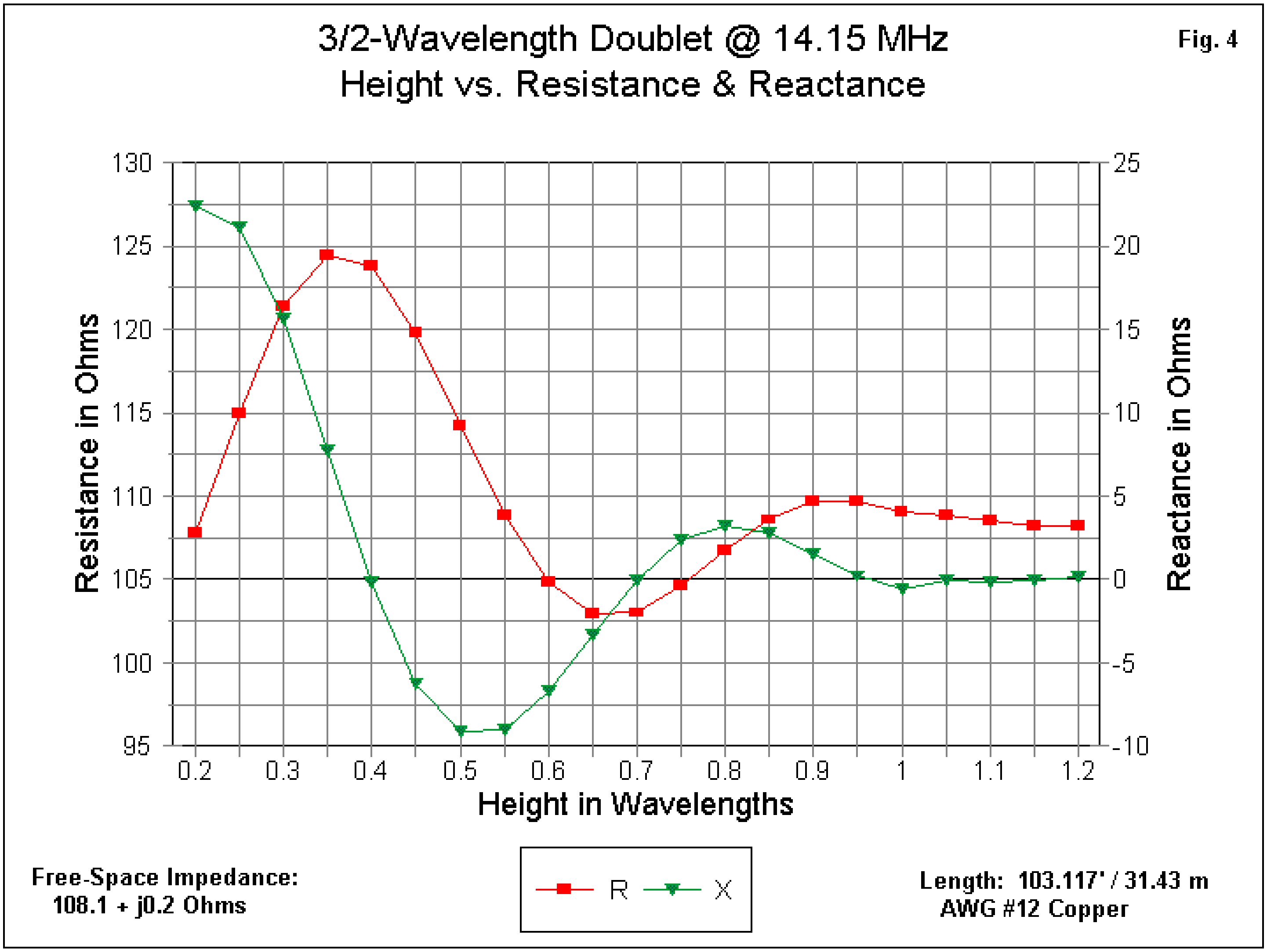


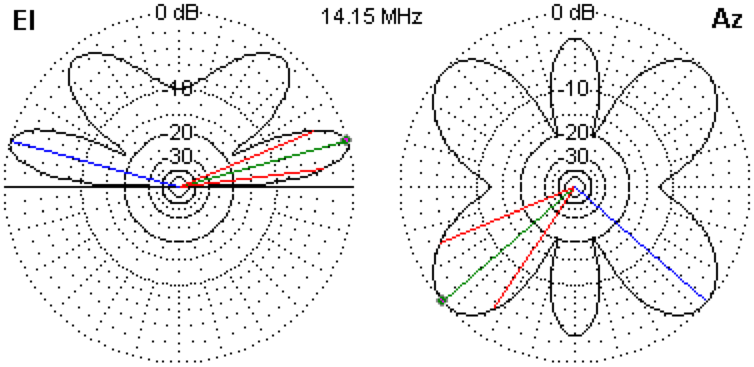
Fig. 4

Free-Space Impedance:
108.1 + j0.2 Ohms

Length: 103.117' / 31.43 m
AWG #12 Copper

Fig. 4 shows the results of our test runs. Once more, the resistance and reactance vary considerably as we change heights. The reactance reaches its peaks about 0.15-wavelength higher than height at which the resistance values peak. Perhaps the most notable differences between the dipole and doublet graphs are two: First, the doublet peaks and dipole peaks do not occur at the same heights above ground, although the impedance components for both antennas show 1/2-wavelength cycles. Second, the feedpoint impedance of the longer doublet smoothes out rapidly above 1 wavelength, while the 1/2-wavelength dipole impedance components continue to show noticeable cycles.

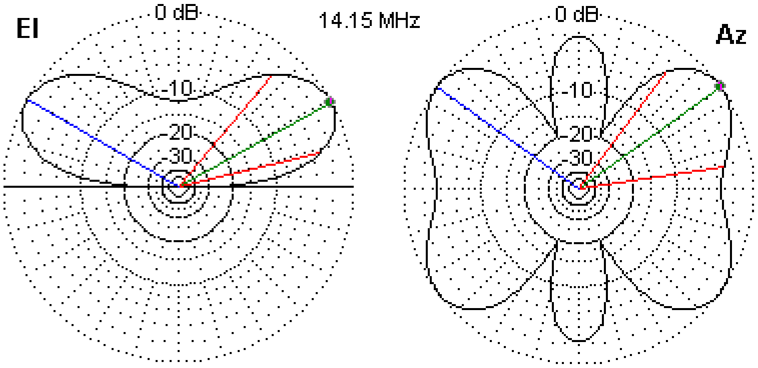
Not only does the impedance show differences with height, but so too do the elevation and azimuth patterns. Here, we may illustrate by taking the elevation and azimuth patterns of the 3/2-wavelength doublet at 20-m and at 10-m heights above ground.



Elevation & Azimuth Patterns
3/2-Wavelength Doublet at 20-m Height

Fig. 5

The elevation pattern in **Fig. 5** shows the typical double lobe structure of any horizontal antenna just below 1-wavelength above ground. The azimuth pattern presumes that the antenna wire is stretched horizontally across the graphic and is taken at the antenna's take-off (TO) angle (the elevation angle of maximum radiation), namely, 14 degrees. It shows 6 lobes, just as we would expect of any wire antenna half-way between 1- and 2-wavelengths long. Note the distinctness of the angular lobes; that is, note the depth of the null off the ends of the antenna.



Elevation & Azimuth Patterns
3/2-Wavelength Doublet at 10-m Height

Fig. 6

Fig. 6 shows the equivalent patterns when the antenna is half the height of the first model. At just below a half-wavelength in height, we have only a single elevation lobe, just as would any horizontal single-wire antenna at the same height. The azimuth pattern uses a TO angle of 28 degrees and is clearly kin to the one taken at 20 m above ground. However, note the shallower null off the ends of the antenna wire. Radiation off the ends of the wire is down only about 4 dB compared to radiation at the maximum gain angles, compared to a 12-dB differential for the higher version of the antenna.

Like any other wire antenna, the 3/2-wavelength doublet--the heart of the G5RV antenna system at 20 meters--requires reasonable careful orientation if the user has in mind any particular target areas for communications. Likewise, height will always benefit a single-wire antenna, at least to the point where the vertical beamwidth matches as best possible the typical variations in the skip angles on 20 meters.

Conclusion to Part 1

We have reviewed some of the design elements that went into the G5RV antenna system at its design frequency of 14.15 MHz, including some apparent confusions surrounding alternative "matching section" lengths when using different parallel transmission lines. As well, we have shown some of the limitations within the simplified design procedure used to develop the basic G5RV length.

Perhaps of equal or greater significance has been our foray into understanding some of the factors that influence the operation of wire doublets that are usually absent from simplified cutting formulas. Every change that we make from a design that we use as a starting point has consequences for how well the antenna performs compared to the original. The importance of these changes can range from negligible to monumental, depending upon our operating circumstances and our expectations.

Louis Varney expected to use his G5RV antenna system with an ATU on many bands without much regard for where on each band his strongest lobes were pointed. Consequently, the antenna worked very well for him. However, much of the indirect reputation of the G5RV has to do with operating on at least some bands without an ATU. As well, expectations of lobe direction have largely been silent, leaving each user to bring his or her own expectations to the table. As a result, many users have been overjoyed, while many other have been disappointed.

Since we have extracted about as much useful data as we can for the basic design frequency--the 20-meter band--we may next turn to trying to use the G5RV on other bands.

The G5RV Antenna System Re-Visited
Part 2: The G5RV on all HF Bands

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The original G5RV antenna system consists of a center-fed horizontal 102' wire plus a 34' length of open-wire 525-Ohm feeder. Louis Varney, the antenna system's developer, intended two other features. First, the main feeder that we connect to the base of the open-wire section should be 75-Ohm twinlead or coaxial cable. Second, the main feeder should go to an antenna tuning unit (ATU) and not directly to a transceiver.

In Part 1, we examined some of the basic properties of the G5RV antenna system at its basic design frequency, 14.15 MHz. We explored some of the variations created by varying the height of the antenna above ground and by using different wire diameters. While none of these variations has much of an effect if we use an ATU between the main feeder and the transceiver, they become important if we attempt to use the antenna system without a tuner. With the physical dimension selected by Varney, the system provides only a partial coverage of 20 meters with a 75-Ohm SWR under 2:1, although a tuner would easily permit full band coverage.

Somewhere along the line of time, the G5RV antenna system has acquired a false aura: namely, that it can cover many amateur bands in the HF region without the use of an antenna tuner. Since almost any rudimentary analysis of the antenna system can show this reputation to be false--and not consistent with what Varney wrote about his antenna system--we shall not dwell on that matter. We shall, of course, present some modeling data that confirms the inaccuracy of the reputation. However, there is a much more interesting question to investigate.

If the antenna system will not provide the desired coverage without an antenna tuner, why use the matching section at all? Why not simply run a feedline of one impedance all the way from the antenna wire to an antenna tuner? Varney recognized that this mode of operation is quite feasible. Nevertheless, he believed that his matching section offered some advantages on most amateur bands. Let's see if we can uncover them.

The 102' Wire Doublet

In Varney's 1984 *RADCOM* article, he noted that whatever feed system the user might provide, the patterns on each of the HF amateur bands depended solely on the radiation from the antenna wire itself. Over the years, I have discovered that many multi-band wire-antenna users remain unaware of the patterns produced by their antennas on different bands. Therefore, it may be useful to review the pattern situation for the 102' wire that is the radiating portion of the G5RV.

A single center-fed linear element (regardless of the element diameter) will have a pattern that is broadside to the element from a length of about 1/3-wavelength (about the shortest practical doublet length) to a length that is a bit over 1 wavelength. The electrical length of a fixed length physical doublet will increase as we increase the operating frequency. A 3/2-wavelength doublet at 14.15 MHz is 1/2-wavelength at one third that frequency, or about 4.7 MHz. Obviously, the 102' wire is well under 1/2-wavelength in the 80-meter band. At 3.75 MHz, the wire is about 0.39-wavelength.

As we increase the operating frequency, the wire become electrically longer. When it is about 1.25 wavelengths, we obtain the typical extended double Zepp pattern with the strongest broadside main lobes that we can achieve from a single element, but with "ears." The ears are emerging new lobes that are part of the natural process of pattern evolution. As we increase frequency--that is, as we make the wire electrically longer--the lobes will evolve in a regular fashion.

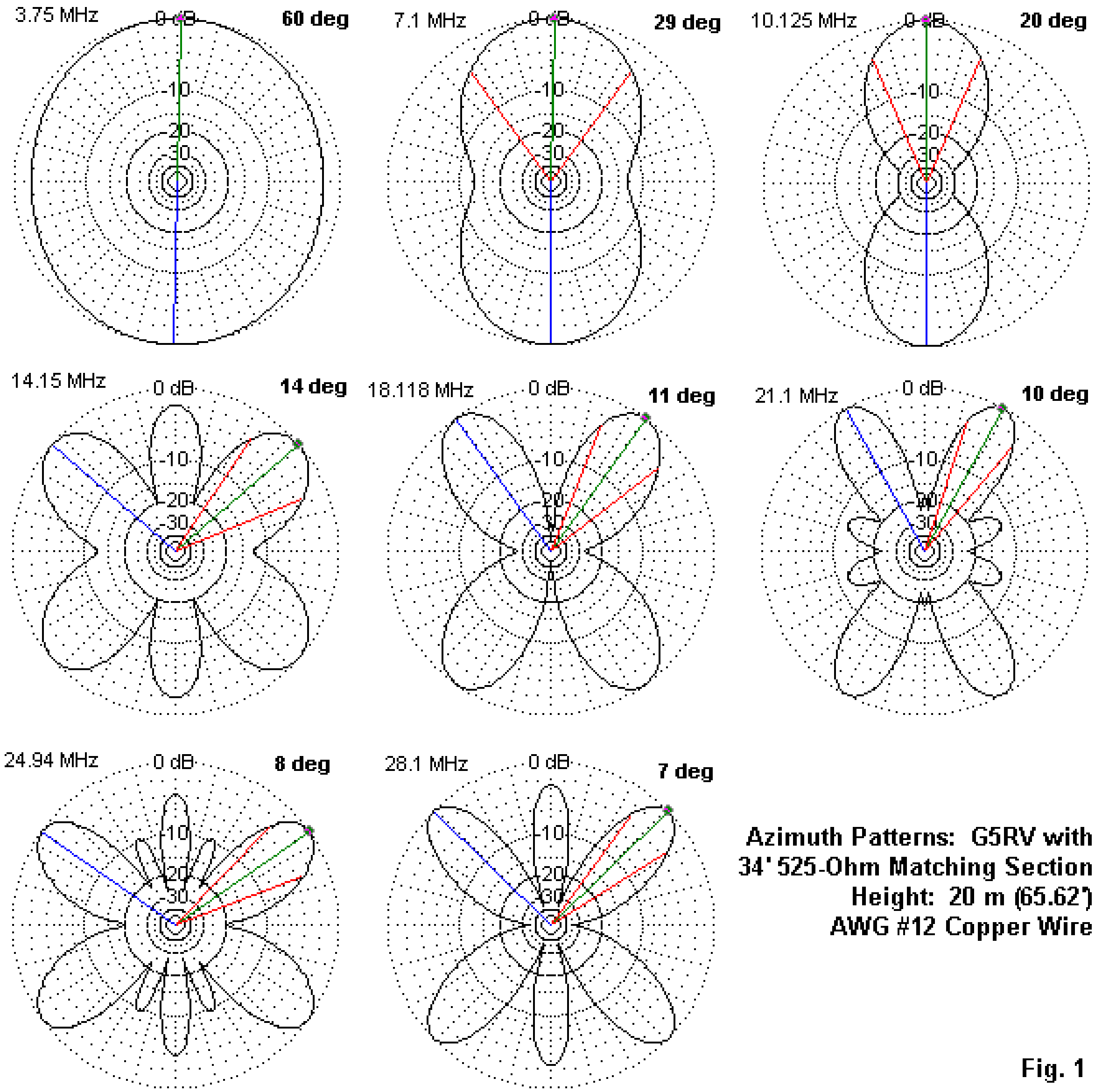
At 1 wavelength, we have 2 lobes--one on each broadside to the wire. At 2 wavelengths, we have 4 lobes, each at quartering angles relative to the wire orientation. At 3 wavelengths, we obtain 6 lobes. In fact, the total number of lobes for any wire that is an integral number of wavelengths will simply be twice the length as measured in wavelengths.

However, lobes do no simply pop into and out of existence. As we pass any integral wavelength marker in making our wire electrically longer, the old lobes will gradually diminish and the new lobes associated with the next integral wavelength marker will emerge and increase in size. At the 1.25-wavelength point of the extended double Zepp, the 1-wavelength broadside lobe have reached their peak and are ready to diminish, while the new lobes--associated with a 2-wavelength wire--have made their appearance. As we move the wire closer to 1.5 wavelengths, the lobes reach a point of roughly equal strength. Since we have both the 1-wavelength and the 2-wavelength lobes, our lobe total is 6. We can apply similar counting methods to any wire that is x.5 wavelengths, where x is any integer.

So for any wire of any electrical length, we can predict the lobe structure. With that fact in mind, let's survey the patterns that we can obtain from a 102' wire. For the sake of brevity, I shall select only one of the 102' wires and one of the heights that we examined in Part 1. Let's use AWG #12 copper wire and place it 20 m or 65.62' above average ground.

The fixed physical height above ground, of course, will have a bearing upon the pattern by changing the take-off (TO) angle, or the elevation angle of maximum radiation as we change frequency. As we increase frequency and shorten the length of a wave, the antenna will be electrically higher. Hence, the TO angle will be lower. As a rule of thumb--although calculation equations exist in the handbooks--the TO angle of an antenna at 1/2 wavelength height is about 25-26 degrees. At 1 wavelength, the TO angle is 14 degrees. At 2 wavelengths, the angle drops to the 7-8-degree mark. One of the benefits of using a single multi-band wire antennas is that the TO angle tends to correlate with skip properties. As we increase frequency, the dominant skip angles decrease, matching our wire antenna TO angles, if we have it high enough in the first place.

Fig. 1 shows the anticipated azimuth patterns of the 102' wire at a height of 20 m above ground--about 1 wavelength high at 20 meters. Unlike the patterns for a long-boom Yagi, which might change across the span of a single amateur band, the patterns of a single wire antenna are stable and change slowly. Hence, there will be no significant difference in the 15-meter patterns from one end to the other of this 450-kHz wide band.



Azimuth Patterns: G5RV with 34' 525-Ohm Matching Section
Height: 20 m (65.62')
AWG #12 Copper Wire

Fig. 1

Each pattern in **Fig. 1** shows the frequency at which it was taken, along with the TO angle. 102' represent a little over 1 wavelength at 10.125 MHz, and so we see two broadside lobes. The antenna is about 2 wavelengths long at 17 meters, revealing a 4-lobe pattern. At 10 meters, the antenna is close to 3-wavelengths long and shows 6 distinct lobes.

At 20 meters, where the wire is 3/2-wavelengths, we also find 6 lobes, but these are the product of the 1-wavelength and the 2-wavelength lobes, one set enlarging and the other set diminishing. The other bands shows lobes in various states of emergence or disappearance because the 102' wire in somewhere between the convenient marker lengths that we have designated.

With any multi-band single-wire antenna, the user has some decisions to make. If he has some latitude in orienting the antenna, he can choose a favorite band and orient the wire so that a major lobe points in the direction or directions of favored target communications areas. Or he can spend nights of pencil and paper planning trying to figure out the best orientation that will yield the best possible results on all favored bands.

Before we try to feed this wire, let's examine one other feature of the lobe structure of the 102' wire. The following table provides the maximum gain and TO angle of the 102' wire as we installed it at 20 m above ground. Maximum gain is the strength of the most major lobe (of which there may be more than one).

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1. 102' AWG #12 Copper Wire Gain and TO Angles

Band Meters	Freq. MHz	Max Gain dBi	TO Angle degrees
80	3.75	6.00	60
40	7.1	7.94	29
30	10.125	9.68	20
20	14.15	8.37	14
17	18.118	9.37	11
15	21.1	10.05	10
12	24.94	10.57	8
10	28.1	10.12	7

Note: Antenna height = 20 m. Maximum gain = gain of the strongest lobe.
TO angle = elevation angle of maximum radiation.

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There is a general trend toward higher gains in the major lobes as we increase the electrical length of the wire by increasing frequency. This property applies to any horizontal wire antenna, regardless of any special name we might give it. However, increase major lobe gain is accompanied by a disadvantage: the width of the major lobes decreases as we electrically lengthen the antenna wire and place more lobes into the pattern. Hence, the higher the frequency of our 102' wire, the more finicky becomes the aim at a target area.

You may also note another trend in the number, most clearly revealed by examining the numbers of 30, 20, and 17 meters. Note that the maximum gain on 20 meters is less than the values for 30 and 17 meters. One of the phenomena of lobe emergence is that, in general, when we are at the x.5-wavelength region, the emerging and diminishing lobes will have a bit less strength, because we are combining two lobe structures.

The final feature that we want to notice is the feedpoint impedance of the 102' wire as taken at the center point of the wire itself. These values will give us some clue as to the rationale behind the G5RV antenna system.

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2. 102' AWG #12 Copper Wire Feedpoint Impedances

Band Meters	Freq. MHz	Feedpoint Impedance R +/- j X Ohms	Notes
80	3.75	46 - j 339	High relative X
40	7.1	397 + j 1037	High relative X
30	10.125	1220 - j 2522	High Z and relative X
20	14.15	104 - j 49	Low X
17	18.118	2281 + j 1624	High Z
15	21.1	337 - j 1038	High relative X
12	24.94	203 + j 328	Moderate relative X
10	28.1	2669 + j 678	High Z

Note: Antenna height = 20 m

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Notice the large range of the resistive components of the impedances on the HF bands--all the way from 46 to 2600 Ohms. (The resistive component at 3.5 MHz would be even lower than 46 Ohms.) As well, note how many of the bands present relatively high values of reactance--some inductive, others capacitive.

To feed this antenna with a single transmission line, we would normally select a characteristic impedance somewhere in the vicinity of the geometric mean between the extremes. Something in the 400-600-Ohm vicinity should prove usable. However, the impedance at the antenna tuner terminals depends upon three general factors--ignoring line losses for the moment: the feedpoint impedance, the characteristic impedance of the feedline, and the electrical length of the feedline. Unless there is a perfect match between the antenna feedpoint impedance and the characteristic impedance of the transmission line, the line itself will continuously transform the impedance components along each half-wavelength of line at the frequency of operation. It is not at all unusual to encounter values of resistance and/or reactance at the tuner terminals that fall outside the matching range of the tuner. The most ready cure is often to insert an additional length of line to see if we cannot arrive at resistance and reactance values within the tuner's range. If we are lucky, the insertion may allow matching at all used frequencies. If we are not so lucky, then we may need to developing a switching system to insert the added line length on the bands for which we need it.

Now we are ready to understand part of the rationale behind the G5RV antenna system, with its 34' of 525-Ohm transmission line.

The G5RV Antenna System and Some Variants on All HF Bands

Varney performed a rudimentary standing wave analysis for his antenna system in his 1984 article. Let's begin by reviewing his results in tabular form. Remember that he is analyzing the likely impedance that will appear at the lower terminals of the matching section.

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3. G5RV's analysis of the system at all HF frequencies
Note: Load Impedance is the impedance at the end of the "matching section."

Band	Analysis	Load Impedance

80 meters	**Wire + Section = shortened Dipole**	**Reactive (R+/-jX)**
40	**Wire + Section = partially folded 2-half-waves in phase**	**Reactive (R+/-jX)**
30	**Wire + Section = partially folded 2-half-waves in phase**	**Reactive (R+/-jX)**
20	**3-half-waves**	**Resistive (ca. 90 Ohms)**
17	**2-full-waves in phase**	**High Z, slight X**
15	**5-half-waves**	**High Z, resistive**
12	**5-half-waves**	**Resistive (90-100 Ohms)**
10	**2 x 3-half-waves in phase**	**High Z, slight X**

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This sort of information style makes it difficult for us to directly compare the results with the matching section with the modeled results that we obtained without the matching section. Therefore, let's do some NEC-4 modeling, using the same TL facility matching section construct that we used in Part 1. As we did initially, we shall confine ourselves to a 20-m height for the 102' AWG #12 copper wire.

While we are at the task, we can also examine some slight variations in the G5RV antenna system. All of the variations represent slight modifications in the matching section transmission line.

Version 1: the original G5RV with 34' of 525-Ohm 0.98 VF open wire line.

Version 2: the common U.S. implementation of the G5RV using 34' of 450-Ohm 0.91 VF vinyl-covered window line.

Version 3: a second common implementation using 28' of 300-Ohm 0.82 VF TV-type ribbon or solid vinyl covered line, noted in the 1984 article.

Version 4: 300-Ohm 0.9 VF windowed vinyl-covered TV-type ribbon line (in the U.S., available from The Wireman in SC, but check his specification for the VF).

Allowing for the possible confusion of the VF attached to the original open-wire line by those who suggest alternative line for the matching section, the sections are all cut to be about 1/2-wavelength at 14.15 MHz. Hence, we should see about the same impedance values in all version as we obtained for the wire alone.

The following table shows the modeled impedance values at the base of the matching section for each version on each of the test frequencies spread across the HF region. As well, for reference, the tables also provide the 75-Ohm SWR values in keeping with Varney's intent that the remaining transmission line to the ATU be 75-Ohm twinlead or coaxial cable.

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4. Impedances at the base of the "Matching Section" for 4 Variations on the G5RV Antenna System

All Versions use a 102' AWG #12 copper wire at 20 m above average ground.
differences appear in the "Matching Section."
Version 1: 34' (10.36 m) 525-Ohm, VF 0.98 open wire system (G5RV

recommendation)
Version 2: 34' (10,36 m) 450-Ohm, VF 0.91 windowed parallel line (common implementation)
Version 3: 28.0' (8.53 m) 300-Ohm, VF 0.82 solid TV-type parallel line
Version 4: 30.6' (9.33 m) 300-Ohm, Vf 0.90 windowed TV-type parallel line

Band meters	Freq MHz	Version 1 Impedance R+/-jX	75-Ohm SWR	Version 2 Impedance R+/-jX	75-Ohm SWR
80	3.75	35 + j 136	9.6	31 + j 112	8.0
40	7.1	88 - j 230	9.9	60 - j 110	4.5
30	10.125	95 + j 584	50.0	103 + j 682	62.0
20	14.15	104 - j 52	1.9	104 + j 51	1.9
17	18.118	157 - j 517	25.2	73 - j 230	11.6
15	21.1	77 + j 219	10.2	86 + j 376	23.9
12	24.94	144 - j 73	2.5	145 + j 156	4.5
10	28.1	2398 + j 1002	37.6	409 - j 917	33.0

Band meters	Freq MHz	Version 3 Impedance R+/-jX	75-Ohm SWR	Version 4 Impedance R+/-jX	75-Ohm SWR
80	3.75	20 - j 10	3.8	20 - j 11	3.8
40	7.1	29 - j 83	5.9	29 - j 85	6.1
30	10.125	25 + j 270	41.9	25 + j 266	41.1
20	14.15	106 - j 64	2.2	106 - j 68	2.3
17	18.118	55 - j 315	26.2	57 - j 326	26.9
15	21.1	24 + j 44	4.2	24 + j 38	4.0
12	24.94	83 + j 24	1.4	83 + j 18	1.3
10	28.1	825 + j 1261	36.8	666 + j 1171	36.4

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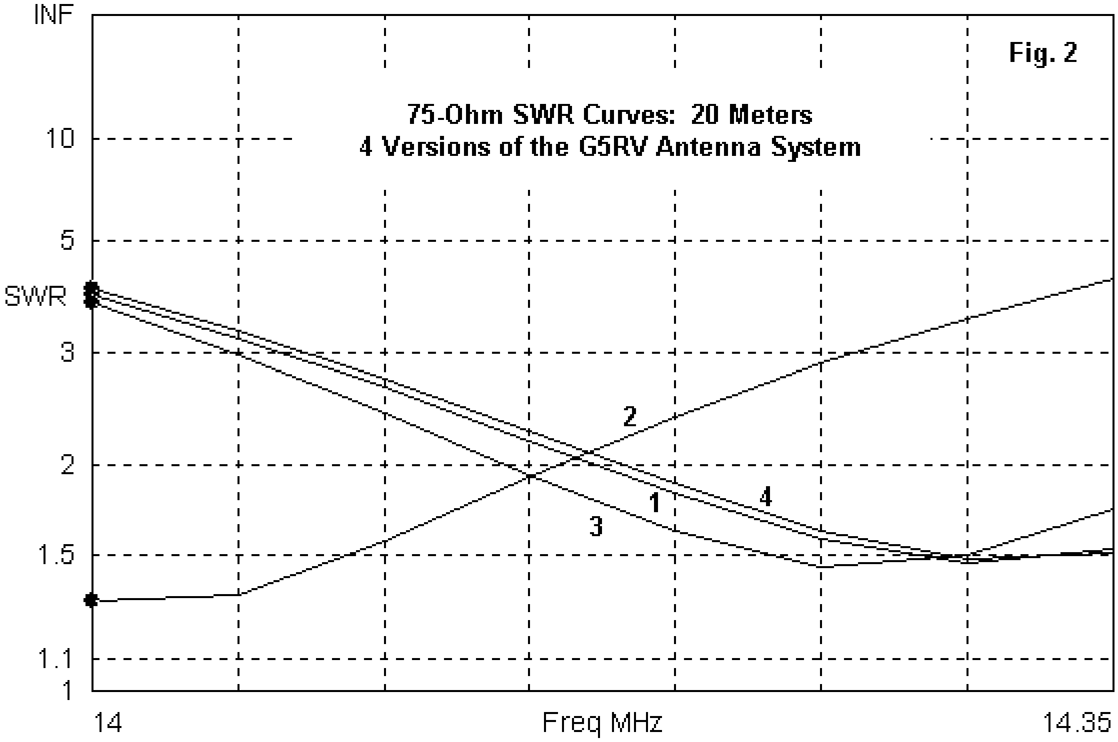
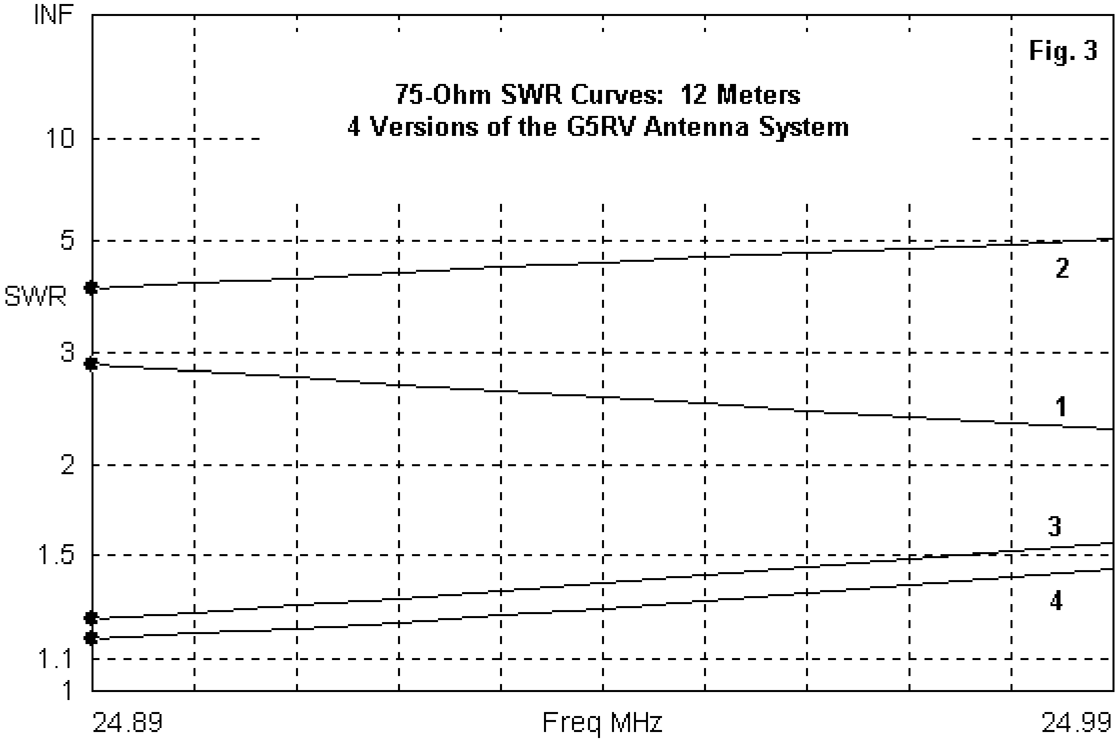
Let's initially look at a couple of bands in the whole range. Although all of the matching sections show similar impedances at 14.15 MHz, we cannot be assured that the 20 meter SWR curves will be identical for all 4 versions. Therefore, **Fig. 2** shows the 75-Ohm curves for the 4 versions.



Versions 1, 3, and 4 show similar curves, since they were cut close to a half wavelength for the line used. However, the common US implementation of the G5RV simply replaces one line with another without allowing for the difference in velocity factor. Hence, the impedance transformation undergoes more than 1/2 wavelength, and the resulting impedance away from the design frequency differs from the other versions. The lesson is that if one wishes to replicate the G5RV system at 20 meters with a different matching section line, one must use some care in accounting for differences in the velocity factor.

Of all the bands, 12 meters shows the greatest promise for avoiding the need for an ATU. **Fig. 3** presents the SWR curves for this narrow ham band.



As may be evident, the two 300-Ohm systems provide a good 75-Ohm SWR, while the two higher-impedance matching sections do not. The unsuspecting novice builder of a G5RV may wonder why.

The matching section is 1/2-wavelength long at 14.15 MHz. However, it has a different electrical length at every other frequency across the amateur bands. Lines having different characteristic impedances will yield different impedance transformations.

We are likely familiar with the fact by now that a transmission line of any characteristic impedance will replicate the wire feedpoint impedance if the line is electrically 1/2 wavelength. We may also be familiar with the fact that if a line is electrically an odd number of quarter-wavelengths, then the impedance at the base or "sending" end will be the square of the line's characteristic impedance divided by the load impedance--in this case the wire feedpoint impedance.

However, these simplified relationships derive from a much more complex equation describing the transformation of the load impedance for any length of line whatsoever. The following equation shows the transformation, but still simplified by omitting the calculation of line losses. As noted in Part 1, the modeling software uses a lossless-line model for its calculations, and the losses in the short parallel line composing the matching section are almost small enough to be negligible.

$$Z_S = Z_O \frac{\frac{Z_L}{Z_O}\cos\left(2\pi \frac{l}{\lambda}\right) + j\sin\left(2\pi \frac{l}{\lambda}\right)}{\cos\left(2\pi \frac{l}{\lambda}\right) + j\frac{Z_L}{Z_O}\sin\left(2\pi \frac{l}{\lambda}\right)} \qquad (1)$$

The terms l and lambda are in the same units, where l is the electrical length of the transmission line, while lambda is a wave length. Zo is the characteristic impedance of the line; ZL is the load impedance, and Zs equals the impedance at the sending end of the line. This particular version of the impedance transformation equation comes from page 186 of Terman's *Radio Engineers' Handbook*. Of course, ZL may be complex (R +/- jX), and so, too, may be Zs. There are a number of utility computer programs that will calculate the impedance transformation--with or without losses--including the resistive and reactive components.

The message of the equation for this context is that the complex transformation of impedance along a transmission line, when the load impedance and the line's characteristic impedance are not a perfect match, depends on the line length and the line's characteristic impedance. The transformation on all bands for which the line is not a nearly exact multiple of a half wavelength will differ as we change the characteristic impedance of the line. Therefore, as we develop alternative types of transmission line for the matching section of a G5RV, we should not expect to replicate the impedance values of Varney's original version on bands other than 20 meters.

We can see the effect of moving from the 450-to-525-Ohm region down to 300 Ohms by looking at the impedance values for the bands below 20 meters. The higher impedance lines yield resistive components between 35 and 95 Ohms, while the 300-Ohm lines produce values in the 20-30-Ohm range. These values are also a good reason not to run the feedline to the 4:1 balun that inhabits so many network tuners in common use today. We do not need an already low resistive component further reduced.

However, the 300-Ohm line has a small advantage. It yields impedance values on more bands with 75-Ohm SWR values under 10:1. Although there is no guarantee, given the very wide variety of components used in today's tuners, the lower the overall SWR value, the more likely it is that the feedline from the matching section to the tuner will provide values within the tuning range of the ATU.

Indeed, it is now time to perform one more comparison: between the overall impedance values in the table for the 4 versions of the G5RV and the impedance values for the feedpoint of the 102' wire alone. In general, the matching section yields lower values of both resistance and reactance. Therefore, with a 75-Ohm line from the matching section to the ATU, we are likely to be able to effect a match. We would only be able to achieve this goal with parallel transmission line all the way from the wire to the ATU--and might have to insert some line on some bands.

The final question in this series in inquiries is simple: why do the job in the G5RV manner?

Setting Up a G5RV Antenna System

For a G5RV antenna system--at least as indicated by both Varney himself and by the modeling results--we shall need several components:

102' of strong copper or copperweld wire--along with sundry end rope, insulators, and a center-junction piece.

A length of parallel transmission line cut to 1/2-wavelength at about 14.15 MHz, accounting for the line's velocity factor.

A length of feedline from the matching section to the ATU. For network tuners, we might as well use 75-Ohm or even 50-Ohm cable. However, since the line will be subject to considerable SWR and hence voltage and current excursions along its length, we should use the shortest possible length to minimize losses. As well, we should use the fattest, lowest loss line that we can obtain (RG-213 or better). Because 75-Ohm transmitting twinlead is no longer made in the U.S., we can only implement the G5RV using coaxial cable, unless we are willing to build our own low-impedance parallel line.

A choke to place at the junction of the matching section and the coaxial cable, as noted in the 1984 *RADCOM* article.

A wide-range network tuner.

Fig. 4 sketches the essential ingredients of the antenna from the wire down to the network tuner.

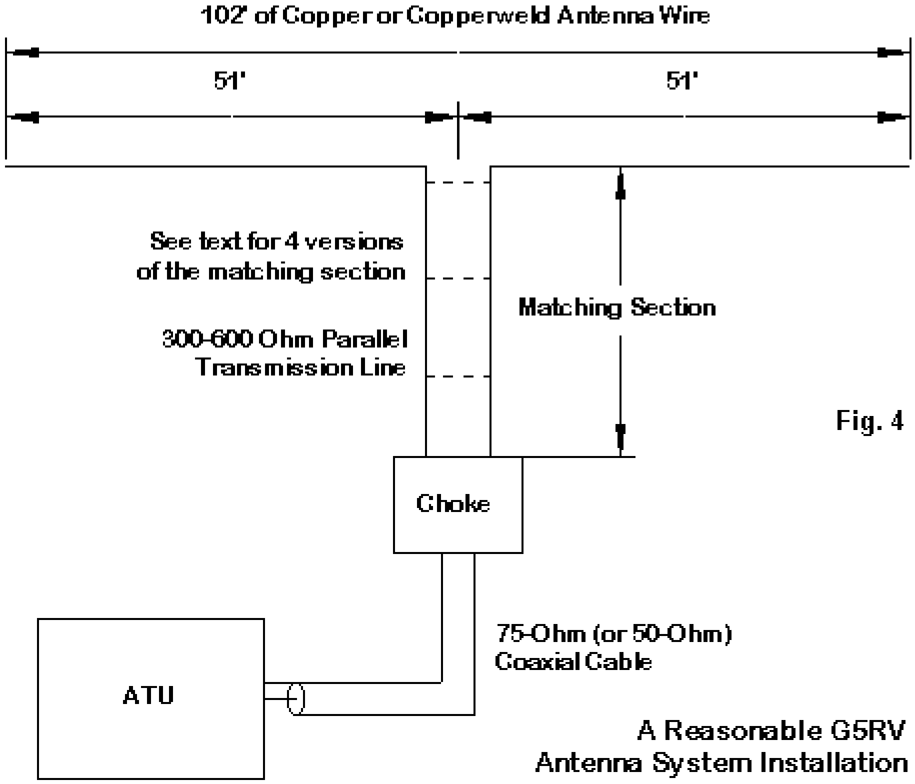


Fig. 4

A Reasonable G5RV Antenna System Installation

When used with a wide-range tuner, there is little to choose among the versions of the matching section illustrated in these notes--or among a large lot of other potential sections. Each should be 1/2-wavelength at about 14.15 MHz. Perhaps the only general rule involved is that the higher the characteristic impedance of the matching section transmission line, the higher the impedance that is likely on the bands below 20 meters. However, 300-Ohm line (the transmitting variety, for lowest losses) offers fewer bands with very high SWR values relative to either 50- or 75-Ohm cable.

Perhaps the only other component of the system calling for comment is the choke. Very often we hear such devices being called choke-baluns or simply 1:1 baluns. Such devices have two functions that are inter-related. They provide a transition between balanced line on the one side and unbalanced line on the other. They also tend to attenuate common-mode currents on the braid of the coax. In fact, these two functions are one and the same, for the only reason for needing a transition device where we effect no impedance transformation is to suppress common-mode currents.

Newcomers to antenna work are sometimes confused by calling these current common-mode currents and also saying that they appear on the coax braid. Normal transmission line currents are ideally equal in magnitude but opposite in phase anywhere along a transmission line. Common-mode currents have the same phase on both conductors. On parallel line, such currents are of equal magnitude on each line. However, on coaxial cable, due to the skin effect which tends to cancel currents at the center of a conductor and place all current at the surface, the current is most measurable on the braid.

Louis Varney warned against the use of transformer-wound 1:1 baluns because many designs show considerable losses when the load reactance is significant. Indeed, Jerry Sevick, W2FMI, who has published the most material on transmission-line transformers, recommends that all reactance compensation occur on the load side of the balun.

In place of such baluns to suppress common-mode currents, Varney recommends a 6" diameter coil of about 8 to 10 turns of the feedline coaxial cable at the junction of the matching section and the main feedline. I have found that W2DU-type ferrite bead chokes also perform well in this function.

One recommendation that I have seen from vendors of commercially prepared G5RV kits is to use as long a run of coaxial cable as possible. Coaxial cable is inherently lossier than parallel transmission line. Any SWR factor acts as a multiplier on the basic matched-line loss of a cable at a given frequency. Hence, the only reason that I can think of for using a very long run of coaxial cable--other than one of necessity for extending from the shack to the antenna--is to use the line losses to mask the SWR at the shack end of the line. If the measured SWR at the shack end of the line is very significantly lower than the sorts of figures produced by these models--or models customized to the system proposed by a user--then they result from line losses. And the only purpose for accepting such losses would be to operate the system without a tuner.

With a wide-range tuner, one achieves the lowest feasible loss level with the shortest possible coaxial cable run.

For a good analysis of the losses associated with various ways of employing combinations of parallel line, coaxial cables, and tuners with the basic G5RV wire, see the extensive notes of Owen Duffy, VK1OD, at http://www.vk1od.net/G5RV.

Conclusion to Part 2

From Louis Varney's own writings, we can derive and confirm with NEC-4 models the fact that the G5RV antenna system is suitable for multi-band operation, just as any wire from about 88 to 140 feet might be. The matching system comes into play, not to do away with the need for an ATU, but to permit the use of a coaxial cable as the main feedline with SWR values that are considerably lower than they would be without the matching section on most HF bands. Nevertheless, the ATU remains an essential part of the G5RV antenna system.

The use of coaxial cable for the main feedline has some advantages in the modern home. Contemporary homes have walls, ceilings, and floors that are rampant with wiring and other metallic conductors associated with heating and air conditioning systems. Hence, indoors, the chances of a parallel line encountering environments that would disrupt the line balance have multiplied with time. A coaxial cable main feedline properly immunized from common-mode currents with a suitable choke offers some isolation from the conductive contents of the modern home with only small losses as the cost.

50-Ohm cable has come to rule the field of amateur feedlines. As well, the ATU remains among many folks a suspect device, since it adds to the number of boxes on the operating desk. As a result, after the appearance of the G5RV antenna system, a search ensued for a combination of antenna wire length and matching section that would yield the highest number of amateur bands offering ATU-less operation on a 50-Ohm cable. We shall devote a final part to this series to explore a G5RV variant, perhaps the most successful effort to reach the 50-Ohm cable goal.

The G5RV Antenna System Re-Visited
Part 3: The Almost-No-ATU G5RV-Type Antenna

L. B. Cebik, W4RNL

In the mid-1980s, Brian Austin (then ZS6BKW, now G0GSF) addressed the quest left as a nearly mythical heritage of the G5RV antenna system: to develop an antenna system that, for the maximum number of HF bands possible, would permit no-ATU operation of the system with a 50-Ohm coaxial cable as the main feedline. There had been other cousins of the G5RV, such as the W5ANB transmission-line translation featured in *QST* for November, 1981 (pp. 26-27). Serious researchers traced the overall design concept to the 300-Ohm based Collins version of the 1930s. However, virtually all of these cousins satisfied themselves--as did Varney--with moderate impedances that would fall easily in the range of the average antenna tuner. They did not seek to free the user completely from the ATU in multi-band operation.

The ZS6BKW/G0GSF Antenna System

Austin's amateur developments appear in *RADCOM* for August, 1985, and in *Radio ZS* for June 1985, with professional efforts reported in *Elecktron* for June/July, 1986, and the *Journal of IERE (UK)* for July/August, 1987. G3BDQ's *Practical Wire Antennas* volume reports on the amateur version of Austin's antenna on p. 22. Essentially, his task was to find a length and characteristic impedance for a matching section that will transform the impedance at the center of a wire of a given length to something close to 50 Ohms. So we have several variables (using Austin's notation) in combination:

L1: the length of the horizontal wire;

L2: the length of the matching section;

Z2: the characteristic impedance (Zo) of the matching section; and

Z4: the characteristic impedance of the main feedline, which is 50 Ohms for most amateur applications.

By computer calculation, Austin arrived at a workable set of relationships that permitted the largest number of bands to arrive at a direct 50-Ohm feed with an acceptable SWR value. Let L1 approximately equal 204/Flow meters or 669.3/Flow feet, where Flow is the lowest frequency to be used. For a Zo of 400 Ohms, let L2 approximately equal 92/Flow meters or 301.8/Flow feet. Of course, L2 must be adjusted according to the velocity factor of the actual parallel transmission line used. (A 400-Ohm Window line is available from The Wireman of SC).

It is interesting that the sum of the two lengths is about 1% under 1 wavelength. More significant than this accidental result is the fact that the combination of L1 and L2 provides a good 50-Ohm match in the following progression of ratios: 1 : 2.02 : 2.57 : 3.54 : 4.14, etc. If we let the lowest used frequency be about 7 MHz, then we may have acceptable matches on 20, 17, 12, and 10 meters. 5 bands with one doublet and no ATU is no mean feat.

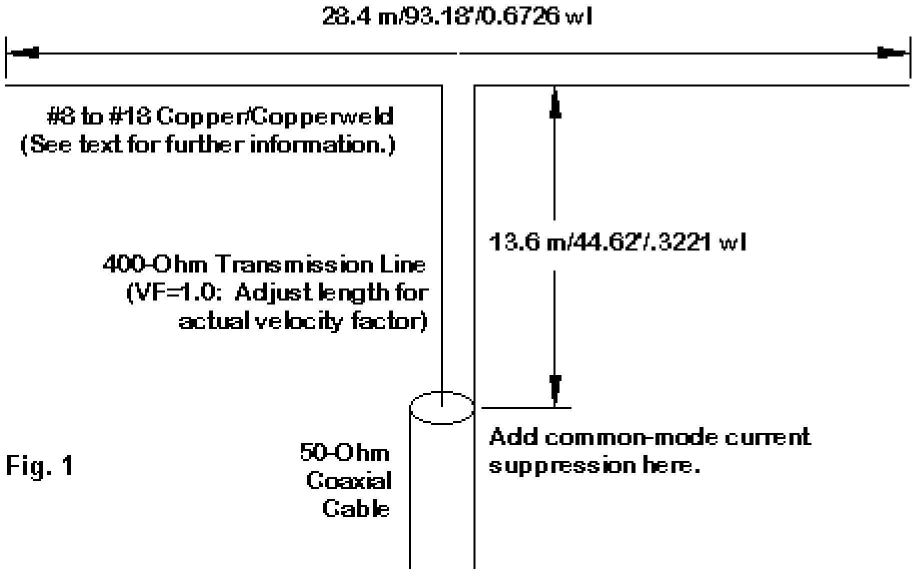


Fig. 1

The ZS6BKW/G0GSF Multi-Band Antenna System

Fig. 1 shows the outline for a ZS6BKW/G0GSF antenna system for 40 through 10 meters. The wire length is 28.4 m or 93.18'. The matching section uses 400-Ohm parallel line and a length of 13.6 m or 44.62'. We shall examine various wire sizes for L1 later, but for the moment we may note the following small table of values for constructing 400-Ohm open wire transmission line using common copper wire sizes.

400-Ohm Open-Wire Transmission Line

Wire Size AWG	Center-to-Center Spacing (inches)	Wire Size AWG	Center-to-Center Spacing (inches)
12	1.137	16	0.715
14	0.901	18	0.567

There are some commercially available vinyl-covered windowed lines that are closer to 400 Ohms than our expected 450-Ohm value. Therefore, if you do not wish to make up the 45' of 400-Ohm line, you may wish to check with vendors. Obtain the velocity factor to determine how much to physically shorten the line to achieve the required electrical length in **Fig. 1**. However, do not rely on the report. Whether you build or buy the match-section line, measure its velocity factor.

The Hayes volume reports the Austin results in the following manner with respect to SWR at the junction of L2 and the main 50-Ohm feedline.

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50-Ohm SWR Values for the ZS6BKW Antenna System

Freq. MHz	50-Ohm SWR	Notes
3.65	11.8:1	poor
7	1.8:1	good
10	88:1	very poor
14	1.3:1	good
18	1.6:1	good
21.2	67:1	very poor
24	1.9:1	fairly good
29	1.8:1	good

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Austin used a free-space calculation of the impedance of L1 as the basis for his matching section calculations. It is not clear that the equations factor in either the effects of height or wire size on the quality of 50-Ohm match. As well, the spot checks of the match do not provide us with a good portrait of the operating bandwidth potential for each band.

Consequently, it may be useful to subject the ZS6BKW/G0GSF antenna system to the same sorts of NEC-4 modeling that we used for the G5RV. We shall begin with a basic model using AWG #12 copper wire, placing it in free space and then at heights of 20 m and 10 m (65.62' and 32.81') above average ground. The models produce the following results.

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Modeled Results for the ZS6BKW/G0GSF Antenna System

Free Space

Band Meters	Freq. MHz	Feedpoint Impedance R +/- j X Ohms	50-Ohm SWR
80	3.75	13 + j 79	13.23
40	7.15	55 + j 6	1.15
30	10.125	502 + j 1506	>100
20	14.175	42 + j 16	1.47
17	18.118	68 + j 37	1.99
15	21.2	1333 + j 1783	74.36
12	24.94	65 + j 28	1.74
10	28.8	77 + j 7	1.56

20 m/65.62' Above Average Ground

Band Meters	Freq. MHz	Feedpoint Impedance R +/- j X Ohms	50-Ohm SWR
80	3.75	16 + j 82	11.68
40	7.15	56 - j 4	1.14
30	10.125	490 + j 1576	>100
20	14.175	43 + j 13	1.37
17	18.118	67 + j 35	1.94
15	21.2	1381 + j 1783	73.69
12	24.94	64 + j 26	1.68
10	28.8	78 + j 6	1.57

10 m/32.81' Above Average Ground

Band	**Freq.**	**Feedpoint Impedance**	**50-Ohm**
Meters	**MHz**	**R +/- j X Ohms**	**SWR**
80	3.75	11 + j 84	18.03
40	7.15	57 + j 19	1.47
30	10.125	598 + j 1460	83.33
20	14.175	43 + j 11	1.31
17	18.118	67 + j 30	1.81
15	21.2	1305 + j 1920	82.61
12	24.94	67 + j 31	1.83
10	28.8	75 + j 7	1.53

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The modeled values for the spot frequencies coincide quite closely with Austin's initially charted SWR reports. 80, 30, and 15 meters are essentially non-usable. 17 and 12 meters show 50-Ohm SWR values near the limits of where modern transceivers begin to reduce power. However, with most coax runs, the SWR values shown at the transceiver will be reduced as a function of line losses on these bands. The SWR values for 40, 20, and 10 meters are highly promising.

Side note: Examine the SWR values for the free-space and the 20-m models. In both cases, the reactance is identical and high. However, the free-space resistive component is lower than the 20-m value, but the SWR is higher. Newcomers often believe that higher impedance values automatically produce higher SWR values and fail to appreciate the role played in the complex SWR calculation equations of the ratio of reactance to resistance in yielding the final result.

Let's look a bit further into the usable bands by taking 50-Ohm sweeps at each height across the bands. This exercise will give us a bit of insight into the operating bandwidth for the antenna system.

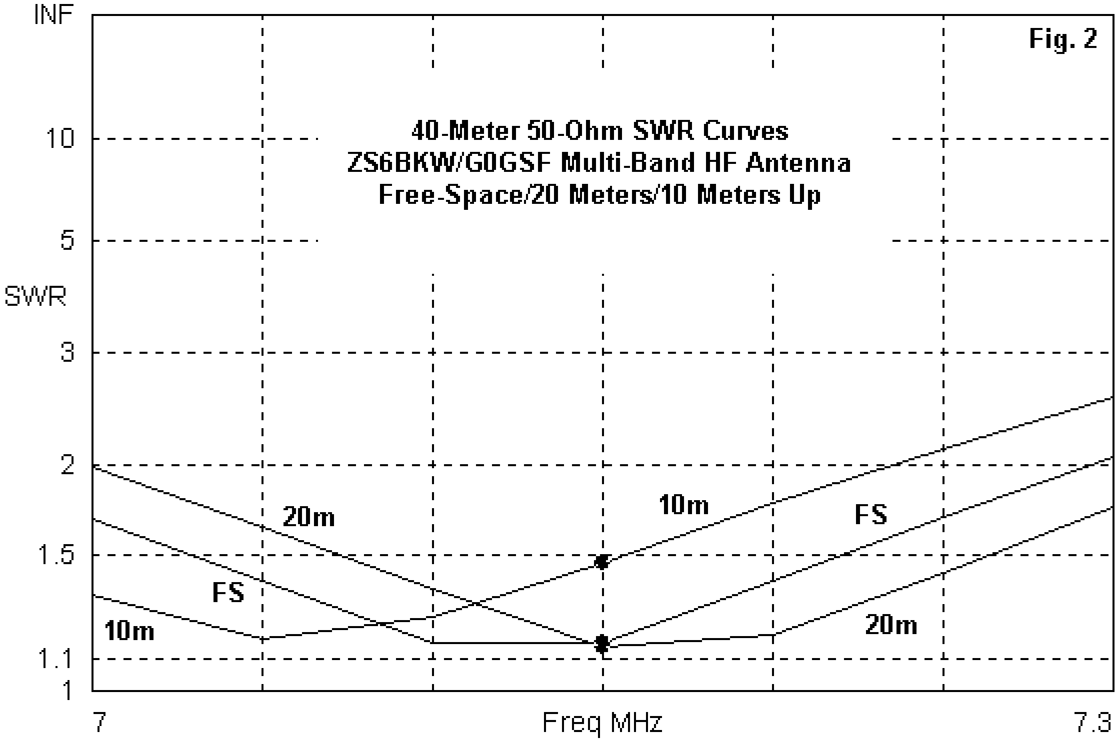
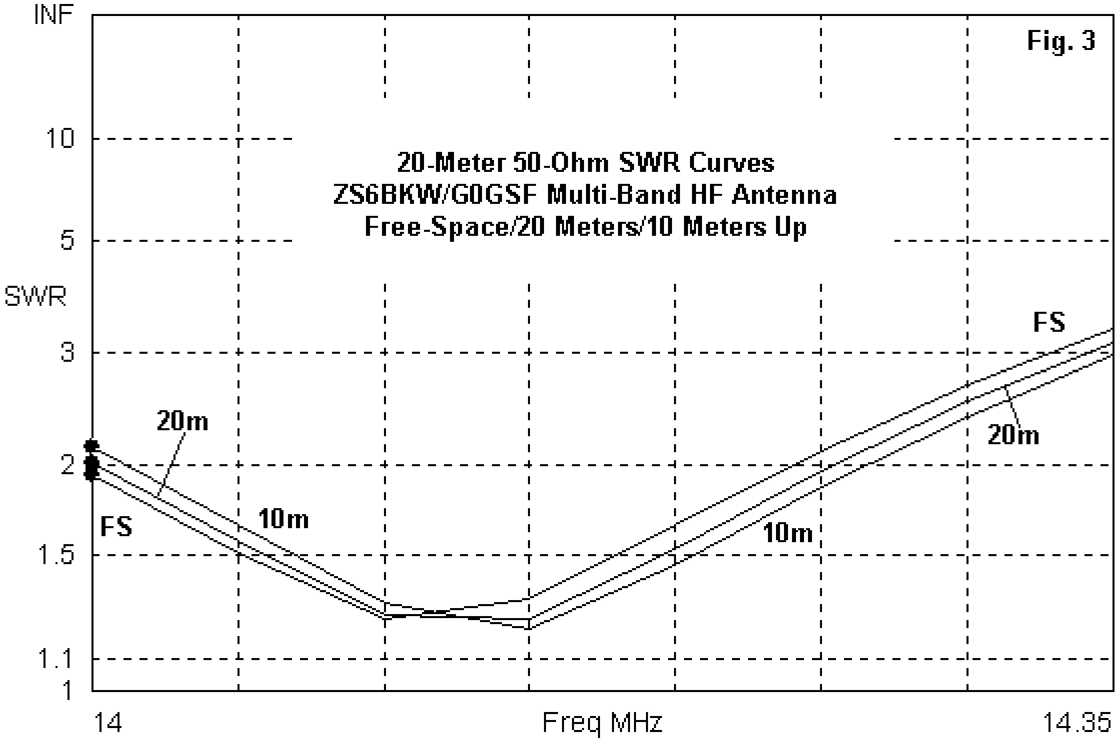
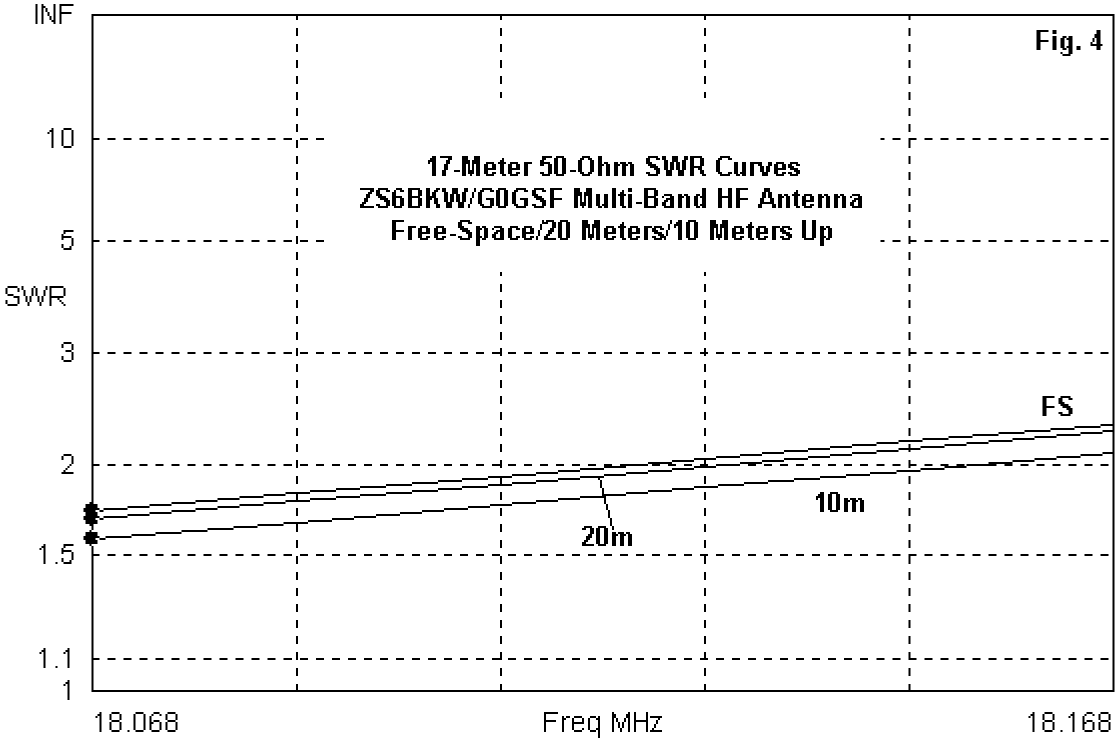


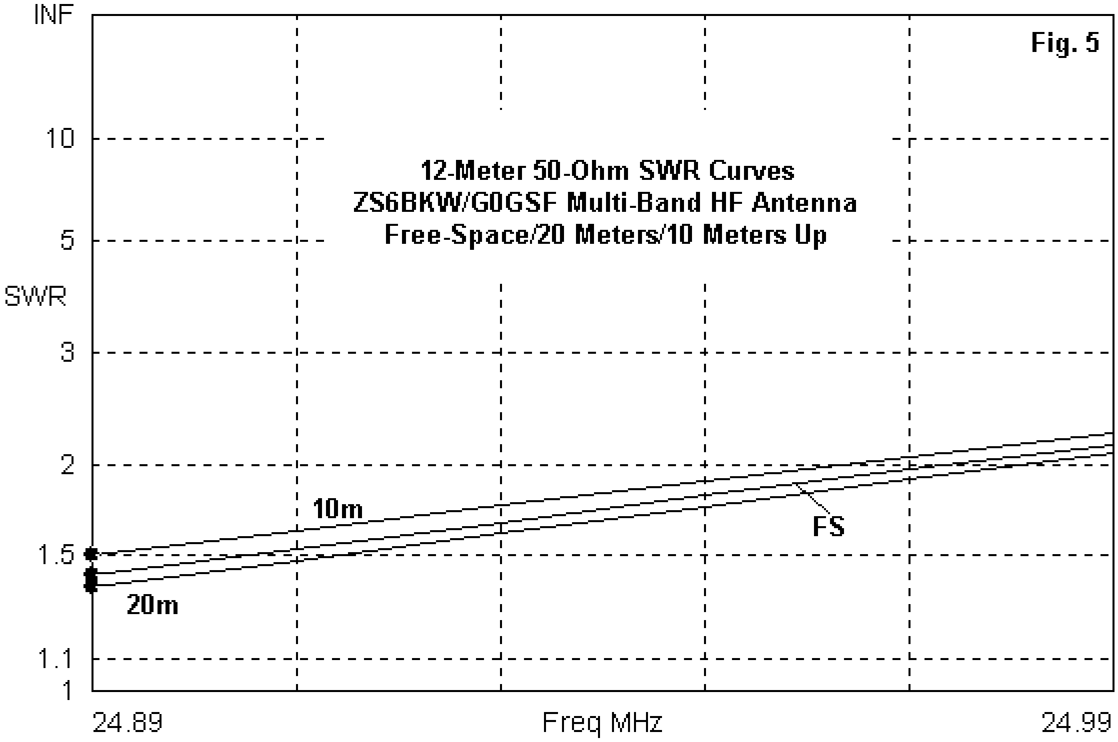
Fig. 2 provides us with a triple sweep of 40 meters. Only the curve for the 20-m height covers the entire band with an acceptable (less than 2:1) 50-Ohm SWR. On 40 meters, that height is about 1/2 wavelength up, while the lower 10-m height is only a quarter wavelength.



The 20-meter curves, shown in **Fig. 3**, coincide more closely, since the heights are 1/2 and 1 wavelength. The SWR bandwidth favors the low end of the band and is narrower than would be the SWR curve for an AWG #12 copper dipole resonated somewhere in the middle of the band.



The 17-meter band is marginal with respect to a 2:1 SWR bandwidth, as shown in **Fig. 4**. With a length of 50-Ohm coax between the matching section and the rig, the measured SWR near the transmitter would be a bit less, allowing the use of this band without triggering most power-reduction features associated with solid-state final amplifiers.



12 meters (**Fig. 5**) shows a similar phenomenon where the 50-Ohm SWR passes the 2:1 mark within the band. However, for most heights, the SWR is a bit lower than on 17, and the same length of coax would show a bit more loss and hence a bit lower SWR at the transmitter end of the line. Hence, the 12-meter band might prove a bit less problematical relative to triggering power reduction circuitry.

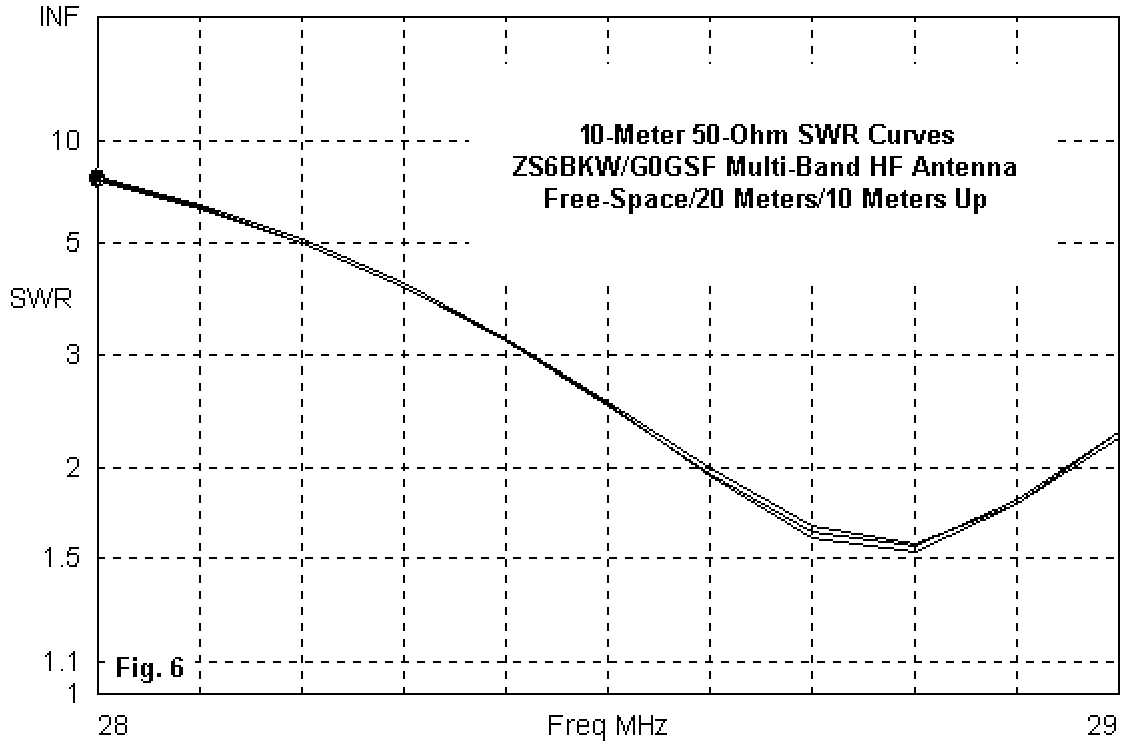


Fig. 6

Because the "good-match" frequency ratios are not harmonically related, the ZS6BKW/G0GSF antenna system favors the upper end of the first MHz of 10 meters, as shown in **Fig. 6**. The window is small, but quite usable. If the transceiver has a built-in narrow range tuner, of course, the entire band would be usable, and the marginal and narrow band conditions on other bands would no longer be a problem.

The ZS6BKW/G0GSF antenna system is also somewhat sensitive to the wire diameter. To show this fact, I modeled the antenna using AWG #8, #12, and #18 wire. The #8 selection is fatter than almost all amateurs would use, but--in conjunction with the other wires--it provides a reasonably graphic illustration of the effects of wire diameter on the performance of the antenna system. The following tables provide the spot frequency data for the runs. For this set of models, the height is 20 m above average ground. The unusable bands have been omitted.

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ZS6BKW Performance Data with AWG #8, #12, and #18 Wire

AWG #82

Band Meters	Freq. MHz	Feedpoint Impedance R +/- j X Ohms	50-Ohm SWR
40	7.15	61 - j 11	1.31
20	14.175	46 + j 26	1.73
17	18.118	73 + j 30	1.86
12	24.94	67 + j 41	2.11
10	28.8	86 + j 2	1.72

AWG #12

Band Meters	Freq. MHz	Feedpoint Impedance R +/- j X Ohms	50-Ohm SWR
40	7.15	56 - j 4	1.14
20	14.175	43 + j 13	1.37
17	18.118	67 + j 35	1.94
12	24.94	64 + j 26	1.68
10	28.8	78 + j 6	1.57

AWG #18

Band Meters	Freq. MHz	Feedpoint Impedance R +/- j X Ohms	50-Ohm SWR
40	7.15	50 + j 7	1.14
20	14.175	40 - j 5	1.29
17	18.118	59 + j 42	2.18
12	24.94	60 + j 7	1.25
10	28.8	68 + j 13	1.46

. . . .

Like all other small adjustments to the ZS6BKW/G0GSF antenna system, including changes of wire length, match section length, and match section Zo, the 17-meter match and the 12-meter match tend to show opposite effects. An improvement to one is accompanied by a degradation of the other.

For the wider usable bands, we might again look at comparative 50-Ohm SWR sweeps using the three wire sizes for an antenna wire at 20 m above average ground.

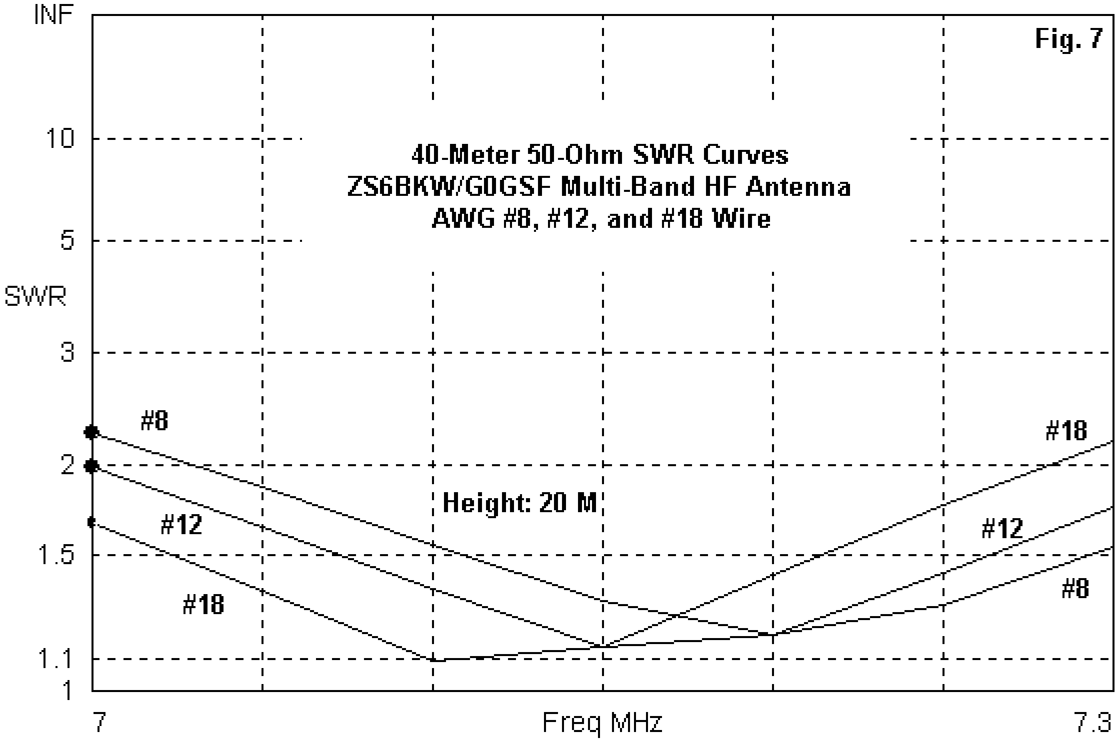
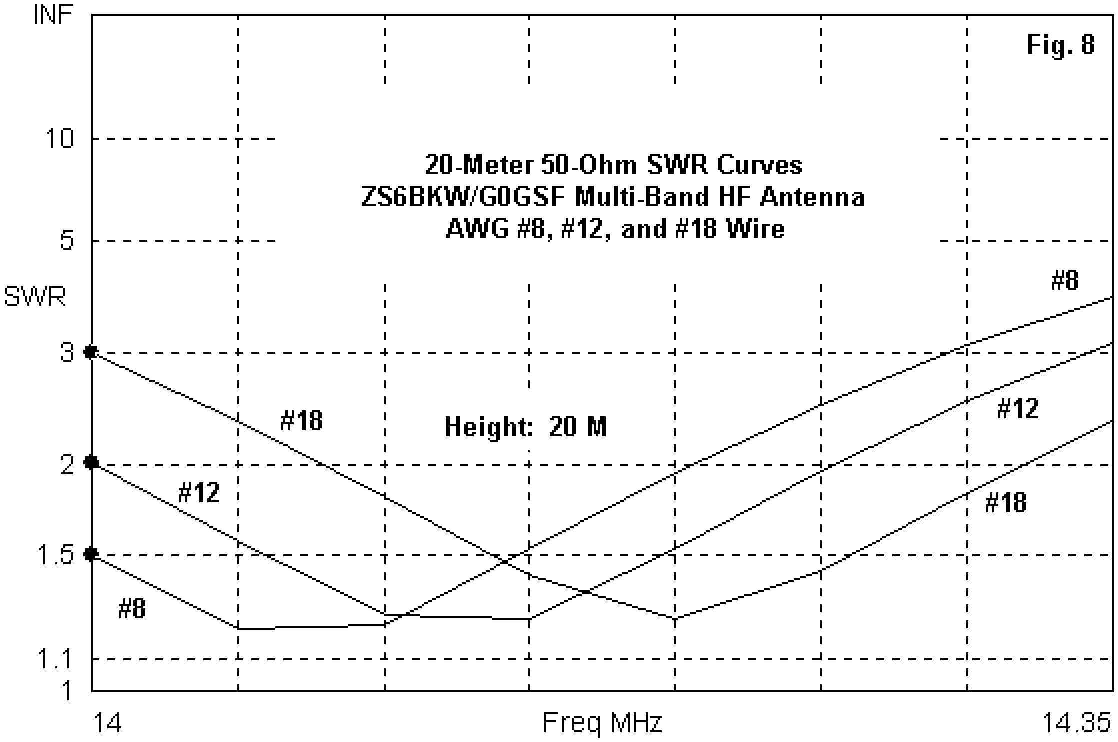
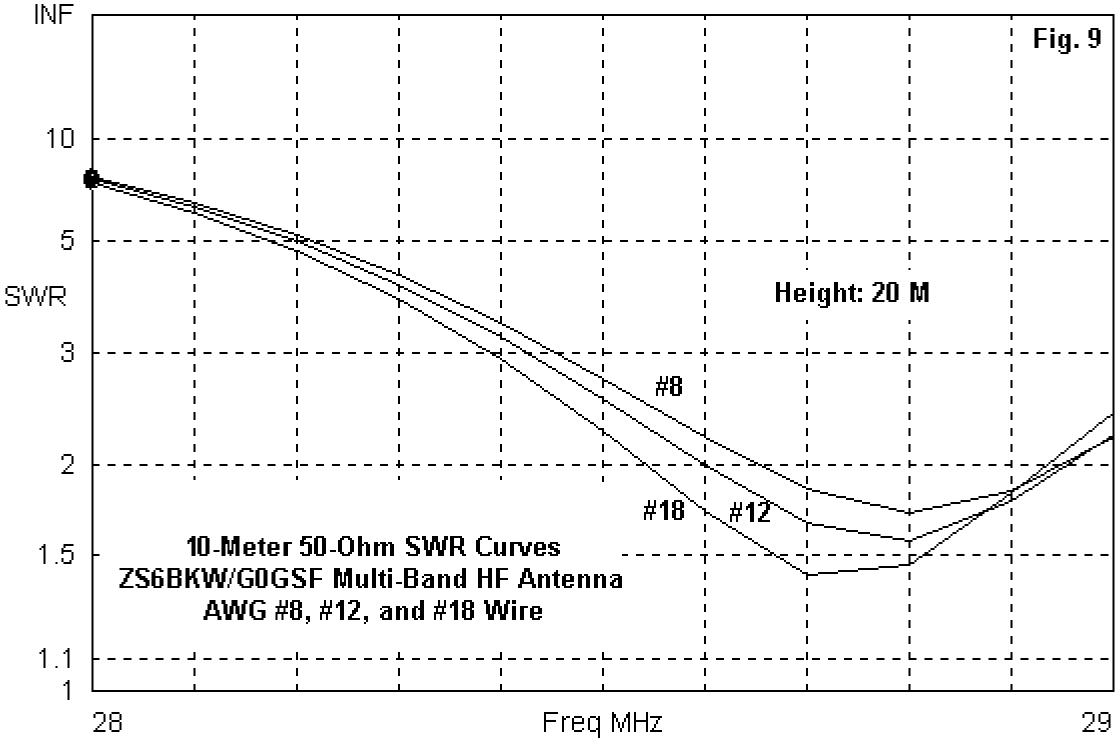


Fig. 7 shows the effects of changing wire diameter across the 40-meter band. #18 through #12 wire seem to show the best promise of full band coverage, although a wire as large as #8 is usable with an in-rig tuner.



See **Fig. 8**: on 20 meters, as the operating bandwidth narrows, the thinner end of the wire scale offer fuller band coverage, with the #18 wire favoring the upper end of the band. Those who use only the low end of the band for CW or digital work might prefer a larger diameter wire for the antenna.



On 10 meters, thinner is definitely better in terms of total operating bandwidth, as demonstrated by **Fig. 9**. However, all three curves miss the popular 28.3 to 28.5 MHz window of major 10-meter activity, along with the "CW" end of the band. In these regions, there is little to choose among the wire sizes, and an in-rig tuner would likely provide the necessary match.

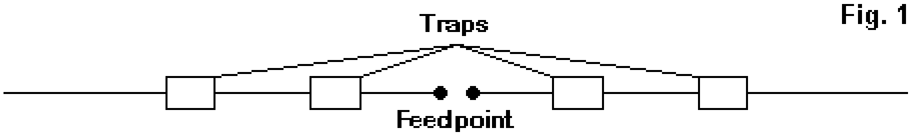
Of the unusable bands--80, 30, and 15 meters--a wide range external ATU would likely provide a usable match on 80 and 75 meters. Since the losses of coaxial cable are low in this band and the SWR loss multiplier for the 10:1 to 13:1 range is moderate, the band might prove to be feasible. The higher losses at 30 and 15 meters, accompanied by very high SWR values, do not bode well for effective use of these bands with the ZS6BKW/G0GSF antenna system. Cable losses may show a lower measured SWR at the transceiver end of the line, and a tuner may effect a match of some sort, but the losses in the cable will remain. As well, the tuner network may operate in a high-loaded-Q condition, further adding to overall losses.

I have not shown azimuth patterns for Austin's antenna system, since those patterns are a function of the radiating wire length. Patterns for a 93' wire and a 102' wire are too similar to need repetition. So you may refer to the patterns in Part 2 for a good idea of where the lobes will go on each usable band with the ZS6BKW/G0GSF system.

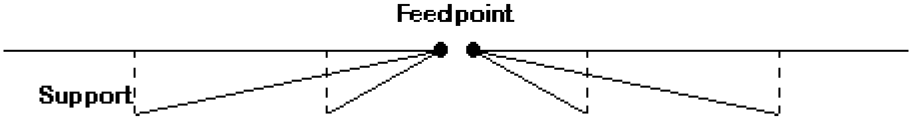
Conclusion to Part 3

Of all the G5RV antenna system cousins, the ZS6BKW/G0GSF antenna system has come closest to achieving the goal that is part of the G5RV mythology: a multi-band HF antenna consisting of a single wire and simple matching system to cover as many of the amateur HF bands as possible. From 80 to 10 meters, Austin's system provides an acceptable match on 5 out of the 8 bands under most conditions without an antenna tuner. This is the best result that has been achieved of any of the systems that has come to my attention.

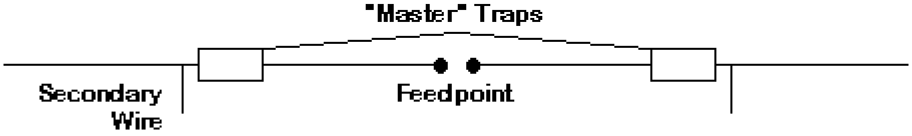
Fig. 10



Trap Dipole: One pair of traps per band, except lowest



Dipole Fan: One pair of wires per band



W3DZZ/W8NX Multi-Band Trap System

3 Alternative Multi-Band Doublet Systems for Coaxial Cable Feed

There are at least three other classic horizontal wire antenna designs that are proven performers in terms of using a coaxial cable as the feedline and in requiring no ATU. They are illustrated in **Fig. 10**. One is the trap doublet. One can make a dipole for as many bands as one wishes by using traps to terminate the wire at the desired length for a given band. Of course, the traps between the feedpoint and the termination for the band in use provided loads, so the antenna would be shorter than full size on the lowest band in use. How short it would be depends on the number of bands for which the builder installs traps.

Since the trap dipole or doublet is a semi-true dipole for each band used, it provides a resonant feedpoint impedance close to optimal for 50- or 75-Ohm cable. The exact feedpoint impedance depends in part on a. the terminating trap design and b. the amount of element loading provided by the interior traps relative to the band in use. The patterns will be broadside oval, peanut, or figure-8 shapes--depending upon antenna height in wavelengths above ground. However, when the ratio of the highest to lowest frequencies is greater than 3:1, there may be significant radiation from the outer portion of the antenna at the higher frequencies, resulting in odd lobes relative to dipole expectations.

The advantages that accrue to the trap dipole or doublet are a 50-75-Ohm feedpoint impedance and mostly true dipole patterns. However, the loading of interior traps creates user worries about losses. As well, the L-C traps are weighty and complex compared to the simple light structure of a single-wire doublet. As well, the bandwidth tends to be narrower than for a simple dipole using the same diameter wire.

The second classic design for direct coax feed on multiple bands is the fan of dipoles. One can support in the normal way a dipole for the lowest band to be used. Then, from the same feedpoint, one can run other dipoles suspended beneath the longest one. The more one allows the higher-band dipoles to droop beneath the longest one, the less the interaction of elements and the greater the ease of trimming each dipole to resonance.

As one adds bands to a single fan structure, the heavier it becomes, with more area to intercept the wind. Hence, durability becomes a significant issue relative to a simple doublet. As well, the initial trimming of the dipole lengths tends to become more finicky, and the operating bandwidth narrows relative to a single dipole for the same band.

A third system, pioneered by C. L. Buchanan, W3DZZ, uses a single trap each side of the feedpoint to provide multi-band coverage. Al Buxton, W8NX, extended the technique. The required traps demand careful construction and placement, and band coverage is not complete. Moreover, the patterns on all bands are not completely predictable by reference to the wire length, since interactions may exist between the inner and outer sections of the wire. Nevertheless, such antennas are capable of covering several bands with acceptable SWR levels on a single coaxial cable feedline.

These classic one-coax-feedline antennas provide part of the rationale for pursuing the G5RV myth of a single doublet for many bands with a single coax feedline and no ATU. A single doublet is mechanically simple for good durability. Operation without an ATU removes one box from the operating desk or field table. The belief that the G5RV antenna system itself could attain these goals--which it could not--literally invented the demand for an antenna that could. And that created the pursuit of techniques that would find a combination of wire length and matching section characteristic impedance and length to come closet to the goal.

These notes are not designed to recommend a particular multi-band wire antenna system to the potential user. There are too many situational variables for me to do much more than mislead someone. Instead, these notes are designed to clarify to some degree the capabilities of the G5RV and the ZS6BKW/G0GSF antenna systems so that you can have reasonable expectations of them. Understanding an antenna system is one way of overcoming the mythology that spreads itself in truncated conversational claims and in advertising.

The G5RV antenna system comes in many commercial packages, simply because it is cheap and easy to produce in a kit. A length of wire, a length of parallel feedline, a few insulators, and a couple of junctions form a low vendor cost high profit item. If all vendors were both honest and knowledgeable, they would label such kits with a warning to use with an ATU. If they wish to sell kits for use without an ATU, they might well consider packaging the ZS6BKW/G0GSF system instead. But even then, they should clearly identify the non-usable bands. (A commercial version of the ZS6BKW/G0GSF antenna system is available from The Wireman of SC.)

Antenna systems using a wire and matching system are but one route to HF all-band antenna service. A simple doublet, parallel transmission line, and an ATU is still an effective system, although truly balanced ATUs are difficult to find. For coaxial feedlines, we have briefly noted three alternative systems that move the complexity of a tuner to the antenna end of the line in the form of traps or multiple dipoles. Selecting the all-band wire antenna system, in the end, depends on the user's careful definition of his needs, limitations, and desires. Some understanding of the requirements of each competing system also goes a long way to assisting the decision-making process. These notes hope to have added a bit to understanding the single-wire-and-matching-section system of achieving multi-band HF operation.