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An All-Band Antenna

In this third article on surface wave transmission line theory and applications for use by radio amateurs, the authors describe a single antenna for the 160 m through 3 cm bands.

This article describes the construction and operation of an antenna that can be used on all of the amateur bands from 160 m through 3 cm. This extremely broad range is made possible by combining two structures; a traditional HF vertical antenna and an extended discone antenna. The HF vertical is used from 160 m through 6 m. An antenna for VHF and above is placed at the top and uses the HF vertical conductor as a surface wave transmission line (SWTL) feed line. This is done by means of an integrated SWTL launcher at the top antenna and a second launcher located at the bottom of the HF vertical. The VHF portion of the antenna can operate from the 2 m amateur band through the 3 cm band. Figure 1 shows this combination of HF and VHF+ as a single All-Band Antenna.

In many ways this article is a combination of previous presentations given at a number of hamfests, conventions and local club meetings. It uses an extended discone antenna at its top and it uses a SWTL similar to that presented in the May/June 2012 issue of *QEX* as a feed line.[1, 2, 3] One difference is that the SWTL for this antenna is made from a relatively large conductor. Instead of using no. 24 AWG magnet wire, it uses the ⅜ inch to 1¼ inch aluminum tubing of the HF vertical.

The addition of the VHF+ antenna to a conventional vertical antenna made from aluminum tubing causes some shift in electrical length of the vertical at HF, but otherwise it functions in these two regions as fairly independent antennas, and with appropriate filtering and matching, can even operate at the same time. If suitable radios are available, with this antenna it is possible to transmit or receive on the HF amateur bands while also transmitting or receiving on 144 MHz and higher frequencies.

The HF vertical is operated in the commonly accepted manner with the possible exception of the use of a base-located antenna tuner and matching transformer. These provide good match virtually everywhere within HF.[4] There is no compelling reason to run a vertical only on bands where it is an odd number of quarter-wavelengths long and near a low impedance resonance, that is, where it has a feed point impedance near 50 Ω. Good matching technique bypasses this restriction and allows the antenna to function well, even in the absence of an extensive grounding system. This is because where it is not an odd number of quarter-wavelengths, and particularly where it is an even number of quarter wavelengths, the impedance is high and the corresponding feed point currents are relatively low. This reduces the power losses in the ground or radial system that is used to provide the ground reference (image plane). Over all of the amateur HF bands, this antenna has relatively low ground current and matching losses.

The antenna does not need to operate at or near a resonance since efficient matching between a 50 Ω radio and the higher antenna impedance is possible down to below 2 MHz without it. In fact, the vertical need not be any particular length, though longer is usually better for the VHF operation of the All-Band antenna, since it places the radiator higher and generally improves communications.

The mode of operation at VHF and above may be less obvious. While it is essentially a vertical SWTL connected to a modified discone antenna, there are practical details that must be addressed in order to get this arrangement to work well. The first of these is the method of coupling to the SWTL. Both at the bottom and at the top of the vertical, the SWTL is made from a conductor considerably larger than that shown in the previous articles. Since the launcher's function is to transform 50 Ω to near 377 Ω while converting the TEM (transverse electromagnetic) mode in coax to the TM (transverse magnetic) mode on the SWTL conductor, increasing the conductor size forces the wide end of the launcher to be larger. This is because in order to reach this high impedance in a coaxial structure, the outer/inner conductor diameter ratio must be more than 500:1. To prevent this dimension from becoming impractical, at the ends of the vertical where the launchers attach, the tubing tapers to a relatively small diameter, ¼ inch or ⅜ inch. Also, at both ends of the HF vertical, the outer conductor of this Klopfenstein taper transformer is fabricated from 1⁄16 inch brazing rod rather than solid sheeting. This has the effect of further reducing the influence of the outer shielding conductor and produces higher impedance from a smaller outer/inner ratio.

As a practical matter, a launcher with a mouth hundreds of times ¼ inch is still many feet in diameter and not structurally viable. Fortunately, because the impedance of coaxial line in the launcher varies as the logarithm of the outer/inner ratio, it is possible to compromise a little on the high impedance end and greatly reduce this size without too much loss of performance. For the integrated launcher/discone at the top of the SWTL, 330 Ω was targeted instead of 377 Ω. This produced a little additional mismatch error but fortuitously, at the high impedance end of the launcher, most of the

[1]Notes appear on page 00.

energy has already been converted to the TM mode, so impedance mismatches have less influence on the overall performance. By limiting the wide end of the extended discone to 36 inches and using ¼ inch as the center conductor diameter, a practical compromise was reached.

The bottom end of the SWTL has an identical problem. Here, even more deviation from ideal was made in the interest of practicality. The launcher shown is actually one that was designed as an all-weather version of the SWTL launcher shown in the first *QEX* article. It was originally designed for use with no. 24 AWG copper wire. For expedience, we simply used this launcher and inserted it into the ⅜ inch aluminum tubing until the tubing inner diameter matched the taper of the center. This is a fairly serious compromise but it avoids a larger structure at the bottom of the antenna, which was not visually acceptable on the backyard lawn at the N6GN station QTH. Using the launcher this way effectively truncated its transformation function and ability to generate 377 Ω impedance at the wide end.

Because of these compromises, the resultant SWTL impedance match is worse than the 1.22:1 SWR (20 dB return loss) target for a properly built and applied Klopfenstein taper launcher shown in the first article. That greater SWR along with the approximately 2:1 SWR of the extended discone results in higher overall SWR for the finished antenna at 2 m and above, but the actual impact of this higher SWR is not as severe as might generally be thought. Even an SWR of 4:1, which equates to a return loss of about 4.4 dB, only results in about 2 dB of mismatch loss. In practice, the degradation due to such a mismatch is barely perceptible and this antenna has SWR much better than this over almost the entire VHF/UHF range.

A somewhat better VHF+ match would be obtained by substituting a 36 inch diameter launcher at the bottom that is similar to the cone portion of the extended discone at the top, but even without this improvement, the version we built shows a final VHF+ SWR as plotted in Figure 4. The antenna works well and is really quite acceptable on all of

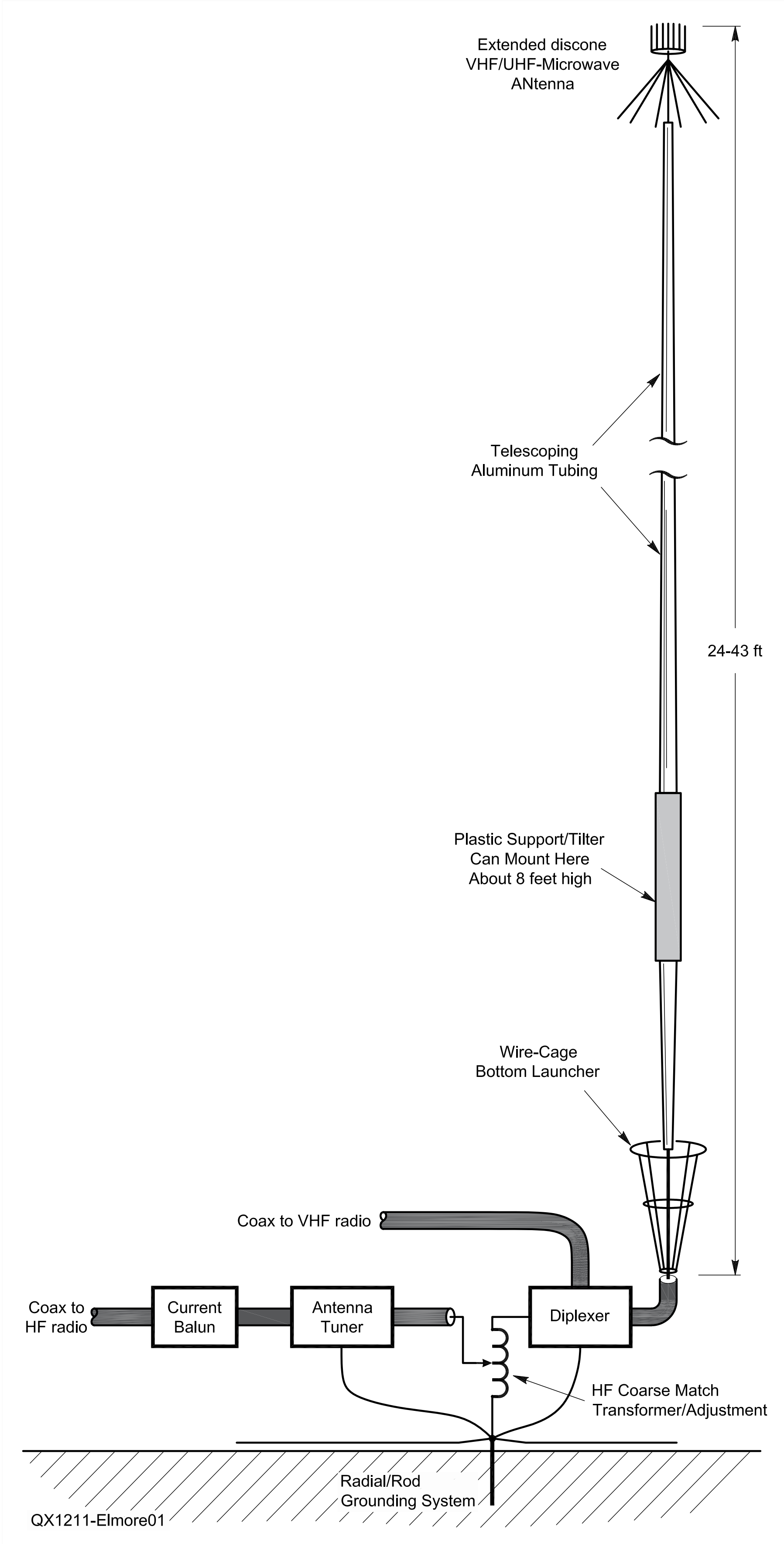


Figure 1 — A combination of an HF vertical and a VHF+ extended discone are used to make an effective antenna that can be used on all amateur frequencies from 1.8 MHz through 10 GHz. The VHF+ antenna is fed by a surface wave feed line, which uses the HF vertical aluminum tubing and special launchers at the top and bottom. The top launcher is integrated into the extended discone itself.

the amateur bands below 2.4 GHz.

Operation on even higher frequency microwave bands is possible, but good performance requires considerable precision. The launchers and SWTL can easily operate past 10 GHz if care is taken to avoid sudden discontinuities. This can best be done by replacing the wire cage with solid sheeting for a few inches near the coaxial ends of each launcher. Similarly, the discone at the top needs to have the region near the apex of the cone carefully constructed. As a practical matter, however, an omni-directional antenna above 2.4 GHz may not be too useful for DX communications. Because the physical aperture of fixed-gain antennas falls as the square of wavelength, communications links using low gain antennas like dipoles or this discone exhibit high path loss at higher frequencies such as the amateur microwave or millimeter wave bands.[5]

In the final analysis, this antenna is "just a vertical" and behaves like one — neither dramatically better nor worse than a vertically polarized dipole at the same location and having the same far field environment. But a vertical can be a very useful antenna, particularly if the regions of radiation are well situated. This antenna offers a relatively low visual profile, can provide excellent results and is truly an All-Band Antenna.

Vertical Construction

The HF vertical portion of the All-Band Antenna is constructed from 6 foot sections of telescoping aluminum tubing of multiple diameters. Each section nests snugly and overlaps with adjacent sections providing a way to taper from the ⅜ inch diameter at the bottom where the bottom launcher attaches, up to 1¼ inch diameter at the plastic support and back down to ⅜ inch diameter at the top, where the ¼ inch threaded rod of the integrated launcher/discone attaches. This tapering provides adequate mechanical strength along with good SWTL performance.

In order to both support and to access the extended discone for changes while we were developing it, we constructed a "tilter" from plastic pipe and fittings in order to hold the vertical at its wide, stronger midsection

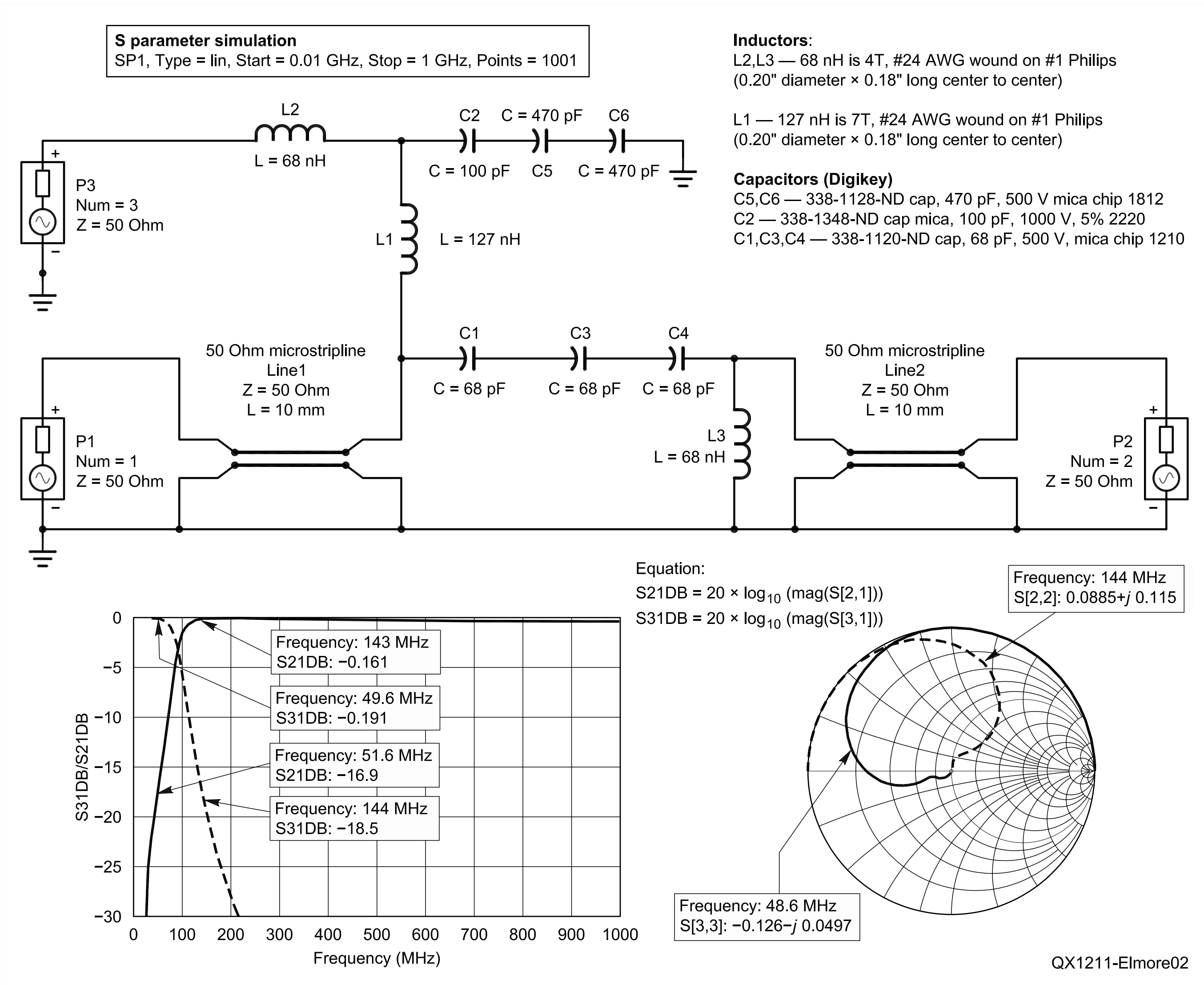


Figure 2 — Schematic and response of a HF/VHF+ diplexer that may be used with the All-Band Antenna.

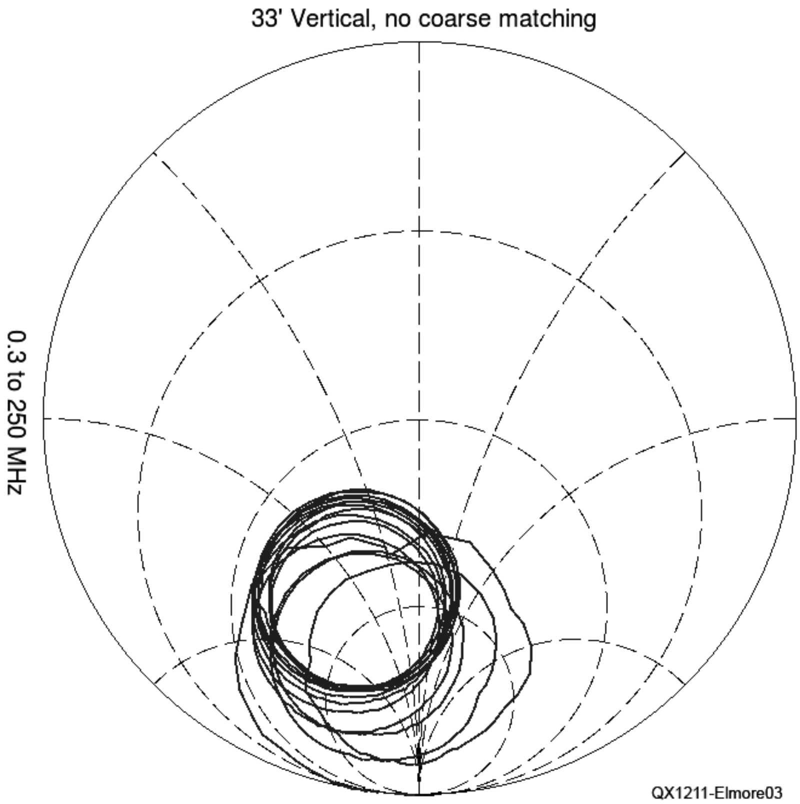


Figure 3 — Measured S11 (50 Ω reference) from 0.3 to 250 MHz of 33 foot vertical (without SWTL) with 24 inch metal disk improving a sod and ground rod image plane. Improvement by this disk is evidenced by the cleaner, lower impedance circles at higher frequencies. Note that in operation the antenna actually uses a transformer to shift the circle centers to nearer 50 Ω.

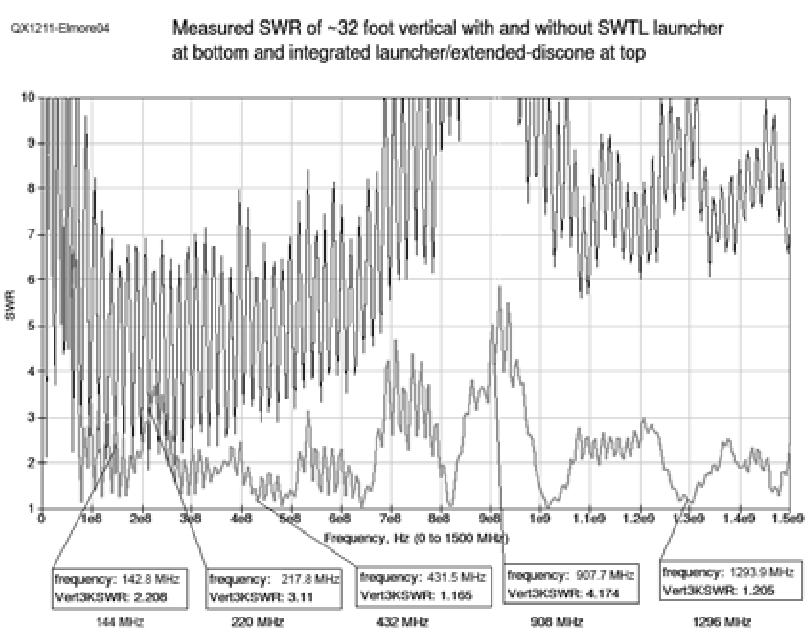


Figure 4 — Measured UHF SWR of All-Band vertical at the bottom launcher N connector without and with the SWTL launchers and extended discone.

and allow lowering the entire assembly to horizontal. This plastic pipe does have some negative impact on SWTL performance but it isn't too severe. A different method of support that doesn't involve any metal or plastic near the aluminum tubing would probably be better but hasn't yet been built. It is likely that a permanent antenna constructed without the tilter but with dielectric guys, perhaps of Dacron, could be simpler and might perform even better than the design we show here.

The tilter supports the antenna at the 7½ foot point so it is necessary to taper rapidly from the ⅜ inch tubing at the bottom to the 1¼ inch diameter tubing at the support point. We used a taper of approximately equal length sections. On the upper part of the vertical, where it is necessary to taper back down from wide to narrow, we used the full 6 foot lengths of the largest three diameters and then tapered linearly down to the ⅜ inch in order to gain as much rigidity as possible. The tilter can be constructed from PVC pipe fittings as shown in Photo 1. Other than keeping the majority of the plastic as far away as possible from the aluminum tubing, there are no special requirements.

Photo 1 — N6GN holding a bottom launcher and pointing toward a second launcher installed at the base of the All-Band HF /VHF/ UHF antenna. The PVC tilter can be seen in this Photo. Styrofoam doughnuts have been added to keep the center conductor concentric with the outer cone.

Table 1

Wire-Cage 144+ MHz SWTL launcher for use with No. 24 AWGwire

Dimensions for bottom launcher inner and outer conductors and spacers. Though designed for #24 magnet wire, it is being used to drive a ¼" to 1¼" tapered aluminum conductor.

This is a wire substitute for the original K&S tubing and Paper Cone SWTL Launcher that was detailed in the first *QEX* article. It is also used as the bottom launcher for the All-Band Antenna.

The tapered center conductor "cage" is made from 6 (hexagonal) 1⁄16" brazing rods. The outer conductor is a conical "cage."

A female bulkhead N connector is mounted on a ½ inch copper water pipe flange and receives the 1/16 inch rods of the outer conductor and also a single connection from the tapered centered conductor to the N center pin.

At about 27 inches, the inner conductor/hex-cage rods end in a 3⁄16 inch OD tube that traps them inside.

For use as an all-weather SWTL launch, the taper continues down to no. 24 AWG wire at the mouth of the launcher.

When used as the bottom launcher on the All-Band antenna, ⅜" aluminum tubing from the vertical slides over the center conductor from about 23 inches forward — truncating the tapered region.

Position, Inch	*Center-center desired Z_0 (Ω)*	*Center-center Outer Wire Spacing Flange*	*Inner Wire Spacing Pin*	*Inner Wire Spacers N Connector Here*
0	61	0.87	0.34	six 1⁄16 inch rods around ¼ inch tube w/ hole for N conn pin
1	62.5	1.05	0.44	
2	64.2	1.23	0.53	
3	66.1	1.41	0.63	0.625 @ 2.95
4	68.3	1.59	0.72	
5	70.8	1.77	0.81	
6	73.5	1.95	0.86	0.875 @ 6.25
7	76.5	2.13	0.92	
8	79.8	2.31	0.96	
9	83.6	2.5	1	1 @ 9
10	87.7	2.68	1	
11	92.2	2.86	1	
12	97	3.04	1	1@ 12
13	102.4	3.22	0.97	
14	108.3	3.4	0.93	
15	114.7	3.58	0.88	0.875 @ 14.9
16	121.6	3.77	0.83	
17	129	3.85	0.74	
18	137	4.13	0.64	
19	145	4.31	0.62	0.625 @ 18.75
20	155	4.49	0.53	
21	165	4.67	0.46	
22	175	4.85	0.4	0.375@ 22.36
23	186	5.04	0.33	11⁄32 inch joiner. For All-Bander, the vertical attaches about here.and smaller indductor conductor diameters aren't used.
24	197	5.21	0.28	
25	208	5.4	0.23	
26	220	5.58	0.18	
27	233	5.76	0.14	3⁄16 inch clump around 1⁄16 inch tube (All-Band antenna)
28	245	5.94	0.11	
29	258	6.12	0.08	
30	271	6.3	0.05	
31	284	6.48	0.03	
32	296	6.61	0.02	No. 24 AWG wire from here to mouth (All-weather SWTL launcher)
33	309	6.85		
34	321	7.03		
35	333	7.21		
36	344	7.39		
37	355	7.57		
38	365	7.75		
39	374	7.93		
39.34	377	8		

Since neither the HF nor VHF modes of operation rely on resonance, there is really no reason that the antenna can't be a length different from the 33 feet we used. If it is possible to go longer and thus higher, both HF and VHF/UHF performance will likely improve.

At this relatively short length, 160 m matching is a bit more challenging and probably not quite as efficient as a longer antenna would be. If you have the possibility of making the antenna longer, using additional sections of larger diameter tubing is perfectly acceptable and probably worthwhile. This will likely require the addition of insulating guy lines placed at one or more points, however, to withstand normal winds.

As we were developing it, we first used plastic hose clamps to capture the vertical within the plastic tilter and to adjust the lengths of the sections, but once we were happy with the mechanical strength and electrical performance we replaced all the clamps, except those at the tilter, with sheet metal screws close to each section end to tie the whole structure together both electrically and mechanically. We avoided using metal hose clamps since they produce discontinuities to the surface wave that can negatively impact the UHF/microwave performance.

Bottom Launcher Construction

The bottom launcher is made mostly from 1⁄16 inch brazing rod, for both the inner and outer conductors of the Klopfenstein tapered coaxial transformer. The result is a sort of wire cage that provides function without being quite as unsightly as sheet metal and solid tubing would be. This launcher should also be able to serve as an all-weather substitute for the metalized paper SWTL launcher shown in the first *QEX* article. It's heavier and more difficult to construct, but is a much better fit for continuous outdoor duty.

Target dimensions and impedances versus length for the coaxial line formed are shown in Table 1. The last column in this table also gives locations and center to center dimension for the metal spacers used to maintain the inner conductor shape. These spacers are made by drilling six holes, laid out in a hexagon with diameters and longitudinal locations shown in the Table 1, in 1½ inch square pieces of 0.01 inch thick brass shim stock. The rods are threaded through these holes and everything set squarely into position on a flat surface. Once everything is correct the spacers can be first tack-soldered and then completely soldered into place. At this point, the square spacers have done their job and can be trimmed and sanded or filed down to smaller circles as shown in Photos 1 and 2A.

Extended Discone/Launcher Construction

The combined SWTL launcher and extended discone antenna is made mainly from 1⁄16 inch brazing rod in generally the same way as the bottom launcher. Table 2 provides the dimensions.

The top disc is 5 inches in diameter and made from copper sheeting, pre-drilled at the center to clear the ¼ inch threaded center support. Four 24 inch pieces of brazing rod are bent into U shapes and soldered to the top of this disc to form a 9 inch high, 6 inch diameter cylinder. Prior to soldering, these can be held in place by drilling two pairs of holes for each of the 8 resulting upright rods, one pair near the outer edge of the disk and the other an inch or two from the center hole. A short piece of bare wire can be stitched around the rod at each location and twisted to hold things tight while soldering. Once soldered, the center of each U is snipped away, to leave room for a ¼ inch brass nut and washer, which attach to the central supporting rod. A 1 inch PVC plastic reducer is attached to the disc with short sheet metal screws. Photo 4 shows the bottom part of the finished cylinder joined with the cone. A setscrew holds the PVC pipe and reducer together and provides a way to easily disassemble the cone and cylinder parts when necessary.

The cone portion, which does double duty as the outer conductor of the top Klopfenstein tapered SWTL launcher, is built on a very short section of 1 inch PVC plastic water pipe. The ends of eight 36 inch long brazing rods were bent and inserted into one of eight equally spaced holes in the pipe. Circular copper wire rings were then soldered at the

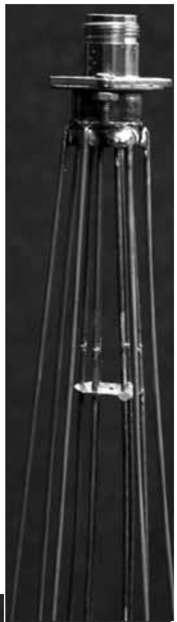
Table 2

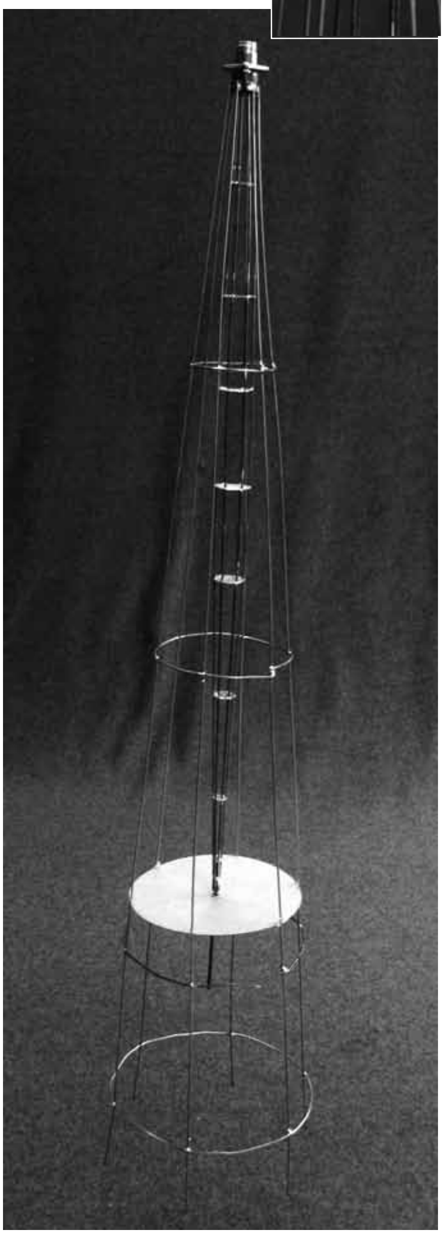
Dimensions for top launcher inner & outer conductors along with target impedance for the Klopfenstein taper. The outer conductor of this launcher doubles as the bottom cone of the integrated extended discone antenna. Although this outer conductor/cone makes no electrical connection to any other part of the SWTL or antenna, its presence is vital to the proper operation of both.

Integrated launcher used in VHF+ extended discone antenna. As for the bottom launcher, this launcher is constructed from 1⁄16 inch brazing rod. The inner conductor is a hexagon of 6 rods, separated by plastic spacers. The outer conductor, which doubles as the cone portion of the antenna, is made from eight brass rods, each 36 inches long. The plastic spacers hold the inner conductor rods in position while copper wire circles help maintain the outer conductor/cone dimensions.

Position from narrow end of cone	*Desired Impedance*	*Outer Diameter of 8 rods in Discone*	*Inner Conductor of 6 rods,| center to center*
0	60	2	1
2	66	4.5	2.7
4	70	6.5	4.2
6	77	8.5	5.2
8	86	11	6.2
10	97	13	6.2
12	111	15.5	6
14	127	17.5	5
16	147	19.5	4
18	168	2105	3
20	193	23.5	2
22	218	26	1.4
24	247	28.5	0.9
26	273	30.5	0.58
28	298	33	0.38
30	320	35	0.26
32	330	36	0.25

Photo 2 — Part A shows the detail of the coaxial end of the bottom launcher, with an N connector mounted on a copper flange. Part B shows the complete bottom launcher with both the inner and outer assemblies constructed from 1⁄16 inch brazing rod. A sheet plastic disc is used to maintain alignment, spacing and shape between the inner and outer conductors. The outer conductor is held in shape by copper wires formed into circles and soldered around the outer rods.





pipe, as seen in Photo 4, and also at a point about ⅔ of the way to the bottom of the cone. The resulting cone apex angle is about 60°.

The inner conductor of the launcher is specially tapered to provide impedance matching between the high impedance of the SWTL line and the lower impedance of the extended discone. As already described, to keep the structure size down, the target transformation was from 50 to 330 Ω rather than to 377 Ω. This was made with eight 1⁄16 inch brazing rods equally spaced around a central ¼ inch threaded rod, which runs almost to the top. Near the top we extended the steel rod with a section of ¼ inch threaded brass. Because the steel is everywhere inside brass or aluminum, no significant RF current flows on it. The conductor taper and shape is set by four plastic and one metal spacer, as seen in Photo 3. Metal or plastic are equally acceptable as spacers but plastic spacers were used at the wider portions for reason of mechanical strength and reduced weight. At the narrow end of the center conductor the eight rod ends are captured inside a length of ⅜ inch brass tubing around the threaded rod and the center conductor from that point on is made either from tubing or ¼ inch rod. When assembled, the threaded rod will slip inside the top vertical aluminum tubing, which is ⅜ inch OD and a little more than ¼ inch ID. The top inch or so of the aluminum rod can be slotted and clamped around the threaded rod with a plastic hose clamp to guarantee good electrical contact or, as an alternative; a short set screw can be used. If you use a set screw, pick the length so that no unnecessary extra length protrudes from the tubing because this can produce unwanted reflections of the surface wave.

The completed SWTL/extended discone mounted on top of the aluminum vertical can be seen in Photo 5. In this picture, the plastic spacers of the center conductor look dark instead of clear only because the protective paper had not yet been removed.

HF/VHF Diplexer Construction

It isn't necessary to build an HF/VHF diplexer in order to use the All-Band Antenna, but when used use with a radio that has separate HF and VHF connections or with separate HF and VHF radios, it can allow all-band operation without requiring any switching. It provides a means of connecting to the 50 Ω VHF-microwave connection from the bottom launcher at the same time a suitable matching section is being used for HF operation. By separating these connections, the antenna is always ready for either or both HF and VHF+ operation. We use the All-Band Antenna with ICOM IC-706 MKIIG transceivers, which cover 160 m through 6 m using one coax connection and 2 m and 70 cm on a second. Of course, a pair of these diplexers could also be used to double-up on a single piece of coax with this or with other types of antennas. For example, a very wide range spectrum analyzer, receiver or transceiver that covers HF through microwave could be fed from a single

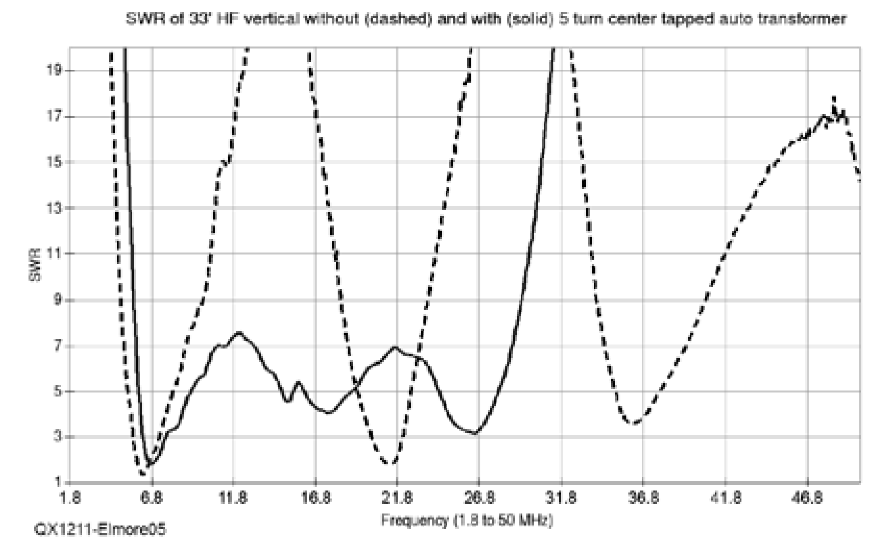


Figure 5 — Measured HF SWR of the 33 foot vertical (with bottom SWTL launcher but without top launcher/discone) without (dashed line) and with (solid line) the auto-transformer coarse matching inductor. The reference impedance is 50 Ω. The inductor improves the SWR presented to the antenna tuner over most of the HF range, to the extent that most automatic antenna tuners can achieve good match on the HF amateur bands. Operation on the 160 m and 6 m band may require different coarse matching inductance or to be operated without any at all in order to achieve 1:1 SWR with some antenna tuners.

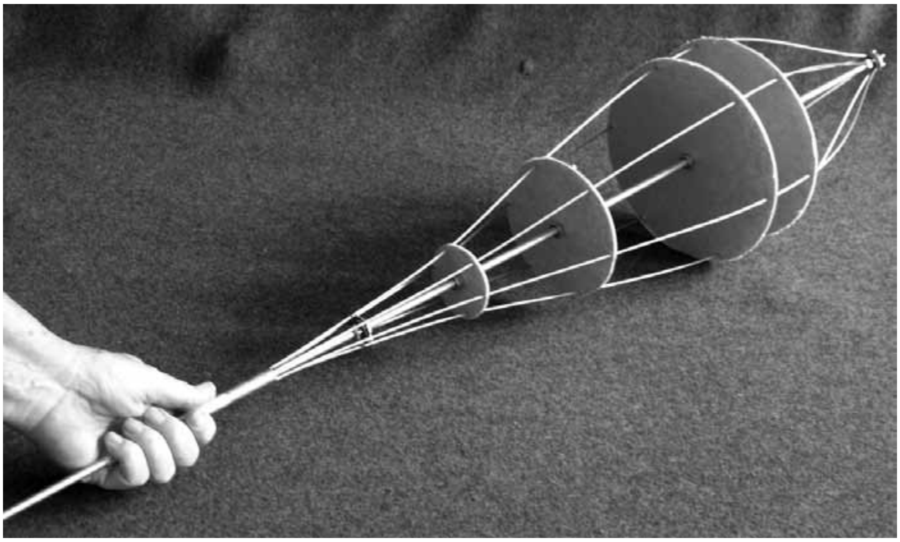


Photo 3 — In conjunction with a conical outer conductor the tapered center conductor of the integrated top launcher uses a combination of metal and plastic spacers to conform it's shape to produce the correct TEM impedance to produce a broadband Klopfenstein coaxial transformer. The conductor is assembled around a central ¼ inch threaded steel rod, which Is extended by a short section of ¼ inch brass rod near the wide end. This brass rod extends through a hole in a PVC plastic cap that the top disc/cylinder is built around (not shown).

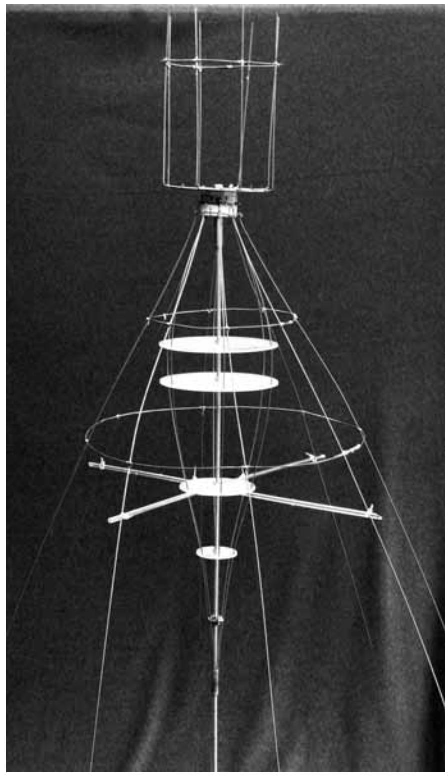


Photo 4 — The top wire cage cylinder is built on a PVC plastic reducer that mates with a short section of plastic pipe on which the cone is constructed. The cone is insulated from both the center conductor and the top cylinder. The central threaded rod from the center conductor of the launcher attaches to a copper disk that, along with the brazing rod, makes up the top cylinder. A single set screw is enough to secure the cone to the reducer on the cylinder and two screws attach the disc to the reducer.

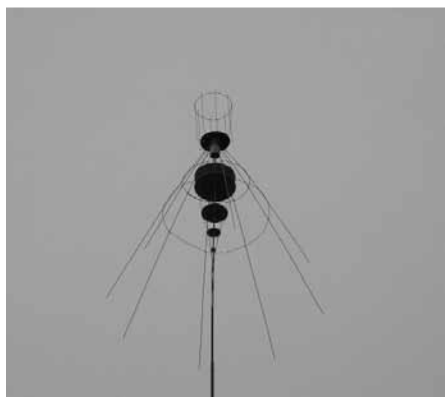


Photo 5 — The extended discone antenna with integrated SWTL launcher mounted atop the HF vertical.

coaxial connection this way.

The goal of this diplexer design was just to protect a second radio from RF energy being transmitted by the first. It was not intended as a low-pass filter for HF or a high-pass filter for VHF/UHF. If this additional functionality is desired, more filtering can still be placed between the radio and the diplexer. By using this diplexer and an automatic antenna tuner for HF with the ICOM transceivers, complete all-band and even automated operation over the entire range of the radio is possible. We can run frequency-hopping WSPR on 160 m through 432 MHz completely automatically this way.

It may also be desirable to insert a high-pass filter in the HF side of the radio. At N6GN, a vertical such as this can deliver a significant portion of one watt from a local AM broadcast station and this causes problems with160 m operation. An additional high-pass filter to protect the receiver from this sort of problem can be inserted between the radio and the diplexer's HF input.

Construction of the diplexer isn't particularly difficult but in order to get good UHF performance, good connectors and a micro-strip transmission line is important. We used surplus Mini-Circuits bias tees as a starting point because they provided a nice package with good sturdy connectors and exactly the internal circuit board micro-strip transmission line we wanted. The bias tee components were removed and replaced with the inductors and capacitors shown in Figure 2. If you don't use the Mini-Circuits package as seen in Photo 6, you should be able to build your own package from scratch by mounting appropriate connectors on package walls made from double side PC board and cutting a piece of the same double-clad material to shape so that the connector grounds can be soldered to the bottom side and the center pins laid and soldered directly on the board trace. For common 1⁄16 inch epoxy board, 50 Ω micro-strip will be a trace about 0.110 inch wide. Really, only the UHF diplexer path needs to be made in this manner and normal lumped techniques and point-to-point wiring can be used on the HF side.

Because the impedance at the base of the All-Band Antenna can be high, so can the RF voltage, even when not driven by a kilowatt transmitter. To withstand this, we used multiple surface mount mica capacitors connected in series. Otherwise, there's nothing special about the components. As shown, the diplexer should be able to easily handle 200 W, even after an antenna tuner and the 1:4 transformer have transformed a 50 Ω transmitter to the impedance required to match the load presented by the antenna. If you contemplate higher power operation, you should calculate or measure to be sure that you won't exceed the ratings of any of the matching components in the antenna tuner, 1:4 transformer or diplexer. You should also verify that the diplexer limits the unwanted power at the other output to an acceptable level.

Wind the inductors exactly as indicated in Figure 2 and you'll obtain the indicated inductance. Mount them with minimum lead length to the surface of the 50 Ω micro-strip.

Lay the capacitors across gaps cut in the 50 Ω micro-strip line.

Measured results of the finished diplexer made this way are so close to the modeled results shown in Figure 2 that we haven't bothered to show them separately.

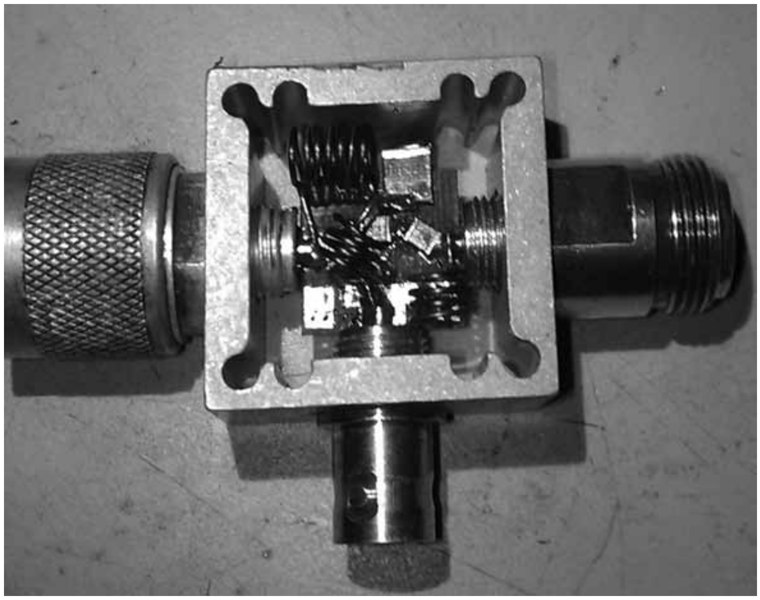


Photo 6 — The HF/VHF+ diplexer seen here was constructed from a surplus Mini-circuits ZFBT-2G-1 bias tee package which already had connectors and a circuit board with 50 Ω micro-strip transmission line.

Impedance Matching

The setup shown in Photo 7 was used to measure the antenna. Various SWR measurements with a 50 Ω reference impedance are plotted in Figures 3, 4 and 5.

Figure 3 shows the feed-point impedance of the HF vertical in the absence of any launchers. This is just a simple monopole-over-ground operated with an 8 foot ground rod, but the image plane (ground) has been further improved for higher frequencies by adding a 2 foot diameter disk at the base, as shown in Photo 7. The transmission line nature of a monopole is particularly obvious where the ground is good. At lower frequencies the impedance is increased due to imperfect conductivity. A larger disk or radial system could improve this. In use, the coarse tuning coil or transformer shifts the center of these circles to more nearly coincide with the 50 Ω impedance of coaxial cable. This measurement was shown in the previous article.[4]

The All-Band Antenna, including the effect of the SWTL at frequencies above the launcher low frequency cut-off is easy to see in Figure 4 and a relatively good match is available for all of VHF and above. The compromises made to achieve acceptable launcher dimensions have hurt the match slightly but the impact on communications is minimal.

Above the launcher cutoff frequency the antenna ceases to act like a monopole. In the transition region between 60 and 100 MHz, however, the All-Band structure is operating partially as a normal vertical and partially as an extended discone fed with an SWTL. In operation, this transition can be observed by the relative strength of FM broadcast stations at 88 MHz as compared to those near 108 MHz, with the higher end stations somewhat stronger as the discone takes over. Had our 1:4 transformer worked better near 100 MHz this difference might have been reduced.

On HF, we used a coarse matching inductor as a 1:4 auto-transformer between the low pass output of the diplexer and the automatic antenna tuner, to transform the HF antenna impedance nearer to 50 Ω. With no transformation, the impedance rotates about a central point on the order of 120 to 200 Ω. By providing the 4:1 impedance step down, SWR and variation of SWR can both be reduced over the entire HF range of the antenna.

The transformer we used is simply a center-tapped air coil with a 1:2 turns ratio and provides a 1:4 impedance transformation along with some leakage inductance. At low HF, this transformation and inductance is helpful to move the nominal center of impedance of the vertical nearer to 50 Ω and thereby reduces the SWR that the antenna tuner needs to accommodate. The best inductor value is somewhat a trade-off between being large enough to improve the 160 m and 80 m impedance match, while not having so much leakage inductance that it worsens the match at 6 m. Our coil was made by winding five turns of no. 14 AWG bare copper wire on a 4 inch diameter Styrofoam form. It was 1¼ inches long and center tapped. This gives a total inductance of a little less than 4 µH, and with the center tap it acts as a 2:1 transformer with a K factor of about 0.8.

Near the low impedance quarter wave resonances, ground resistance may influence the SWR, but with the 33 foot length "top loaded" by the extended discone, none of the amateur bands should show much of this effect. As already described, one advantage of the All-Band antenna is that it need not be operated near an odd quarter wave resonance, and so it can be set to present a higher impedance in the higher HF bands so that even with poor grounds a simple ground rod is adequate to achieve efficient match.

Figure 5 shows the SWR of the vertical before and after addition of the air core auto-transformer. For 160 m operation, a larger inductance might be needed with some tuners and for 6 m operation the auto-transformer could probably be removed entirely, depending upon the capability of the antenna tuner used. But using only the air core auto-transformer and an LDG IT-100 automatic antenna tuner, we were able to achieve a match at least as good as 1.5:1 on all amateur bands from 160 m to 6 m.

Generally the tuner should be placed as close to the auto-transformer and diplexer as possible. Cable length between the tuner and the N connector adds capacitance, which is not what is needed to improve the 160 m match, which is high impedance and already quite capacitive. Coaxial cable between the tuner and the transformer is somewhat less of a problem than between the diplexer and N connector, but length should still be minimized, even though this will no doubt require a weatherproof enclosure for the tuner. At N6GN, after Photo 8 was taken, the tuner was mounted along with the 1:4 transformer in a plastic NEMA enclosure right at the base of the antenna.

Performance and Use

This antenna performs well on both HF and VHF. Although we've only used it for a short time, it is a pleasure to operate WSPR and span bands from low HF all the way through 432 MHz — the full range of our ICOM IC-706 MKIIG transceivers.

Signal reports on HF appear to be typical for a ground mounted vertical. For low angle communications, which can provide particularly long DX at the MUF just as a band is opening or closing, this antenna consistently beats a horizontal dipole by a wide margin. For stateside QSOs from California it doesn't have the high angle component of a low horizontal antenna but we have no trouble working US stations with it. It is not uncommon to have WSPR spots from all seven continents in a 24 hour period with it.

As with any HF antenna where the ground characteristics in the far-field affect the take-off angle, its pattern may vary seasonally due to changes in the ground surrounding the QTH. The lower take-off angle can also make it much more susceptible to local suburban neighborhood QRN, which generally seems to come from near the horizon. Because of this low angle response, in a suburban QTH, this antenna can be noisier on receive than other antenna types at the same time that it works better on transmit.

Performance of the All-Band Antenna on VHF and above has been excellent. It appears to act very nearly the same as a ground plane, dipole or discone located at the same height above ground. On 432 MHz, signals are about 10 dB stronger on both transmit and receive when compared to an omnidirectional vertical antenna mounted at roof height. The attenuation of the bottom launcher, vertical/SWTL and integrated top launcher appears to be no more than a few dB and competitive with a similar length of common coaxial cable.

Photo 7 — The All-Band Antenna measurement setup is shown In these photographs. On the left it is being operated only as a simple vertical with good grounding. For the photograph on the right the SWTL launchers and VHF+ antenna are present. In addition to the hexagonal aluminum foil disk, which provides a good VHF ground, an 8 foot ground rod near the wooden post is also connected to the disk. This arrangement was left in place for all measurements even though the disk is not necessary when the launcher is in place.

Modifications and Improvements

It seems that any good project always inspires ideas for changes to make it better, more useful and more fun. We think this project is no exception. While we are pleased with the results we've experienced building and using the All-Band Antenna as shown, other Amateur Radio operators will certainly have different needs and desires and, we hope, will want to experiment. The following are a few possible changes we've thought of so far:

1) Weatherize.

Although the Photos show the antenna free-standing, for all-weather use in most climates this antenna will probably need to be guyed. As a guy line, don't use anything that is conductive within a few feet of the attachment point on the vertical, because doing so could interfere with the SWTL operation of the antenna — if not with the HF performance as well. If you have to use a conductive guy beyond this region, break its length up in a non-periodic fashion as you would for any HF vertical by using suitable insulators. Except for fair weather, we'd recommend that you use Dacron or similar non-conductive twine. We also found it necessary to drill holes in the copper flange at the N connector on the bottom launcher to keep rain water from accumulating at the feed point.

2) Use Noise Cancellation.

Particularly in suburban locations, the noise level on receive is sometimes higher with a vertical than with a horizontal antenna, but signals seem bigger too. Because of the lower take-off angle, WSPR often reports little improvement in S/N ratio on distant stations in the presence of the increased noise — indicating that the vertical is actually capturing more signal power. A future project is to add noise cancellation to further improve the reception of weak signals. With the improved performance of the vertical and if the noise floor can be reduced, the All-Band Antenna may be one of the best multi-band solutions possible — short of multiple large and highly directive arrays.

3) Improved 1:4 Transformer.

A toroidal ferrite 2:1 voltage transformer might be an alternative to the air core inductor we used. A W2AU 2:1 current balun works fine at 160 m and 80 m but not as well at the high end of HF and 6 m. With some antenna tuners it may still be possible to match using it. A better solution might be a toroidal transformer with fewer turns wound on a lower permeability core. This could reduce leakage inductance yet still be adequate for 160 m operation while not operating above self-resonance at 6 m. Band-

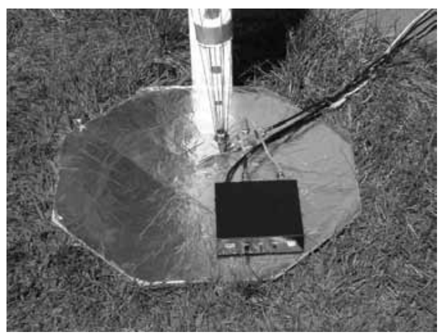


Photo 8 — Bottom of the completed All-Band Antenna with diplexer and antenna tuner. Two coaxial cables and one control cable go to the ham shack. The metal foil hexagon is not necessary for normal operation but was left from the measurements shown in Photo 7 and Figures 3 and 4. For normal operation the foil disk is replaced with a simple coax-braid jumper since the launcher provides ground reference for VHF and only a relatively high-impedance connection is required for HF as long as the antenna is not operated near an odd quarter wave resonance.

switched matching transformers are another possibility.

4) Make it Taller.

Because operation at resonance is not necessary, there is no particular length required for the HF section. K6PZB has been experimenting with a 43 foot design. Making the HF section longer reduces the burden on the matching network at the low frequency end. Generally speaking, the impedance gets higher and capacitive at frequencies below one quarter-wavelength. Extra length has negligible effect on VHF+ operation except for the great benefit from the "height gain."

5) Make it Shorter.

If low frequency operation can be sacrificed, the matching over most of the amateur HF bands, certainly 30 m and higher frequency is easy even with a vertical considerably shorter than 33 feet. On both HF and VHF, height is useful to get the radiating regions above surrounding clutter but in some situations this may be less of a problem and a short antenna may be a desirable alternative.

6) Operate HF-Only.

The SWTL and VHF portion of the antenna and the diplexer can be eliminated and the result operated only as a conventional vertical, but with broadband matching. If a really good planar ground is used near the base, like the one shown in Photo 7, but perhaps ten feet in diameter, and with short, direct connections between a flange N connector mounted in its center and the bottom of the antenna tubing, above about 90% of the quarter-wave length frequency the impedance can be transformed down such that the SWR is almost constant and nowhere much greater than 3:1. This is within easy range of almost any antenna tuner.

7) Move the Transition Frequency.

We chose to make the HF/SWTL transition between 6 m and 2 m. This transition could have been placed elsewhere, however. Pushing it higher reduces the effect of the SWTL launchers on HF operation and reduces negative visual impact and wind loading. Pushing it lower gives broader VHF-and-above operation with the top antenna.

8) Replace the Discone with Single-Band Antenna(s).

We have built single band antennas with built-in SWTL launchers and successfully used them with SWTL feed. One of the first narrow-band antennas we made was a metalized paper halo antenna for 432.1 MHz horizontally polarized operation on SSB and CW. This was to match the polarization of the UHF DX and terrestrial weak signal operations in our area. A 50 Ω connector can be placed where the discone cylinder attaches. and used to allow easy VHF-and-above antenna changes.

9) Integrate Coarse and Fine Matching.

Operate the antenna on HF only, as described above plus automatically switch coarse tune inductors and 2 to 3 transformers to cover 137 kHz to 144 MHz.

10) Build 2 or 3 HF-only antennas spaced by their height and add an automatic phasing network to produce 6 to 9 dB of wide band gain along with electronic steering.

These are just a few of the alterations that can be considered. Hopefully you will build and use this antenna or one similar to it and think of more changes for yourself. If you do, please contact us and let us know. We would like to learn from both your successes and failures.

Permission to Use

The surface wave transmission line technology described here is patented and requires licensing agreements to build or use. Corridor Systems Inc, the patent holder, is permitting licensed Amateur Radio operators worldwide to build and deploy devices and systems that use it for their personal, non-commercial use, under the terms of their Amateur Radio licenses. Any other use requires licensing from Corridor Systems Inc, 3800 Rolling Oaks Road, Santa Rosa, California 95404, USA.[6]

Glenn Elmore, N6GN, has been a licensed Radio Amateur for the past 51 years, and has held call signs of WV6STS, WA6STS and now N6GN. He has held an Amateur Extra class license since 1972. For most of his working career, Glenn has been an electrical engineer involved with the design of RF and microwave test and measurement equipment, notably scalar, vector network and spectrum analyzers.

Glenn's Amateur Radio interests have included weak signal VHF/microwave operation including meteor scatter, EME, terrestrial DX as well as higher speed Amateur TCP/IP radios and networks. He has recently been active on WSPR, the weak signal reporting network. Glenn is an ARRL Member.

John Watrous, K6PZB, is an ARRL Member who was first licensed in 1956. Several times he has won the San Francisco VHF Contest in the QRP category. He is active in WSPR and has been working with Glenn Elmore on radio projects for over 20 years. For 34 years he taught people to behave more creatively in an Art Department at Santa Rosa Junior College, where he first used computers in art in 1983. He initiated the college's first on-line class in 1995. Retiring in 2007, John has focused his energy toward brainstorming ideas with Glenn, and building models in his shop. John holds a Masters Degree in sculpture and has always been interested in art and technology.

Notes

[1]Glenn Elmore, N6GN, and John Watrous, K6PZB, "The Mercury Capsule, A Light Weight Broadband Antenna," ARRL Pacificon, 2011, San Jose, CA.

[2]Glenn Elmore, N6GN, and John Watrous, K6PZB, "The Flying Antenna". **www.youtube.com/watch?v=-VWBUDJv2n0**. [This video shows operation of a balloon supported antenna, which is a potentially dangerous and even lethal activity that *QEX* suggests should not be attempted. — Ed.]

[3]Glenn Elmore, N6GN, and John Watrous, K6PZB, "A Surface Wave Transmission Line," *QEX*, May/Jun 2012, pp 3-9.

[4]Glenn Elmore, N6GN, "A New Antenna Model," *QEX*, Jul/Aug 2012, pp 8-18.

[5]Glenn Elmore, N6GN, "Physical Layer Considerations in Building an Amateur Radio Network," 9th ARRL Computer Networking Conference Proceedings.

[6]You can find more information about the patent and this license for Amateur Radio operators at Corridor Systems' website: **www.corridorsystems.com**.

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