Wire and Plate Zagi Elements

By David Jefferies and Dan Handelsman

Introduction

In the March 2004 issue of *antenneX* magazine (now in Archive VI article #87), we reported the concept of the Zagi, an antenna made from slow wave structures which has controlled coupling between the elements and which can be made significantly smaller than a standard rod Yagi-Uda antenna.

In that article we suggested that the slow wave elements could be made from zig-zagged wires (hence the derivation of the name). Here, we present a variant based on a serrated plate element, together with some simulations and measurements of both variants of the structure.

The advantage of the plate Zagi reported here, over its wire cousin reported last time, is in the bandwidth of the antenna structure. It is also physically stronger, but it is subject to greater wind loading.

Using a perforated or mesh metallic structure may address the latter problem. There is no reason to believe that such an antenna should perform any differently from the one constructed from a solid metallic plate. With capacitor plates, one may remove a fairly large amount of metal and still leave performance unaffected. Moreover, the NEC model used here is based on a grid structure, which serves to adequately model the solid plate antenna. See http://www.ee.surrey.ac.uk/Personal/D.Jefferies/perfcap.html for a discussion of capacitors having perforated plates.

Slow wave structures

Lengths of wire and areas of plate have what is termed "distributed" inductance and capacitance. Thus the inductance of a piece of wire is roughly proportional to the length of wire. If we fold the wire up into a Zagi structure the total inductance and capacitance along the length of the structure is greater than if the wire were straight. Also, if we can imagine the electromagnetic radiation progressing at the speed of light along the length of the wire, it takes longer to get to the end (and therefore appears to be travelling more slowly parallel to the length of the structure) if the wire takes a circuitous path.

For those people who still have trouble envisaging a slow wave structure, imagine trying to drive up University Avenue in Palo Alto by taking a left at the first traffic lights, going right, right, and then left to rejoin the road a block downstream, and then repeating this for the next-but-one block. Assuming square blocks, this takes your car twice the physical distance to traverse Palo Alto and so it takes twice the time driving at the speed limit of 25 MPH.

Antenna descriptions

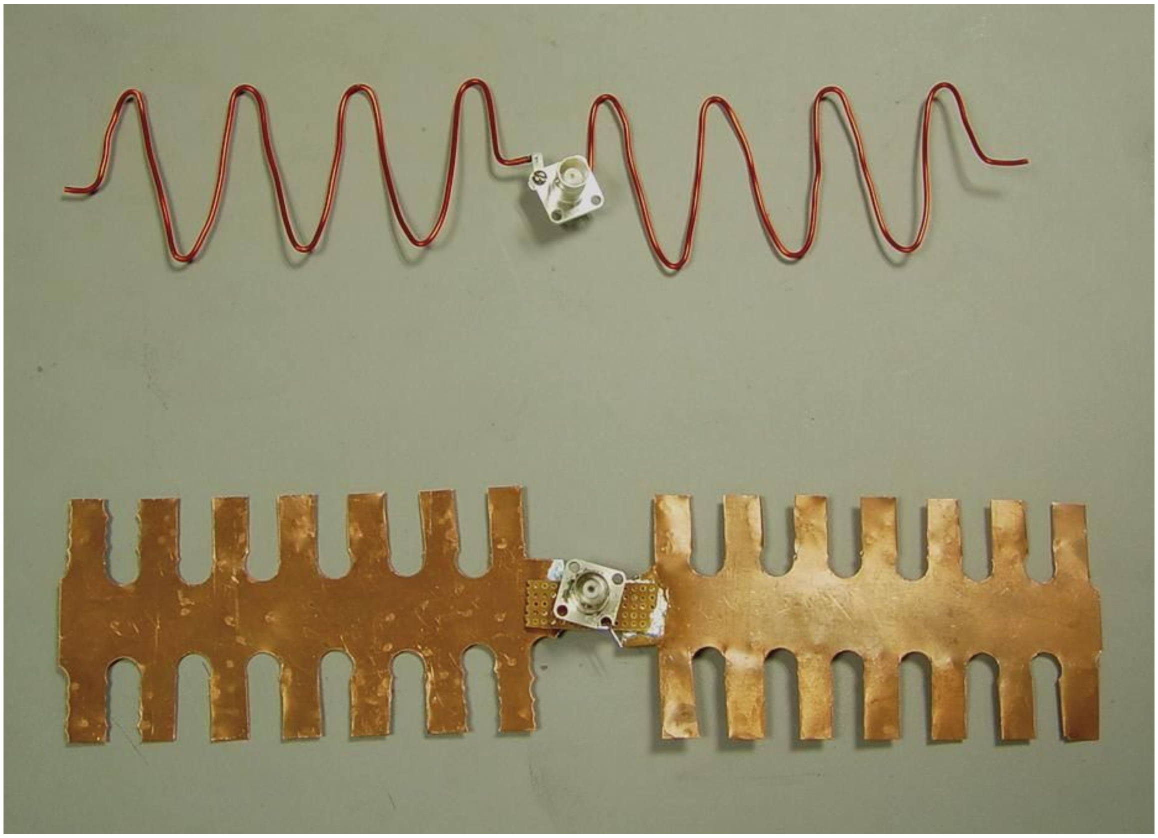


Fig. 1.

To start with, we show a photo of experimental wire and plate Zagi elements in **Figure 1**. **Figure 2** shows the plate Zagi used in the measurements reported here, with scales. The plate Zagi had overall length 302 mm plus or minus 2mm, and the stubs were 10 mm wide and 25 mm long plus or minus 2mm. The central strip was 20 mm wide plus or minus 2mm. The central feed gap was 5 mm plus or minus 2mm.

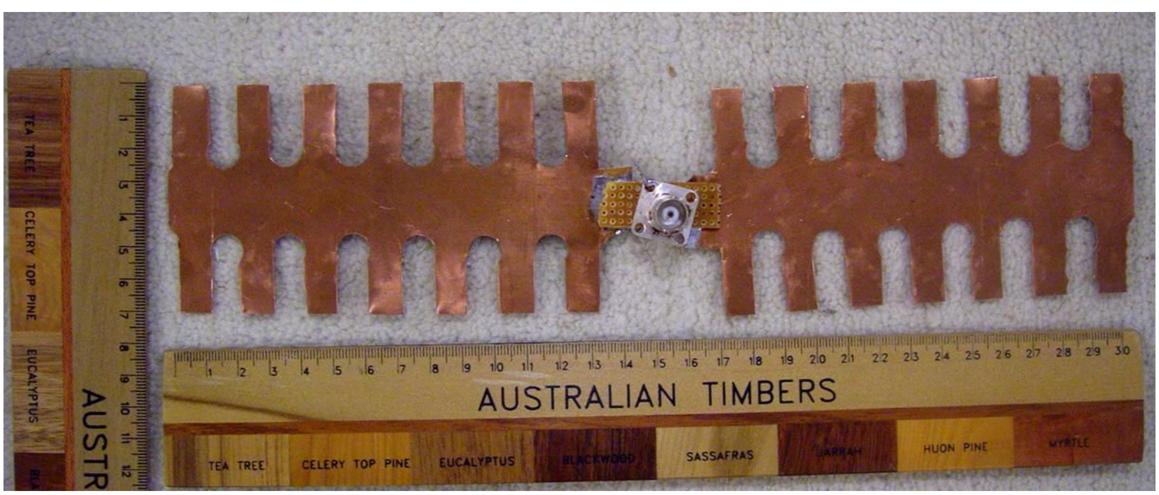


Fig. 2.

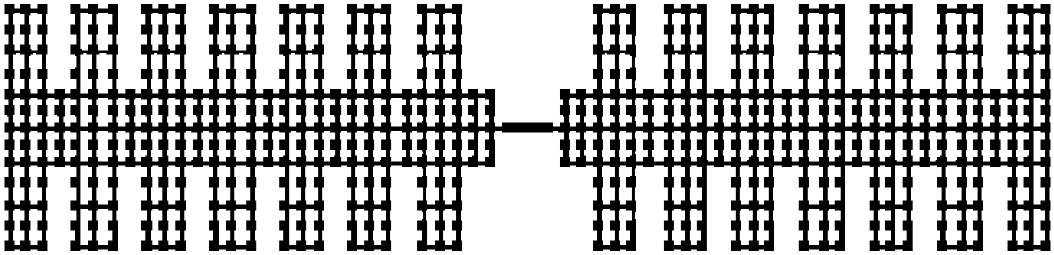


Fig. 3.

Figure 3 shows a representative model of the approximation to the plate Zagi element using a NEC wire grid. **Figure 4** shows a representative model of the wire Zagi.

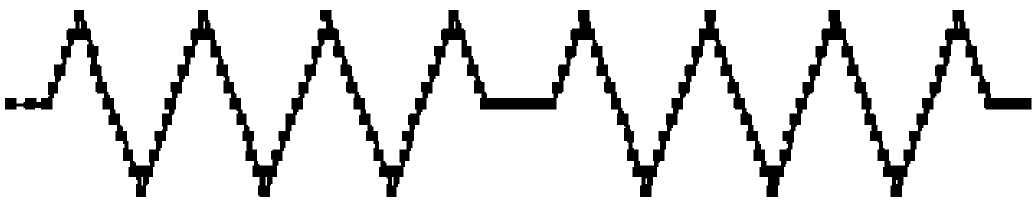


Fig. 4.

Figure 5 shows the suppressed coaxial cable used to feed the plate Zagi element inside the damped screened room (**Figure 6**). This room has 200mm thick pyramidal absorbers (**Figure 7**) and is anechoic above about 1500MHz, whereas our measurements were taken below this frequency. Nevertheless, as was reported in David Jefferies's and G G Johnstone's article in May *antenneX* the damped screened room facilitates measurements at these low frequencies.

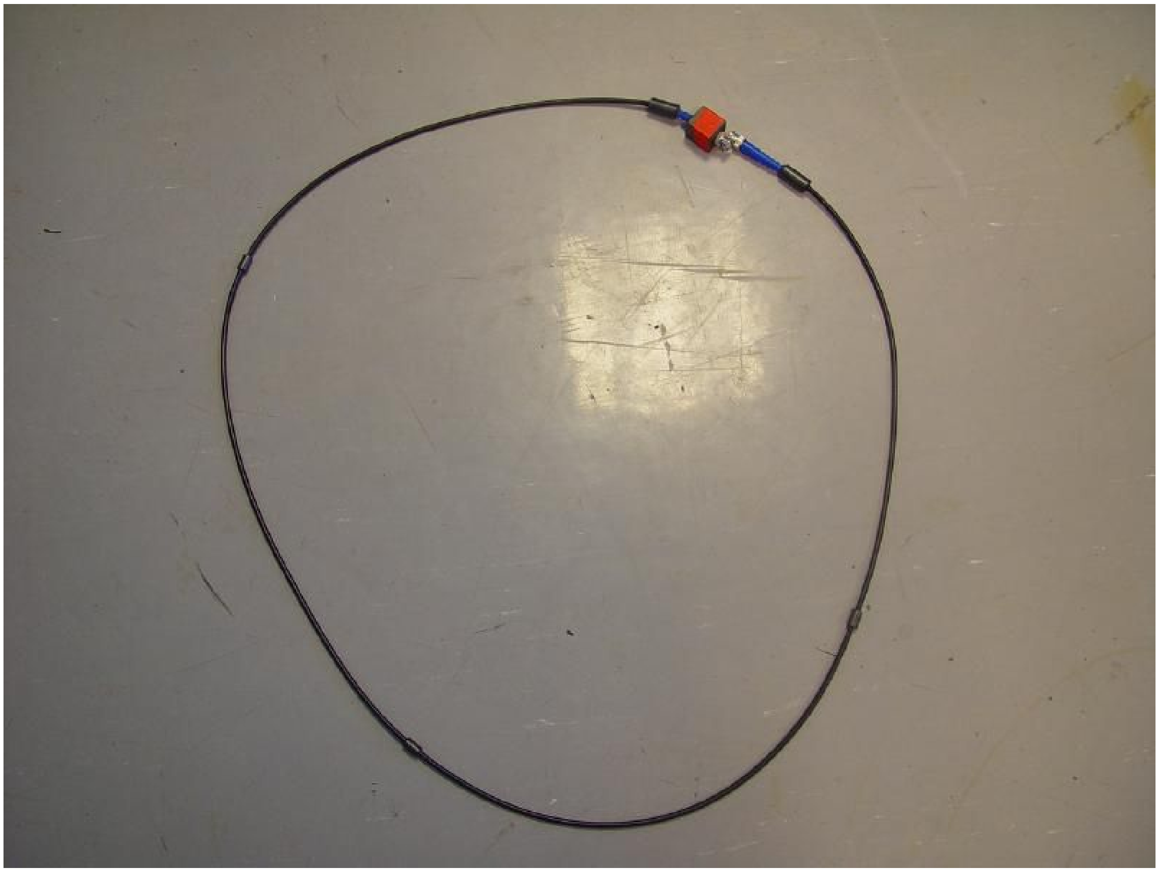


Fig. 5.

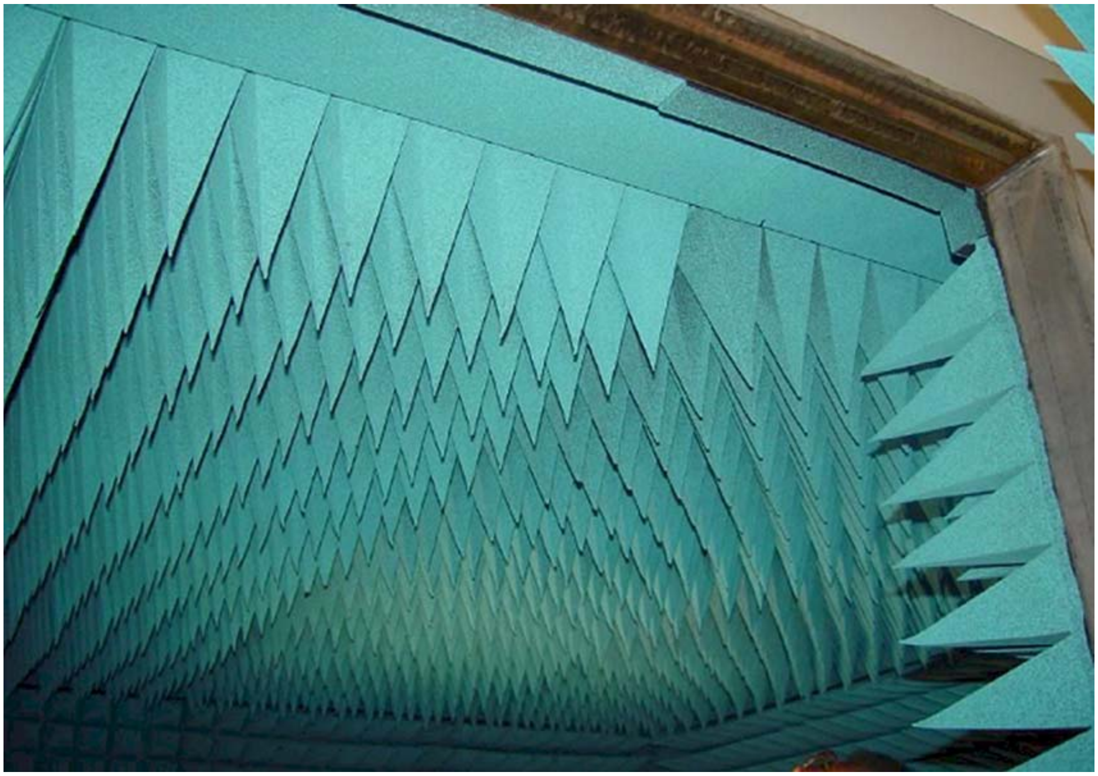


Fig. 6.

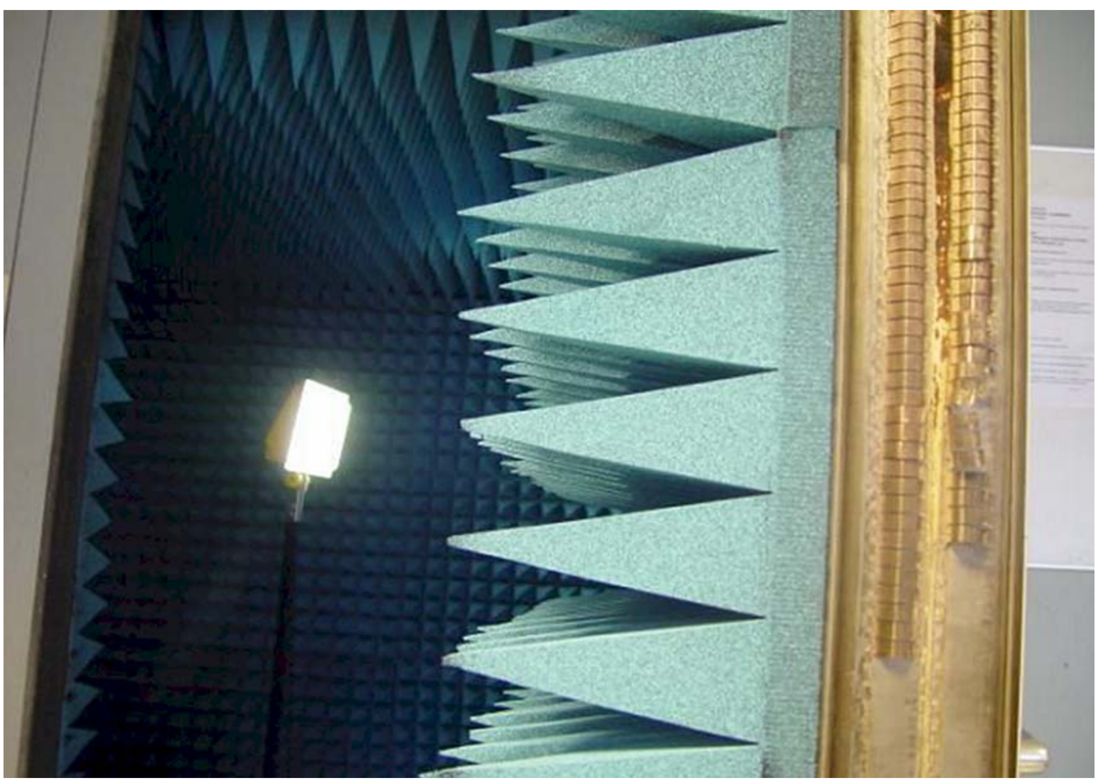


Fig. 7.

Wire and plate Zagi element performance comparison

Looking at **Figure 1** we see that the lengths of the wire and plate Zagi models are comparable. The plate Zagi is 302 mm plus or minus 2mm and the wire Zagi is 285 mm plus or minus 5mm (it is also extensible and flexible). The slowing factor is more for the wire Zagi; its resonant frequency is 244 MHz plus or minus 2 MHz and its bandwidth (between the X=R points) is 14 plus or minus 1 MHz. That results in a fractional bandwidth of 14/244 or 5.7 percent. The velocity factor is 0.46.

The plate Zagi element was tried as an alternative design solution to making a slow wave structure. There are many parameters that remain to be investigated, and so the results given here, for just the first example we made, are very preliminary. For example, one could mount the sheet metal stubs at the apexes of a bent wire Zagi element.

We also do not know the "equivalence" between the sizes of the stubs of a plate Zagi and the height of the folds on a wire Zagi. In other words, we have to ascertain the total distance that a wave travels along the stubs of the plate Zagi and how this correlates with the more easily measured wire length in the wire Zagi's folds.

The plate Zagi element that we constructed had total length of 302 mm plus or minus 2mm, and the velocity factor, for a measured resonant frequency of 317MHz, was 0.60. The measured bandwidth between X=R points is 59 MHz, a fractional bandwidth of 59/317 or 18.6 percent. This is comparable to an ordinary thick rod dipole.

Thus, we find that, for the same design frequency, the wire Zagi is smaller but has narrower bandwidth. The bandwidth is a property of the velocity factor and the radiation resistance. A shorter antenna has lower radiation resistance, but the shortening is obtained by increasing the inductance and the capacitance per unit length. A combination of more reactance and less resistance gives us a higher Q factor and a lower bandwidth.

Initial simulations of multi-element plate Zagi structures were interesting. It appears that the plates couple much less strongly than a wire Zagi's elements, and so they have to be placed much closer together to achieve a maximum in the front-to-back ratio. A typical simulation suggests, for a two-element plate Zagi, a separation of only 0.07 wavelengths. Consequently the advantageous front-to-back ratio is maintained only over a narrow frequency range, for example 15 MHz at a design frequency of 300 MHz. This reduces the useful bandwidth of the structure to only 5%, compared to the intrinsic useful bandwidth of the single element of 18%. However, this property means that the antenna is a very compact design; it is only 60% of the width of the equivalent Yagi and its overall length is only about one fifth of its width. If you can tolerate the low bandwidth, this is a useful design. As we mentioned above, the feedpoint resistance of this low bandwidth antenna is also low, of the order of 10 ohms. This is also a consequence of the close spacing of the elements.

With both plate and wire versions of the Zagi idea, the novelty lies to a large extent in the ability to control the coupling between the elements. For a given coupling strength, the spacing of the elements dictates the maximum achievable front-to-back ratio. For closer spacing, we have a lower driving point resistance and bandwidth, but higher gain. But we have the additional parameter to adjust, that of the overlap of the element serrations, so the consequences of a given element spacing are to some extent under our control.

Given wire Zagi elements, the novelty of this antenna class is that you can arrange for an antenna structure of half the width of the equivalent Yagi, which has a roughly comparable boom length for the same number of elements, but has enhanced driving point resistance and bandwidth, and also decent gain, front-to-back ratio and sidelobe performance.

The wire Zagi would appear to be preferable in that the elements couple more strongly and the coupling may be varied over a wider range.

The velocity factor of around 46 percent for the wire Zagi means that it has application to compact antennas for use at the 225MHz band of frequencies devoted to digital audio broadcasting (DAB) in the UK. For amateur radio applications, anything that shrinks the size of an array antenna is useful, and with the large f/b ratios we have discovered for the wire Zagi in its two-element form, it seems to be a serious contender for some experiments by interested Hams.

However, the greater bandwidth of the single element plate Zagi gives it a niche in the frequency range 100 to 500 MHz, where the element will be about the same size as the apparatus to which it is connected.

Experimental data and simulations

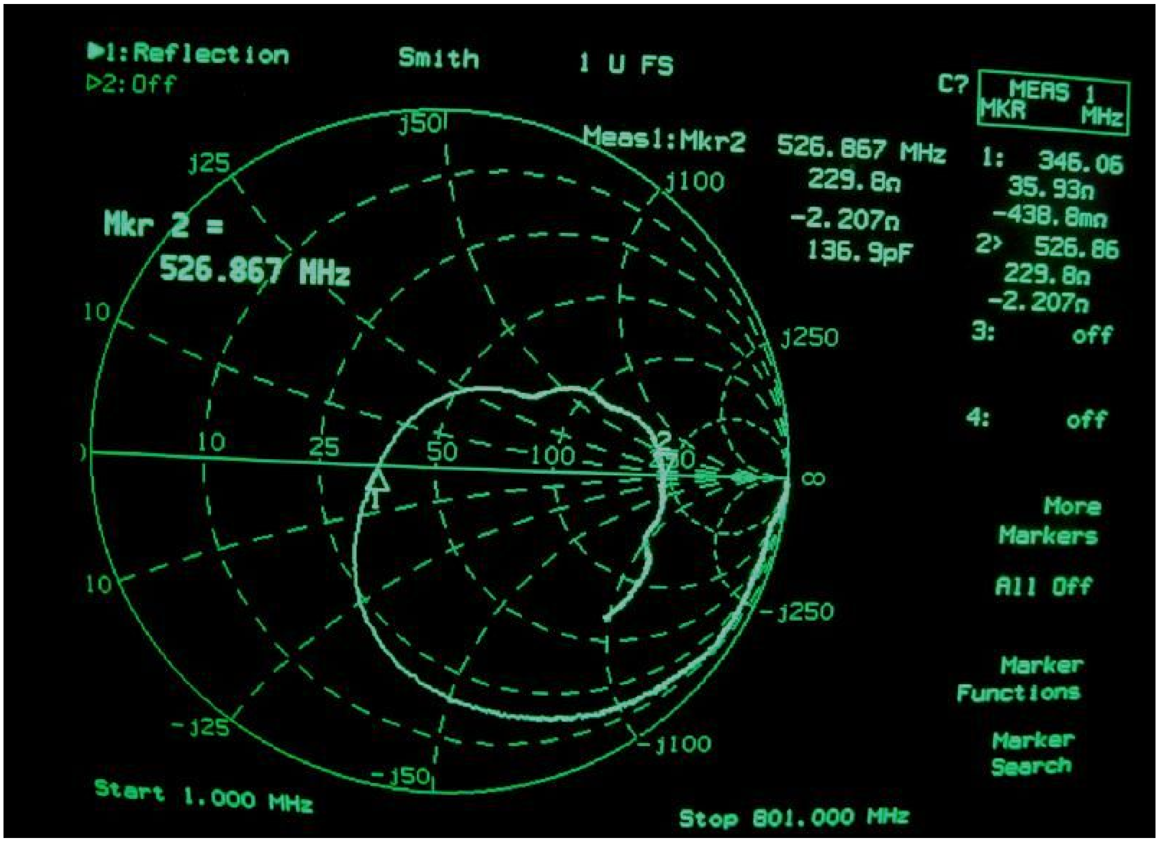


Fig. 8.

For completeness, in **Figure 8** we show the plate Zagi element experimental SMITH chart plot and in **Figure 9** a comparison with a simulation of a grid model, shown in **Figure 3**, over the same frequency range.

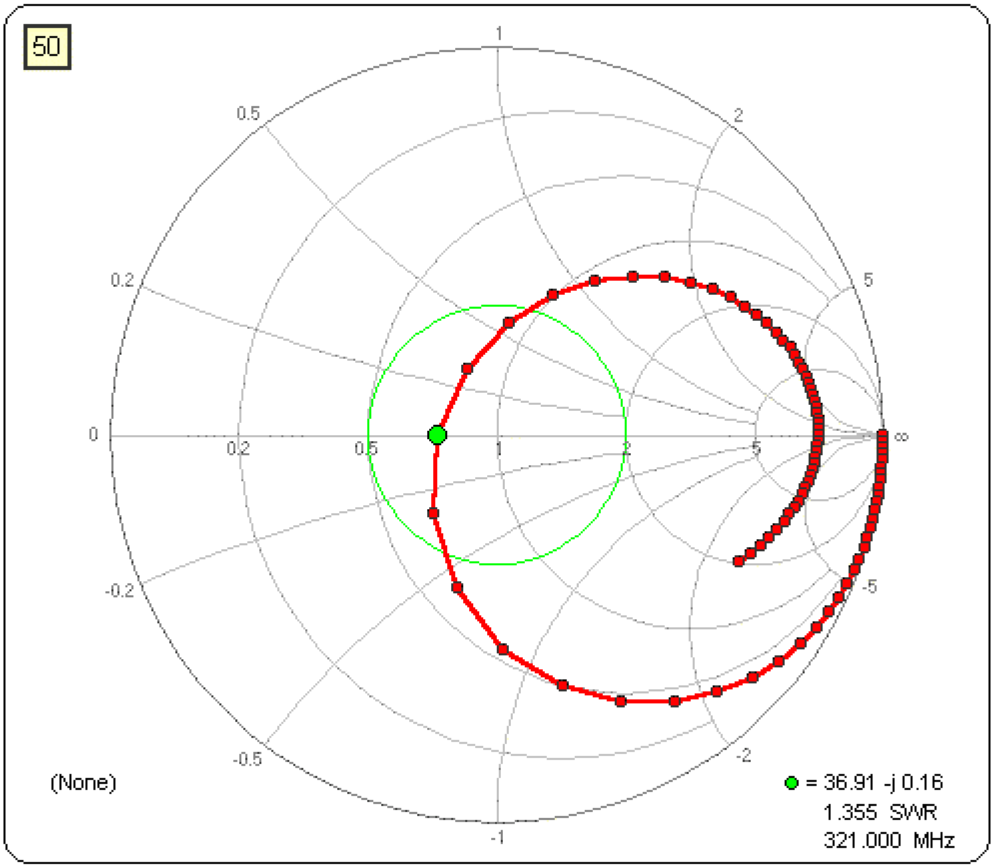
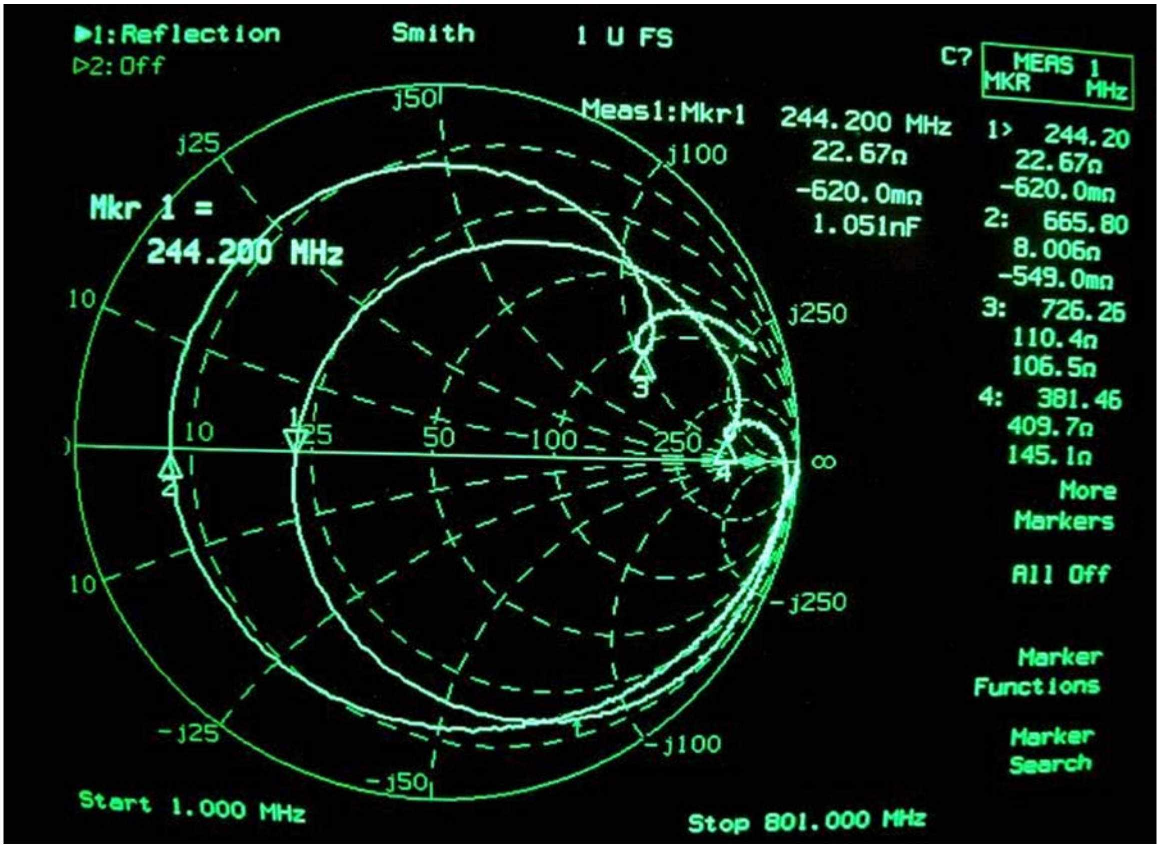


Fig. 9.

Then, in **Figure 10** we show the experimental wire Zagi SMITH chart plot, and in **Figure 11** the simulation of a wire model, shaped as in **Figure 4**, over the same frequency range.



▶1:Reflection
Smith
1 U FS
▷2:Off
C?
MEAS 1
MKR MHz
Meas1:Mkr1
244.200 MHz
22.67Ω
-620.0mΩ
1.051nF
1> 244.20
22.67Ω
-620.0mΩ
2: 665.80
8.006Ω
-549.0mΩ
3: 726.26
110.4Ω
106.5Ω
4: 381.46
409.7Ω
145.1Ω
More
Markers
All Off
Marker
Functions
Marker
Search
Mkr 1 =
244.200 MHz
j50
j25
j100
j250
10
25
50
100
250
∞
-j25
-j50
-j100
-j250
Start 1.000 MHz
Stop 801.000 MHz

Fig. 10.

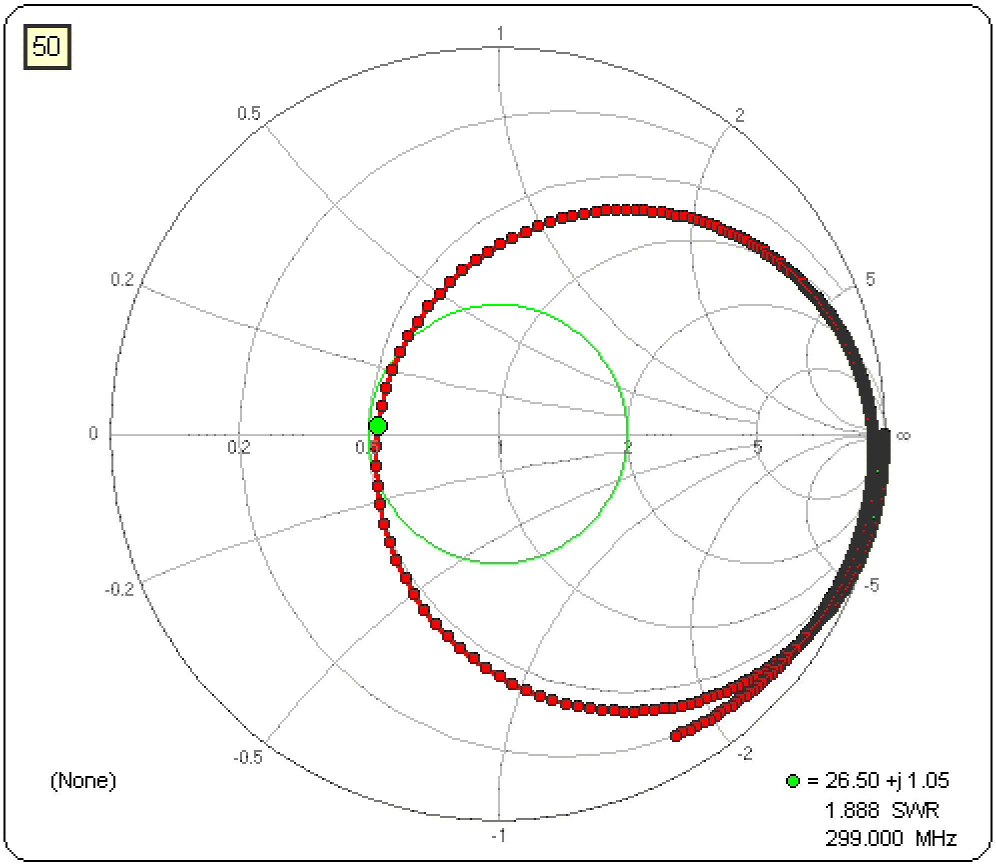


Fig. 11.

It was felt that the triangular Zagi in **Figure 4** could not adequately model the quasi-sinusoidal shape of the wire Zagi, as shown in **Figure 1**. The experimental antenna has clearly more wire in its folds than does the triangular model. Therefore an alternative NEC model, using rectangular folding, was tried.

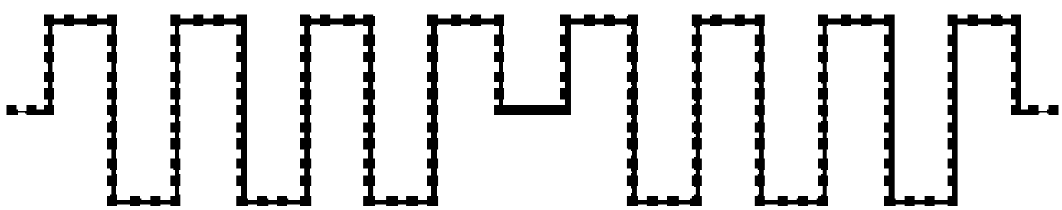


Fig. 12.

In **Figure 12** we show the alternative rectangular model approximation to our bent-wire Zagi element. When the dimensions of this model are adjusted so that it has the same total length of wire as the hardware version, we obtained the improved simulation (shown in **Figure 13**) which agrees more closely with the experimental plot of **Figure 10**.

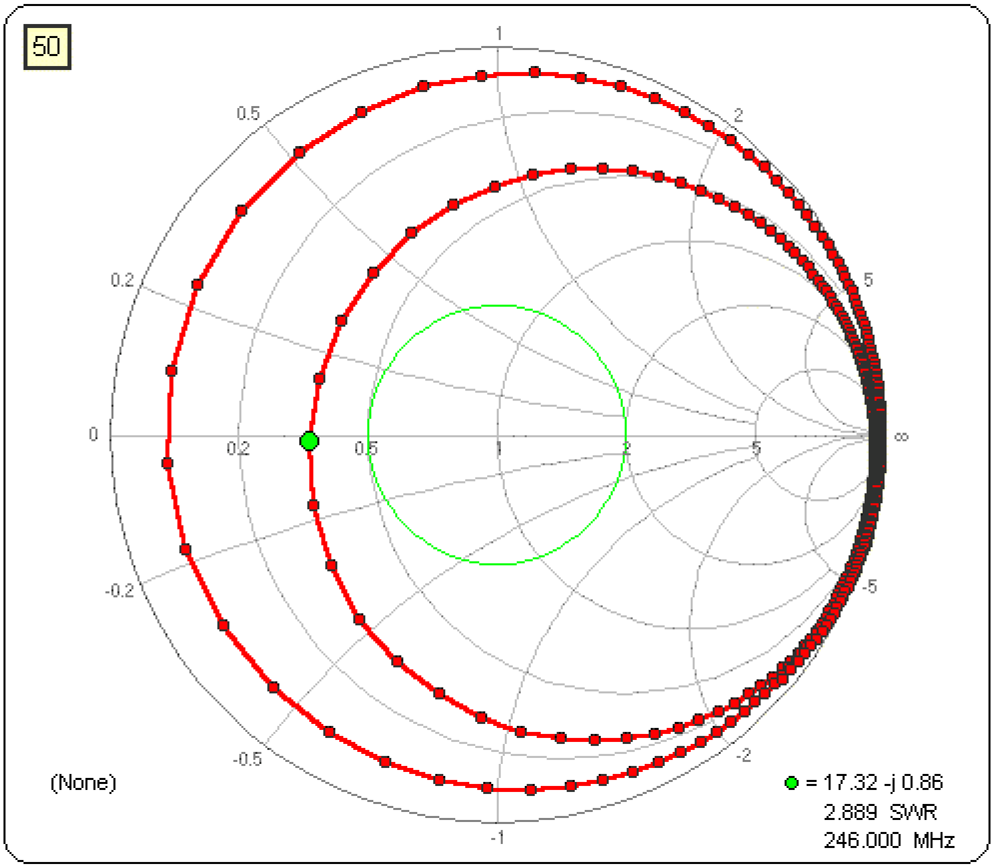


Fig. 13.

More careful construction of another wire Zagi was then attempted, and the simulation of this one, which can be more accurately described in geometry by the NEC model, produces most satisfactory agreement with the experimental data. The radiation pattern is indistinguishable from that of a straight rod dipole, and the boresight gain simulates to be 2.06 dBi. The reduction from the expected directivity of a half wave dipole is due to the resistive loss in the copper.

Conclusions

This work is still in progress. It is possible that slow wave structure antennas similar to this have been tried and reported in the professional literature, but we believe that this important class of antenna should be brought to the attention of amateurs, as they are not difficult to design, build, and model, and have the potential for useful performance improvements. *antenneX* magazine has a track record of encouraging compact antenna designs.

It would be desirable to build and measure multi-element Zagi antenna designs, to verify the NEC simulation figures on terminal resistance and on radiation pattern. We believe that these measurements may be very much harder to get right than the SMITH plots we have presented here. Nevertheless, we are intending to measure the coupling between two Zagi elements spaced further apart than their joint Rayleigh distances, and to explore the sensitivity of the measured radiation pattern to local laboratory disturbances. It appears that there is no problem with the accuracy of the NEC modelling for this class of antenna, other than with the problem of sensitivity to design parameters.

We can envisage all kinds of alternative geometry of antenna elements, which might achieve the slow wave property needed for Zagi antenna designs. It would provide a very fertile ground for those people seeking a novel patent, and indeed, for patent lawyers. It may not even be necessary for the perturbing structure to be electrically physically connected to the main antenna. This gives interesting possibilities for constructing micro-structures for radiation up to the THz range of frequencies.

We hope that these articles on the Zagi antennas will be of some interest to readers of *antenneX*, and provoke experiment as well as some thought. In this current article we have presented empirical data that confirm the basic idea and the initial simulations.

Happy experimenting… **-30-**

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Dan was first licensed as WA2BCG in 1957at age 13. He became interested in antennas at that time when he had to figure out a way to operate from the 6th floor of his apartment house. This resulted in a mobile whip being stuck out from a window without a counterpoise. At that point he became an "expert" in TVI. He was licensed as N2DT in 1977 and is a DX'er and contester. He is now playing with experimental antennas and low power.

Professionally, he is a Pediatric Endocrinologist and holds M.D. and J.D. degrees and is Clinical Professor of Pediatrics at the New York Medical College. As far as his antenna work he is an "amateur" in the truest sense of the word (Dan's words!).

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