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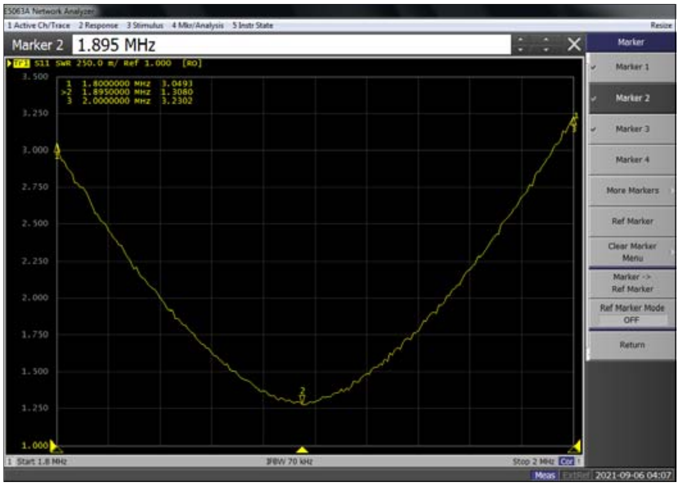
AR-003

Amateur Radio Application Note

THE N6DC 5-BAND "SUPER-VERTICAL" ANTENNA FOR 160/80/60/40/30 METERS



Marker 2 1.895 MHz

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Tr1 S11 SWR 250.0 m/ Ref 1.000  [RO]
 1  1.8000000 MHz  3.0493
>2  1.8950000 MHz  1.3080
 3  2.0000000 MHz  3.2302
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Super-Vertical 160m Swept VSWR

Rev. A01/09-21/ar003_apl_01
By Alex J. Burwasser, N6DC
Original Writing: Sep 2021

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SECTION I - INTRODUCTION AND OVERVIEW

This paper presents a 5-band “Super-Vertical” antenna design for the 160, 80, 60, 40 and 30 meter amateur bands. The primary features that distinguish this design from others are as follows:

1. Unlike the vast majority of multi-band verticals, the Super-Vertical employs in-line relay modules rather than resonant traps to change the effective vertical element length. This important feature eliminates the losses, bandwidth reduction, and other ills associated with traps. The net result is a multi-band antenna with performance matching that of single-band designs. Band changing is accomplished by a variable DC voltage sent up the coaxial feed line to successively activate these in-line band selection relays.

2. The Super-Vertical employs an elevated feed ground plane radial configuration that greatly reduces the excessive ground losses employed by more traditional buried radial configurations. This results in greatly improved antenna efficiency.

3. A single-wire capacitive top-”Tee”-hat is employed for 160 meters to permit a much shorter vertical element with no loss in performance. This wire is strung between two tall trees and also serves to support the vertical element.

Additional features are as follows:

1. Low VSWR on all five bands.

2. Ability to handle the full 1,500 watt US legal power limit.

Detailed design and summary construction information is provided so that radio amateurs with experience in antenna construction and testing can build this antenna with readily available components. EZNEC4 modeling is also presented.

Finally, information is presented for the benefit of radio amateurs wishing to pursue customized variants of this design, as well as how this same concept can be applied to horizontal dipoles.

Visit my N6DC vintage and amateur radio website at www.rdfproducts.com/n6dc.htm for possible revisions to this paper. This website hosts a variety of vintage and amateur radio technical papers.

SECTION II - WHY VERTICAL ANTENNAS?

While verticals cannot match the performance of beam antennas, many radio amateurs lack the space and the resources to purchase and install beams. Also, beams become too large in most cases to be practical in the lower HF range. As a result then, the more realistic choice below 14 MHz for most radio amateurs is between dipoles and verticals.

With this more practical choice in mind, verticals offer significant advantages over dipoles:

1. They provide low-angle radiation (a significant benefit for long distance communications).

2. Vertically-polarized signals exhibit less ground absorption loss than horizontally-polarized signals. (Ground absorption loss is not to be confused with ground losses associated with an inefficient ground radial system.)

This latter benefit is especially the case for the lower HF bands. Horizontally-polarized dipoles need to be elevated by a significant fraction of a wavelength to reduce ground absorption. This is often impractical on 160 and 80 (and even 40) meters.

On the other hand, verticals have some disadvantages as well:

1. They tend to be noisier receiving antennas than horizontal dipoles.

2. Since they are installed on or just above the ground, there can be more signal absorption due to nearby trees and structures than is the case with for higher elevated dipoles.

3. They are subject to high losses unless the ground plane is well-designed and implemented.

There is no “magic antenna” that is optimal in all respects, but a good vertical antenna will enhance any station’s capabilities, especially in the lower HF range. With this in mind, a good solution is as follows:

1. In addition to having a well-designed and implemented vertical antenna, also have a dipole available for the lower HF bands.

2. To benefit from the dipole’s ability to provide quieter reception, have the option to use the dipole as a separate receive antenna when using the vertical for transmitting.

SECTION III - VERTICAL ANTENNA SHORTCOMINGS

A. GROUND LOSS

I remember a QST article written back in the ‘60s where the author stated that vertical antennas “radiate uniformly poorly in all directions”. While poor performance is not always the case, the author was correct in that there can be much about vertical antennas to dislike.

To better facilitate the discussion that follows, Figure 1 illustrates the basic model for a vertical antenna (also referred to in the literature as a “monopole”). In this simple model, R_R represents the antenna radiation resistance (i.e., the portion of the total antenna system load that represents useful radiated transmitter power) and R_L represents the loss resistance (i.e., the portion of the total load that represents the heat dissipation loss due to antenna system imperfections). The power absorbed by R_L is thus wasted (i.e., non-radiated) power. For simplicity and clarity, no reactances are shown (i.e., it is assumed the antenna is resonant).

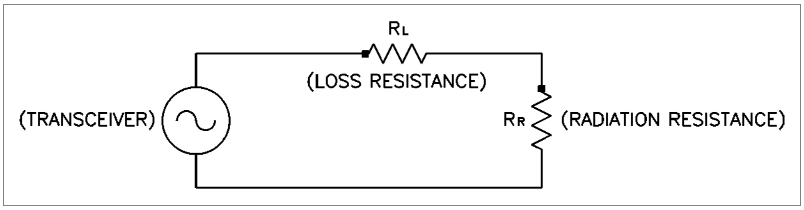


Figure 1 - Simplified Vertical Antenna Model (at resonance)

In its classical configuration, vertical antennas employ a large number of buried ground radials to enhance ground plane conductivity. This in turn diminishes ground losses (i.e., reduces R_L in Figure 1).

Unfortunately, the improvement gained by adding more radials rapidly reaches an area of diminishing returns. Even using 120 quarter-wavelength buried radials, ground loss is still high. The reason for this can be seen in EZNEC4 (which can model buried radials). The soil in the immediate vicinity of each radial “smothers” the radial currents (in effect acting much like an RF choke) along with the electromagnetic fields generated by these currents).

As visually illustrated in EZNEC4, this in turn causes the outbound currents to diminish very rapidly along the radials. (This is the reason that longer radials are often only marginally more effective than shorter ones.) Stated alternatively, the soil resistively loads the radials which in turn dissipates transmitter output power. This added resistance then adds to the net loss resistance R_L as illustrated in Figure 1.

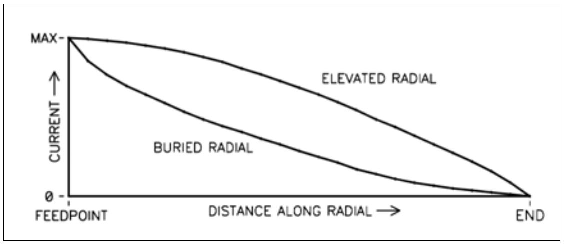


Figure 2 - Antenna Currents for Elevated vs. Buried Radial

Figure 2 is a conceptual sketch that illustrates this concept graphically. The X-axis represents the distance along the radial (from the feed point at the origin and the radial wire end at the right). The Y-axis represents the antenna current (with zero at the origin and maximum at the top).

For both the elevated and buried radials the current is maximum at the feed point and then tapers off along the radials. This current reaches zero at each radial end (since there is no more wire through which the current can flow).

Notice, however, that for the elevated radial the current tapers off gradually along the radial before reaching zero at the end. The current through the buried radial, however, falls much more sharply before finally reaching zero at the end.

The explanation for this difference is straightforward, but very illuminating. For the elevated radial, the current diminishes due to radiation (i.e., the intended result). In contrast, the buried radial current diminishes due to radiation *plus dissipated loss due to the significant ground resistance.* In plainer language, the ground resistance chokes off the radial current rather quickly.

The net effect is to raise R_L (the loss resistance component of Figure 1) thus reducing antenna system efficiency. In most installations, it is likely that this loss resistance R_L is much higher than the radiation resistance R_R. In plainer language, most of the applied power is dissipated by the lossy soil.

Ground loss further increases with trap and inductively loaded verticals. While traps are beneficial in that they permit multi-band operation using a single vertical element, they add losses.

In a multi-band trap vertical the traps appear inductive on the lower bands. As a case in point, for an 80/40/20/15 meter trap vertical operating on 80 meters, the 40/20/15 meter traps appear as distributed loading inductors. It is thus necessary to shorten the total vertical length appropriately to achieve the desired 80 meter resonance. While this may appear as a positive attribute (e.g., having an 80 meter vertical that is only 30' rather than 65' tall), this reduces the radiation resistance.

Since the Figure 1 loss resistance R_L is not correspondingly reduced, a *higher percentage* of the transmitter power is now consumed by R_L (rather than R_R), thus reducing efficiency. Also, since the trap inductors are not lossless, they likewise have a resistive component that is effectively in series with R_L (thus effectively further raising R_L and reducing efficiency).

B. BANDWIDTH

Since traps have significant Q, they reduce operating bandwidth. This is also the case for single-band electrically short verticals using loading inductors to achieve resonance.

Traps and loading inductors thus trade off efficiency and bandwidth for convenience and compactness. While these configurations are useful for limited space applications, performance is significantly compromised due to higher losses.

C. SECTION SUMMARY

Traditional multi-band verticals employing buried radials and traps have poor efficiency. The biggest culprit is the excessive loss imposed by the buried radials. This is caused by the soil absorbing power from these radials which makes them appear more resistive than conductive. Since this resistance is large compared to the vertical radiation resistance, losses are high.

Traps compound this problem by effectively acting as distributed loading inductors on all but the highest band. Since the presence of these loading inductors requires that the vertical be appropriately shortened to achieve resonance, the feed point impedance (i.e., the radiation resistance, or R_R in Figure 1) decreases. Since the Figure 1 loss resistance R_L is not correspondingly reduced, a *higher percentage* of the transmitter power is now consumed by R_L (rather than R_R), thus reducing efficiency. Also, since the trap inductors are not lossless, they likewise have a resistive component that is effectively in series with R_L (thus effectively further raising R_L and reducing efficiency).

Traps impose a further disadvantage in that they have significant Q and thus reduce operating bandwidth. Given their numerous ills, traps should be avoided unless antenna compactness is the compelling issue.

SECTION IV - IMPROVING MULTI-BAND VERTICAL ANTENNA PERFORMANCE

A. ELEVATED GROUND RADIALS

As discussed, the dominant contribution to vertical antenna losses is soil power absorption in the buried radial system. It would thus seem intuitively reasonable that we could reduce these losses by placing the radial system *on the ground* rather than *underground*.

This turns out to be the case. Although EZNEC4 is not able to directly model radials placed *on the ground*, it can model radials placed *just above the ground* subject to certain limitations. When radials are modeled in this fashion, ground losses are confirmed to be significantly reduced.

Continuing along this same intuitive path, the next move is to *elevate* the radials to further reduce ground loss effects. Most readers, of course, will recognize this as the well-known and long-established elevated-feed ground plane vertical.

Elevated radials still have ground loss. The loss mechanism is the same as that for buried radials, but the effect is greatly mitigated by the separation of the radials from the ground. Referring back to Figure 1, this translates into a smaller loss resistance R_L and thus improved efficiency.

This being the case, the astute reader would suspect that the higher the radials can be elevated above ground, the lower the ground losses. This is definitely the case. The practical limitation is imposed more by construction and installation constraints rather than theoretical issues.

Also, a point of diminishing returns is rapidly reached where further elevation provides only marginal benefit. As a case in point, only a minor efficiency improvement is achieved by changing the radial elevation height from 2' to 10'. The more compelling reason for choosing 10' is to make it easier to mow the field.

B. REQUIRED NUMBER OF ELEVATED GROUND PLANE RADIALS

The reader might suspect that the more elevated ground plane radials employed, the lower the losses (i.e., the same as would be the case with buried radials). Actually (and fortunately), *this is not the case*.

Surprisingly, EZNEC4 modeling shows that a two-radial implementation works as well as a three-, four-, or even higher-radial configuration. Efficiency and radiation patterns are not significantly different. Thus, there is no reason to employ more than two radials.

Regardless of the number of radials selected, symmetry is important. More specifically:

1. The radials should all be the same length.

2. The horizontal angle between the radials should be the same.

3. If the radials droop, they should all droop at similar angles.

If these conditions are met, *the radials will (mostly) not radiate even though antenna currents flow into them.* This is a result of their symmetry causing their radiating fields to substantially cancel (at least in the far field).

This is important from the standpoint the there is little resulting horizontal polarization. To explain, the primary benefit of a vertical antenna is its low-angle radiation. If the radials are asymmetrical and radiate as a result, this causes the signal to contain a horizontally-polarized component which, like a dipole, will produce high-angle radiation. An extreme case would be a vertical antenna having only one radial.

EZNEC4 radiation pattern plots are presented for the interested reader in Appendix A. These plots are for both two- and four-radial implementations for a 10.0 MHz elevated ground plane vertical so the reader can verify that there is negligible performance difference between these two implementations.

C. ELIMINATING TRAPS

The remaining issue for an improved multi-band vertical is how to overcome the issues associated with resonant traps. The intuitively obvious solution is to employ relays along the vertical element to switch in the correct wire lengths, but implementation of this approach is far less obvious (and much more complicated). This is especially the case if the antenna must handle high power.

This technique is not new and there have been successful implementations. The most elaborate of these is that presented by Jim Weit, KI8BV, in a 2008 QST article (reference 1). That article presents a relay switching method for multi-band dipoles. The relay switching modules include microprocessors to receive digital data from the controller (which also employs a microprocessor and is located at the station console). This article is a good read and presents an elegant solution. However, it was designed for 100-200 watt power levels and would likely be difficult to redesign to handle 1,500 watts.

Mr. Weit obtained a patent on this implementation. Although I have not read it, I am certain that the novelty of this scheme was in the technique he used to send the digital band switch codes to the relay modules. It would not seem reasonable to claim that the patent covers the idea of using relays for band switching since this is an old (and obvious) concept.

D. SECTION SUMMARY

Vertical antennas with elevated radials are much more efficient than implementations using buried radials. The bulk of this efficiency improvement can be achieved with the radials only 2' off the ground. Further elevation results in only marginal incremental efficiency improvement, but might be desirable for convenience (i.e. for mowing the field).

Only two radials are needed. Additional radials do not significantly alter the antenna patterns or improve efficiency. Regardless of the number of radials, however, symmetry is important to ensure radiation field cancellation (i.e., so that the radials themselves do not radiate).

Band switching relays work much better than traps, effectively eliminating all of their disadvantages. While conceptually straightforward, a practical and effective relay switching technique requires thoughtful design and careful implementation, especially for high power.

SECTION V - GROUND PLANE VERTICAL ANTENNA GEOMETRY CONSIDERATIONS

A. OVERVIEW

“Geometry” in this context refers to the lengths of the vertical element relative to the radials. More specifically, a vertical can have a tall vertical element and shorter radials, or vice versa. This is analogous to an off-center feed dipole.

The ratio of the vertical element to radial length primarily affects the feed point impedance but has very little effect on the radiation pattern. This is fortunate in that it allows the same radial length to be used on more than one band. If these bands are close to each other (e.g., 30 meter/40 meter), the same radial set can be used for both bands with only a modest VSWR compromise. (Of course, the vertical element must still be switched to a suitable length for resonance.)

This in turn allows a reduction in the number of relay switching modules (i.e., by having the same radial lengths for more than one band, fewer switching modules are required). The concepts underlying this technique are discussed in the following paragraphs.

B. VERTICAL ANTENNA SYMMETRY

For the purpose of this discussion, a “symmetrical” ground plane vertical is one where the vertical element is 1/4 wavelength tall at the operating frequency and the radials are cut to whatever length is required for resonance. For the sake of simplicity (as well as to observe good practice), we further specify that all the radials are the same length.

Although one might think that adding more radials would require that these radials be shorter for the same resonant frequency, this surprisingly is not the case. (This is based on an EZNEC4 modeling exercise increasing the number of radials from two to four.) Also, the feed point impedance changes only very slightly.

An important corollary to this phenomenon is that if we change the vertical element length and then correspondingly change the radial length so as to maintain the same resonant frequency, the feed point impedance also changes. This is analogous to the off-center feed dipole.

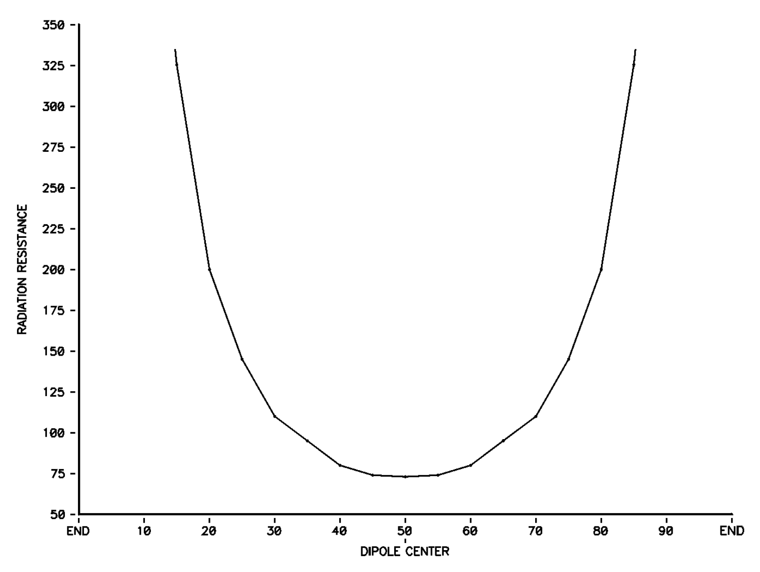


Figure 3 - Dipole Radiation Resistance as Function of Feed Point Location

To illustrate this important point, Figure 3 Is the graph of a free space thin-wire dipole radiation resistance as a function of the placement of that feed point along the dipole. Notice that when the dipole is center-fed, its radiation resistance is very close to 73 ohms, but as the feed point is moved along the dipole (in either direction), this resistance rises (i.e., the graph has a symmetrical "cup" shape). The resonant frequency, however, does not change.

Notice also that for feed point placements out to 35/65 and 65/35 the feed point resistance change is fairly modest. However, as the feed point is moved closer to either dipole end, the radiation resistance rises sharply. For feed point placements at 15/85 and 85/15, for example, the radiation resistance jumps to 326 ohms. Although off-scale in Figure 3, the radiation resistance further jumps to 688 ohms at the 10/90 and 90/10 feed point placements.
L. B. Cebik (W4RNL; SK) has written that the feed point impedance becomes less stable when it becomes too high (i.e., when the feed point is very far off-center). He further points out that it also becomes more susceptible to perturbations caused by proximity to ground.

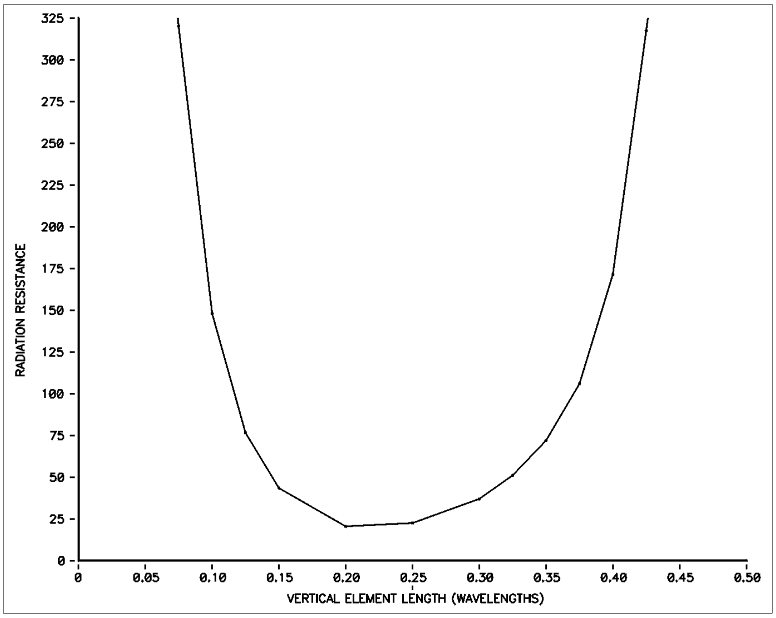


Figure 4 - Ground Plane Vertical Radiation Resistance as a Function of Vertical Element Length (see text)

A similar impedance change also occurs for ground plane verticals (although the behavior is somewhat different) as illustrated in Figure 4. This graph is less straightforward than the graph of Figure 3 above and requires some explanation.

The Figure 4 X-axis represents the *vertical element length* (in wavelengths at the operating frequency), with the radial lengths *suitably adjusted for resonance for that particular vertical element length*. The Y-axis is the resulting feed point radiation resistance. Figure 4 is valid for a ground plane vertical having two identical length opposing horizontal radials.

Notice that the behavior is similar to that of Figure 3 above, but that the curve is somewhat asymmetrical. At vertical element lengths near 0.25 wavelength, the radiation resistance is low. As the length becomes much shorter or much longer, the radiation resistance rises sharply.

C. SECTION SUMMARY

As is the case for a dipole, a vertical's feed point impedance can be varied at a given frequency by suitably lengthening the vertical element and shortening the radials, or alternatively by shortening the vertical element and lengthening the radials.

For a multi-band vertical employing relay switching modules for band changing, this allows an important degree of freedom that can allow the same set of radials to be employed for more than one band (and still obtain reasonable VSWRs). This in turn can facilitate a design that employs fewer relay switch modules for the radials (as well as fewer radials).

This added degree of freedom is put to good use in the Super-Vertical. Although this antenna covers five bands, only two active sets of radials per band are employed.

SECTION VI - N6DC “SUPER-VERTICAL” FUNCTIONAL DESCRIPTION

A. OVERVIEW

Having presented the necessary underlying concepts, we now can move on to a more detailed functional description of the Super-Vertical. Refer to the functional block diagram of Figure 5 for the following discussion.

B. BASIC FUNCTIONAL DESCRIPTION

1. BIAS TEE

As discussed, band changing is accomplished by a variable DC voltage sent up the coaxial feed line to successively activate the in-line band selection relays (i.e., these relays are voltage threshold activated). A “bias Tee” is employed to inject this variable DC voltage into the feed line.

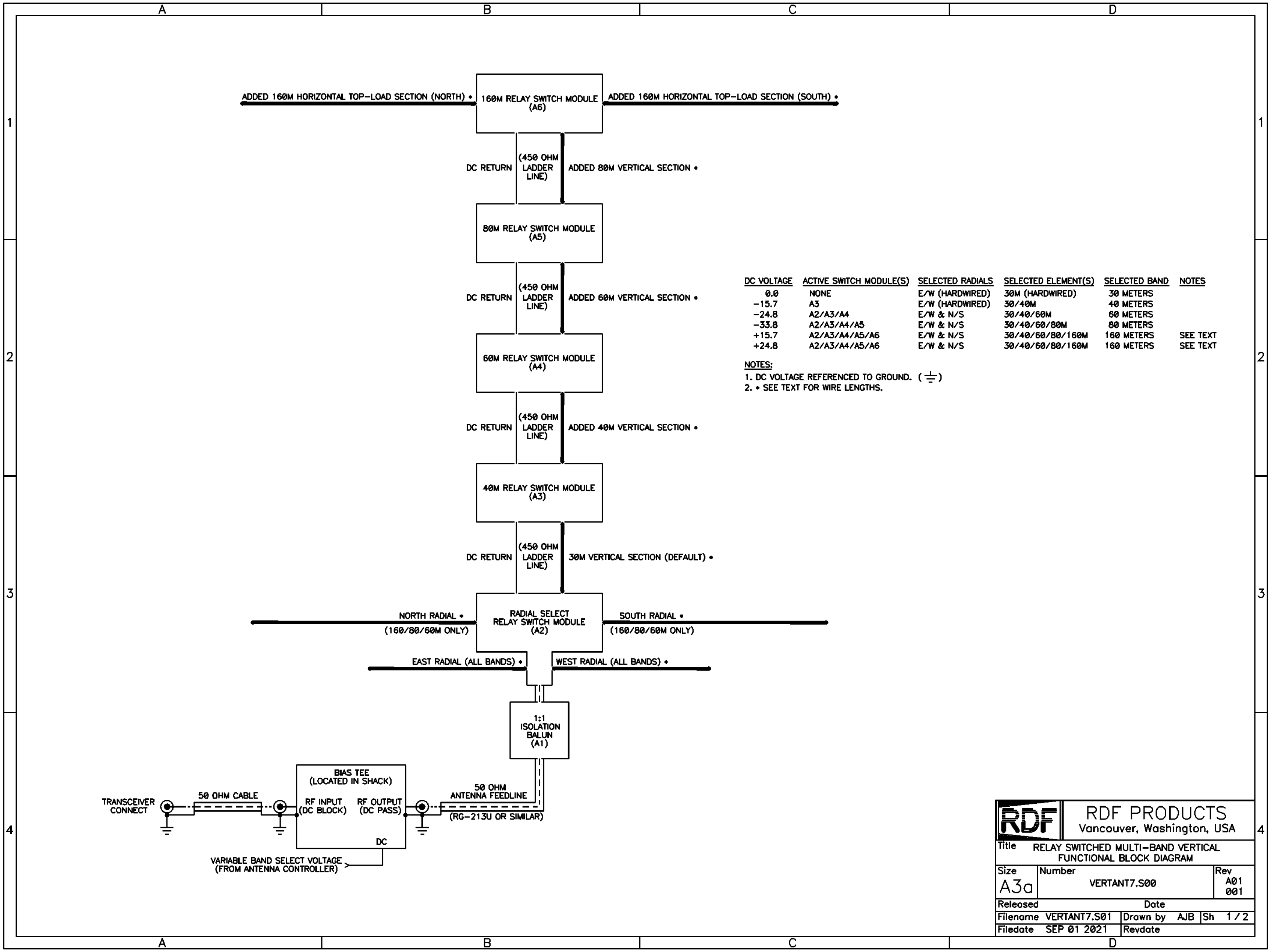
This bias Tee must accomplish two objectives. First, it must prevent the variable DC voltage from backing into the transceiver. This is accomplished using a suitable series capacitor as a DC block at the RF input terminal. This capacitor must have very low reactance at the lowest operating frequency (i.e., 1.8 MHz for this antenna), as well as very low inductance at the highest frequency (10.150 MHz). For high power applications, this capacitor must have a high AC current rating.

Second, the DC voltage must be introduced into the feed line through an isolation choke that offers a very high impedance throughout the antenna operating frequency range (i.e., the choke impedance must be much greater than the nominal 50 ohm feed line impedance). For high power applications, this choke must have a high voltage rating as well. Additionally, this choke must be able to handle the maximum relay DC current (i.e., the total relay DC current with all the relays activated) without saturation. (Saturation reduces effective choke impedance and thus choke effectiveness.)

Although bias Tees for amateur radio are available from several manufacturers, most of these have significant design compromises (especially for high power applications). For this reason, I designed and constructed my own as presented in detail in my paper AR-002 (reference 2) for the benefit of interested readers.

2. 1:1 ISOLATION BALUN (A1)

To prevent the coaxial feed line from becoming part of the vertical radiating element, a 1:1 isolation balun is located directly at the vertical feed point. The purpose of this isolation balun is to choke-off antenna currents so that they will not flow into the feed line (causing undesired feed line radiation). I used a Balun Designs model 1115 (suitable for high power) with good results.



DC VOLTAGE	ACTIVE SWITCH MODULE(S)	SELECTED RADIALS	SELECTED ELEMENT(S)	SELECTED BAND	NOTES
0.0	NONE	E/W (HARDWIRED)	30M (HARDWIRED)	30 METERS	
-15.7	A3	E/W (HARDWIRED)	30/40M	40 METERS	
-24.8	A2/A3/A4	E/W & N/S	30/40/60M	60 METERS	
-33.8	A2/A3/A4/A5	E/W & N/S	30/40/60/80M	80 METERS	
+15.7	A2/A3/A4/A5/A6	E/W & N/S	30/40/60/80/160M	160 METERS	SEE TEXT
+24.8	A2/A3/A4/A5/A6	E/W & N/S	30/40/60/80/160M	160 METERS	SEE TEXT

NOTES:

1. DC VOLTAGE REFERENCED TO GROUND. (⏚)
2. • SEE TEXT FOR WIRE LENGTHS.

RDF PRODUCTS
Vancouver, Washington, USA
Title RELAY SWITCHED MULTI-BAND VERTICAL FUNCTIONAL BLOCK DIAGRAM
Size A3a
Number VERTANT7.S00
Rev A01 001
Released
Date
Filename VERTANT7.S01
Drawn by AJB
Sh 1 / 2
Filedate SEP 01 2021
Revdate

Figure 5 - N6DC Super-Vertical Functional Block Diagram (1 of 2)

3. RADIAL SELECT RELAY MODULE (A2)

Two radial pairs are employed in this design. The longer of these pairs (the North/South radials) is used for the 160/80/60 meter bands whereas the shorter pair (the East/West radials) is used for the 40/30 meter bands. A relay is used to switch in the longer radial pair for 160/80/60 meter operation, but then disconnects them for 40/30 meter operation where the shorter radial pair is used.

The 40/30 meter radial pair is hardwired (i.e., no relay is used to switch them in and out - they are always connected). The underlying rationale is that these radials are electrically short enough on 160/80/60 meters so that the antenna currents flowing into them are very low (as compared to the antenna currents flowing into the longer radial pair on these bands).

Thus, even though the 40/30 meter radial pair is still “active” on 160/80/60 meters, their effect on overall performance in those bands is minor. The advantage of this approach is that one less radial switching relay is required.

4. 40 METER RELAY SWITCH MODULE (A3)

If no DC band select voltage is applied at the bias Tee, no antenna relays activate. The only elements used in this case are the hardwired 40/30 meter radials and the hardwired 30 meter vertical section. The “default” band with no DC band select voltage applied is thus 30 meters.

When the DC band select voltage is set to -15.7 volts (nominal), the 40 meter relay switch module activates and connects the added vertical wire required for 40 meter resonance. Since the same radial pair is used for 40/30 meters, however, the radial select relay does not activate.

Note that only the rightmost wire of each ladder line (illustrated as bold vertical lines in Figure 5) functions as a radiator and is switched by the relays. The leftmost wire is used only as a DC return path for the relays and is isolated via RF chokes in the switch modules.

5. 60 METER RELAY SWITCH MODULE (A4)

When the DC band select voltage is set to -24.8 volts (nominal), the 60 meter relay switch module activates and connects the added vertical wire required for 60 meter resonance. Note that for 60 meter operation the 40 meter relay is still activated (since the DC band select voltage is above the -15.7 volt 40 meter relay module activation threshold).

The 60 meter -24.8 volt DC band select voltage is also the threshold at which the radial select relay module activates and connects the longer (North/South) radial pair. As discussed, the longer radial pair is required for 60 meters (as well as for 160/80 meters).

6. 80 METER RELAY SWITCH MODULE (A5)

When the DC band select voltage is set to -33.8 volts (nominal), the 80 meter relay switch module activates and connects the added vertical wire required for 80 meter resonance. Note that for 80 meter operation the 60 and 40 meter relays are still activated, along with the radial select relay switching in the longer (N/S) radial pair.

7. 160 METER RELAY SWITCH MODULE (A6)

As per Figure 5, the 160 meter relay switch module activates and connects a single horizontal wire that serves as a symmetrical capacitive top-"Tee"-hat (having a length suitable for resonance near 1.900 MHz). Note that for 160 meter operation the 80, 60 and 40 meter relays are still activated, along with the radial select relay switching in the longer (N/S) radial pair.

The relay module switching format is different for 160 meters than for the other bands. Based on the previous paragraphs and Figure 5, the reader will notice that the relay switch module voltage thresholds are separated by close to 9.0 volts (i.e., -15.7 volts for 40 meters, -24.8 volts for 60 meters, and -33.7 volts for 80 meters). It would thus seem reasonable that the corresponding voltage threshold for 160 meters should be close to -42.7 volts.

While this would be a logical progression and a valid approach, there are two complications that must be considered:

1. Voltages exceeding 40 volts are somewhat high for convenient voltage regulation. (A regulated variable voltage generator should be employed for precision and repeatability.)

2. The overall DC power consumption likewise becomes high at higher voltages.

To mitigate these issues, the relay switch module relay drivers were designed with a special feature that *allows all relays to activate simultaneously with the application of a relatively low* ***positive*** *voltage* (+15.7 volts nominal). Thus, the 160 meter band is activated with +24.8 volts rather than -42.7 volts, and with much lower power consumption. This feature is necessary only for 160 meters.

The only drawback to this approach is that the regulated variable DC voltage source must be capable of switching polarity for 160 meters. However, this is straightforward to implement and is therefore no real disadvantage.

8. TABLE

The Table in Figure 5 succinctly summarizes the above discussion in a compact format. Since the 160 meter relay switching scheme is somewhat complicated, it will be discussed in detail in a subsequent Section.

9. LADDER LINE CONNECTIONS

Notice that the relay switch modules are connected via 450 ohm ladder line. The reason is that *two* conductors are required to interconnect these modules; one for the applied variable voltage and the other for the DC return path (so that a complete DC circuit is established to switch the relays).

Only the ladder line wires switched by the relays (i.e., the bold vertical lines in Figure 5) are used as radiating antenna elements. The DC return line is interrupted with RF chokes in each module so that antenna currents are blocked and flow only in the intended wires selected by the relays.

The reason for selecting ladder line is that their relatively wide conductor separation (as opposed to the conductor separation in coaxial cable or a twisted pair) results in lower capacitance between the conductors (and thus less RF coupling between the radiating conductors and the DC return wire). This is important in that it reduces the extent of filtering and bypassing required in the relay switch modules to prevent performance anomalies caused by RF coupling.

The specific brand of 450 ohm ladder line used is DX Ham Radio Supply #LL450-HD. This is heavy duty ladder line employing #14 AWG conductors. In addition to being able to handle 1,500 watts, it is also strong enough to be self-supporting when hung vertically.

C. DETAILED FUNCTIONAL DESCRIPTION

1. OVERVIEW

A somewhat more detailed functional block diagram is presented in Figure 6. This illustration provides more specific information on the six antenna modules.

2. 1:1 ISOLATION BALUN (A1)

1:1 isolation balun A1 is illustrated with its common connection points and is also seen to include the hardwired E-W radial pair. For convenience of illustration, this radial pair was shown as part of the radial select relay switch module (A2) in Figure 5, but in practice it was more convenient to physically include this radial pair with the 1:1 balun (A1).

This alteration has no effect on performance. Note that the radials are connected to the “cold” (DC return) side of the 1:1 balun isolated end.

3. 160/80/60 METER RADIAL SELECT RELAY MODULE (A2)

Figure 6 illustrates the RF isolation chokes, the relay driver, and the relay itself. Note that the relay that switches in the N-S radial pair activates on 160/80/60 meters only. The RF chokes keep RF out of the relay driver and also RF isolate the DC return path.

4. 40/60/80 METER RELAY SWITCH MODULES (A3/A4/A5)

These modules are identical in all respects except for their voltage activation thresholds. The RF chokes keep RF out of the relay driver also RF isolate the DC return path.

5. 160 METER RELAY SWITCH MODULE (A6)

This module is similar to A3-A5, but uses two relays (K1 and K2). Both relays must activate to switch in the capacitive horizontal top-”Tee”-hat for resonance on 160 meters.

At the risk of confusing the reader, I wanted to be able break up the top horizontal wire into two segments due to its proximity to a nearby multi-band beam antenna. By being able to change the top horizontal wire resonant frequency, this resonance could be moved as necessary to avoid interaction with the beam antenna .

To explain, when the DC band select voltage is 0 volts, neither K1 nor K2 activate. The relay contacts are therefore open and the horizontal top wire is broken in two (and also disconnected from the top vertical wire). When the DC band select voltage is +15.7 volts (nominal), only K1 activates with the result that the horizontal top wire length is doubled (causing its resonant frequency be reduced by 1/2). This feature is used only when the nearby beam is the selected station antenna (rather than the Super-Vertical).

Both K1 and K2 activate when +24.8 volts (nominal) is applied from the band select voltage generator. This connects both sections of the horizontal top wire together (via K1) and also connects the horizontal top wire to the vertical element (via K2) for 160 meter operation. Note also that K1 and K2 do not activate for negative voltages.

Since this feature will likely not be necessary for most readers, the 160 meter relay module can be configured similarly to modules A3-A5 and triggered with +15.7 (rather than +24.8) volts (nominal). A fuller explanation of this issue is discussed in a subsequent Section.

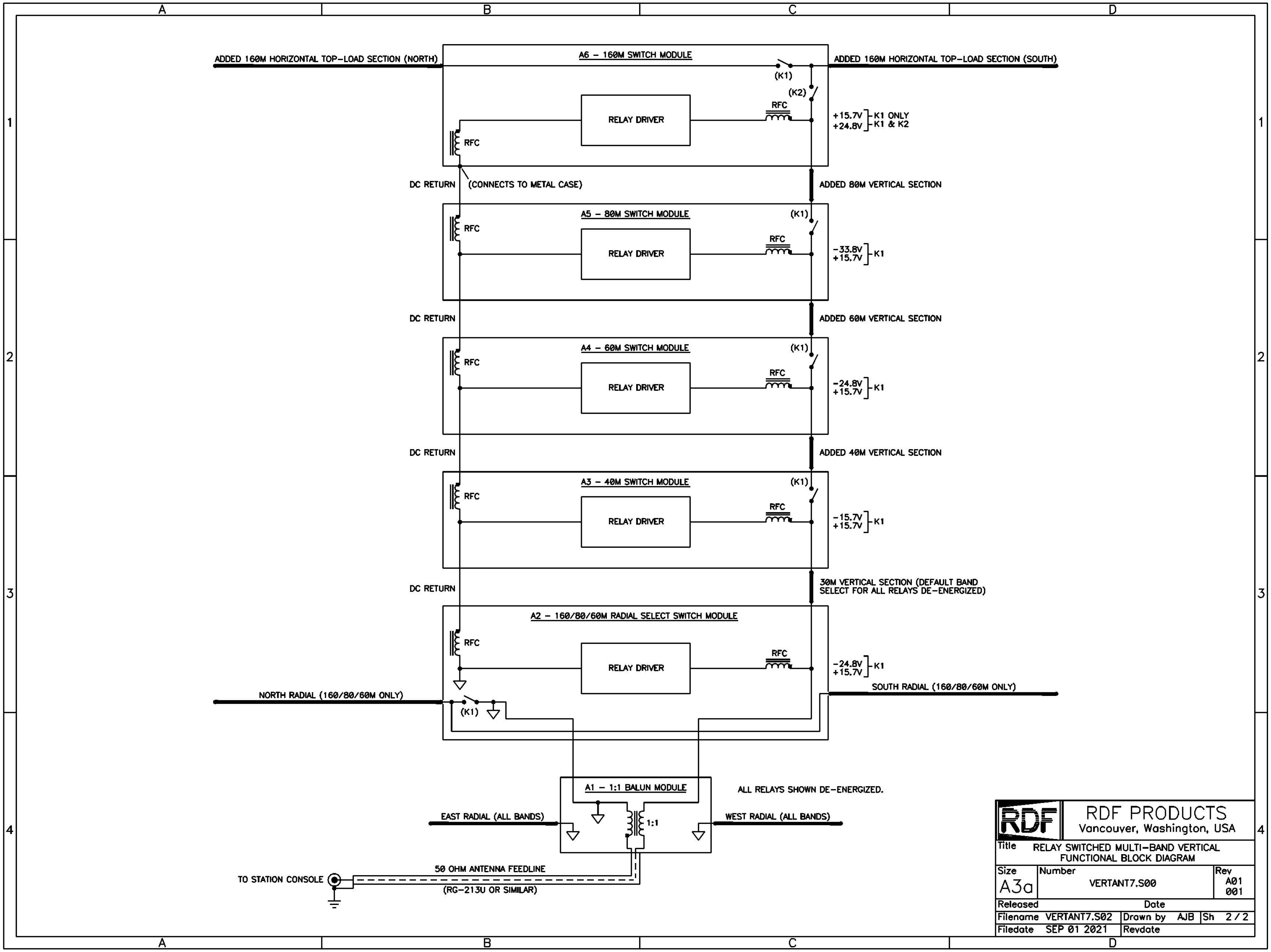


Figure 6 - N6DC Super-Vertical Functional Block Diagram (2 of 2)

SECTION VII - RELAY DRIVERS

A. OVERVIEW

In an earlier iteration of this project, the relay modules employed passive components only (i.e., resistors, diodes, Zeners, bypass capacitors, and RF chokes). Active components (i.e., transistors and integrated circuits) were avoided out of concern that their performance would be impaired by the proximity of strong RF fields at 1,500 watts.

This passive technique, however, required excessive DC current to implement. The issue was that power Zener diode voltage clamps had to be placed in parallel with the relay coils to prevent excessive coil voltages. As a case-in-point and using 12 volt DC relay coils, the 40 meter relay had to be Zener clamped at just over 12 volts to prevent the coil from burning out when higher voltages were applied (i.e., to activate the 60 and 80 meter relays). This resulted in very high current consumption thru the power Zeners.

With this experience in mind, I implemented an improved and more effective active technique and relied (successfully) on enhanced RF filtering and bypassing to ensure good performance even at power levels of up to 1,500 watts. This technique is presented in detail in the paragraphs below.

B. CURRENT REGULATOR VERSUS ZENER VOLTAGE CLAMP

The concept underlying this improved technique is to place an active current regulator in series with the relay coil. The principle underlying this current regulator is that when the applied voltage reaches some defined threshold, the current becomes fixed at that desired level. Thus, even if the applied voltage increases, the current regulator prevents the relay coil current from rising any further.

This “current clamp” is a far better technique than the Zener diode voltage clamp discussed above. Although Zener clamps protect the relay coils, they draw excessive current when higher voltages have to be applied to activate the successive relays.

To elaborate somewhat on the above-mentioned case-in-point for the abandoned passive technique, the 40 meter relay coil drew approximately 35 mA for a nominal applied DC voltage of 12 volts. However, when approximately 32 volts was applied to activate the 80 meter relay, the total current drain for the 40 meter relay coil was several hundred mA (with most of this current flowing through the Zener clamp).

Using the active current regulator, however, no Zener clamp is required and all the relay coils draw under 40 mA each. This active technique is therefore clearly the superior technical approach.

C. VOLTAGE REGULATOR REVIEW

Current regulators are easy to design and build, but are likely less familiar than voltage regulators to most readers . This discussion therefore begins with a review of the LM317T, which most readers will recognize as a classical 3-terminal variable voltage regulator. The salient features of the LM317T are as follows:

Maximum Input Voltage: +40 VDC
Maximum Output Voltage: +37 VDC
Minimum Output Voltage: +1.25 VDC
Maximum Output Current: >1.0 amperes (with suitable heat sink)

A typical application circuit is illustrated in Figure 7a below. The regulator output voltage is established by the ratio of R1/R2 and is determined as follows:

Vout = 1.25V x (1 + R2/R1)

Using the R1 and R2 values from Figure 7, the regulator output voltage is +13.75V.

Although the LM317 internal equivalent circuit is "busy" (and somewhat complicated), the easiest way to visualize its operation is as follows:

1. The output voltage always adjusts itself to whatever value is required to maintain 1.25V (the LM317 internal reference voltage) across R1 (240 ohms). This is accomplished with negative feedback via the ADJ (adjust) terminal. This in turn establishes the current through R1 at 1.25V/240 = 0.005208 A.

2. Since R1 is in series with R2 (and since the current flowing out of the ADJ terminal is negligible and can be ignored), this same current must flow through R2 (2,400 ohms). Thus, the resulting voltage across R2 is 0.005208 x 2,400 = 12.5V.

3. The total regulator output voltage is the sum of the voltages across the series resistors, or 1.25V + 12.5V = 13.75V.

4. If the input voltage (Vin) changes, Vout does not change since the reference voltage remains constant at 1.25V resulting in the same current (0.005208 A) through R1 and R2 and thus resulting in the same Vout.

Voltage regulators require a certain minimum overhead voltage to ensure that full regulation is maintained. Good design practice for the LM317T requires that this overhead be at least +3V. Thus, the minimum required input voltage for the Figure 7a is +16.75V. If this input voltage falls to substantially less than +16.75V, the circuit will drop out of regulation.

The 0.22 uF input capacitor is required for stability (i.e., to prevent the LM317T from oscillating). (This value is taken from the original National Semiconductor applications circuit.) The optional 1.0 uF output capacitor is not required for stability but reduces output noise.

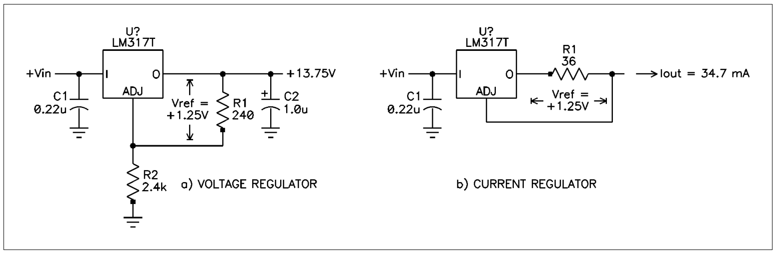


Figure 7 - LM317T Basic Voltage and Current Regulators

The LM317HVT is an enhanced version of the LM317T than can handle higher input voltages. Its maximum input/output voltages are 60/57 volts, respectively.

The LM337T is very similar to the LM317T but is designed for negative voltages. Aside from the fact that more input and output capacitance is required to guarantee stability, its performance is identical and its associated circuitry is the same.

D. CURRENT REGULATOR BASICS

As discussed above, the LM317T employs negative feedback in such a fashion as to always maintain the same 1.25V reference voltage across R1. (See Figure 7). This suggests a simple scheme to operate the LM317T as a current regulator.

Referring to Figure 7b, if R1 is placed in series with the LM317T output and R2 (from Figure 7a) is eliminated, and keeping in mind that the current through R1 is always 1.25V/R1, the result is a constant current output. In other words, this circuit serves as a simple and highly effective current regulator and is the basis for the relay drivers employed in the Super-Vertical.

Although not a serious issue for most applications, since this technique inherently adds a 1.25 volt drop at the LM317T output, this adds to the required overhead voltage. More specifically, this circuit raises the minimum required overhead voltage from +3V to +4.25V.

This same circuit can be implemented for negative voltages using the LM337T.

E. SELECTED RELAY

Before continuing with a more detailed discussion of the relay drivers, we first address the relay type to be used. For my installation, I wanted a premium relay capable of handling the voltage and current requirements for an antenna capable of handling 1,500 watts of RF power.

After some research, I selected the Schrack - TE Connectivity model RTD14012. This relay is advertised as a power relay capable of switching 250 VAC circuits and handling 16 amperes. It is also rated for up to 1,000 VAC between its open contacts and 5,000 VAC between its coil and contacts. These are very exceptional specifications. The RTD14012 product data sheet is available at this link:

http://www.farnell.com/datasheets/1869190.pdf

Furthermore, this relay is modestly priced and available from a number of suppliers. For readers not requiring a relay capable of handling 1,500 watts, smaller relays can be substituted.

The RTD14012 has SPDT contacts and a 12 VDC nominal coil with a nominal winding resistance of 360 ohms for a nominal coil current of 33.3 mA. The typical trip (activation) voltage was measured at 6.8 VDC, while the typical release voltage was close to 2.0 VDC. The relevance of these voltages is explained in a subsequent Section.

Assuming the margin for a safe operating voltage to be +/-10% of the 12 VDC specification, the corresponding nominal coil current is then 30.0-36.7 mA. Referring to Figure 7b, if R1 is 36 ohms (a standard resistance value), the resulting current at the specified 1.25V reference voltage is 1.25V/36 = 34.7 mA. This is comfortably within the safe operating current range.

Readers preferring a different relay can do so simply by changing R1 to accommodate the coil current rating. As an example, if the selected relay coil current is rated at 20 mA, the appropriate value of R1 is 1.25V/.02 = 62.5 ohms (or 61.9 ohms for the nearest 1% standard resistor value).

F. RELAY DRIVER FULL SCHEMATIC

Having presented the current regulator concepts above, Figure 8 illustrates the actual relay driver circuitry employed in the Super-Vertical switching modules.

The reader will notice that this circuit actually comprises two relay drivers in parallel. As discussed above, both positive and negative drivers are required (since the voltage polarity reverses for the 160 meter module to avoid excessive current consumption as per that discussion).

Referring to Figure 8, the positive relay driver comprises an LM317HV (U1, configured as a current regulator) and its associated components. Similarly, the negative relay driver comprises an LM337T (also configured as a current regulator) and its associated components. (**Note:** Since the maximum regulator input voltage does not exceed 40 volts, an LM317T may be substituted for the LM317HV.)

Addressing first the LM317HV positive current regulator, R2 (36 ohms) establishes the maximum regulator current into relay K1. As per the above discussion, this current is 1.25V/36 = 34.7 mA.

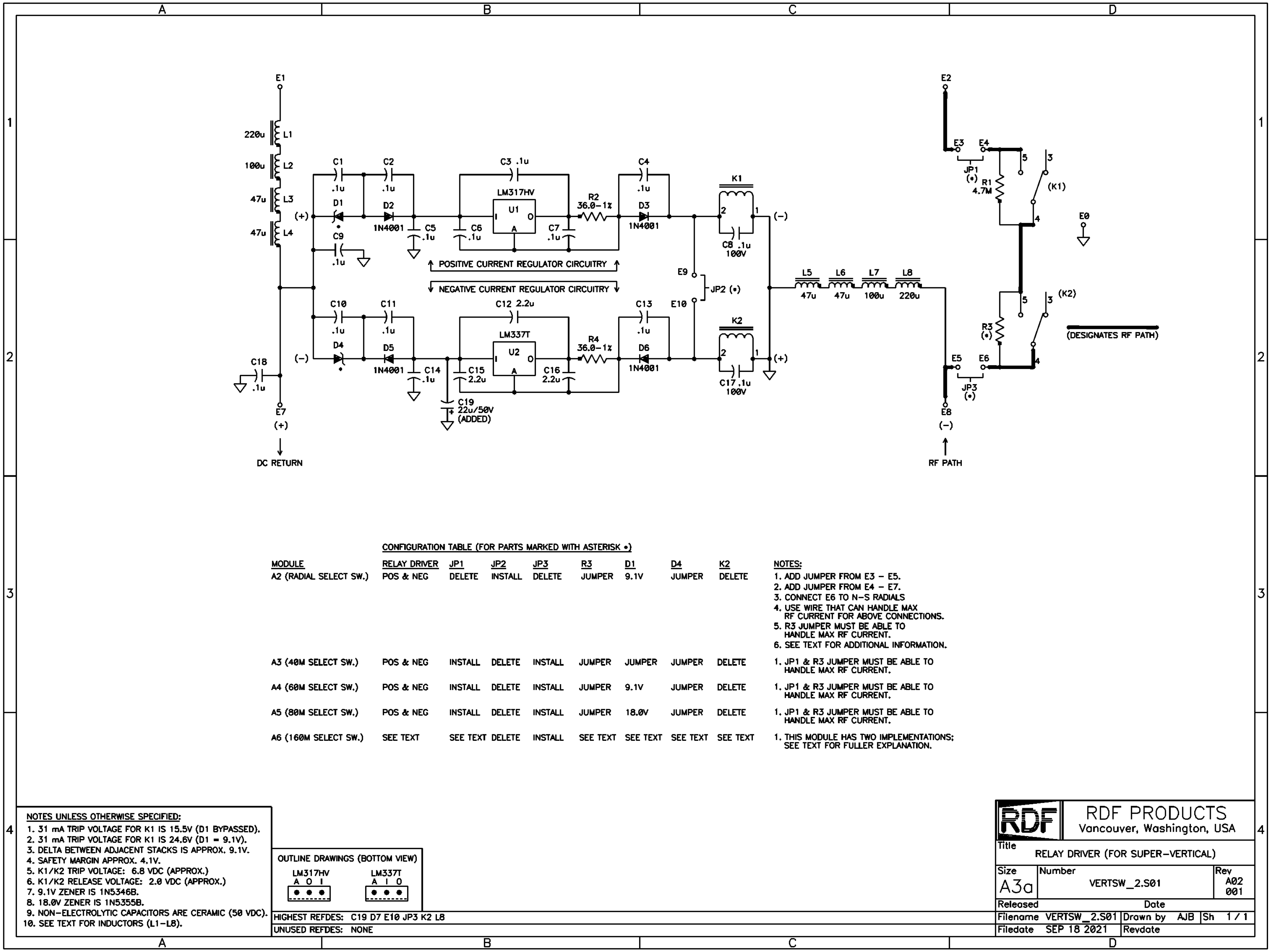
Zener diode D1 establishes the circuit offset voltage (i.e., the regulator circuit does not begin to become active until the voltage across D1 exceeds the Zener voltage). In this application, the Zener is 9.1V (for the 60 meter module) or 18.0V (for the 80 meter module). For the 40 meter module, no offset is required so the Zener is replaced by a jumper wire. For 160 meters, the drive voltage polarity is reversed so the negative regulator is used instead.

D2 and D3 are polarity protection diodes that prevent reverse polarity current from flowing through U1 when the negative regulator is used (i.e., for 160 meters). The bypass capacitors (C1-C8) shunt RF around the diodes, the LM317HV, and the relay K1 coil. This is necessary to prevent erratic performance during transmit (especially at high power levels).

While the voltage rating of C1-C7 can be low (50 VDC), the relay bypass capacitor C8 must be rated at 100 VDC. This is necessary due to the inductive kick-back voltage spike generated when K1 activates.

The LM337T negative current regulator functions very similarly, with all diode polarities reversed. For this circuit, Zener diode D4 establishes the circuit offset voltage. It is replaced by a wire jumper in all modules except the 160 meter module where this Zener is 9.1V. If only one relay is to be used in the 160 meter module (as will likely be the case for most reader implementations), D4 can also be replaced by a wire jumper. (See Section VI-C-5 for a fuller explanation of this issue.)

Since this LM337T negative regulator is more prone to instability (i.e., its tendency to oscillate), electrolytic capacitor C19 is included. Also, regulator bypass capacitors C12, C15,



CONFIGURATION TABLE (FOR PARTS MARKED WITH ASTERISK •)

MODULE	RELAY DRIVER	JP1	JP2	JP3	R3	D1	D4	K2	NOTES:
A2 (RADIAL SELECT SW.)	POS & NEG	DELETE	INSTALL	DELETE	JUMPER	9.1V	JUMPER	DELETE	1. ADD JUMPER FROM E3 - E5. 2. ADD JUMPER FROM E4 - E7. 3. CONNECT E6 TO N-S RADIALS 4. USE WIRE THAT CAN HANDLE MAX RF CURRENT FOR ABOVE CONNECTIONS. 5. R3 JUMPER MUST BE ABLE TO HANDLE MAX RF CURRENT. 6. SEE TEXT FOR ADDITIONAL INFORMATION.
A3 (40M SELECT SW.)	POS & NEG	INSTALL	DELETE	INSTALL	JUMPER	JUMPER	JUMPER	DELETE	1. JP1 & R3 JUMPER MUST BE ABLE TO HANDLE MAX RF CURRENT.
A4 (60M SELECT SW.)	POS & NEG	INSTALL	DELETE	INSTALL	JUMPER	9.1V	JUMPER	DELETE	1. JP1 & R3 JUMPER MUST BE ABLE TO HANDLE MAX RF CURRENT.
A5 (80M SELECT SW.)	POS & NEG	INSTALL	DELETE	INSTALL	JUMPER	18.0V	JUMPER	DELETE	1. JP1 & R3 JUMPER MUST BE ABLE TO HANDLE MAX RF CURRENT.
A6 (160M SELECT SW.)	SEE TEXT	SEE TEXT	DELETE	INSTALL	SEE TEXT	SEE TEXT	SEE TEXT	SEE TEXT	1. THIS MODULE HAS TWO IMPLEMENTATIONS; SEE TEXT FOR FULLER EXPLANATION.

NOTES UNLESS OTHERWISE SPECIFIED:

1. 31 mA TRIP VOLTAGE FOR K1 IS 15.5V (D1 BYPASSED).
2. 31 mA TRIP VOLTAGE FOR K1 IS 24.6V (D1 = 9.1V).
3. DELTA BETWEEN ADJACENT STACKS IS APPROX. 9.1V.
4. SAFETY MARGIN APPROX. 4.1V.
5. K1/K2 TRIP VOLTAGE: 6.8 VDC (APPROX.)
6. K1/K2 RELEASE VOLTAGE: 2.0 VDC (APPROX.)
7. 9.1V ZENER IS 1N5346B.
8. 18.0V ZENER IS 1N5355B.
9. NON-ELECTROLYTIC CAPACITORS ARE CERAMIC (50 VDC).
10. SEE TEXT FOR INDUCTORS (L1-L8).

Figure 8 - Relay Driver Schematic

and C16 are large values for this application (2.2 uF versus 0.1 uF for the LM317HV). As per the schematic, C12, C15, and C16 are ceramic (rather than electrolytic) capacitors for lower impedance bypassing.

R1 and R3 are 4.7M static discharge resistors placed in parallel with the relay contacts. Although these resistors do not dissipate any significant power, they are exposed to high voltages if the transmitted power levels are high. Since my station can output up to 1,500 watts, I selected high-voltage resistors rated for 3,000 volts.

All components are readily available from online electronics suppliers. The "specialty" components are as follows:

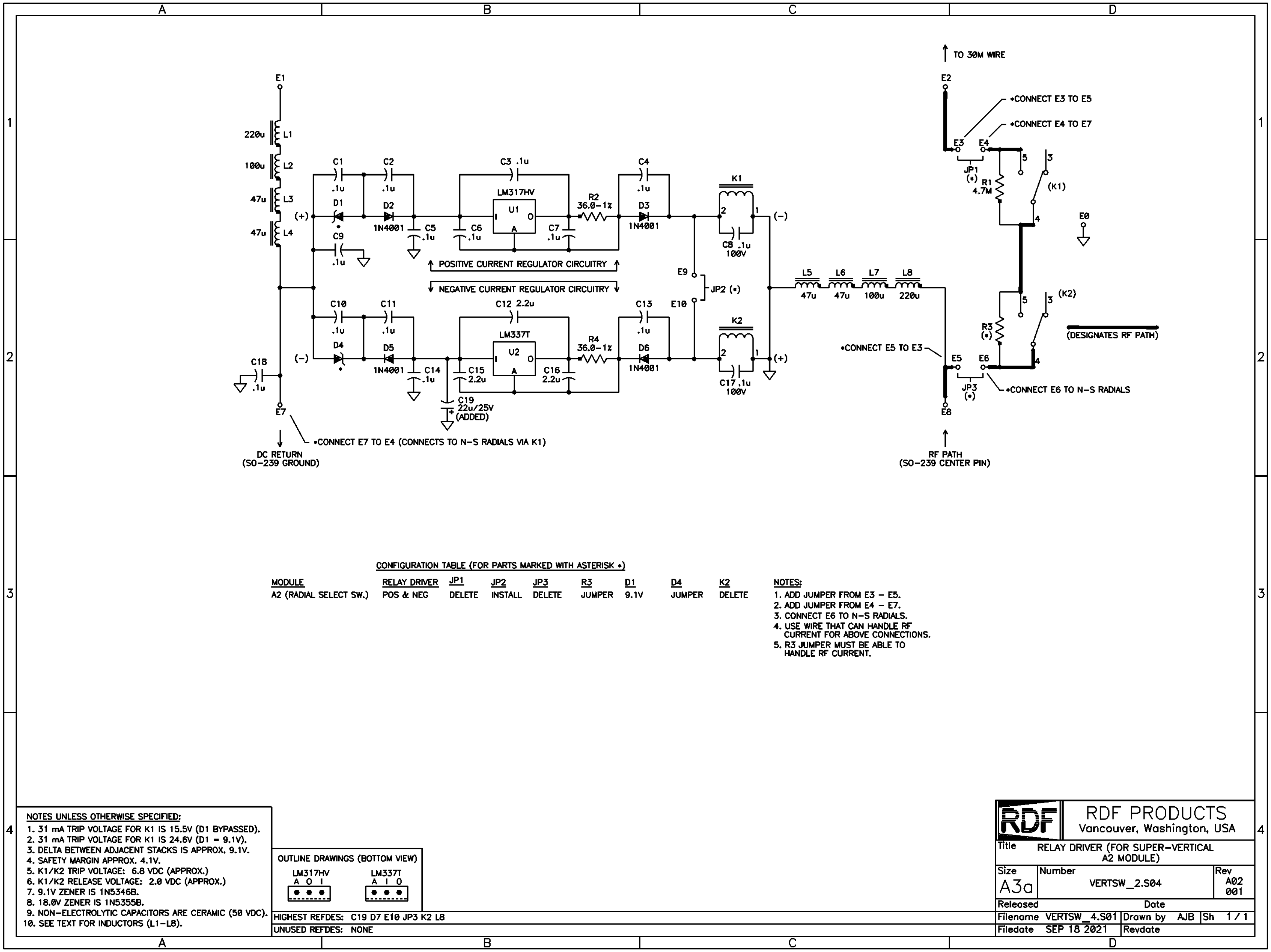
C8, C17 -	0.1 uF/100V ceramic capacitor (Mouser Electronics P/N 80-C320C104K1R).
C12, C15, C16 -	2.2 uF ceramic capacitor (Mouser Electronics P/N 810-FG26X7S2A225KRT). Although this capacitor is rated at 100 volts, a 50 volt capacitor may be substituted.
D1 -	9.1 volt 5 watt power Zener diode (Mouser Electronics P/N 863-1N5346BRLG); or 18.0 volt 5 watt power Zener diode (Mouser Electronics P/N 610-CZ5355B).
K1, K2 -	SPDT high-power relay (Mouser Electronics P/N 655-RTD14012).
L1, L8 -	220 uH power inductor (Mouser Electronics P/N 580-32221C).
L2, L7 -	100 uH power inductor (Mouser Electronics P/N 580-32101C).
L3-L6 -	47 uH power inductor (Mouser Electronics P/N 580-32470C).
R1, R3 -	4.7M high-voltage resistor (Mouser Electronics P/N 660-HV733ATTE475J).
Heat Sinks -	T0-220 heat sinks (Mouser Electronics P/N 532-507302B00) should be used for the LM317HV and LM337T regulators.

See my paper AR-002 for a fuller discussion of the power inductors (L1-L8). These serve as RF chokes and required significant research and testing to qualify them for this application.

Finally, a printed circuit board is available for the convenience of readers wanting to pursue this project. See Appendix B for more information.

G. A2 (RADIAL SELECT SWITCH) RELAY DRIVER CIRCUITRY

Since the circuitry for the A2 radial select switch relay driver is somewhat different than that for the A3-A5 vertical wire switch modules, the modified schematic is presented in Figure 9 for clarity. This schematic is similar to that of Figure 8, but with supplementary annotations specifying the added connections.



CONFIGURATION TABLE (FOR PARTS MARKED WITH ASTERISK •)

MODULE	RELAY DRIVER	JP1	JP2	JP3	R3	D1	D4	K2
A2 (RADIAL SELECT SW.)	POS & NEG	DELETE	INSTALL	DELETE	JUMPER	9.1V	JUMPER	DELETE

NOTES:

1. ADD JUMPER FROM E3 - E5.
2. ADD JUMPER FROM E4 - E7.
3. CONNECT E6 TO N-S RADIALS.
4. USE WIRE THAT CAN HANDLE RF CURRENT FOR ABOVE CONNECTIONS.
5. R3 JUMPER MUST BE ABLE TO HANDLE RF CURRENT.

NOTES UNLESS OTHERWISE SPECIFIED:

1. 31 mA TRIP VOLTAGE FOR K1 IS 15.5V (D1 BYPASSED).
2. 31 mA TRIP VOLTAGE FOR K1 IS 24.6V (D1 = 9.1V).
3. DELTA BETWEEN ADJACENT STACKS IS APPROX. 9.1V.
4. SAFETY MARGIN APPROX. 4.1V.
5. K1/K2 TRIP VOLTAGE: 6.8 VDC (APPROX.)
6. K1/K2 RELEASE VOLTAGE: 2.0 VDC (APPROX.)
7. 9.1V ZENER IS 1N5346B.
8. 18.0V ZENER IS 1N5355B.
9. NON-ELECTROLYTIC CAPACITORS ARE CERAMIC (50 VDC).
10. SEE TEXT FOR INDUCTORS (L1-L8).

OUTLINE DRAWINGS (BOTTOM VIEW)

LM317HV A O I

LM337T A I O

HIGHEST REFDES: C19 D7 E10 JP3 K2 L8

UNUSED REFDES: NONE

RDF PRODUCTS
Vancouver, Washington, USA

Title	RELAY DRIVER (FOR SUPER-VERTICAL A2 MODULE)		
Size A3a	Number VERTSW_2.S04		Rev A02 001
Released		Date	
Filename VERTSW_4.S01	Drawn by AJB	Sh 1 / 1	
Filedate SEP 18 2021	Revdate		

Figure 9 - **Relay Driver Schematic (for module A2 radial select switch)**

H. A6 (160 METER SWITCH MODULE) RELAY DRIVER CIRCUITRY

Since the circuitry for the A6 160 meter horizontal top-wire switch relay driver is somewhat different than that for the A3-A5 vertical wire switch modules, the modified schematics are presented in Figures 10 & 11 for clarity. These schematics are similar to that of Figure 8, but with additional annotations illustrating the added connections and other changes.

Figure 10 illustrates the A6 circuitry as implemented here at N6DC. This implementation allows the top horizontal wire to be broken up into two segments.

To explain, the Super-Vertical is located in the proximity of a multi-band beam antenna. When the beam antenna (rather than the Super-Vertical) is in use, this proximity of the Super-Vertical horizontal wire section can cause pattern interference to the beam pattern if the horizontal wire resonant frequency is near the beam operating frequency. By being able to break the horizontal wire into two sections, its resonant frequency can be moved as required to avoid interference to the beam pattern.

Referring to Figure 10, the two major module modifications are as follows:

1. A jumper is added to K1 as illustrated. When K1 activates, this jumper connects the South horizontal top-wire (connected to E2) to the North horizontal top-wire (connected to E4).

2. Since the 160 meter activation voltages are both positive (+15.7 and +24.8 VDC nominal as per Figure 5), both current regulators (U1 and U2) must be LM337Ts. This requires that the U1 current regulator circuit be modified as per Figure 10.

The K1/K2 relay activation sequence is explained in Figure 10.

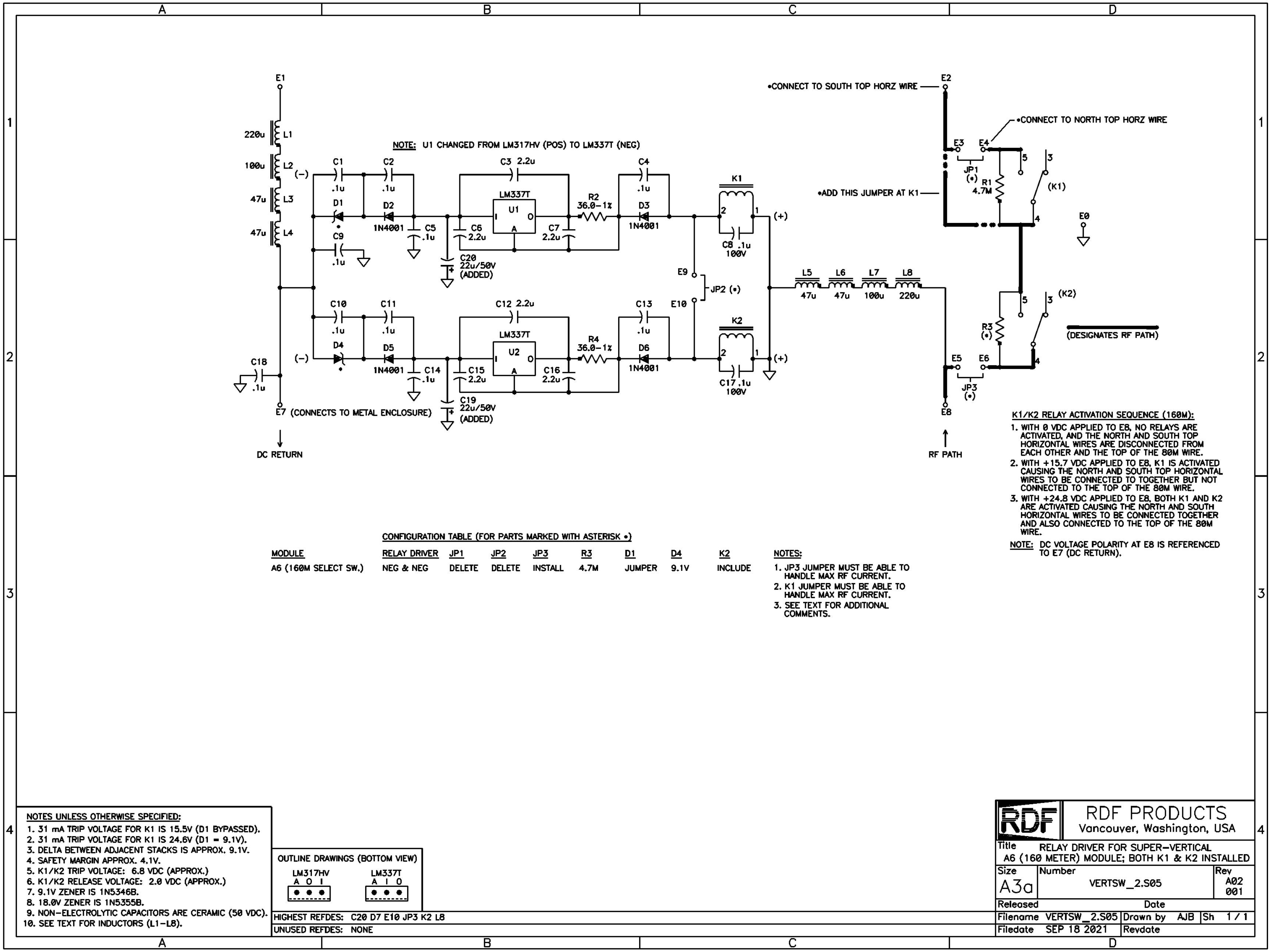
Figure 11 illustrates the A6 schematic for installations where it is not necessary to break the horizontal wire into two sections (the likely case for most readers). In this case, A6 functions in mostly the same fashion as modules A3-A5 with the exception that only the negative regulator is installed. The horizontal wire is left intact and is connected to the top of the 80 meter wire using a single relay (K1) for 160 meter operation.

I. CONSTRUCTING THE RELAY DRIVER MODULES

The relay driver modules were constructed on a printed circuit board specifically laid out for this application. For modules A2-A5, these circuit boards were then installed in Carlon model E987N 4" x 4" x 4" PVC electrical junction boxes. These junction boxes have a weather gasket on the top cover so that they are waterproof.

The module A6 (for 160 meters) components were installed in a sturdy cast aluminum box (although with the benefit of hindsight the same Carlon PVC junction box could have been used).

See Appendix C for more information on these enclosures.



NOTE: U1 CHANGED FROM LM317HV (POS) TO LM337T (NEG)

K1/K2 RELAY ACTIVATION SEQUENCE (160M):

1. WITH 0 VDC APPLIED TO E8, NO RELAYS ARE ACTIVATED, AND THE NORTH AND SOUTH TOP HORIZONTAL WIRES ARE DISCONNECTED FROM EACH OTHER AND THE TOP OF THE 80M WIRE.
2. WITH +15.7 VDC APPLIED TO E8, K1 IS ACTIVATED CAUSING THE NORTH AND SOUTH TOP HORIZONTAL WIRES TO BE CONNECTED TO TOGETHER BUT NOT CONNECTED TO THE TOP OF THE 80M WIRE.
3. WITH +24.8 VDC APPLIED TO E8, BOTH K1 AND K2 ARE ACTIVATED CAUSING THE NORTH AND SOUTH HORIZONTAL WIRES TO BE CONNECTED TOGETHER AND ALSO CONNECTED TO THE TOP OF THE 80M WIRE.

NOTE: DC VOLTAGE POLARITY AT E8 IS REFERENCED TO E7 (DC RETURN).

CONFIGURATION TABLE (FOR PARTS MARKED WITH ASTERISK •)

MODULE	RELAY DRIVER	JP1	JP2	JP3	R3	D1	D4	K2
A6 (160M SELECT SW.)	NEG & NEG	DELETE	DELETE	INSTALL	4.7M	JUMPER	9.1V	INCLUDE

NOTES:

1. JP3 JUMPER MUST BE ABLE TO HANDLE MAX RF CURRENT.
2. K1 JUMPER MUST BE ABLE TO HANDLE MAX RF CURRENT.
3. SEE TEXT FOR ADDITIONAL COMMENTS.

NOTES UNLESS OTHERWISE SPECIFIED:

1. 31 mA TRIP VOLTAGE FOR K1 IS 15.5V (D1 BYPASSED).
2. 31 mA TRIP VOLTAGE FOR K1 IS 24.6V (D1 = 9.1V).
3. DELTA BETWEEN ADJACENT STACKS IS APPROX. 9.1V.
4. SAFETY MARGIN APPROX. 4.1V.
5. K1/K2 TRIP VOLTAGE: 6.8 VDC (APPROX.)
6. K1/K2 RELEASE VOLTAGE: 2.0 VDC (APPROX.)
7. 9.1V ZENER IS 1N5346B.
8. 18.0V ZENER IS 1N5355B.
9. NON-ELECTROLYTIC CAPACITORS ARE CERAMIC (50 VDC).
10. SEE TEXT FOR INDUCTORS (L1-L8).

OUTLINE DRAWINGS (BOTTOM VIEW)

LM317HV
A O I

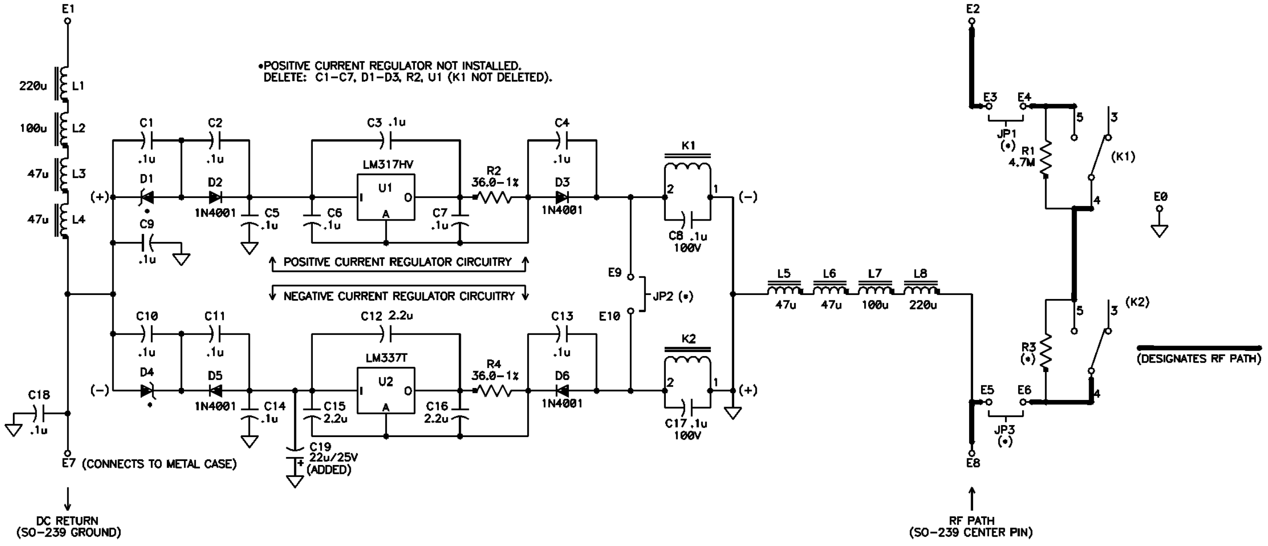
LM337T
A I O

HIGHEST REFDES: C20 D7 E10 JP3 K2 L8
UNUSED REFDES: NONE

RDF PRODUCTS
Vancouver, Washington, USA

Title RELAY DRIVER FOR SUPER-VERTICAL A6 (160 METER) MODULE; BOTH K1 & K2 INSTALLED
Size A3a
Number VERTSW_2.S05
Rev A02 001
Released
Date
Filename VERTSW_2.S05
Drawn by AJB
Sh 1 / 1
Filedate SEP 18 2021
Revdate

Figure 10 - Relay Driver Schematic (for module A6 160 meter horizontal top wire; 1 of 2)



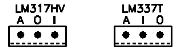
CONFIGURATION TABLE (FOR PARTS MARKED WITH ASTERISK •)

MODULE	RELAY DRIVER	JP1	JP2	JP3	R3	D1	D4	K2
A6 (160M SELECT SW.)	NEG ONLY	INSTALL	INSTALL	INSTALL	JUMPER	N/A	JUMPER	DELETE

NOTES:
1. R3 JUMPER MUST BE ABLE TO HANDLE RF CURRENT.
2. SEE TEXT FOR FULLER EXPLANATION.

NOTES UNLESS OTHERWISE SPECIFIED:
1. 31 mA TRIP VOLTAGE FOR K1 IS 15.5V (D1 BYPASSED).
2. 31 mA TRIP VOLTAGE FOR K1 IS 24.6V (D1 = 9.1V).
3. DELTA BETWEEN ADJACENT STACKS IS APPROX. 9.1V.
4. SAFETY MARGIN APPROX. 4.1V.
5. K1/K2 TRIP VOLTAGE: 6.8 VDC (APPROX.)
6. K1/K2 RELEASE VOLTAGE: 2.0 VDC (APPROX.)
7. 9.1V ZENER IS 1N5346B.
8. 18.0V ZENER IS 1N5355B.
9. NON–ELECTROLYTIC CAPACITORS ARE CERAMIC (50 VDC).
10. SEE TEXT FOR INDUCTORS (L1–L8).

OUTLINE DRAWINGS (BOTTOM VIEW)



HIGHEST REFDES: C19 D7 E10 JP3 K2 L8
UNUSED REFDES: NONE

RDF PRODUCTS
Vancouver, Washington, USA

Title	RELAY DRIVER (FOR SUPER–VERTICAL A6 MODULE; K1 INSTALLED)	
Size A3a	Number VERTSW_2.S06	Rev A02 001
Released	Date	
Filename VERTSW_2.S06	Drawn by AJB	Sh 1 / 1
Filedate SEP 18 2021	Revdate	

Figure 11 - Relay Driver Schematic (for module A6 160 meter horizontal top wire; 2 of 2)

J. RELAY HYSTERESIS

All electro-mechanical relays exhibit “hysteresis”, which is a succinct way of stating that the relay trip (activation) voltage is greater than the release voltage. For the Shrack RTD14012 relays used in this project, the trip (activation) voltage is 6.8 VDC and the release voltage is 2.0 VDC (both typical values). This hysteresis can cause design complications if not recognized and taken into account.

The potential issue at play here is that the relays in two adjacent switch modules (e.g., the 80 meter and 60 meter relays) could both activate simultaneously unless design precautions are taken to avoid this. As a case-in-point, if the 80 meter band has been selected (which is to say that the 80/60/40 meter relays are all activated) and then the 60 meter band is selected, the voltage applied to the 80 meter relay coil must drop from its nominal value (12 VDC) to a value safely below the relay 2.0 VDC release voltage. If this does not occur, both relays will be activated and the actual operational band will still be 80 meter rather than 60 meter.

This hysteresis issue is handled in the Super-Vertical in firmware. More specifically, the Antenna Controller Unit (discussed below) microprocessor is programmed to cut the DC band select voltage to zero for 50 milliseconds immediately prior to initiating a band change. This ensures that the relays are momentarily fully de-energized between band changes and thus effectively eliminates the hysteresis issue.

A related issue is that while only 6.8 VDC is required to trip the relay, the specified operating voltage is 12.0 VDC (i.e., the voltage required for reliable contact closure). The issue at play here is that when, for example, the 60 meter relay is activated, its 12.0 VDC coil voltage must not result in 6.8 VDC or more across the 80 meter relay coil.

This issue is handled in the Super-Vertical by employing voltage offset Zeners (D1 and D4 in Figure 8) that add a 9 volt offset threshold between adjacent switch modules. With this arrangement, there is a 4 volt safety margin.

To be completely accurate, the actual offset threshold is higher than 9 volts. This is due to the forward voltage drops of the two 1N4001 silicon diodes (approximately 0.7 volts each) and the current regulator overhead voltage (approximately 3.5 volts).

K. N6DC ANTENNA CONTROLLER UNIT (ACU)

Figure 12 - N6DC Antenna Controller Unit (ACU)

Referring to the functional block diagram of Figure 5 and the bias Tee discussion in Section VI-B-1, a variable band select voltage must be applied to the bias Tee DC port to appropriately activate the Super-Vertical band switching relays. This paragraph provides a brief overview as to how this was implemented here at N6DC.

As background information, I already had designed and built an antenna controller unit (ACU) to allow me to conveniently select the various station antennas. This ACU is illustrated in Figure 12. It allows for selection of two different transceivers (using the “A/B” switch), independent selection of transmit and receive antennas (where possible), and a blinking Error indicator for invalid selections.

This ACU employs two 16-position BCD rotary switches to independently select the TX/RX antennas as illustrated. The BCD switch outputs are read by a PIC 16F877A microprocessor that then decodes these inputs and appropriately firmware-maps them to the various PIC output ports. These output ports then toggle relay drivers that select the appropriate antenna switching relays for the selected antennas.

To accommodate the new Super-Vertical, additional circuitry was added to create a microprocessor-controlled programmable variable voltage regulator (along with the necessary output voltage polarity reversal circuitry). This voltage and polarity selection is done automatically upon vertical antenna band selection and is thus transparent to the operator (i.e., no additional operator intervention is required to ensure that the correct band select voltage is generated).

Microprocessors provide great flexibility. If changes are made in the station antenna setup, the microprocessor code can be suitably reprogrammed to accommodate them.

I created the ACU front-panel overlay artwork using my printed circuit board layout software (Tango PCB). I then printed the artwork on my laser printer using light blue index stock material. (Index stock is available in various colors and thicknesses from most office supply stores.) Finally, I carefully cut out the artwork and laminated it using a matte finish laminating pouch. (The matte finish eliminates glare and reflection.) This technique allows professional-quality overlays to be designed and fabricated using home office software and equipment.

In practice, the ACU need not be so elaborate. Simpler (but capable) solutions that do not require microprocessors can be implemented using switching circuitry to select the voltage regulator output voltage and polarity.

SECTION VIII - TESTING AND ADJUSTING THE SUPER-VERTICAL

A. WIRE LENGTHS

The wire lengths used for the Super-Vertical here at N6DC are as follows:

N-S Radials - 2 x 27' 3"

E-W Radials - 2 x 44' 6"

30 Meter Wire Section - 15' 4" (distance from A2 upper terminals to A3 lower terminals)

40 Meter Wire Section - 13' 7" (distance from A3 upper terminals to A4 lower terminals)

60 Meter Wire Section - 9' 4' (distance from A4 upper terminals to A5 lower terminals)

80 Meter Wire Section - 16' 2" (distance from A5 upper terminals to A6 input connector)

160 Meter Horizontal Wires - 2 x 84'

Refer to the Figure 6 functional block diagram for the relative location of these wires. Also see Appendix D for photos of the Super-Vertical as implemented here at N6DC.

Although the above lengths are good starting points for a first-cut implementation, the optimum lengths depend on a number of site variables. These include radial height above ground, proximity to nearby trees and buildings, soil conductivity, and other local variables.

It will therefore be necessary for readers to adjust wire lengths as appropriate for their installations. This is most conveniently done using a hand-held antenna analyzer. I strongly recommend a premium model capable of conducting swept (graphical) VSWR measurements.

I used the RigExpert model AA-35 Zoom illustrated in Figure 13. I found this instrument to be highly capable yielding measurement results in good agreement with my Keysight E5063A laboratory network analyzer.

In order to conduct the necessary VSWR measurements, it is necessary to have a means of sending voltages up the feed line to switch bands. This requires a special bias Tee that allows the voltage to be applied concurrently with measuring the VSWR.

I constructed a fixture specifically for this purpose. As per the Figure 14 photo, this fixture (built into a discarded MFJ-4712 enclosure) has three ports as follows:

ANALYZ - This port connects to the antenna analyzer.

DC - This port connects to a variable voltage DC power supply.

ANT - This port connects to the antenna feed line.

Figure 13 - RigExpert Model AA-35 Zoom Antenna Analyzer

The schematic for this fixture is presented in Appendix E. Note that the three RF chokes employed are 2.5 mH pi-wound types as per Figure 15. As per the AR-

002 bias Tee paper, these chokes provide an exceptionally high RF impedance in the HF range and are thus well suited for this task.

Figure 14 - Bias Tee

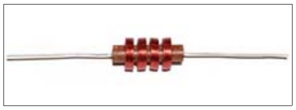


Figure 15 - 2.5 mH Pi-Wound RF Choke

I used a "Wilco" 2.5 mH choke that I obtained from RF Parts Company in San Marcos, California. The reason I placed two of these in parallel for the DC feed as per the Appendix E schematic is that a single choke overheated when passing the maximum relay module current. Although placing two chokes in parallel lowered the overall impedance slightly, this impedance reduction was not sufficient to noticeably affect performance.

If a suitable 2.5 mH RF choke is unavailable, the bias Tee circuit presented in AR-002 can be used instead with good results. The reason I built a separate bias Tee for antenna test purposes is that the one I built as per AR-002 was already installed in my station and inconvenient to remove.

B. ANTENNA ADJUSTMENT PROCEDURE

Once the antenna is installed, check the VSWR for the 30 meter band first (i.e., zero bias voltage applied to the relay modules). Trim the 30 meter vertical wire as required for good VSWR. See Figures 16-20 for the swept VSWR results I measured for my Super-Vertical.

Next, repeat this same procedure for the 40 meter band (being sure to apply the correct bias voltage to activate the 40 meter module).

If difficulty is experienced obtaining good VSWRs on both bands, adjust the *short* radial pair lengths and try again. I found that a certain amount of trial-and-error was necessary to obtain good VSWRs on both bands.

Once good results are obtained for both 30 and 40 meters, repeat this same procedure for the 60 meter band (again being sure to apply the correct bias voltage to activate the 60 meter module). Once done, repeat this procedure for the 80 and 160 meter bands. If adjustments to the radial lengths are required, be sure to adjust the *long* radial pair lengths only. (Although the short radial pair is active on all bands, they are non-dominant since very little antenna current flows thru them on 60, 80, and 160 meters.)

There is not much band adjustment interaction *provided that the adjustments are done in the sequence specified in the preceding paragraphs*. More specifically, adjusting the 40 meter wire length will have very little effect on the 30 meter band, but adjusting the 30 meter wire length will directly affect the 40 meter band. I did find that obtaining a good VSWR in the 60 meter band seemed a little "slippery".

I was initially concerned that the unused wire section lengths (i.e., the sections above the active elements) might have an effect on the active element via co-linear coupling. However, I did not see evidence that changing the lengths of these sections affected the active element.

Although the above procedure is very abbreviated, this brevity understates the magnitude of this task. This effort will likely be time-consuming and requires patience for good results.

C. VSWR MEASUREMENT POINT

The question sometimes arises as to where to measure the VSWR. On the one hand, measuring VSWR directly at the antenna feed point yields the most accurate results. On the other hand, one could argue that the "real" VSWR that the transceiver has to deal with is at the station end of the transmission line.

The issue is that in the general case a transmission line transforms the antenna feed point impedance to a different value. The two exceptions are as follows:

1. The VSWR is 1:1 (i.e., if the transmission line characteristic impedance is the same as the antenna feed point impedance). This would be the case if the transmission line impedance is 50 ohms and the antenna feed point impedance is also 50 ohms (resistive).

2. The transmission line is an integral multiple of ½ wavelength at the operating frequency.

As a practical matter then, the impedance seen by the transceiver is almost always different than the true antenna feed point impedance, and dependent on the transmission line length.

I believe that the best VSWR measurement point is as close to the antenna feed point as possible. The primary reason for this is that in a poor match scenario, the VSWR seen by the transceiver can badly understate the true antenna VSWR and conceal serious line losses.

This is most likely to happen if an antenna must be operated out-of-band (e.g. for a MARS or CAP application where the channel frequency is outside an amateur band) where the VSWR is likely to be high. The issue is that if the true antenna VSWR is 50:1 (as an extreme example), impedance transformations and coaxial line losses could make this VSWR appear well under 10:1 at the transceiver. When this happens, this means that the transmission line is extremely lossy and is thus burning up a good portion of the transmitted power.

As a case in point, suppose an antenna operating at 10.125 MHz has a 50:1 VSWR. This would result in a mismatch loss of 11.14 dB. For a 100 watt input (at the antenna feed point), this would result in 7.7 watts of forward power and 92.3 watts of reflected power.

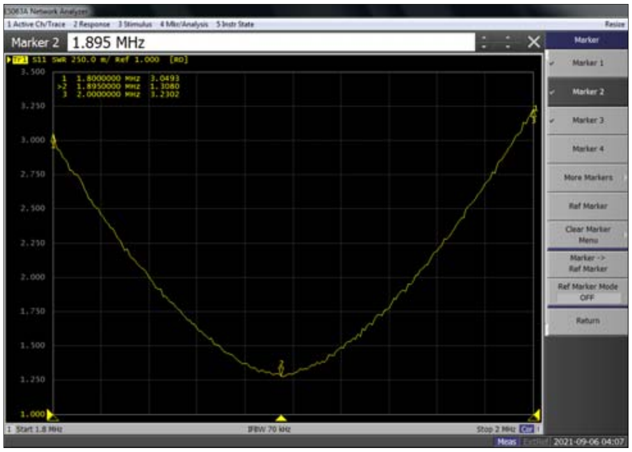
Now suppose that we feed the antenna through a 100' length of RG-213 coaxial cable. Let us further stipulate that the transceiver has a lossless antenna tuner that provides a perfect impedance match to the antenna *system* (i.e., the antenna plus the 100' RG-213 cable). Although the RG-213 cable *matched* loss is minor (0.55 dB), transmission line loss is magnified when standing waves are present. As a result, the additional loss imposed by a VSWR of 50:1 for 100' of RG-213 at 10.125 MHz is 5.69 dB, meaning that 23.8 watts is delivered to the antenna while 76.2 watts is dissipated in the transmission line.

As a result of this excessive loss, the VSWR *as measured at the RG-213 transceiver* end would almost certainly be much lower than the 50:1 antenna VSWR. It is even possible that it could appear as low as 3:1 or 4:1 for a very long line, but this would only mean that the coaxial cable impedance transformation and dissipation are understating (i.e., concealing) the poor antenna system performance. The operator would likely not realize there was a problem.

I measured the Super-Vertical VSWR as close to the feed point as was practical. This measurement point was at the end of the 13' RG-213 cable running down the 10' support mast. Since this 13' feed line is only 0.2 wavelength at the highest frequency (10.150 MHz), the impedance transformation effects are minor.

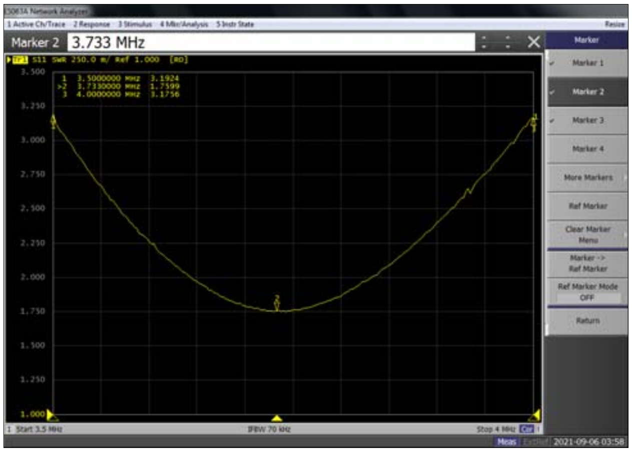
D. N6DC SUPER-VERTICAL SWEPT VSWR MEASUREMENTS

See Figures 16 - 20 below for actual swept VSWR measurements for the Super-Vertical on all five bands. These measurements were taken and recorded using a Keysight E5063A network analyzer.


Marker 2 1.895 MHz

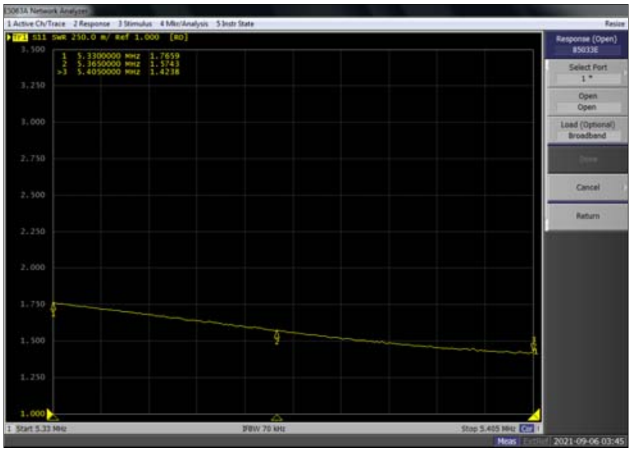
```
Tr1 S11 SWR 250.0 m/ Ref 1.000 [RD]
  1   1.8000000 MHz  3.0493
 >2   1.8950000 MHz  1.3080
  3   2.0000000 MHz  3.2302
```

Figure 16 - **Super-Vertical 160m Swept VSWR**


Marker 2 3.733 MHz

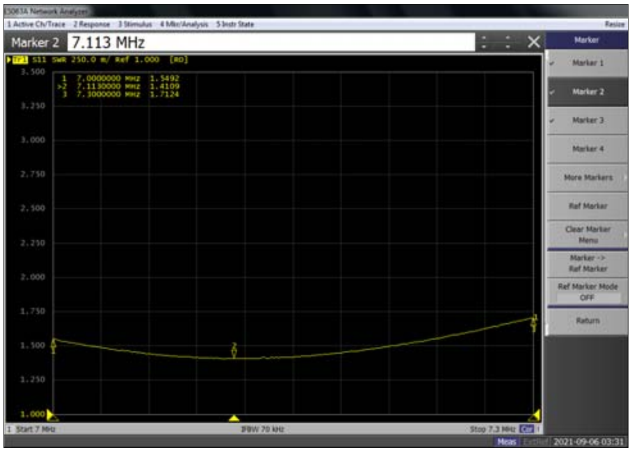
```
Tr1 S11 SWR 250.0 m/ Ref 1.000 [RD]
  1   3.5000000 MHz  3.1924
 >2   3.7330000 MHz  1.7599
  3   4.0000000 MHz  3.1756
```

Figure 17 - **Super-Vertical 80m Swept VSWR**



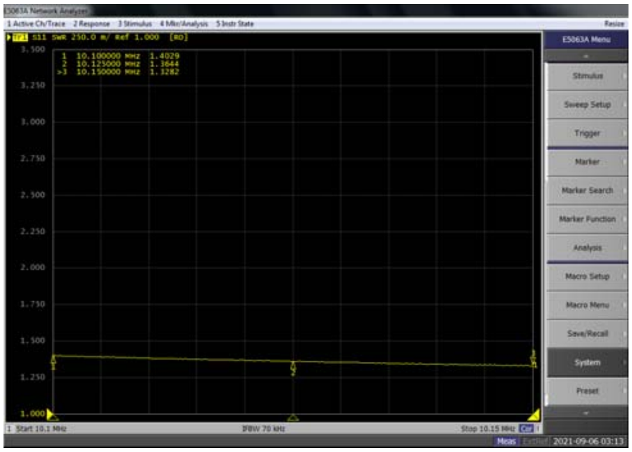
```
Tr1 S11 SWR 250.0 m/ Ref 1.000 [RD]
  1   5.3300000 MHz  1.7659
  2   5.3650000 MHz  1.5743
 >3   5.4050000 MHz  1.4238
```

Figure 18 - **Super-Vertical 60m Swept VSWR**


Marker 2 7.113 MHz

```
Tr1 S11 SWR 250.0 m/ Ref 1.000 [RD]
  1   7.0000000 MHz  1.5492
 >2   7.1130000 MHz  1.4109
  3   7.3000000 MHz  1.7124
```

Figure 19 - **Super-Vertical 40m Swept VSWR**



```
Tr1 S11 SWR 250.0 m/ Ref 1.000 [RD]
  1   10.100000 MHz  1.4029
  2   10.125000 MHz  1.3644
 >3   10.150000 MHz  1.3282
```

Figure 20 - **Super-Vertical 30m Swept VSWR**

E. WHAT IS A "GOOD" VSWR?

Although this question has been addressed many times elsewhere and is somewhat outside the purview of the paper, it is still reasonable and relevant.

Other things being equal, a low VSWR is better than a high VSWR. If someone installs a 40 meter dipole and observes a 3:1 mid-band VSWR (where we would expect it to bottom out near 1.5:1 or so), this would be an indication that something is wrong with the antenna installation. The issue might be a construction problem or a site-induced error caused by proximity of the antenna to a conductive structure with an in-band resonance.

High VSWRs also magnifies transmission line loss as quantified for the hypothetical 10.125 MHz antenna scenario presented in Section VIII-C above. In that example a 10.125 MHz antenna driven by a 100' length of RG-213 was shown to incur an additional transmission line loss of 5.69 dB (i.e., an added dissipation loss of 73% of the transmitted power) as a result of the high VSWR.

Fortunately, this additional loss tends to be small in the HF range for moderate cable lengths for even moderately high VSWRs. This is very convenient in that it allows the antenna tuner to be placed in the station rather than at the antenna.

High VSWRs can also impose power limitations on the station antenna tuner. My KPA1500 1,500 watt HF amplifier has a built-in antenna auto-tuner. Although it is an exceptionally capable tuner that can match into high VSWR loads, a relatively low VSWR is required to allow the full KPA1500 1,500 watt output. (The KPA1500 automatically shuts down if the VSWR is too high for the auto-tuner.) I thus have to accept less output power for even modestly high VSWRs (although I prefer not to run my KPA1500 very hard anyway, limiting my maximum forward output power to 1,000-1,200 watts), so this provides an incentive to design and build low to moderate VSWR antennas. However, this is much less of an issue for stations running under 300 watts. For typical amateur radio stations running exciter power levels only, high VSWRs are more easily accommodated.

The biggest design complication of the Super-Vertical was obtaining good VSWRs on all five bands with limited degrees of freedom (i.e., since the radial set lengths had to work for multiple bands). This required a great deal of trial and error, not to mention patience and persistence (and a little luck as well). I was pleased with the VSWR results, but will let the swept VSWR responses above speak for themselves.

SECTION IX - ALTERNATIVE IMPLEMENTATIONS

A. OVERVIEW

It is likely that some readers may be interested in implementing a vertical antenna using the DC voltage switched relay concept presented in this paper but may want to construct their unit for a different band coverage or antenna configuration (e.g., a dipole). Such alternative implementations are outlined in the paragraphs below.

B. DELETING BANDS

Deleting bands is straightforward. As a case in point, if the 60 meter band is not needed, the 60 meter module (A2) would be deleted and the 60 meter wire section would just be added to the 80 meter wire section. Note that the vertical distance between the upper and lower A2 terminals (2" for my modules) should be added to the specified 60/80 meter wire section lengths (since this is part of the effective radiating wire).

Similarly, if the 160 meter band is not needed, the horizontal top wire would be deleted and replaced with a length of antenna rope to support the vertical wire sections.

C. ADDING BANDS

Some readers might want to construct a version covering the upper HF bands (i.e., 20-10 meters). This can be done, although the procedure is less straightforward than deleting bands. Adding new bands would require testing to determine the required vertical wire length as well as the associated radial wire length.

The practical limitation to adding bands is that the required band select voltage can become excessive. One work-around for this issue would be to use a lower voltage relay. The Schrack - TE Connectivity model RTD14012 12 volt relay used in this project is also available in 5, 6, and 9 volt windings, so the relay driver circuit could be redesigned to accommodate a desired lower voltage. Keep in mind, however, that the required relay coil drive current is much higher at these lower voltages, so appropriate design accommodations would have to be made.

D. DIPOLE IMPLEMENTATION

Some readers might also ask if this same DC voltage switched relay concept could be implemented for a multi-band dipole. The answer is an emphatic “yes”, with two benefits and one caveat:

1. There would be no radials that would have to be switched.
2. As a result, determining the required dipole wire lengths between relay switch modules

would be straightforward since there would be little or no band interaction. Standard dipole length formulas could be used, so little guesswork would be required.

3. However, two relay switch modules would be required for each band (i.e., one per dipole wire). As a result, a total of eight relay switch modules would be required for a 5-band implementation (versus five for the 5-band Super-Vertical).

In fact, the concept would be very similar to the microprocessor controlled relay switching technique developed by Jim Weit, KI8BV discussed in Section IV-C. The fundamental difference is that the relay modules would be switched by a variable DC voltage rather than a digital data stream. This relay switching technique would be superior to a multi-band trap dipole for the same reason that the Super-Vertical is superior to a multi-band trap vertical (i.e., avoiding the ills associated with traps as discussed in Section III-B).

Figure 21 is a functional block diagram illustrating a dipole implementation. Module A1 for this implementation is a dipole junction module comprising the same 1:1 isolation balun employed in the Super-Vertical plus RF chokes to isolate the DC return paths. Module A2a and A2b are the 40 meter relay switching modules while A3a and A3b are the 60 meter relay switching modules. Module pairs for additional bands could be added as required.

As implemented, module A1 results in opposite control voltage polarities for the two dipole wires. To explain, if this voltage polarity is positive for the left dipole wire, it will be negative for the right dipole wire. This can be accommodated easily enough in the switch modules. To clarify, the dipole configuration of Figure 21 would result in the same voltage polarity to the dipole left leg as it would for the Super-Vertical radiating element. Thus, the left 40 meter relay switch (A2a) for the dipole would be configured the same as for the corresponding Super-Vertical 40 meter relay switch (A3 as per Figures 5 and 6).

However, the *opposite* voltage polarity would be applied to the right 40 meter relay switch (A2b). This would reverse the roles of the positive and negative current regulators. Fortunately, this reversal can be accommodated by swapping relay module Zener diodes D1 and D4.

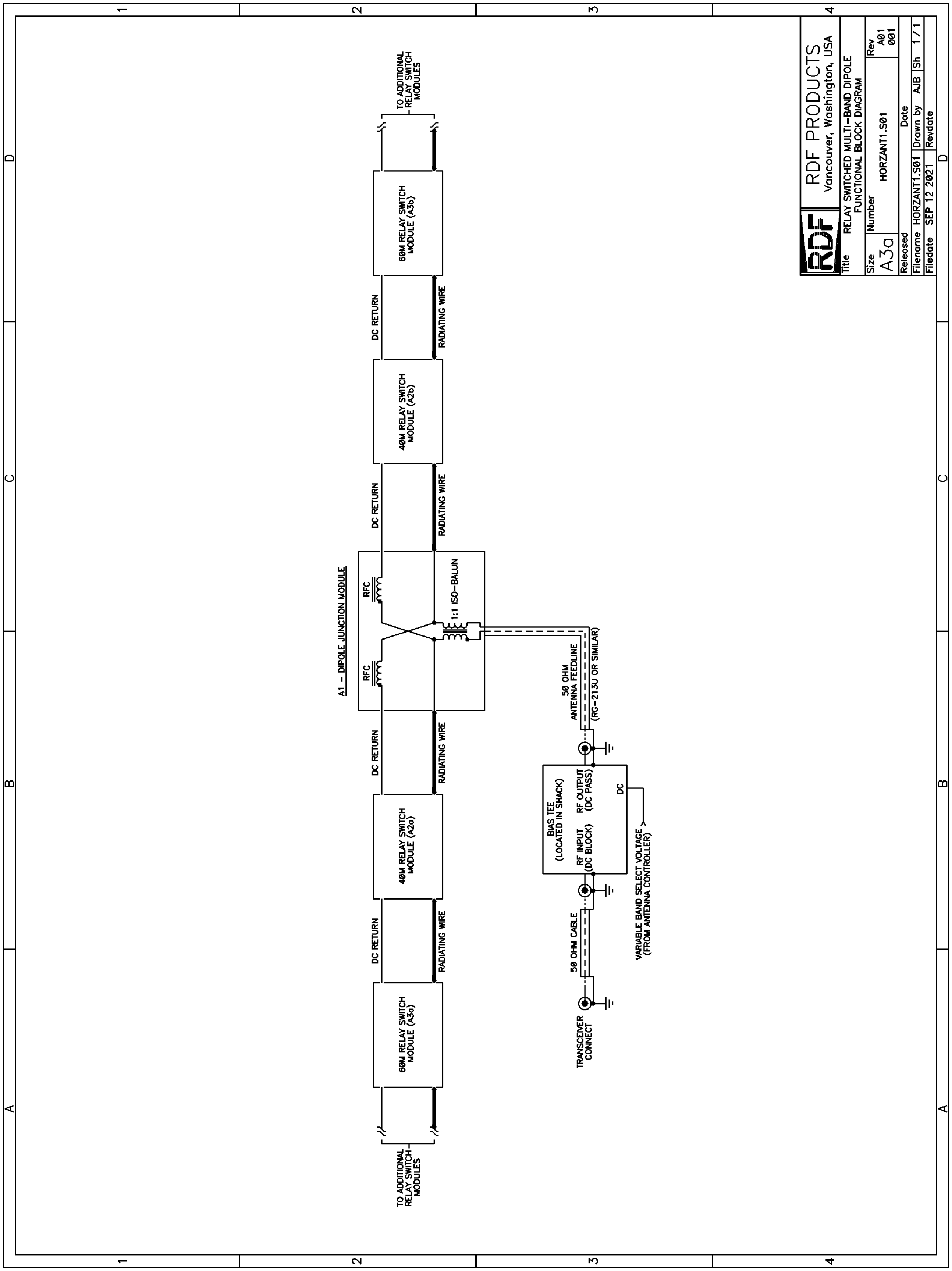


Figure 21 - Multi-Band Dipole Implementation Functional Block Diagram

SECTION X - SUMMARY & CONCLUSION

A new elevated feed ground plane radial 5-band HF vertical antenna design was introduced for the 160, 80, 60, 40, and 30 meter amateur bands using in-line band switching relays. These relays are successively activated by a variable DC voltage sent up the transmission line. The antenna can handle up to 1,500 watts.

An elevated feed and radial technique was shown to offer much lower ground loss than a traditional buried radial configuration. It was also shown that only two active radials per band are necessary to achieve full performance.

Using relays for band switching eliminates the inefficiencies and bandwidth limiting drawbacks of trap dipoles. The 160 meter band is accommodated using a switched-in horizontal top wire as a capacitive loading hat. Thus, 160 meter coverage is achieved with a total structural height of only 65'.

An earlier design implementation employed only passive components (i.e., capacitors, diodes, and relays) for band switching. This was due to a concern that active components (i.e., transistors and ICs) would be susceptible to damage or erratic performance in the presence of the strong RF field from a 1,500 watt transmitter. This passive implementation, however, lacked flexibility and resulted in excessive DC current consumption. An active approach using IC current regulators was then substituted with excellent results. DC current drain was much lower and good RF bypassing techniques adequately protected the active components.

Good VSWR responses were achieved for all five bands as confirmed by the swept VSWR images presented.

Alternative implementations were also discussed. These alternatives included different band coverage and a version suitable for dipoles.

SECTION XI - AFTERWORD

This Super-Vertical project came about as a result of wanting an efficient and effective antenna for the low HF bands (especially for 160 and 80 meters where dipole ground losses are high and where rotatable beams are impractical). I was aware that many radio amateurs had reported mixed results with vertical antennas over the years, but my thinking during this time had evolved to the point where I believed that the reported shortcomings were mostly implementation related issues.

This thought evolution was further confirmed by modern antenna modeling software. Using EZNEC4, I was able to gain valuable insights on vertical antenna performance with relative ease as compared to relying on difficult, time consuming, and often inconclusive empirical methods. More specifically, I came to realize that buried radial ground systems are very lossy regardless of how elaborately they are implemented.

In tandem with this, I found that elevated ground radial systems provide far better efficiency and require only two active radials to achieve this superior performance. I further came to realize that many elevated ground plane radial antennas suffered from poor performance due to the absence of a feed line isolation choke necessary to prevent the feed line from becoming an unintended (and detrimental) radiating element.

The total time required to complete this project from beginning to end spanned nearly 10 years (although the actual time I worked the project was only a small fraction of this). Much of the effort was in the design concept phase. I tried and discarded several “paper” (conceptual) designs before building any hardware. My first hardware implementation employed a passive technique as discussed in Section VII-A. Although this technique was functional, it was marginal and not suitable for publication. Even so, this effort was not wasted, however, since valuable knowledge was gained even from the discarded concepts. This was truly an evolutionary design process.

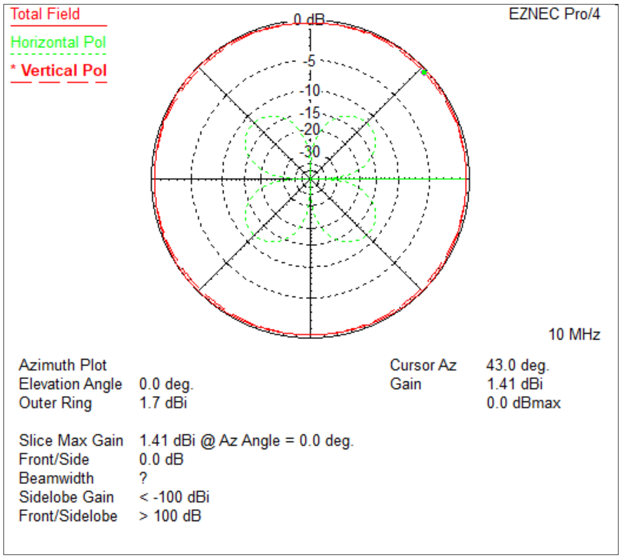
This brings to mind an old saying to the effect than in certain endeavors the journey can be more important than the destination. While successfully completing the Super-Vertical was an important and highly desireable “destination” for my amateur radio station, the knowledge I gained from pursuing this project is equally important. The greater purpose of this paper then is to share this knowledge and experience with other interested radio amateurs having similar interests and goals.

I hope readers have found this paper interesting, constructive and useful. Constructive feedback and corrections are welcome.

Alex, N6DC
Sep 2021

APPENDIX A - RADIATION PATTERN (FOR TWO VERSUS FOUR RADIALS)

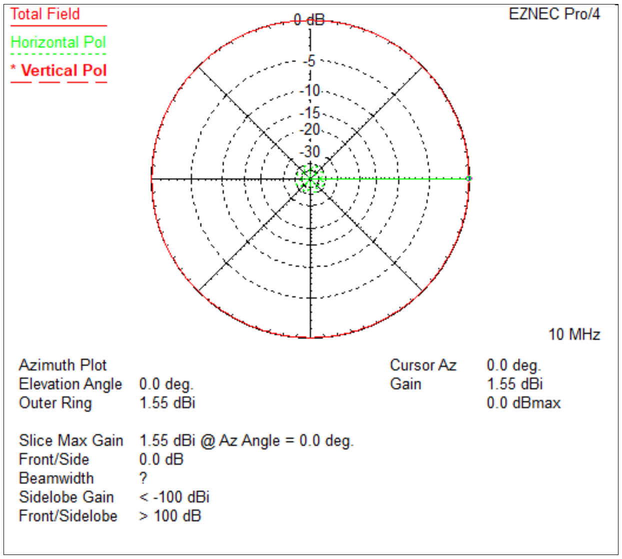
Many radio amateurs believe that it is standard practice for elevated ground plane verticals to have four ground plane radials. As it happens, there is negligible performance difference if only two radials are employed as illustrated by the azimuth plots in Figures 22 (for two radials) and 23 (for four radials) below.



Azimuth Plot
Elevation Angle 0.0 deg.
Outer Ring 1.7 dBi
Cursor Az 43.0 deg.
Gain 1.41 dBi
0.0 dBmax

Slice Max Gain 1.41 dBi @ Az Angle = 0.0 deg.
Front/Side 0.0 dB
Beamwidth ?
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

<u>Figure 22</u> - Azimuth Plot for 10 MHz Vertical (two symmetrical radials, 0° elevation, free space)



Azimuth Plot
Elevation Angle 0.0 deg.
Outer Ring 1.55 dBi
Cursor Az 0.0 deg.
Gain 1.55 dBi
0.0 dBmax

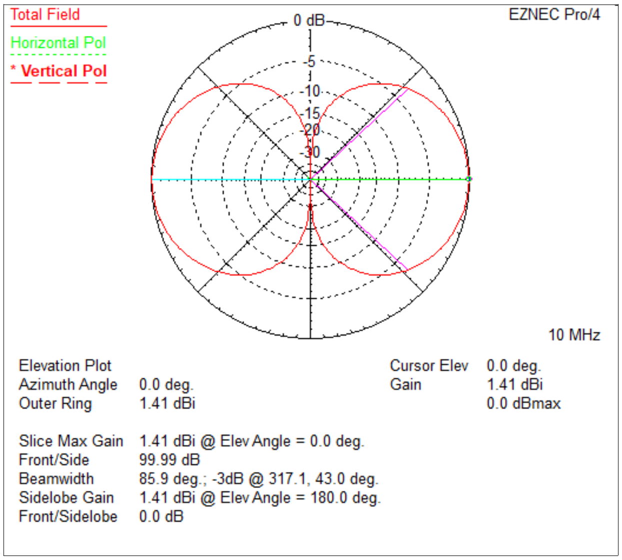
Slice Max Gain 1.55 dBi @ Az Angle = 0.0 deg.
Front/Side 0.0 dB
Beamwidth ?
Sidelobe Gain < -100 dBi
Front/Sidelobe > 100 dB

<u>Figure 23</u> - Azimuth Plot for 10 MHz Vertical (four symmetrical radials, 0° elevation, free space)

Both of these plots are for resonant 10 MHz verticals with symmetrical radials in free space. The azimuth patterns (red plots) are vertically polarized and omnidirectional as one would expect. The two radial implementation azimuth plot is very slightly less circular than that of the four radial plot.

Note the presence of a small horizontally polarized component (green plots) for both implementations (which is more significant in the two radial implementation). This is due to the imperfect horizontal field cancellation from the radial wires. Apparently, additional symmetrical radial pairs result in more perfect cancellation as per the plots. Even so, this horizontally polarized component is not large enough to adversely affect antenna performance and can be ignored.

Figures 24 and 25 illustrate the corresponding elevation patterns of these same antennas. Once again, the differences are negligible. There is thus no advantage to having more than two radials.

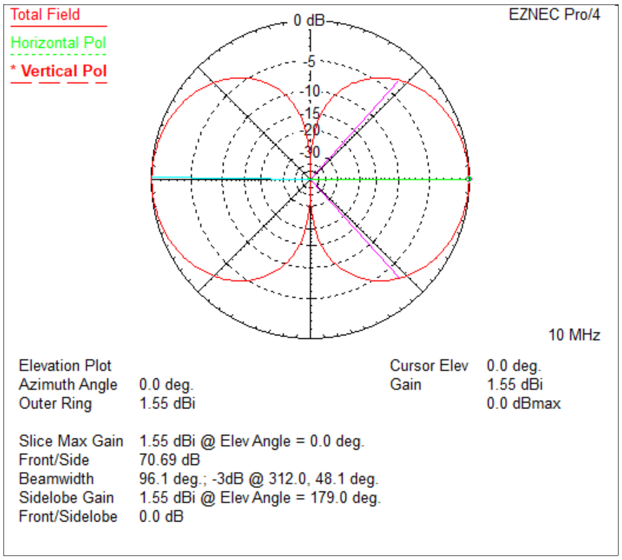


Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 1.41 dBi

Cursor Elev 0.0 deg.
Gain 1.41 dBi
0.0 dBmax

Slice Max Gain 1.41 dBi @ Elev Angle = 0.0 deg.
Front/Side 99.99 dB
Beamwidth 85.9 deg.; -3dB @ 317.1, 43.0 deg.
Sidelobe Gain 1.41 dBi @ Elev Angle = 180.0 deg.
Front/Sidelobe 0.0 dB

<u>Figure 24</u> - Elevation Plot for 10 MHz Vertical (two symmetrical radials, 0° azimuth, free space)



Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 1.55 dBi

Cursor Elev 0.0 deg.
Gain 1.55 dBi
0.0 dBmax

Slice Max Gain 1.55 dBi @ Elev Angle = 0.0 deg.
Front/Side 70.69 dB
Beamwidth 96.1 deg.; -3dB @ 312.0, 48.1 deg.
Sidelobe Gain 1.55 dBi @ Elev Angle = 179.0 deg.
Front/Sidelobe 0.0 dB

<u>Figure 25</u> - Elevation Plot for 10 MHz Vertical (four symmetrical radials, 0° azimuth, free space)

APPENDIX B - RELAY MODULE CIRCUIT BOARD

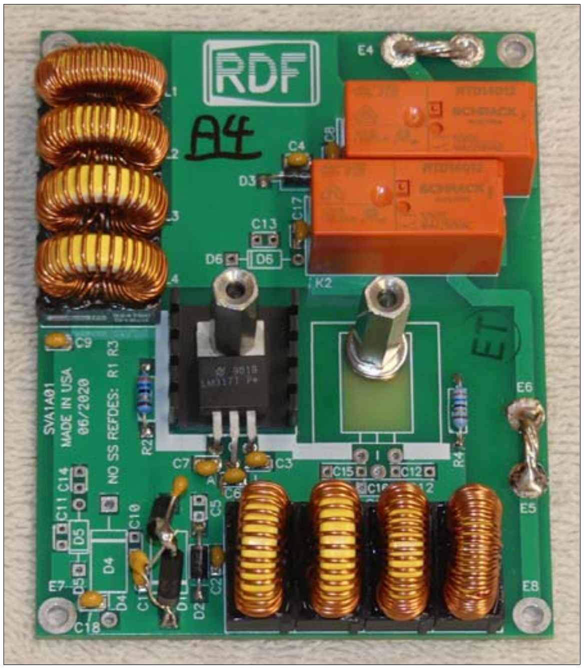


Figure 26 - **Relay Switch Module PC Board (component side)**

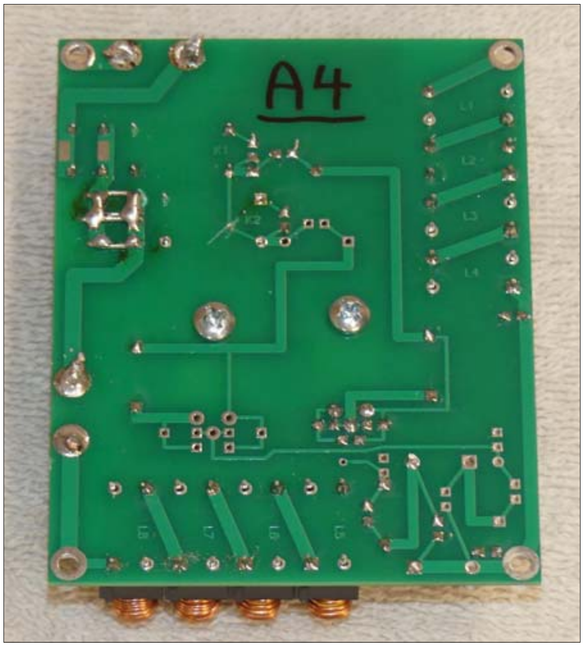


Figure 27 - **Relay Switch Module PC Board (circuit side)**

A printed circuit board was designed and fabricated for the relay switch modules. The PC board illustrated in Figures 26 & 27 is configured for the A4 (60 meter) relay switch module. See also the Figure 8 board schematic.

Note that some of the components are “no-loads” since they were not required for the A4 module. These components are required, however, for other modules. No components are mounted on the PC board underside.

The PC board is double-sided with plated-thru holes. The board dimensions are 3.000" x 3.800". They are fabricated using 0.062" FR4 glass-epoxy laminate.

Some modules may require PC board modifications (i.e., “cuts and jumps”), depending upon the specific configuration.

The two #6 threaded spacers are used to secure the regulator ICs to their heat sinks and also to serve as mounting spacers to mount the boards inside their PVC enclosures.

The PC board Gerber (fabrication) files are public domain and will be provided upon request to interested readers who wish to fabricate their own boards.

Although the Figure 8 schematic shows C19, E9, and E10, these components are not included in the current PC board revision. C19 must be added to the LM337T negative regulator (U2) for improved stability. E9 & E10 are for a configuration jumper (JP2). In modules where JP2 is not required, a circuit side board trace must be cut between K1-2 and K2-2. This trace cut is visible in Figure 27.

These omissions will be corrected in the next PC board revision.

APPENDIX C - RELAY MODULE ENCLOSURES

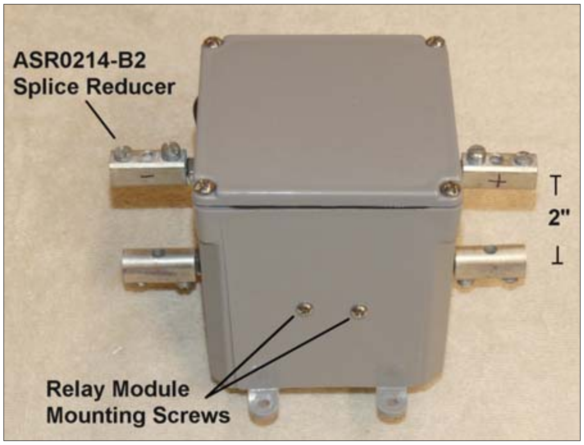


Figure 28 - **Relay Module Enclosure**

Modules A2-A5 are installed inside Carlon model E987N 4" x 4" x 4" PVC outdoor electrical junction boxes as illustrated in Figure 28. These boxes are very sturdy and are suitable for permanent outdoor installation.

The four terminals are 1/4-20 x 1" stainless steel machine screws. These serve as connection points for the ladder line wires. Four ea. 1/4" diameter holes are drilled into the box wall at the terminal locations. The screws are then inserted into these holes from inside the box and secured using 1/4-20 stainless steel hex nuts outside the box. Note that the vertical separation between these screws is 2".

The relay modules are mounted to the inside walls of the box using #6 stainless steel screws as illustrated. These screws are secured to the relay module #6 spacers (used also to secure the two regulator ICs as discussed and illustrated in Appendix B and elsewhere in this paper).

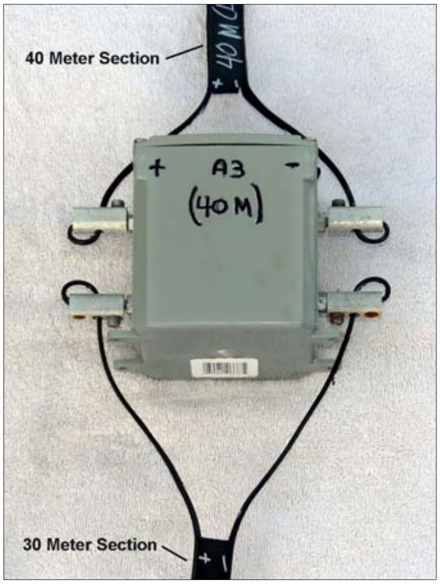


Figure 29 - **Relay Module Ladder Line Connections**

ASR0214-B2 “splicer reducers” are then fastened to the protruding screws as illustrated. These splicer reducers are available in the electrical departments of many home improvement stores.

An additional hole is drilled thru the splicer reducers as illustrated. These are used as strain reliefs for the ladder line wires that are fastened to the terminals as illustrated in Figure 29.

Additional A3 modules photos are presented in Figures 30 and 31. These photos show the module relay driver circuit board and interior wiring.

Figure 32 Illustrates the A2 module. This module is different than the others in that it directly connects to the A1 (balun) module via a male-to-male PL-239 connector. Also, the bottom wire terminals connect to the N-S (long) radials. The top wire terminals connect to the 30 meter ladder line section.

Figure 33 illustrates the A6 module. This is the module that connects the 160 meter top horizontal wire. A Hammond 1590WJ die-cast aluminum box (measuring 5.71" x 3.74" x 1.77") was used (Mouser 546-1590WJ). With the benefit of hindsight, this enclosure likely could have been the same outdoor PVC electrical junction box employed for the other modules.

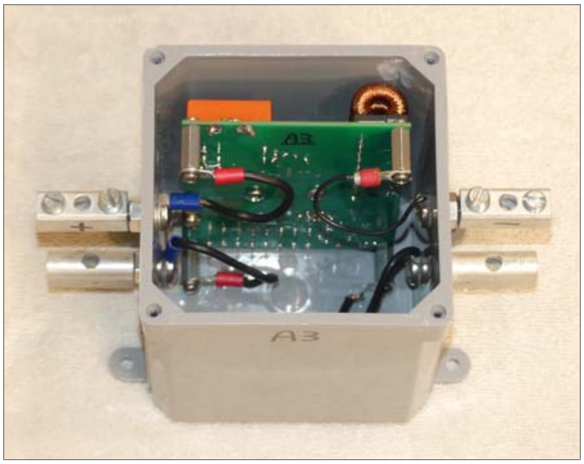


Figure 30 - A3 Relay Module Interior (1)

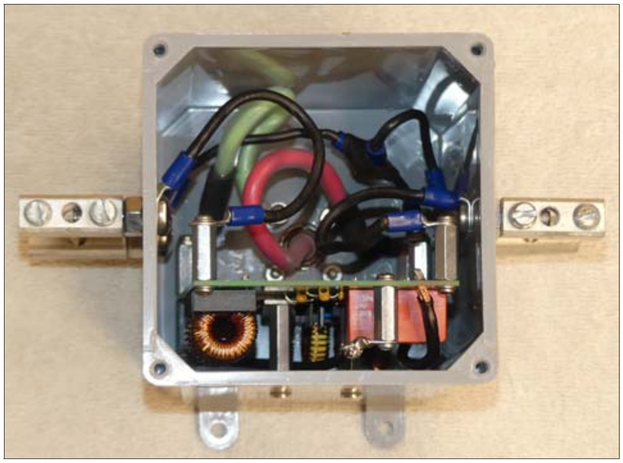


Figure 31 - A3 Relay Module Interior (2)

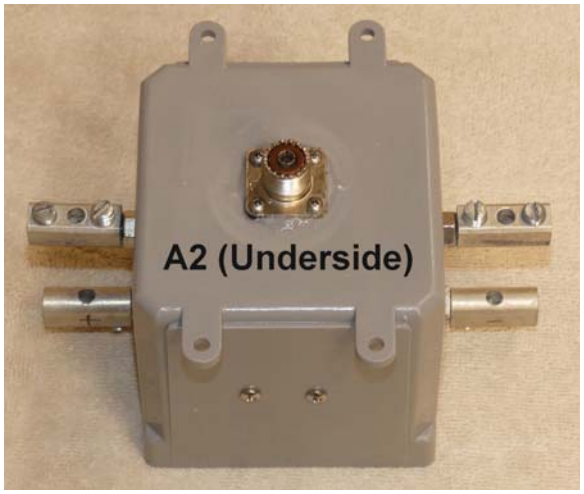


Figure 32 - A2 Relay Module (underside view)

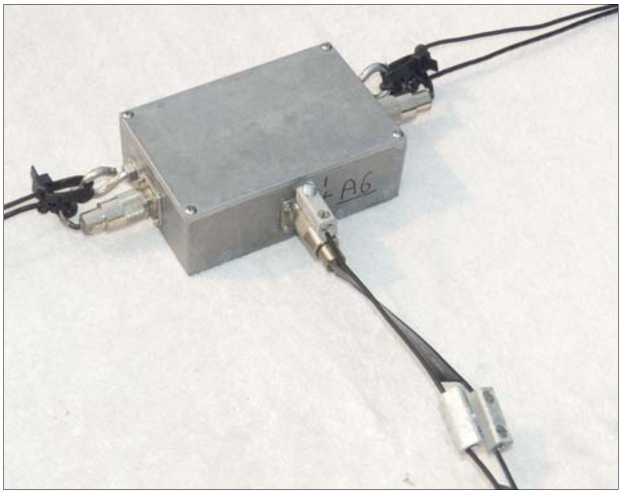


Figure 33 - A6 Relay Module

APPENDIX D - N6DC SUPER-VERTICAL CONSTRUCTION TIPS

Although this paper was not written as a step-by-step construction article, this Appendix includes photos and other information that readers pursuing this project should find helpful. See also the relay module circuit board photos in Appendix B and the relay module enclosure photos in Appendix C.

Addressing first the radials, I had persistent problems with the wires breaking during high winds. To fix this, I added 3 mm diameter Mastrant antenna rope (available from DX Engineering) and relied on this rope (rather than the radial wires) to maintain tension as per Figure 34.

ASR0214-B2 splicer reducers are used to secure the radial wires to the antenna rope. This technique eliminates tension on the radial wires.

The vertical ladder line (DX Ham Radio Supply #LL450 employing #14 AWG conductors), in contrast, is heavy-duty, self-supporting, and so far has never broken. I do not recommend using a ladder line with thinner wire.

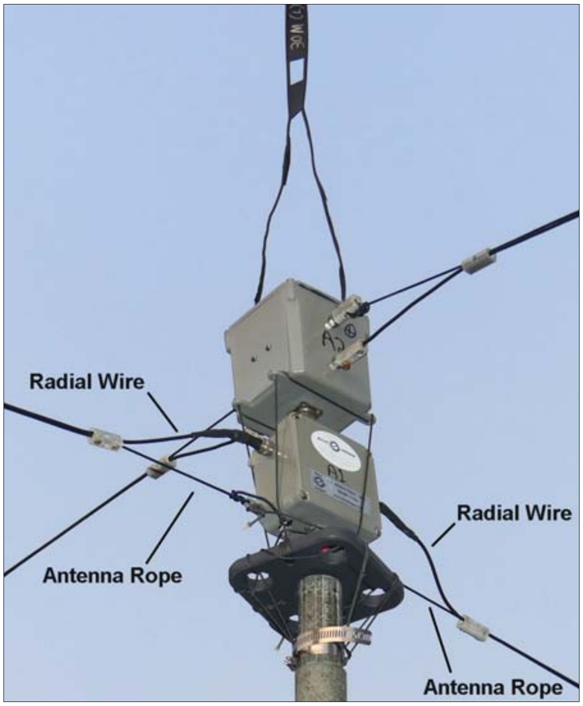


Figure 34 - Using Antenna Rope to Support the Radial Wires

For additional protection against wire breakage, I drilled an additional hole in each ASR0214-B2 splicer reducer so that the ladder line leads could be strain relieved. This technique is illustrated in Figure 35.

These splice reducers also conveniently allow ladder line sections to be added as required as illustrated in Figure 36. This is especially convenient when changing the ladder line lengths to obtain best VSWR.

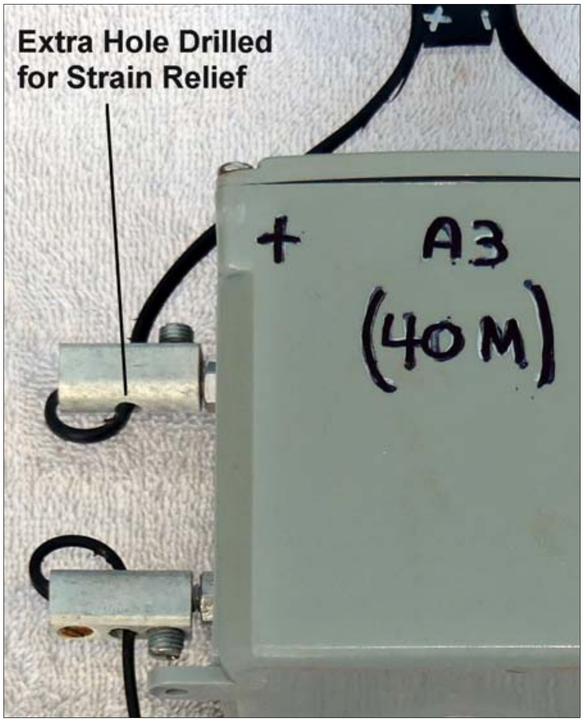


Figure 35 - Strain Relieving the Ladder Line Wires

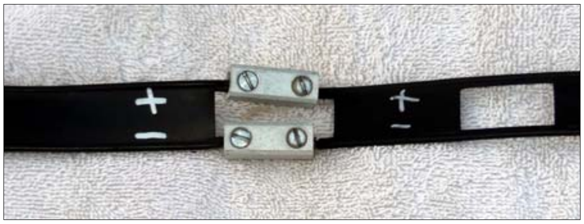


Figure 36 - Using Splice Reducers to Connect Ladder Line Sections

There was also a breakage issue with the coaxial connectors. The feed line PL-259 connector (connected to the module A1) input would eventually fail due to the wind causing modules A1 and A2 to lift up and thus pulling on that connector. The same issue also occurred with the PL-259 male-to-male adaptor connecting modules A1 to A2.

Both issues were solved by using additional Mastrant antenna rope to secure the feed line PL-259 and modules A1/A2 together as illustrated in Figure 34 above. This eliminated stress on the connectors when modules A1 and A2 were lifted by the wind. The hose clamp around the mast helped to secure the antenna rope.

Although not visible in the photos, the feed line PL-259 connector was reinforced using adhesive heat-shrink tubing. Additional strength was provided using a small hose clamp.

Figure 37 - Mast Base

The mast supporting modules A1/A2 is a 10' length of hollow fiberglass pipe as illustrated in Figure 37. As per that photo, the 13' long coaxial feed line enters the mast at the base. The PL-259 connector allows for convenient connection/disconnection to the much longer feed line from the station console. (Both ends of this cable are terminated in PL-259 connectors.)

Figure 38 (mast base detail) illustrates how the feed line cable is secured. Notice that this cable enters the mast through the slotted cut-out. Two hose clamps are then used to secure the cable to the mast so that the cable stays in place when the wind lifts the mast.

Figure 38 - Mast Base Detail

Figure 39 - 24" Mast Stake

To prevent the mast from tilting or “walking” during high winds, a steel stake was pounded several inches into the ground to keep the mast in position as illustrated in Figure 39. The mast was installed onto the stake by lifting it up and dropping it onto the 24" exposed section. Although high winds can cause the mast to lift somewhat, it will not lift high enough to jump off the 24" stake. The mast is secured by the four radials at its top end.

Due to concern for possible parasitic coupling between the 13' mast feed line plus main transmission line and the vertical radiating element, I placed 10 LFB259128-000 ferrites (Mouser P/N 875-LFB259128-000) on the cable to break up any possible resonances. These ferrites were installed at a point along the cable at the bottom of the mast and bunched together. It is likely that this precaution really is not necessary for most installations.

Although not illustrated in the photos, a silicone caulking compound was used to weather seal the modules at all potential water intrusion points. This compound was also applied to the ASR0214-B2 splicer reducers at the wire entry/exit points.

Additional Super-Vertical photos are presented below.

Figure 40 - N6DC Super-Vertical Photo (1)

Figure 41 - N6DC Super-Vertical Photo (2)

Figure 42 - N6DC Super-Vertical Photo (3)

Figure 43 - N6DC Super-Vertical Photo (4)

APPENDIX E - BIAS TEE SCHEMATIC

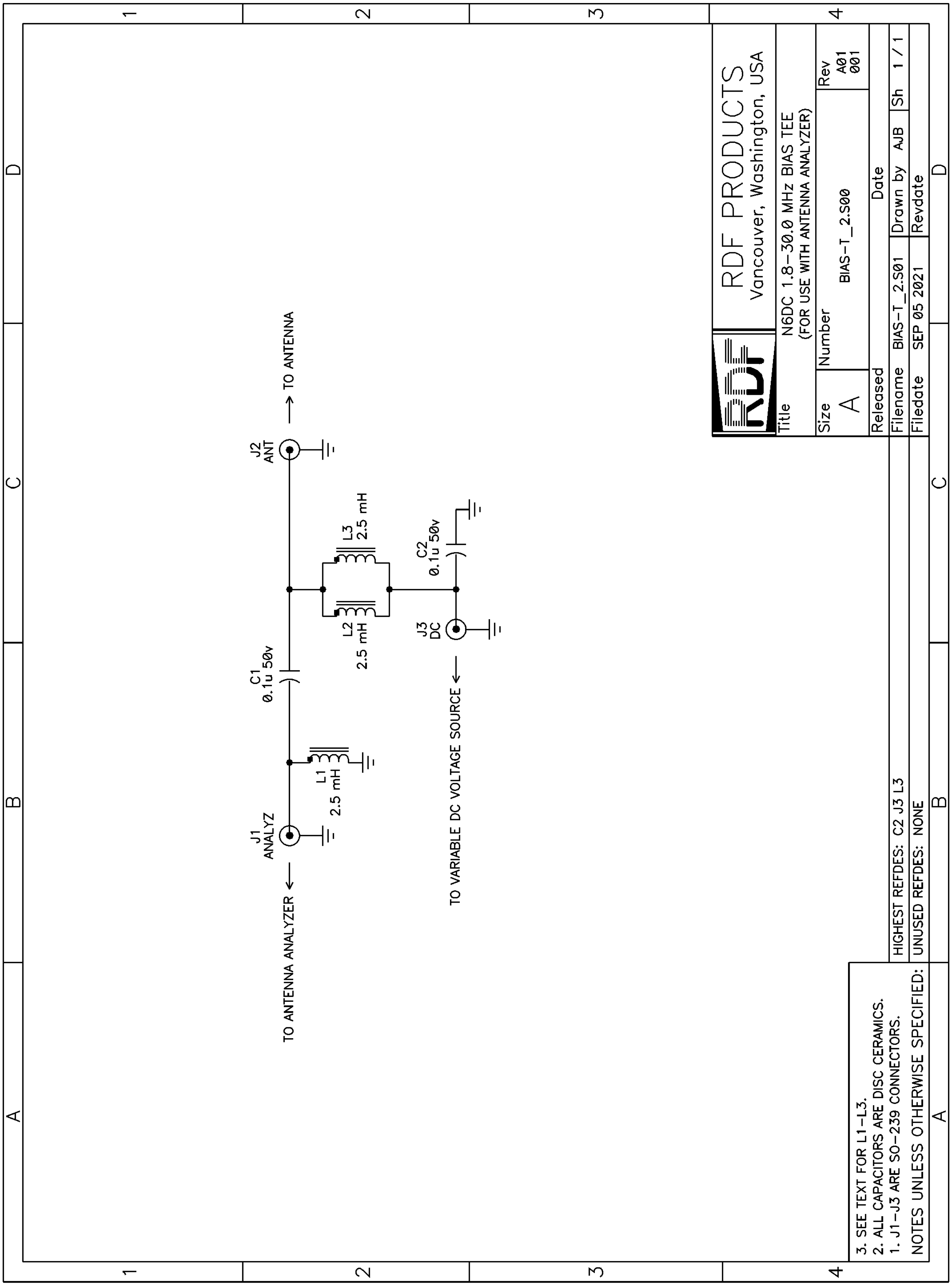


Figure 44 - Bias Tee Schematic (for antenna analyzer)

REFERENCES

1. Jim Weit, KI8BV, “An All Band HF Dipole Antenna”, QST Magazine, Sep 2008
2. Alex J. Burwasser, N6DC, “An Improved Bias Tee for 1.8-30.0 MHz”, N6DC Amateur Radio Application Note AR-002, Apr 2021

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