

SWTL and Launcher



SWTL inside launcher on winder



Klopfenstein taper with SMA connector and brass portion of cone

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The Surface Wave Transmission Line

(Second of three construction articles at ARRL Pacificon 2011)



Because many we've shown this to have a first response of something like "How can a signal hooked to a long wire not radiate?" and also because this particular type of transmission line has not been previously shown but may be mistaken for one that has, it's worth taking a few words to explain it. Surface wave propagation has been known for a very long time. In fact, in the early days of radio, prior to 1900, theoretical work was done by Sommerfeld to explain beyond the horizon propagation. Then in the 1950's Georg Goubau¹ introduced a new surface wave transmission line (SWTL) that required only a single conductor. That line, known since as "G-line" required dielectric (insulation) around the wire or else special featuring of the conductor to slow the relative velocity of propagation in order to keep the signal from leaving the wire conductor. Reference books, including the ARRL VHF manual², provided information from Goubau's work and a 1974 QST article³ by George Hatherell, K6LK, further described use of this unusual mode for amateur radio purposes.

The SWTL being described here does not use the same mode as described for G-Line. Unlike G-line, no insulation or conditioning around the conductor is necessary. In fact a bare conductor can actually work better than one with insulation, at least while the surface is bright and shiny. Also there is no slowing of the propagating wave. The wave may travel more than

1 C. E. Sharp and G. Goubau, "A UHF Surface Wave Transmission Line," PROC. IRE, vol. 41, pp. 107-109; January, 1953.

2 *The Radio Amateurs VHF Manual*, Eleventh edition, ARRL, 1968, p 175

3 *Putting the G-Line to Work*, George Hatherall, K6LK, June 1964 QST p 11.

50% faster than signals in common coax and has been measured to have a relative propagation velocity of unity - it travels right at the speed of light.

For those that are familiar with antennas and have difficulty understanding that this SWTL isn't one, it is perhaps useful to first consider the familiar dipole. A dipole can make a good antenna, particularly when it is an odd number of half wavelengths long. You may have operated a 40 meter dipole on both 40 and on it's 3rd harmonic at 15 meters. A dipole can be fed from the middle and exhibits resonance⁴⁴ at the fundamental, 3rd, 5th and higher odd harmonics. In a sense, a resonant dipole, "knows" how long it is – that is, by connecting only at the center responses due to total length can be seen. A dipole's response depends upon the length and on something happening at the element ends. Fed from one end, the signal (wave) travels to the far end of an element and is reflected back from the discontinuity there. Since the conductor ceases at the end, real current is zero and voltage is highest there. As a result of that discontinuity a free wave is radiated into the surrounding space while at the same time a reflected wave returns toward the center.

A single dipole, simultaneously exhibits properties characteristic of a radiator, a transmission line and a resonator⁵. However, if at that far end we put a load that is able to couple to the signal (wave) and prevent both reflection and radiation, then the resonance disappears and signal energy goes into that load. If you've ever grabbed the end of a driven element of a VHF or UHF Yagi with your hand while watching a SWR meter you have witnessed this effect. The structure operated less like an antenna. Depending on whether you were transmitting or receiving, signal power to or from a distant locations was reduced, resonance was suppressed and some of any transmitted energy was absorbed in your hand. Under these conditions, the driven element became more a transmission line and less a radiator. Energy put into the element traveled as a wave along the conductor and was absorbed into a load at the end. With appropriate coupling and loading, this behavior can occur at all frequencies, not just at frequencies where the unloaded element happens to be resonant. With proper connections, called "launchers", at each end of a conductor a simple transmission line that exhibits very low attenuation along with very wide bandwidth operation can result. The plot in Figure 1 compares the measured attenuation of 100 feet of an SWTL made from #24 AWG copper wire conductor with the attenuation of LMR400 coax. Not only is this SWTL simpler, less expensive and lighter than coax but above a lower frequency limit which is determined by the launcher design, it can also exhibit lower loss than even this excellent coax.

While the preceding may help describe the SWTL for those familiar with antennas, the question "How can a transmission line as simple as this not have been discovered and used before?" may still occur. For those that prefer to examine the SWTL from the point of view of transmission line rather than antenna theory, more detail on the theory, historical background and operation of this SWTL is available⁶⁶. In the rest of this article we'll just show you how to make and use it.

4 *Antenna Book*, 21st edition, ARRL, Newington Connecticut, page 23pp

5 *Antennas*, John Kraus W8JK, McGraw-Hill Book Company, 1950, p 2

6 Introduction to the Propagating Wave on a Single Conductor,
<http://www.corridorsystems.com/FullArticle.pdf>

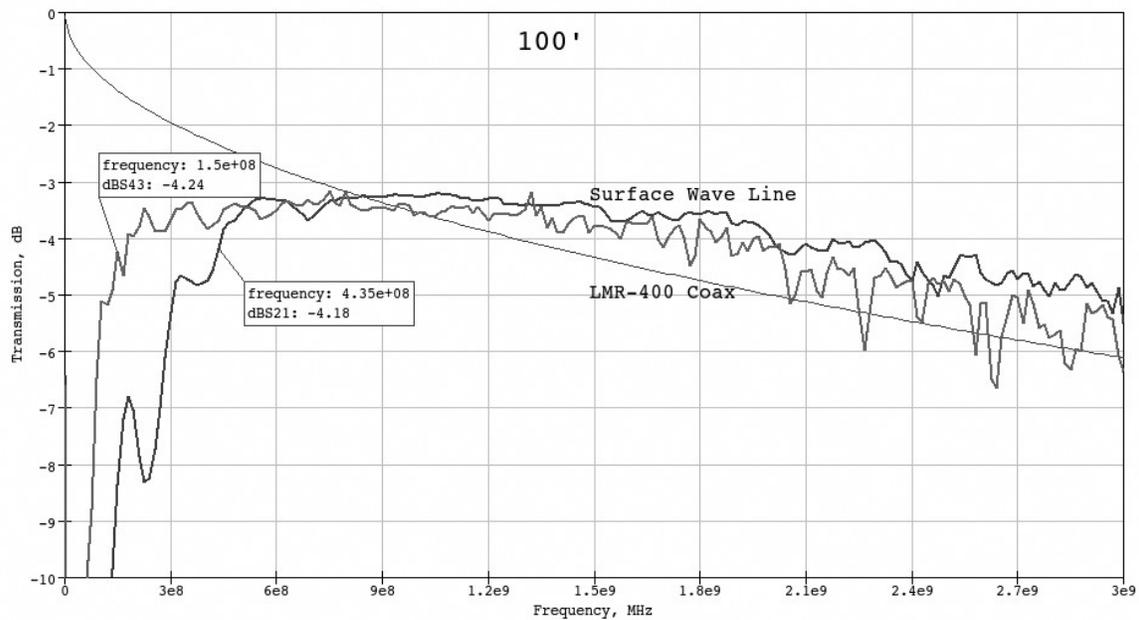


Figure 1 Measured performance of SWTL compared with measurement of Times Microwave LMR-400 coaxial cable. Plots of 100 feet of #24 AWG conductor with a pair of 400 MHz launchers and a pair of 140 MHz launchers are shown. The main difference between these is the cut-off frequency

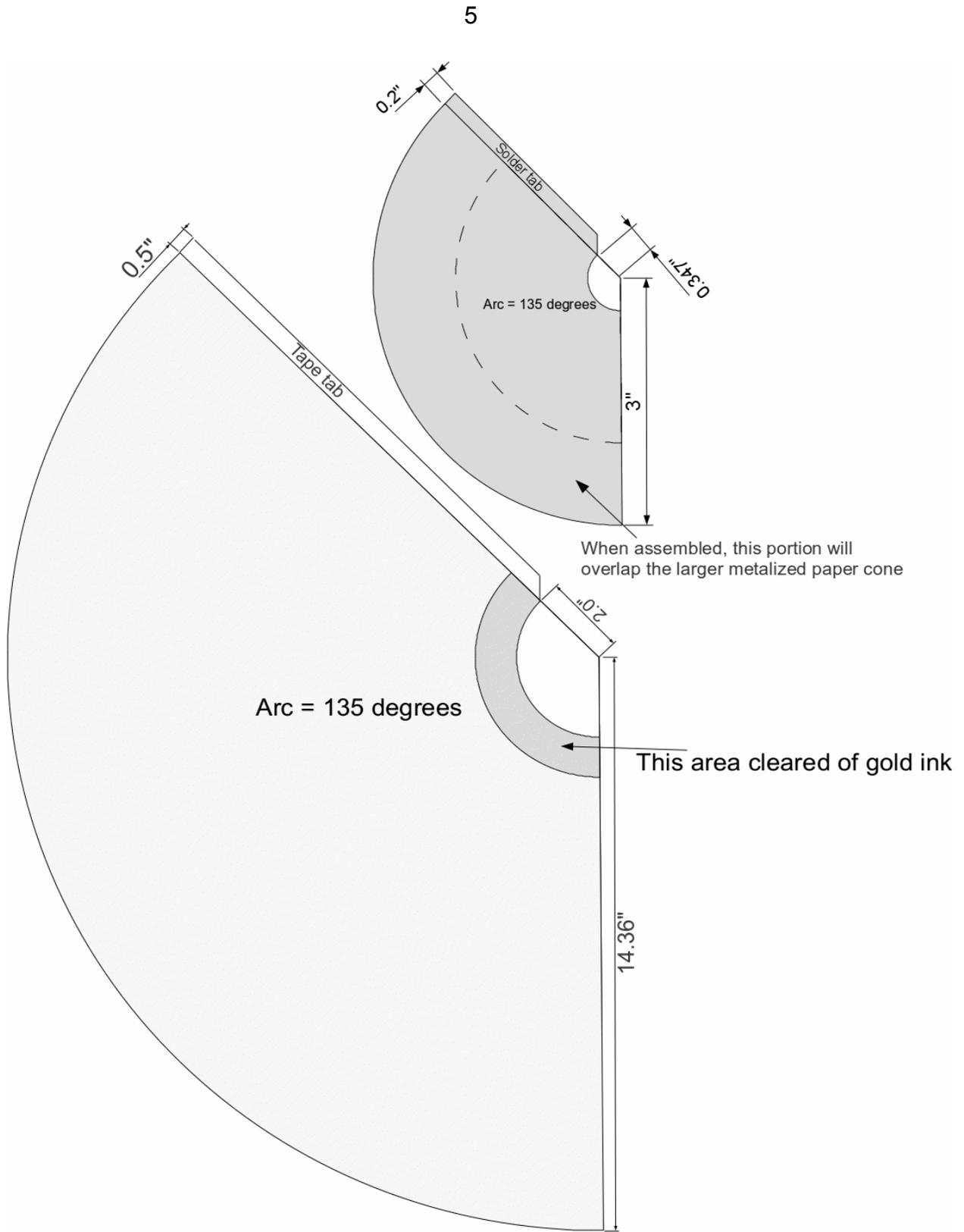


Figure 2A Cone patterns before folding, metalized paper and brass shim stock

Fabrication

The launchers use coaxial transmission line transformers described by Klopfenstein⁷ and having a Chebyshev impedance taper that matches a 50 ohm coaxial connection at the narrow end to the 377 ohm impedance at the wide end where the SWTL conductor attaches. This transformation has a low frequency limit set by the lowest frequency at which the total transformer length is approximately one half wavelength. Two designs are shown here, one with a 400 MHz lower limit and the other with a 144 MHz lower limit. Both designs should operate from their low frequency cut-off to well above 3 GHz. The outer conductor of these coaxial transformers is a cone made from metalized paper while the inner conductors which have specially varying diameters to provide the correct impedance profile along the length of the launcher are made from tubing.

440 MHz Launcher Fabrication

Cut the metalized paper and the brass shim stock from flat stock using the patterns shown in Fig. 2A. Using a cloth and some acetone, clear the gold ink away from the paper in the indicated area prior to folding it into a cone with the metalization on the outside. With the overlapping tab lined up along the entire inside length, temporarily tape on the inside with transparent or masking tape, then go back and tape the entire outer seam with metal foil tape. It may help to have two people for this operation.

Similarly with the brass shim pattern, once cut out, overlap carefully and tack solder to hold in place before going back and completely soldering the seam.

When you are finished building these, the brass cone should fit snugly over the narrow end of the metalized paper cone and the brass and cleared metalization should have good electrical contact.

The center conductor is fabricated from K&S metals brass tubing stock as shown in Figure 2B. This brass tubing is available in 1/32 inch diameter steps. Figure 2B shows the lengths of each diameter and at what position along the tapered center the next size begins. Cut the tubing about 1/2" longer than the required length to allow for overlap at each end. Carefully position these, both as to length and straightness and tack solder. Once you have the entire tapered center conductor together and are pleased with the lengths and alignment, you can go back and solder each joint completely. Finally, sand or file away any excess solder so that you finish with a smooth step-tapered center conductor.

Cut a Styrofoam stiffener from 2" stock. This is available from home supply stores for use as thermal insulation. If possible, cut the circle using a small band saw with the table tilted to provide a about a 22 degree angle so that it will fit snugly in the finished paper cone about 2/3 of the way toward the open end. Drill an 1/8 inch hole through it's center.

For final assembly, shown in Figure 3, first slip the brass cone over the center conductor and

⁷ R W Klopfenstein, *A Transmission Line Taper of Improved Design*, Proc. Of the IRE, January 1956 p31 pp

then solder the SMA connector center pin into the end tube, as shown in the figures. Set the paper cone on a flat work surface, wide end down, and seat the brass cone over the paper cone while guiding the tapered center conductor through the Styrofoam stiffener. The center hole will enlarge slightly as the center conductor pushes into it. With everything in alignment, you can then solder the SMA connector flange to the brass cone. Use metal tape to fasten the brass cone to the paper cone and your 400 MHz Klopfenstein taper launcher is complete. You only need to solder the #24 copper line to the center conductor at the wide end of the tube to use it.

144 MHz Launcher

The 144 MHz version of the launcher is simply a “stretch” version of the 400 MHz version. Both should operate to well beyond 3 GHz but the 144 MHz version, at a little over 40 inches of overall length, will operate at lower frequencies as well – including the 2 meter and 1 ¼ meter amateur bands.

Construction is basically the same as already described for the 400 MHz version except that significantly more brass tubing is required for the center conductor and three sheets of metalized paper to construct the outer cone.

Figure 4 provides a template for the paper cone and Figure 5 a template for the brass cone. The inner conductor dimensions are shown following these. Note that the order of the columns is reversed compared to the inner conductor dimensions for the 440 MHz launcher. A SMA connector is used the same as for the 400 MHz launcher.

The target impedance profile for a 20 dB return loss Klopfenstein taper wideband transmission line transformer is shown in Figure 6. This same profile can be scaled in length for different lower frequency limits. When built from stepped diameter tubing sections rather than continuously varying line diameters, the performance is just slightly poorer than this target.

Figure 7 shows the measured transmission attenuation and impedance match of the line, both as return loss and SWR. As shown it has a corner frequency just below 2 meters but the line is actually usable from below 100 MHz and has a usable upper limit well above 3 GHz. Actual performance is probably somewhat better than shown by the measurement because the calibration of the vector network analyzer used was compromised due to variations in the 100 foot long test cables and connections that were required for measuring this large structure. After calibration with precision standards the lines had to be dragged to the ends of the SWTL and were flexed in the process. This reduced the resulting measurement accuracy.

Materials

Pacon® Metallic-Colored Four-Ply Poster Board

http://www.amazon.com/Pacon%C2%AE-Metallic-Colored-Four-Ply-Poster-Carton/dp/B002XJHGDK/ref=sr_1_3?ie=UTF8&s=office-products&qid=1309381399&sr=8-3

SMA connector

http://www.jameco.com/webapp/wcs/stores/servlet/Product_10001_10001_159531_-1

0.005" brass shim stock

<http://www.amazon.com/Brass-Shim-Stock-0-005-Thick/dp/B00065UXZG>

#24 Magnet wire

<http://www.frys.com/product/6279330>

Metal tape

<http://www.amazon.com/Shurtech-Brands-50-47523-01-Metal-Repair/dp/B0050BY230>

Figure 2B: Taper & Brass Cone

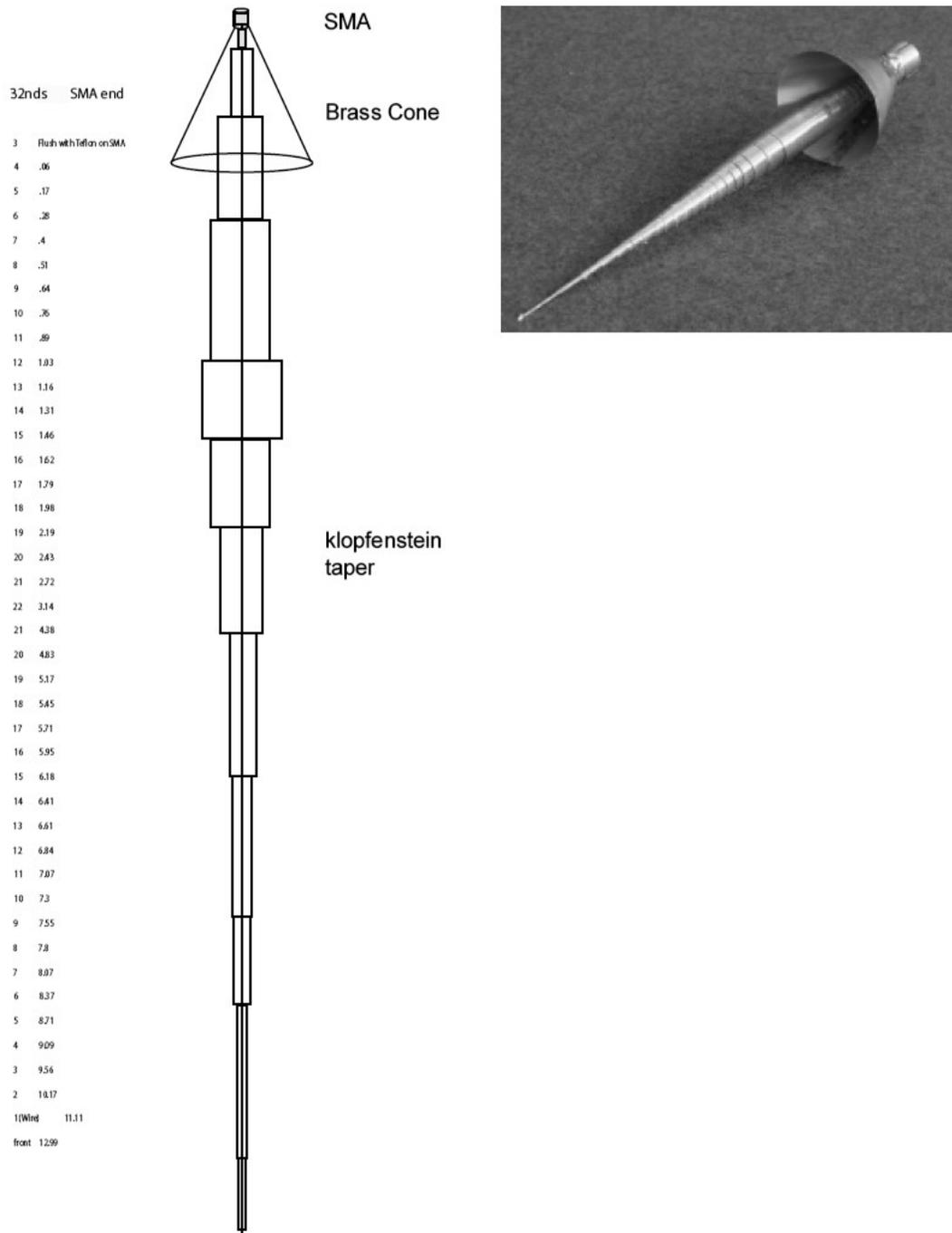


Figure 2B. Dimensions of inner launcher tapered conductor sections made from K&S Metals brass tubing (in 32nds of an inch) vs. position from the SMA connector for the 400 MHz launcher.

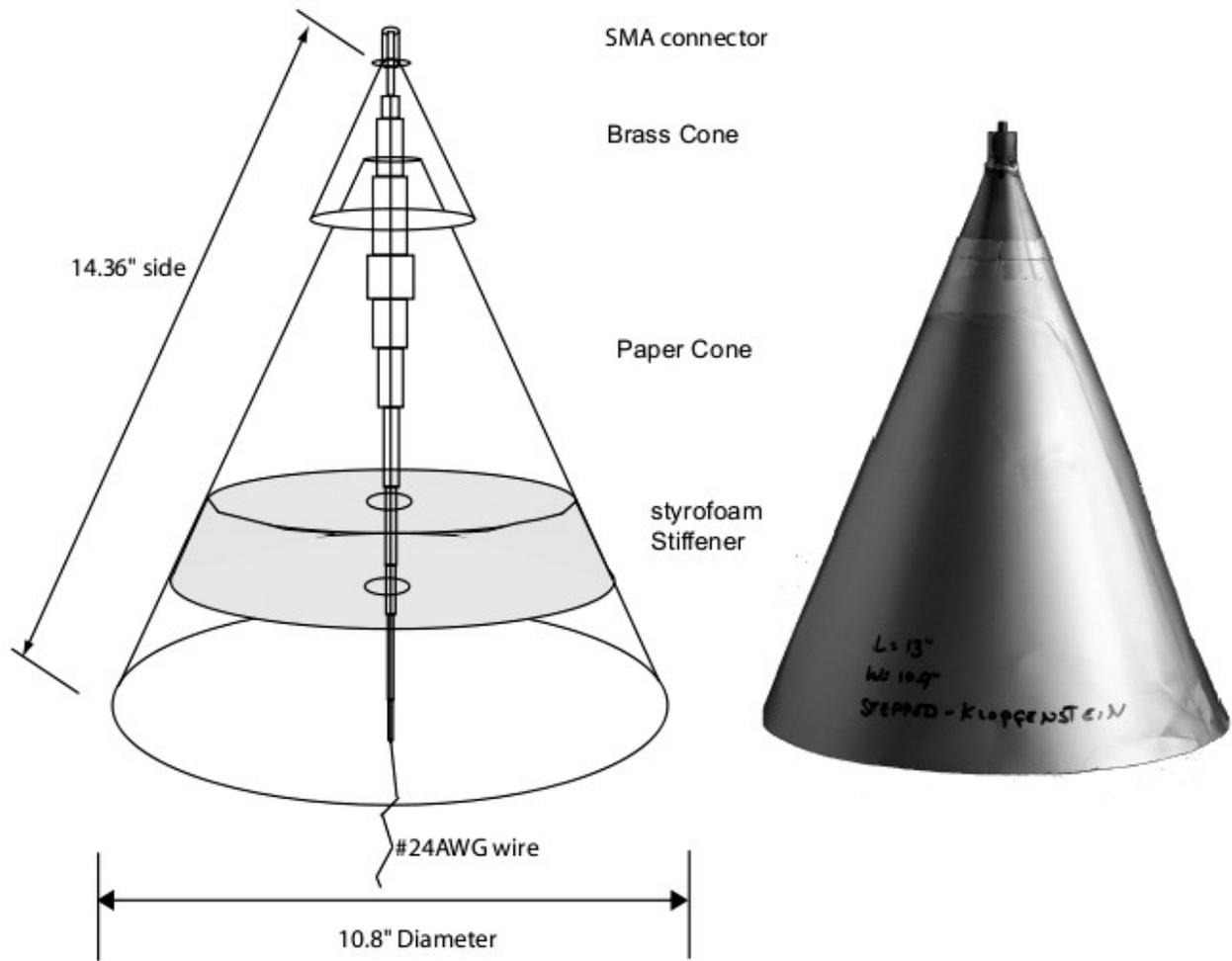


Figure 3 Assembly of the 400 MHz Launcher

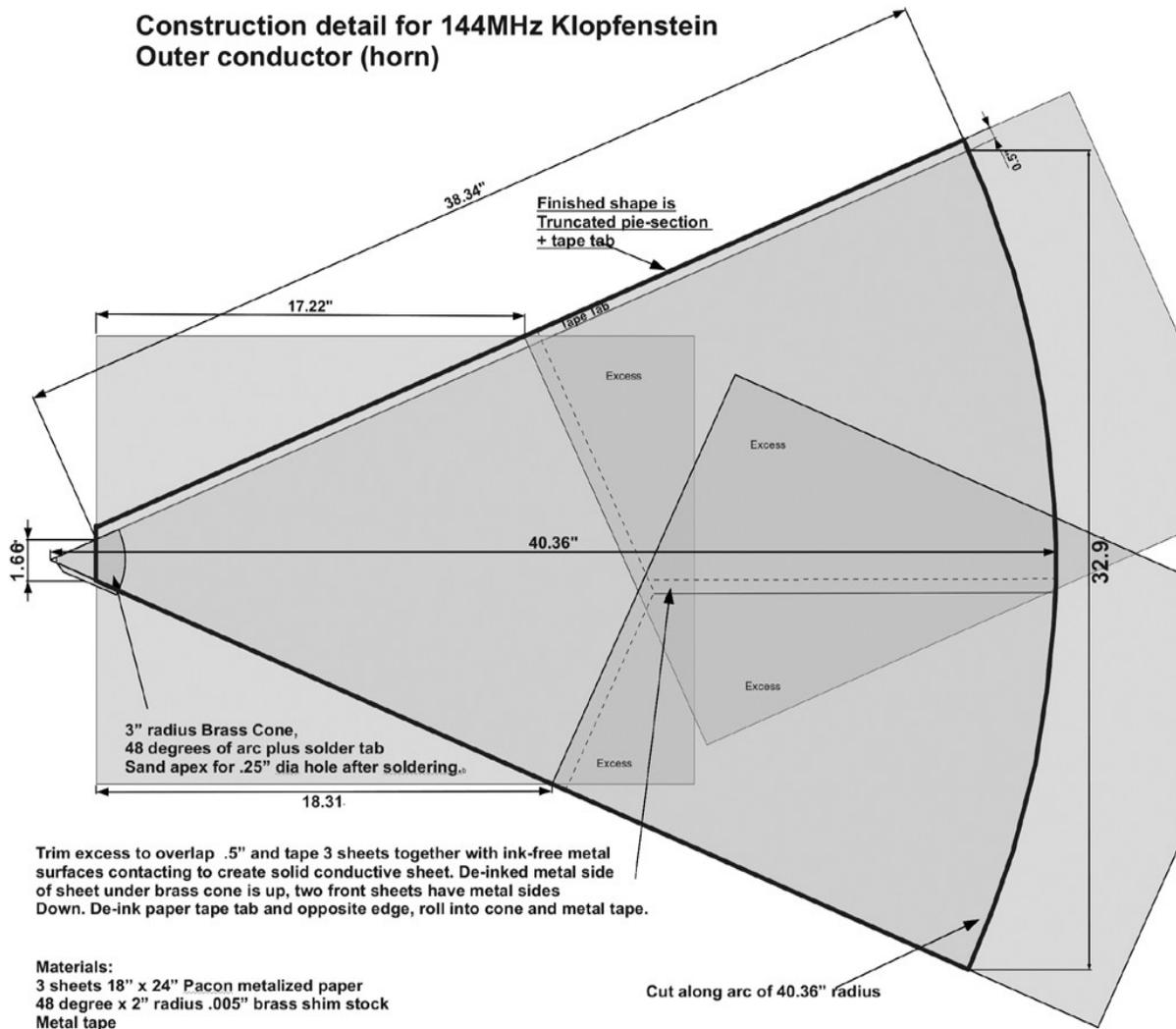


Figure 4 The paper cone for the 144 MHz version of the launcher requires three 18x24 inch sheets of metalized paper.

Template for the brass portion of 144 MHz launcher outer cones. Material can be .01" brass shim stock.

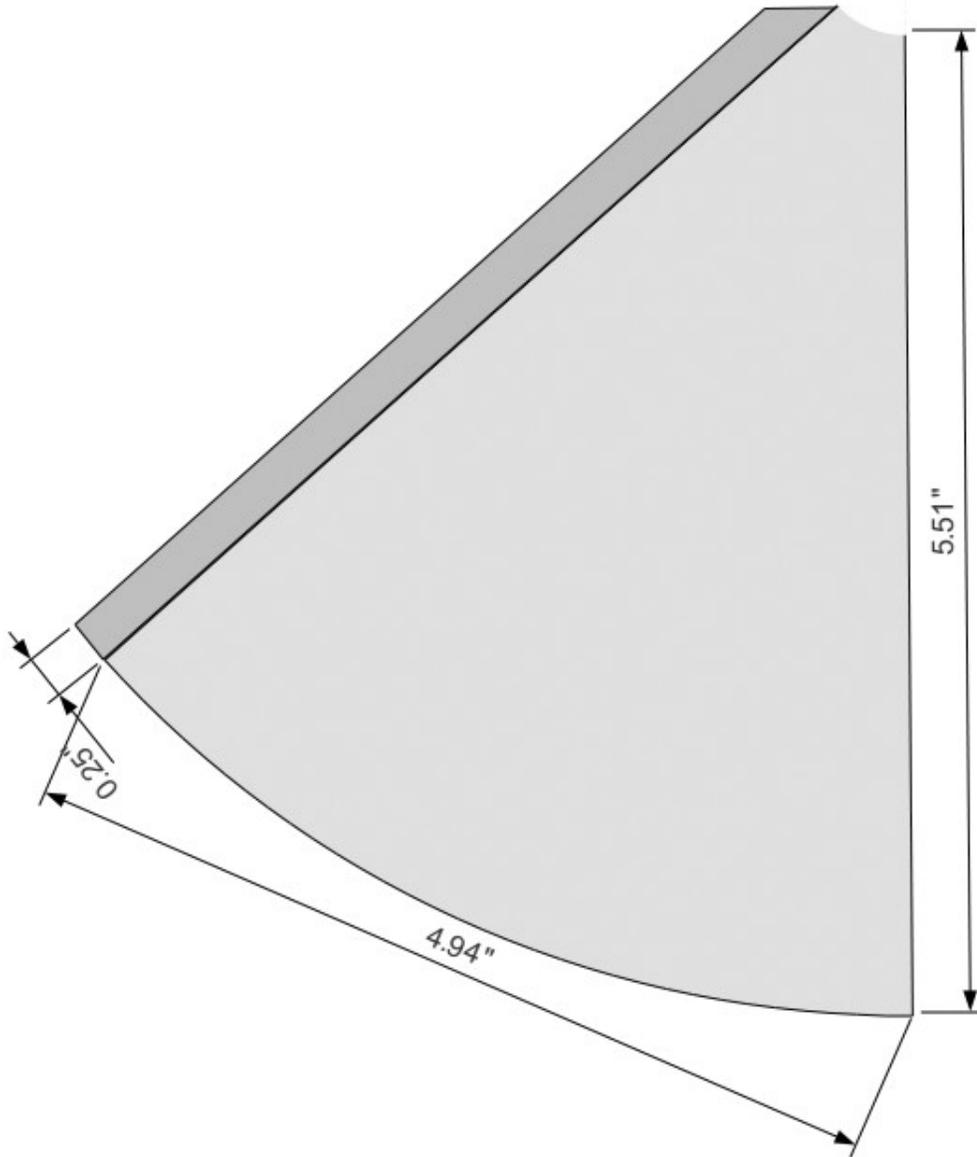


Figure 5 Template for brass portion of 144 MHz launcher outer cone.

Step-tapered Center Conductor Dimensions for the 144 MHz Launcher

Position from SMA, inches	K&S Tubing OD, 32nds of an inch
0	3
0.18	4
0.51	5
0.85	6
1.20	7
1.56	8
1.93	9
2.30	10
2.70	11
3.11	12
3.52	13
3.96	14
4.43	15
4.92	16
5.43	17
6.00	18
6.63	19
7.36	20
8.25	21
9.53	22
13.27	21
14.65	20
15.67	19
16.52	18
17.30	17
18.03	16
18.74	15
19.43	14
20.04	13
20.73	12
21.42	11
22.13	10
22.87	9
23.64	8
24.47	7
25.37	6
26.40	5
27.56	4
28.96	3
30.81	2
33.66	1

The last tubing section is 1/32nd inch OD and extends to the front of the paper cone where it solders to the #24 wire SWTL conductor.

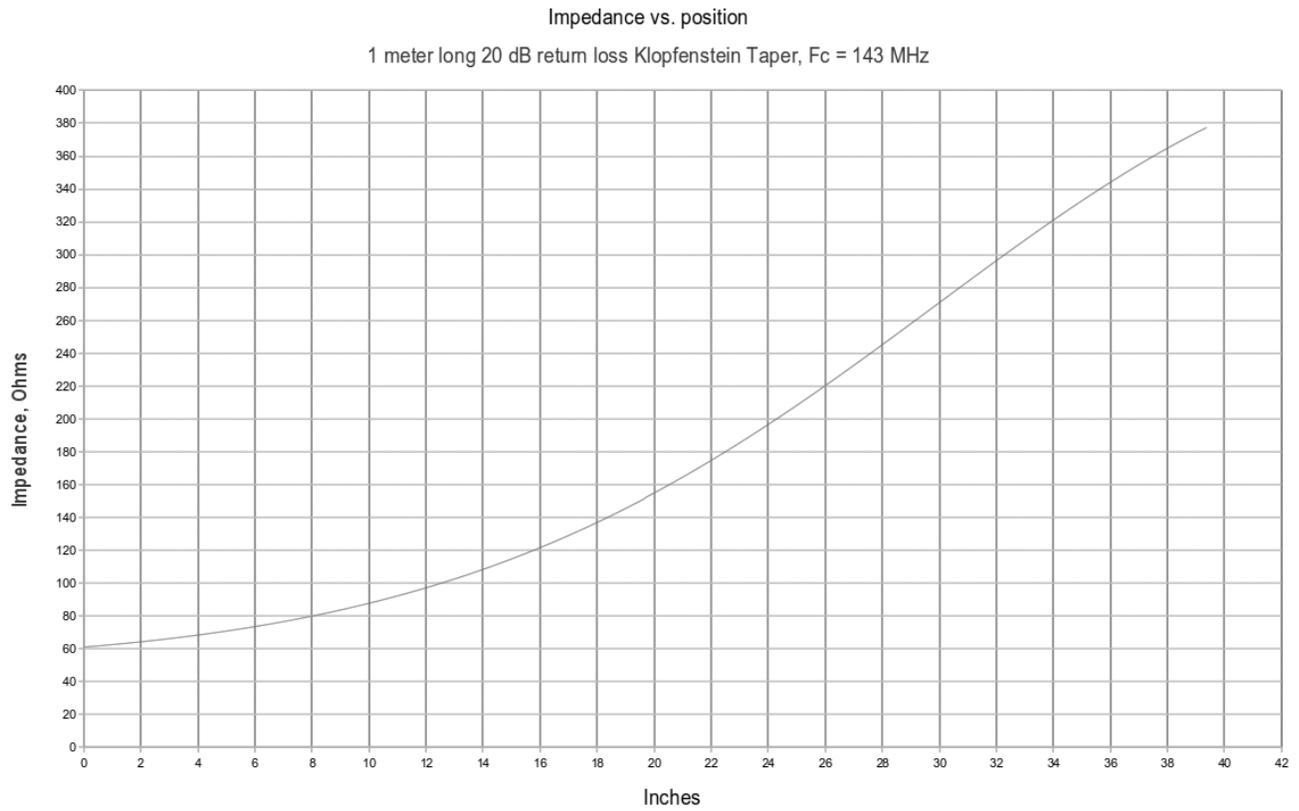


Figure 6: Line Impedance vs. position for a 20 dB return loss Klopfenstein taper with corner frequency of 143 MHz.

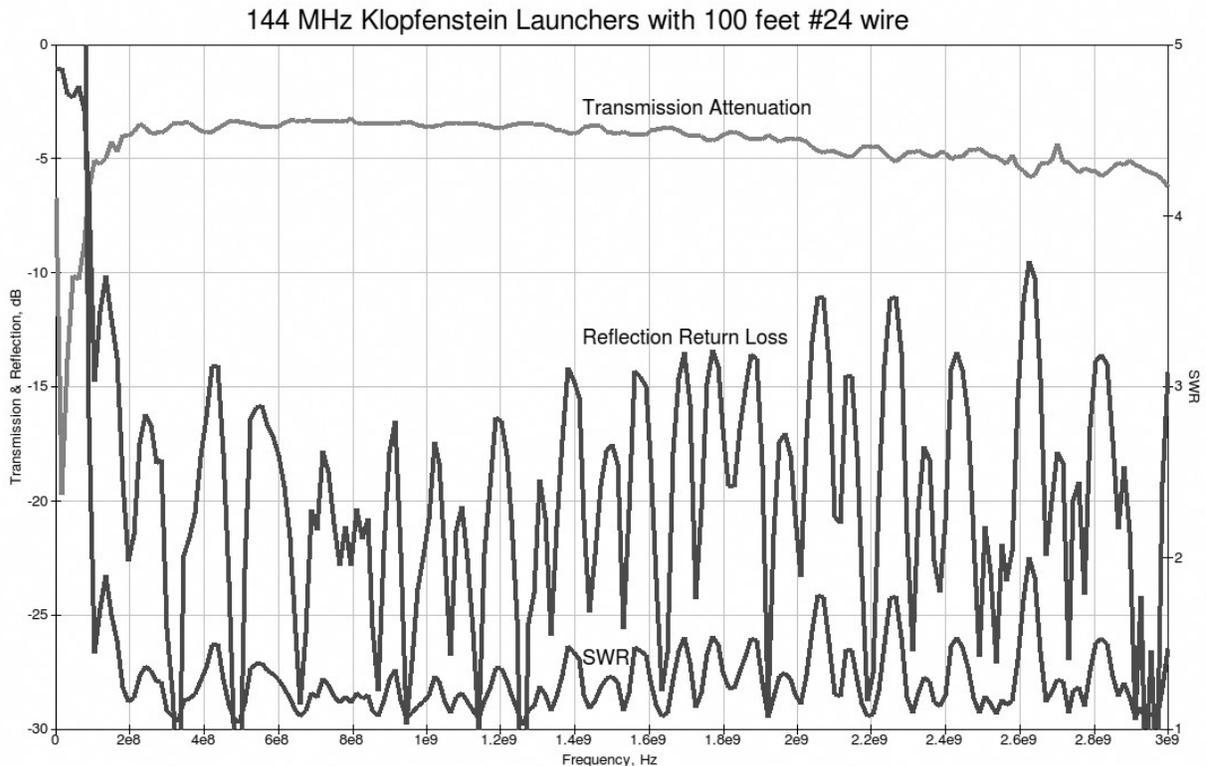


Figure 7: Measured Performance of 100' SWTL line with 144 MHz Launchers

SWTL line Use

For simple transmission line use, you'll need to make two of the above launchers, of either the 400 MHz or the 144 MHz versions. Once these are built, to use simply reel out the desired length of #24 bare copper or enameled magnet wire, tin the ends and solder into the center conductors of each launcher. Some sag in the line is really not much of a problem but it is important that the line be kept away from the ground and obstacles, preferably by at least a foot or more, over its entire length. If you use it this way, you should have a low attenuation, very broadband transmission line that can be used just like any other line for connecting a receiver or transmitter to an antenna or any similar transmission line use over the 400 MHz to 3 GHz or 144 MHz to 3 GHz range, as shown by Figure 1.

As you can see in Figures 2B and 3, we soldered a 1/2" copper water pipe coupling on the back of the brass cone and around the SMA connector to facilitate mounting each launcher. Prior to soldering, we slotted the open end of this fitting so that the entire launcher could be supported from a piece of standard 1/2" copper pipe and an SMA fitted coaxial cable could be run down the center of that same mounting pipe and secured with a small metal hose clamp.

Very long runs of this line may be quite useful in connecting a transceiver to a distant antenna, perhaps one located at the top of a tower or a nearby hill. If very long lines are used,

the weight of the line may be partially borne by intervening Styrofoam supports, periodically placed along the span, to keep the wire away from ground and obstacles. However, use of insulators that have higher relative dielectric constants such as ceramic or glass will tend to unbalance the wave on the line and will cause additional attenuation and reflection so should be avoided.

If you accidentally break the #24 conductor, even if you are using enamel covered magnet wire, it isn't necessary to re-solder in order to reattach. A linesman's splice made by twisting one to two inches of each end tightly and closely around the other end will provide a "gimmick" capacitor that will make quite a good connection at 400 MHz and above. Because the characteristic impedance of the line is 377 ohms, it doesn't take much capacitance to make a very adequate RF connection even if there is enamel that prevents a DC connection. At lower frequencies you should make the splice longer or else solder any break, keeping the overall length and diameter of the splice as small as is practical.

It is possible to substitute different wire diameters. Particularly for very long lines that are supported at intermediate points with Styrofoam, you may find you can achieve lower losses by going to significantly larger and heavier wire or conductor sizes. Particularly if you taper gently between different diameters, perhaps by using intermediate diameters for a few inches at the transition, you should be able to achieve very low loss on extremely long runs. Because line attenuation is primarily influenced by the conductivity of the SWTL conductor used and further limited by skin effect, large diameter conductors made from copper will tend to show better performance than small ones made from metals having poorer conductivity. Even so, because of the high characteristic impedance of the line, materials that might not normally be considered for RF and microwave use, such as iron or stainless steel, may be used to create a very adequate SWTL. Commercial applications of this SWTL have used 1/4" to 2" diameter aluminum power line cables to achieve good performance even at 5 GHz and above. It is common to see attenuation at microwave of around 2 dB/100' with these larger conductors. For amateur radio applications, it may prove convenient to use a tower or mast guy cable as a feedline as well as a mechanical support. If this is to be done, a different launcher design that doesn't put mechanical strain directly onto the launcher's coaxial cable center pin must be arranged. A launcher that mechanically and electrically clamps to the cable with an RF attachment one quarter wavelength in front of the attachment point is one possibility but is not detailed in this article.

It is also possible to use non-circular cross-section conductors, as long as they are radially symmetric. There has been a report⁸ of use of metalized Mylar ribbon of very great lengths, a kilometer or more, as a SWTL transmission line conductor. While this report implied that this was a form of Goubau line, it seems likely that it was actually operating in the same manner as the SWTL lines described here, in a TM_{00} mode, longitudinal e-field wave guide rather than as line described by Goubau.

This SWTL should have quite high power handling capacity, particularly with larger diameter

⁸ *Low-Loss RF Transport Over Long Distances*, M. Friedman and Richard Fernsler, IEEE Transaction on Microwave Theory and Techniques, Vol 49, No. 2, February 2001

conductors. The authors have not tried kilowatt level transmitting, but it is very likely that the SMA connector will be the limiting factor rather than the line itself.

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⁹ <http://www.corridorsystems.com>



Photo 1: Completed 144 MHz launcher mounted on a "holder". The #24 SWTL conductor extends from the center of the horn but is too small to be seen in this photograph.



Photo 2 A pair of 144 MHz Launchers being measured with 100 feet of #24 magnet wire conductor in the driveway at N6GN. The vector network analyzer used for the measurement can be seen to the right, between the two ends.