

A study on vertical-tower interactions

Rudy Severns N6LF

Introduction

Single verticals and arrays of vertical elements are widely used by amateurs on the lower bands, 160m-40m. Unfortunately a typical amateur installation is likely to have one or more towers (with one or more antennas mounted on them) in the area where a vertical is to be erected. As a practical matter most sites will not allow the vertical to be spaced many wavelengths away from the existing tower(s). Very likely the vertical will have to be spaced less than one wavelength from the tower (>270' on 80m) and in some cases the spacing may be much less. For these close spacings it is almost a certainty that the tower will interact with the vertical, degrading or at least altering its performance in some way. As we will see shortly, the tower does not have to be resonant at the operating frequency of the vertical to be a problem.

There is nothing new in this observation but I have not seen a careful exposition quantifying the problems of vertical-tower interactions and so I was curious as to just how much affect towers would actually have. It's well known that a tower near resonance can act as either a director or reflector and greatly distort the pattern but I wondered what happens when the tower is not near resonance.

There are at least three ways in which a tower could degrade the performance of a vertical:

- 1) pattern distortion
- 2) increased ground loss
- 3) altered feedpoint impedance

The possibility of shape and magnitude distortion of the pattern is usually the first concern. However, we also have to keep in mind that if there is interaction there will be currents induced in the tower and if the tower is grounded (the usual case!) current will flow in the ground system. Very often towers are not themselves being used as vertical radiators and the associated ground system may be very simple. This means that there can be substantial loss in the ground system which represents power radiated by the vertical, coupled to the tower and then dissipated in the soil. In a single vertical, modifications to the input impedance by the presence of a tower may not be all that hard to deal with, just modify the matching arrangements a bit. But in the case of an array with multiple verticals, changes in the feedpoint impedances and coupling between the elements can be a serious problem. This is especially true if the tower is sited asymmetrically to the array. The result is that each element behaves somewhat differently and while you might be able to tune the feed network to get the correct current amplitudes and phases in one direction, when you try to switch the network to rotate the pattern, the feed network may see a very different set of impedances. The result could be a very distorted pattern. Even if you can tune the feed network to give the desired currents the tower is still a radiating part of the array and the pattern will be distorted.

I decided to explore these problems via a NEC modeling study and follow that with a series of field experiments on actual towers. The following is a discussion of the results of NEC study. The experimental work will be reported in subsequent articles.

The EZNEC model

A sketch of the EZNEC model is shown in figure 1.

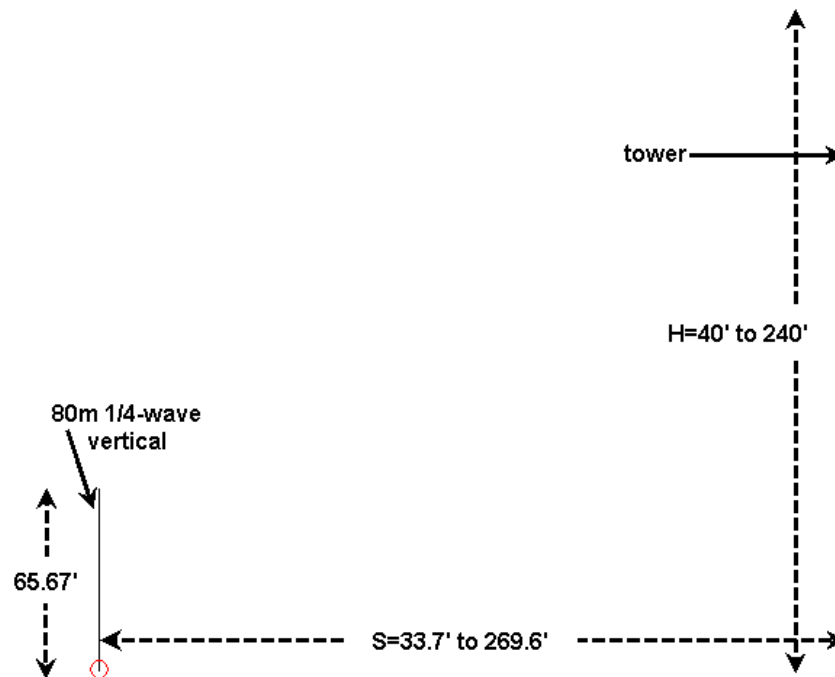


Figure 1, EZNEC model used for the vertical-tower interaction study.

The vertical was a #12 wire resonant at 3.650 MHz without the tower. All of the modeling was done at 3.650 MHz. The tower height (H) was varied from 40' to 240'. This covered the range from below 1/4-wave resonance to above 3/4-wave resonance at 3.650 MHz (for the tower). The spacing between the tower and the vertical (S) was varied from 33.7' (1/8-wavelength) to 269.6' (1-wavelength) in 1/8-wave steps. At each value of S, H was varied from 40' to 240' and the input impedance and pattern noted. The conductors were assumed to be perfect as was the ground.

This is a very simple model but I felt that it would still shed light on the kind of problems to expect and shed some light on possible remedies. In particular I wanted to see if the tower would have a significant effect even when it was nowhere near resonance at 3.650 MHz. Obviously real towers are usually more complicated, with one or more Yagis and other antennas mounted at various points. In a particular situation it would be a very good idea to model the actual arrangements.

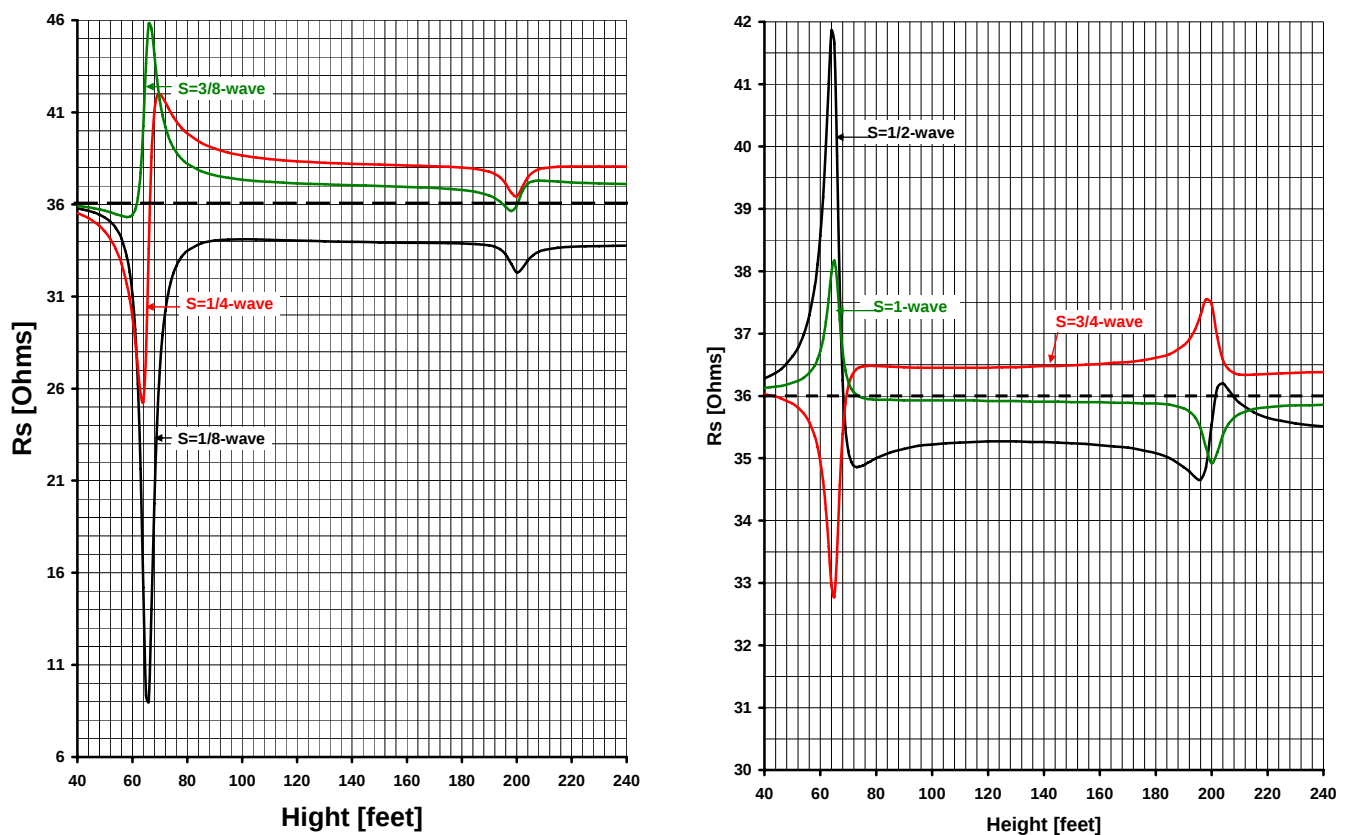
Two tower configurations were examined: first, with the tower grounded and second, with a gap between the bottom of the tower and ground. While most towers will be grounded it is important to look at the case where a tuned shunt loop is placed at the base to detune the tower. This can result

in 1/2-wave resonances which can also interact with the vertical. This relates to the problem of where to place a decoupling element. I haven't explored all the possibilities but I've made a start by moving the "gap" up into the tower for a couple of examples.

Keep in mind that during the modeling only the vertical is excited directly, the tower is a parasitic element, and the frequency of excitation is constant at 3.650 MHz.

Modeling results

Figure 1 illustrates the effect of coupling on the resistive part of the input impedance (R_s) and figure 2 shows the effect on the reactive part (X_s). In figures 1 through 6 the base of the tower is grounded.



Figures 1, resistive part of the feedpoint impedance (R_s) as a function of tower height and spacing. $S=1/8$ to $3/8$ -wave on the left and $1/2$ to 1-wavelength on the right.

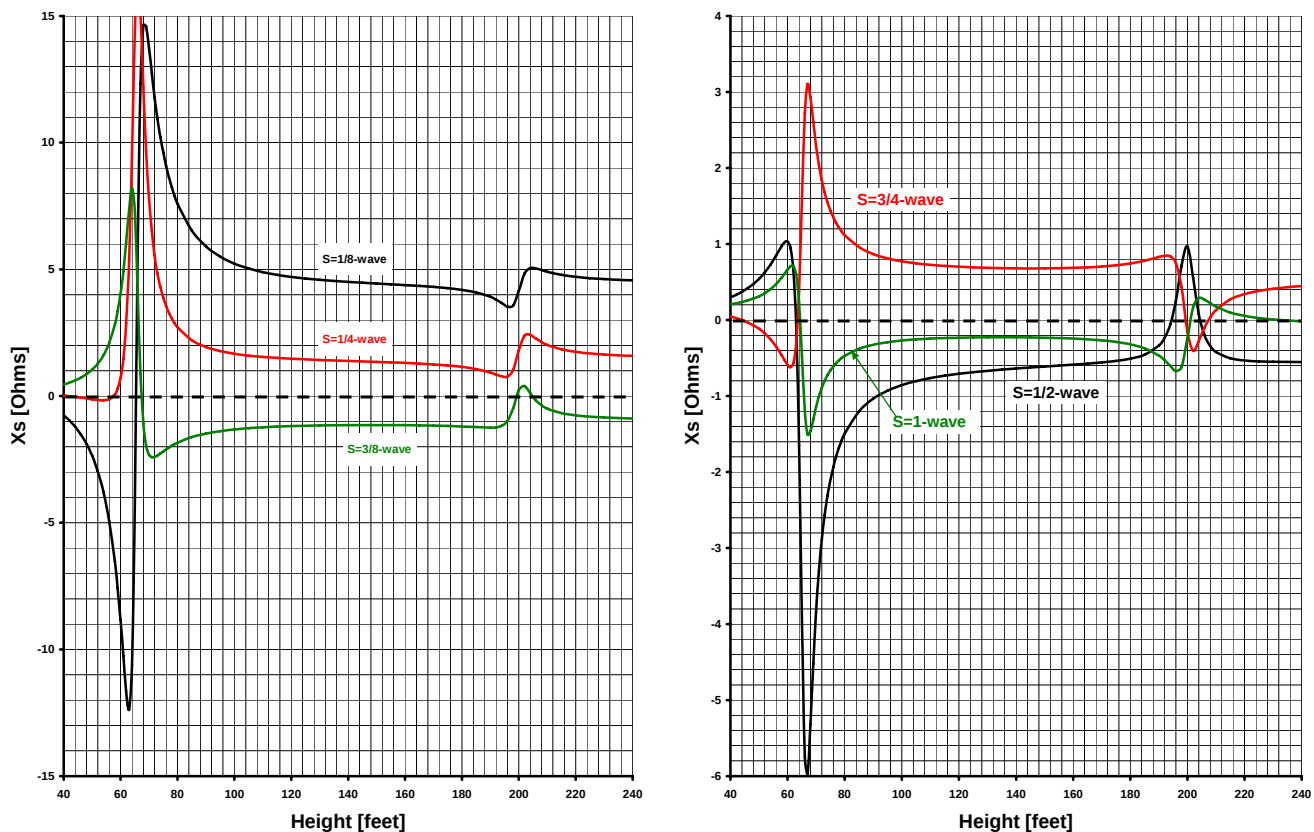


Figure 2, reactive part of the feedpoint impedance (X_s) as a function of tower height and spacing. $S=1/8$ to $3/8$ -wave on the left and $1/2$ to 1 -wavelength on the right.

The graphs show us the following:

- 1) The greatest effect on impedance is around the two resonant modes for the tower, $1/4$ -wave and $3/4$ -wave.
- 2) The effect for the $3/4$ -wave mode is noticeably smaller than that for the $1/4$ -wave mode.
- 3) As S increases the interaction decreases but even at one wavelength there is still some effect.
- 4) For tower heights away from the resonant modes, there is still a very substantial effect, especially at the smaller values of S .

Items 1 through 3 are expected, certainly no surprises there except perhaps that even at one wavelength there is still substantial coupling.

Item 4 however, is a bit of a surprise and is very important. Basically it says that the even if the tower is not resonant anywhere near the operating frequency of the vertical there can still be substantial interaction!

What about the effect on the pattern? One way to explore this is to look at the front-to-back ratio (F/B) of the pattern as we vary H and S. This does not give a full picture but it's a start. Figure 3 is a graph of F/B for several values of S.

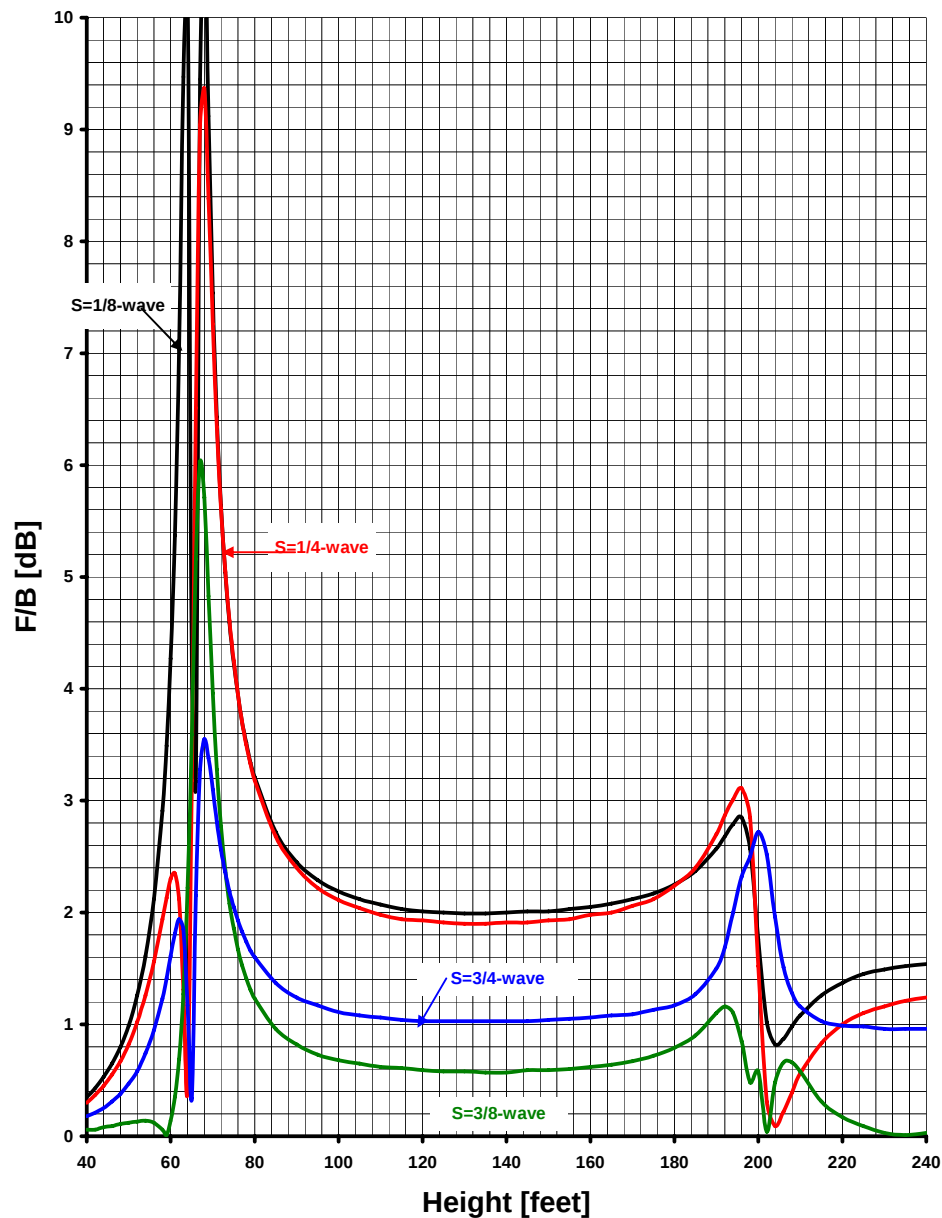


Figure 3, F/B as a function of S and H.

It's no surprise that near the 1/4 and 3/4-wave tower modes that the pattern distortion is very large. The tower is acting as either a director or a reflector. The notch around the $H=1/4$ -wave point is the changeover from director to reflector as H is increased. Again, no surprise here but what's disturbing is that even between the two tower resonances there is still substantial pattern distortion even where the tower is not resonant at the operating frequency.

Note that in figure 3 I have not included plots for S=1/2-wave or 1-wave. That's because at these spacings there is very little F/B distortion. Most of the distortion is off to one side. This can be better seen in pattern plots like those in figures 4 and 5. All the patterns are for zero degree elevation.

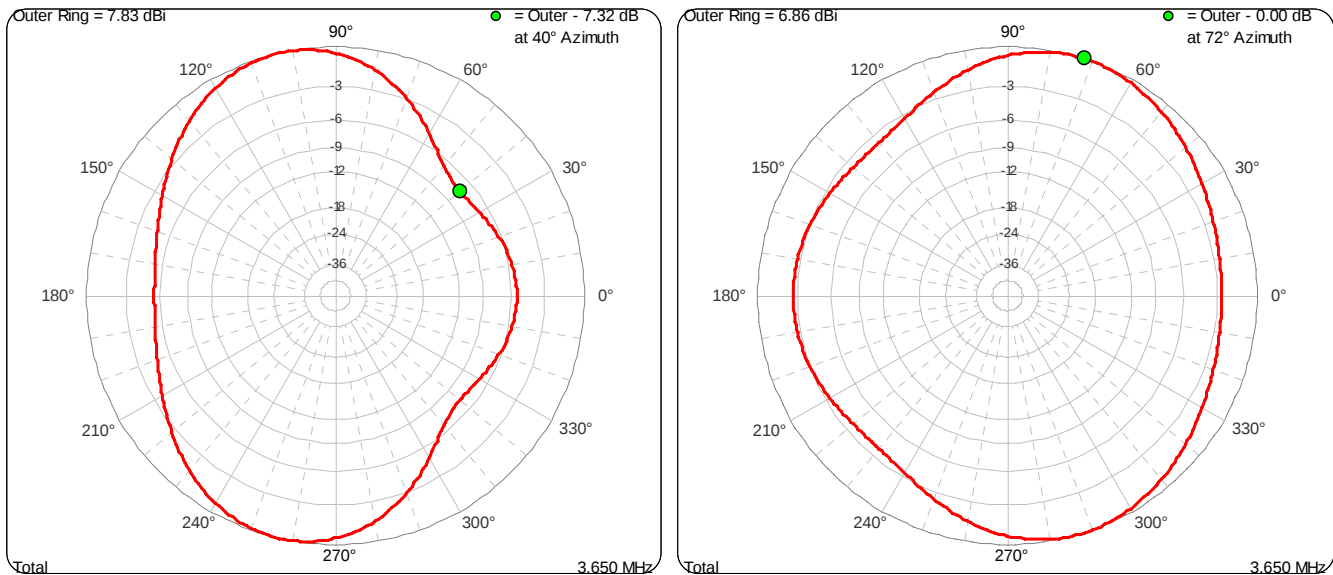


Figure 4, azimuth pattern for H=67' (left) and H=202' (right). S=134.8'.

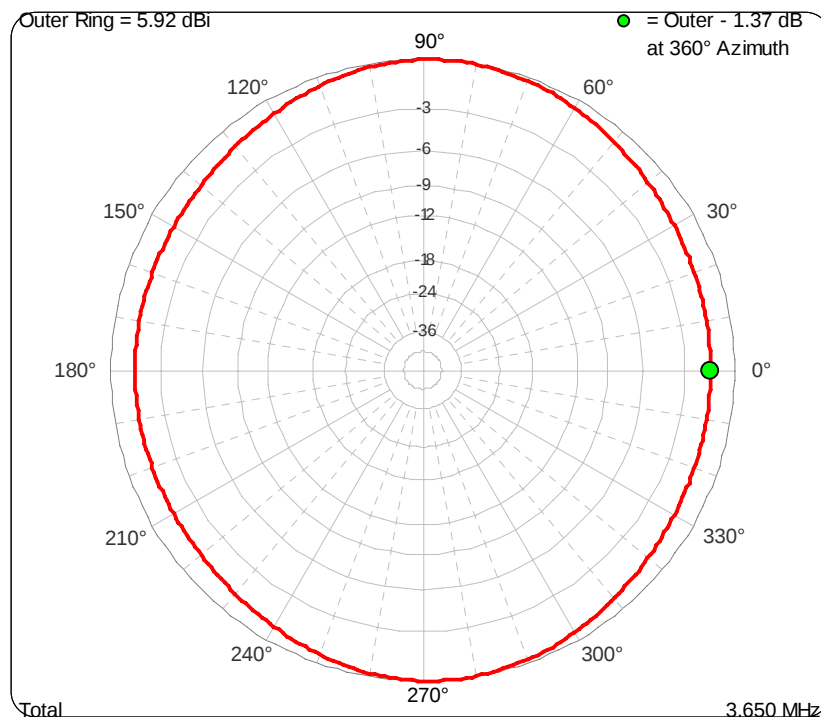


Figure 5, azimuth pattern for H=140' and S=134.8'.

We can increase the spacing to a full wavelength but there will still be a lot of distortion (>3 dB) as shown in figure 6. No matter what the spacing and/or tower height there will be substantial pattern distortion when the tower is within a wavelength of the vertical.

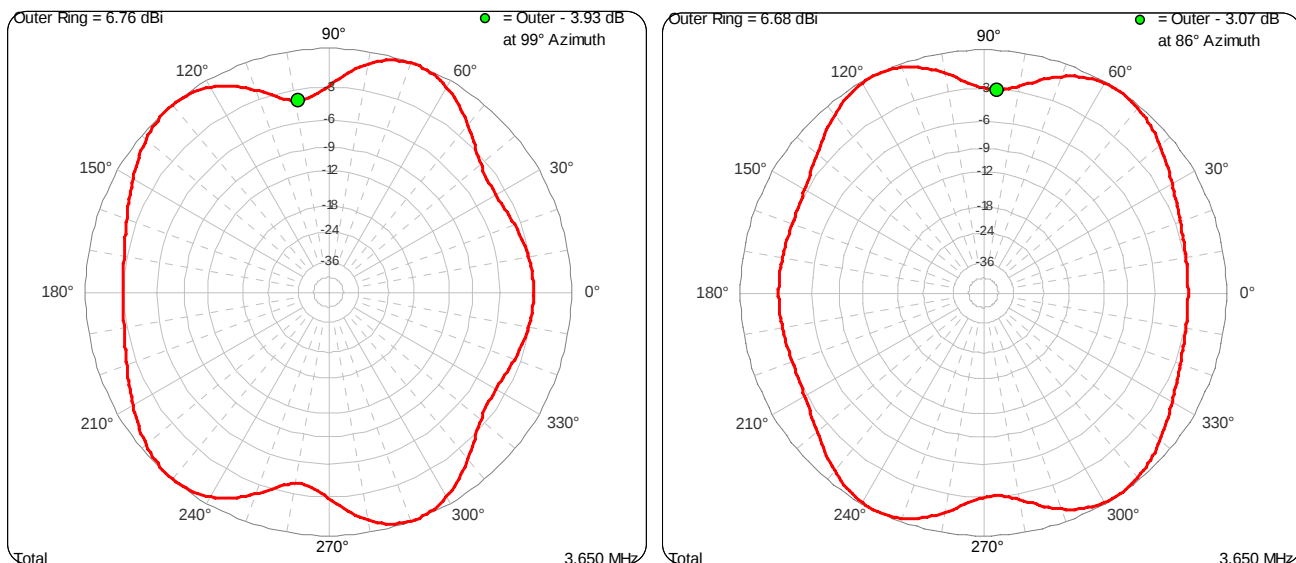


Figure 6, azimuth pattern for H=67' (left) and H=202' (right). S=269.8'.

Decoupling the tower

That's the bad news, now what can we do about it? One very common approach to the problem is to install a loop at the base (or in some cases further up) of the tower and resonate the loop with a series capacitor so that it behaves like a parallel resonant trap in series with the tower. Figure 7 is picture of a typical installation.



Figure 7, example of a shunt loop at the base of a tower. The loop is resonated with a series capacitor to form a parallel resonant trap, decoupling the base and the tower over a narrow range of frequencies.

We can model this situation by disconnecting the base of the tower from ground in the model. Comparisons between tower base short-circuited (s/c) and open-circuited (o/c) are given in figures 8 through 11. For these figures $S=134.8'$ (1/2-wave) and $H=67'$ (1/4-wave) or $202'$ (3/4-wave). The results shown are for a particular spacing but other spacings give very similar results.

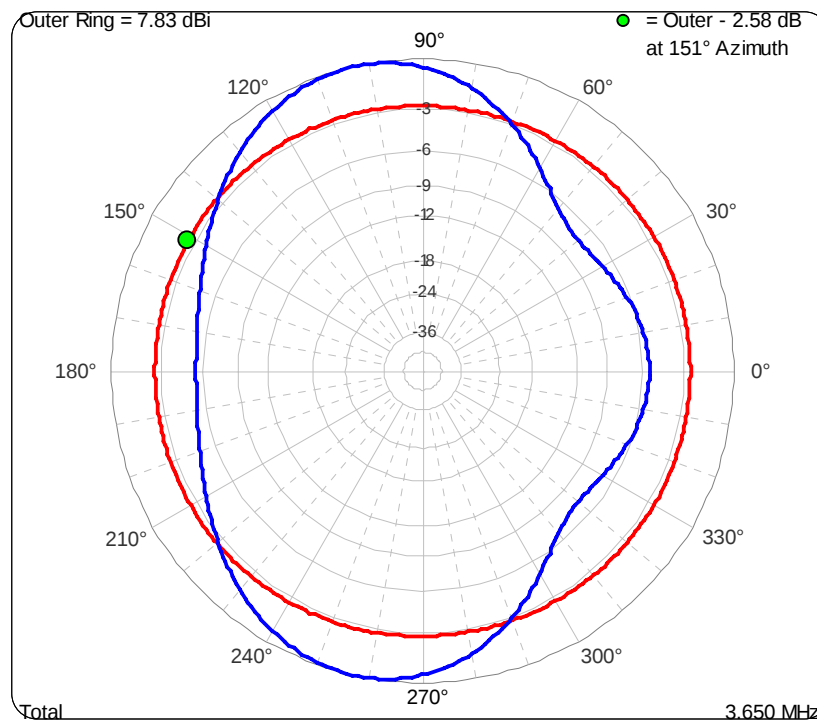


Figure 8, $H=67'$ and $S=134.8'$ with base o/c (red) and s/c (blue).

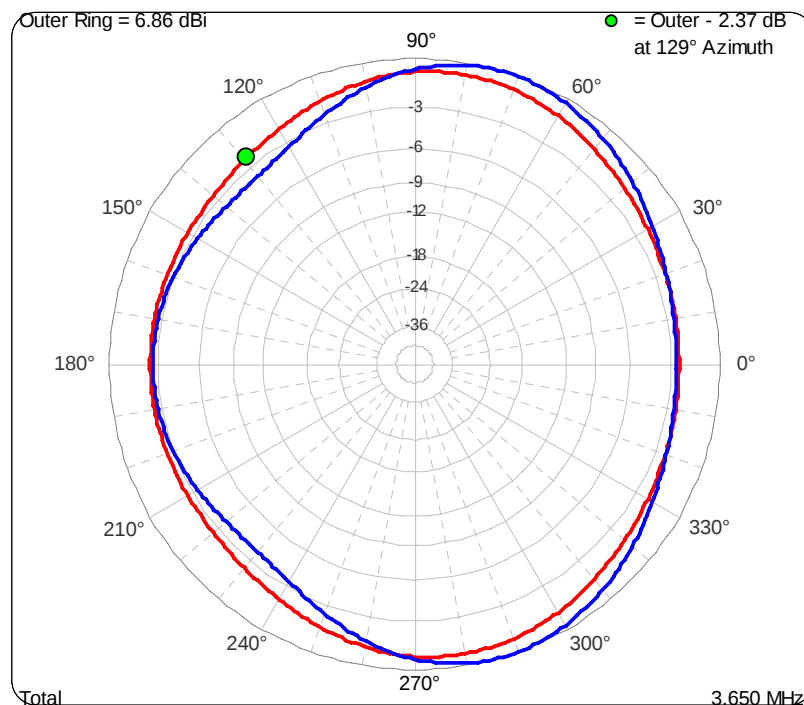


Figure 9, $H=202'$ and $S=134.8'$ with base o/c (red) and s/c (blue).

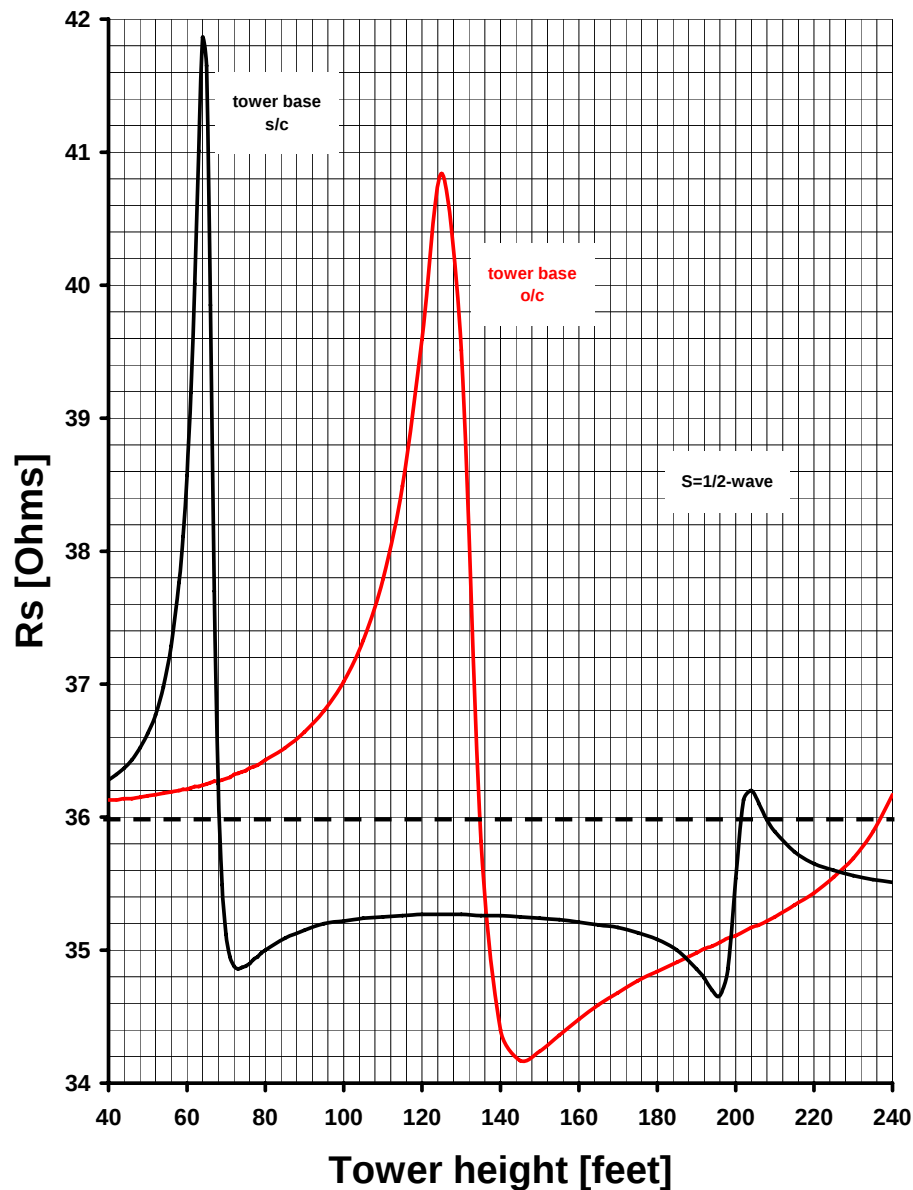


Figure 10, Rs comparison with the tower base s/c and o/c for $S=1/8$ -wave (left) and $1/2$ -wave (right).

From figures 8 and 10 we can see that for tower heights in the neighborhood of $1/4$ -wave the series decoupling at the base appears to be very effective. However, as the tower gets taller and approaches $1/2$ -wave resonance, decoupling at the base becomes a very poor idea as indicated by the patterns in figure 11. No surprise here since the tower becomes a $1/2$ -wave vertical isolated from ground in the region around $H=140'$ and we would expect strong interaction. As the tower height approaches $3/4$ -wave there is again some improvement using the trap but it is not as dramatic as it is for the $h=1/4$ -wave case as can be seen in figure 9.

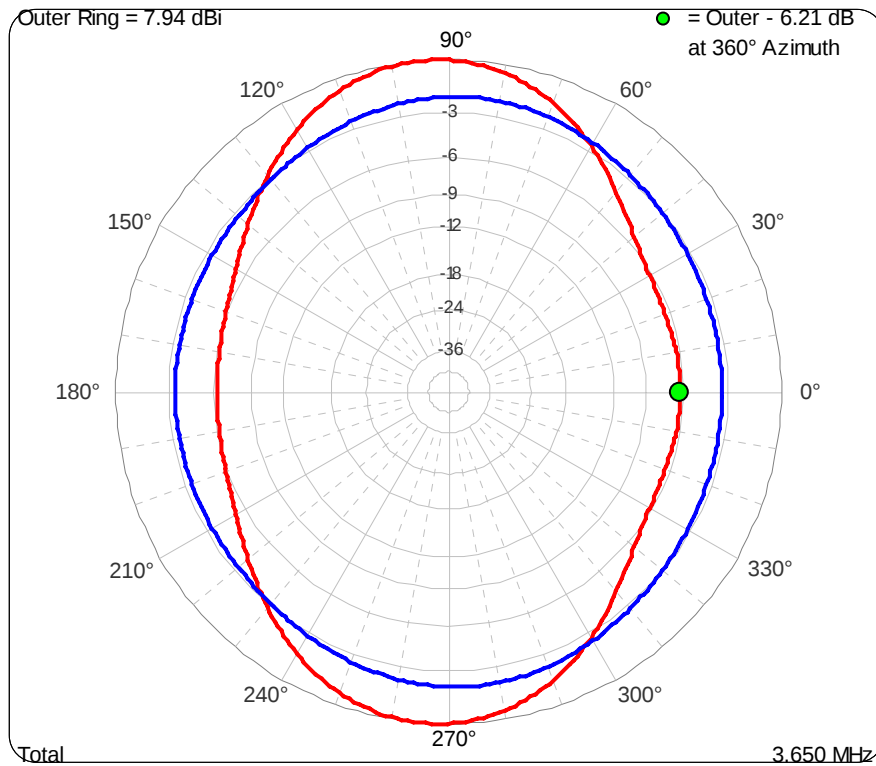


Figure 11, H=140' and S=134.8' with base o/c (red) and s/c (blue).

Locating the trap at the base works very well for resonances around the 1/4-wave height but for taller towers it may be necessary to locate the trap higher up and/or use multiple traps. The situation for taller towers is much more complicated. This is a major reason for wanting to know the actual resonant frequencies of a given tower so you will have some idea of what problem you are dealing with. Techniques for determining the tower resonances are presented in a separate article as part of the experimental work.

Looking at the earlier figures, it's clear that if the tower is only 40' high (about 1/8-wave) the effect on the vertical is small. This suggests that moving the trap up to 35' or 40' would improve decoupling for taller towers. A comparison of Rs between the trap at the base and at 34' is given in figure 12. It's pretty clear that moving trap up on the tower improves the decoupling for greater tower heights.

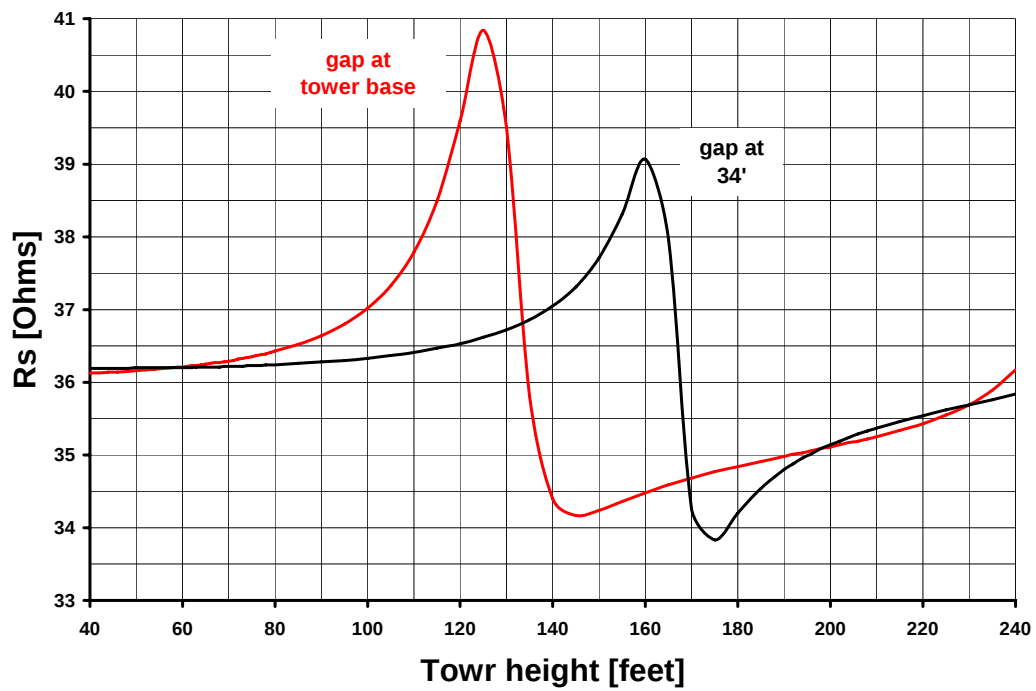


Figure 12, comparison between R_s with the gap at the tower base and at 34' above the base.