Broadband High-Power Pylon Antenna

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Abstract – *Slotted coaxial antennas have many advantages over traditional broadband panel antennas including much smaller size and wind load, higher reliability and a greater degree of azimuth and elevation pattern flexibility. The one disadvantage of slotted coaxial antennas has been their inherently narrow bandwidth. In most applications their usage is only considered for single channel operation, approximately 1% bandwidth for UHF. In the past decade, techniques have been applied to increase the bandwidth, but have been limited to side mounted antenna configurations. Top mounted dual channel operation has historically been accomplished by structurally stacking two single channel antennas on top of each other. A disadvantage of this technique could be the effect of the top antenna's feedline has on the circularity of the bottom antenna since it must run through the bottom antenna's aperture. This paper will go into detail on how new technology has allowed a single broadband pylon antenna to be designed in a free standing, top mount configuration without sacrificing azimuth pattern circularly from the presence of external feedlines or the extra windload associated with two antennas.*

INTRODUCTION

In the communication industry, what is acceptable VSWR varies widely depending on the application. In some cases, such as broadcast, the VSWR must be close to unity where in other cases it can be as high as 10:1. The frequency bandwidth can be expressed as the ratio of the band of operation to the center frequency as a percent:

$$\%bw = \frac{f_h - f_l}{f_0}(100) \quad (1)$$

The natural bandwidth of a coaxial slot radiator is typically on the order of one to two percent depending on the maximum allowable VSWR within the operating bandwidth. The fundamental limitation of a coaxial slot stems from the frequency dependence imposed on the structure by connecting the two sides of the slot together by wrapping the outer conductor to form a cylinder as shown in Figure 1 [1].

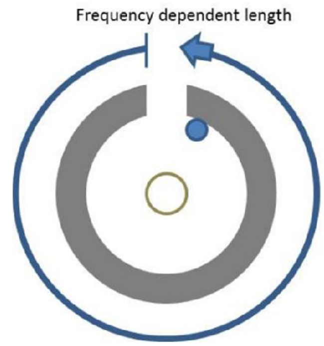


Figure 1: Outer conductor of slotted coaxial antenna creates a frequency dependence causing narrow band operation.

MULTI-SECTIONAL PHASE CANCELLATION

Feeding broadband panel antennas by a corporate feed network is common practice. It provides a stable elevation pattern frequency response and can provide a level of impedance cancellation if phased correctly. The feed system makes use of the fact that multiple voltage reflections from similar unmatched loads can be made to arrive at a common point in the system, in the proper phase relation, causing a net cancellation to occur. The most cost effective, reliable, and lowest wind load method to feed slotted coaxial antennas is to have a single input feeding multiple slots in parallel. This design eliminates feed lines, power dividers and connections, but does not provide broadband performance. In order to take advantage of phase cancellation to extend the impedance bandwidth, the slotted coaxial antenna must be broken down into multiple sections as shown in Figure 2.

Figure 2: Single section vs. multi-section side mounted slotted coaxial antenna designs

To analyze the bandwidth improvement associated with using phase cancellation between antenna sections, an arbitrary number of loads are connected in parallel as shown in Figure 3.

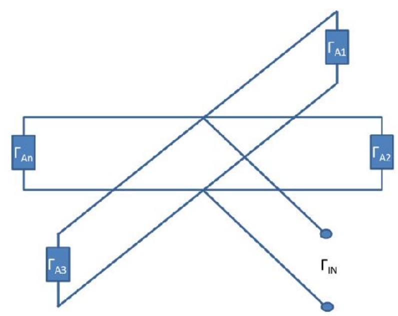


Figure 3: Arbitrary number of loads connected in parallel

Γ_{An} represents the complex reflection coefficient of the individual antenna sections. Assuming the input combining point is matched to the number of loads, the total system input refection coefficient is the summation of the individual loads or antenna sections each with a phase offset $\emptyset_{l_n}$ looking into each feed line at the feed point divided by the number of sections.

$$\Gamma_{IN} = \frac{\sum_{p=1}^{n} \Gamma_{A_n} e^{-j2\pi\emptyset_{l_n}}}{n} \qquad (2)$$

For the case where Γ_{IN}=0, full cancelation of all the loads, the phase offset between the loads must be of the solution:

$$\emptyset_{ln} = \frac{180}{n} \qquad (3)$$

PHASE CANCELATION AND APERTURE EFFICIENCY

Aperture efficiency is the figure of merit which defines how effectively the physical area of the antenna is utilized. The gain for which an antenna can provide is given by [2]:

$$G = \eta\left(\frac{4\pi}{\lambda^2}\right)A \qquad (4)$$

Where η is the aperture efficiency and A is the area the antenna consumes. Large phase spreads reduce the antennas gain and thus the aperture efficiency, so it is not always possible to achieve full cancellation in practical multi-sectional antenna designs. In general, the greater number of sections or load splits, the more efficient the aperture becomes. It is also true that in general, greater number of load splits provide larger operating bandwidth. This is due to reducing the progressive phase runout across the band from loads placed in series as well as reducing load impedance randomness sensitivity. For example, a 20 layer slotted coaxial antenna can provide a maximum rms gain of 24.27. If split into two sections and fed with the optimum phase offset of 90 degrees between sections, the aperture efficiency is reduced to 85%. If partial cancellation is sufficient to achieve the bandwidth requirements, then this can be improved. If that same antenna is split into four sections with an optimum phase offset of 45 degrees, the aperture efficiency is now 95%.

PRCTICAL APPLICATION OF PHASE CANCELLATION TECHNIQUE

Desired null fill and beam tilt also dictate how practical aperture illuminations are applied to multi-sectional slotted coaxial antennas. Large phase spread can cause unwanted excessive beam tilt and low aperture efficiency. It is always a trade-off of trying to provide optimum phase offset while maintaining a desired beam tilt, null fill, and gain. The following example illustrates how a 32 layer slotted coaxial UHF broadcast antenna can be optimized for coverage performance and efficiency while adding phase offset to increase the operating bandwidth for multichannel use. The 32 layers are broken into 4 sets of 8 layers and phased in two levels as shown in Figure 4.

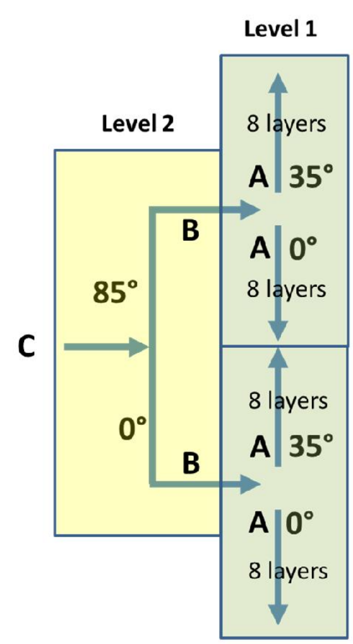


Figure 4: Phase offsets incorporated into a 32 layer coaxial antenna design to provide increased operating bandwidth while maintaining practical elevation pattern parameters.

Figure 5 shows the resulting pattern that can be formed with the phasing shown in Figure 4.

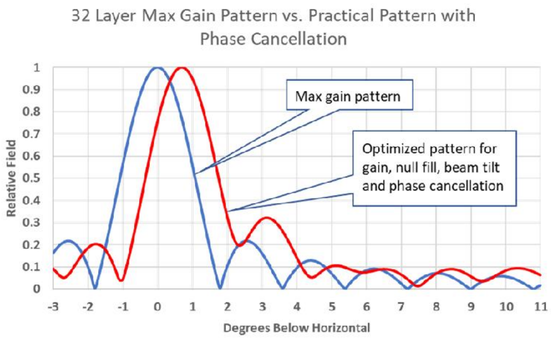


Figure 5: 32 Layer slotted coaxial antenna elevation patterns. Red pattern uses the phase cancellation shown in Figure 4 to increase the operating bandwidth while maintaining .75 degrees of beam tilt, 20% null fill and high gain.

The two level phase offsets used in this example maintain an aperture efficiency over 90%. To determine the maximum increase in bandwidth that can be realized from the phase cancelation scheme, equations 2 and 3 are used along with the appropriate phase runout vs. frequency. A typical slotted coaxial antenna impedance and corresponding VSWR response is shown in Figure 6. This would be the impedance as seen at points A in Figure 4.

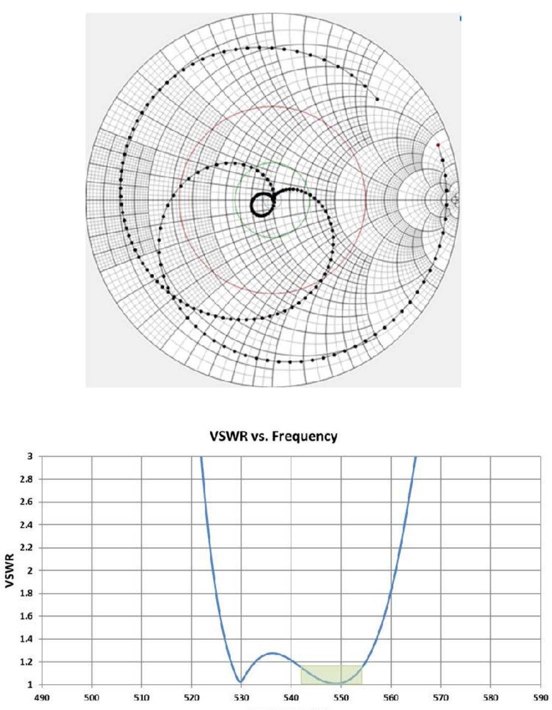


Figure 6: Typical 8 layer slotted coaxial antenna impedance - VSWR response

Note this typical response has 2.0% bandwidth at a maximum allowable VSWR of 1.15:1 as shown in the shaded green area of the VSWR vs. Frequency plot. The impedance at points B in Figure 4 with level 1 cancellation of 35 degree offset is shown in Figure 7.

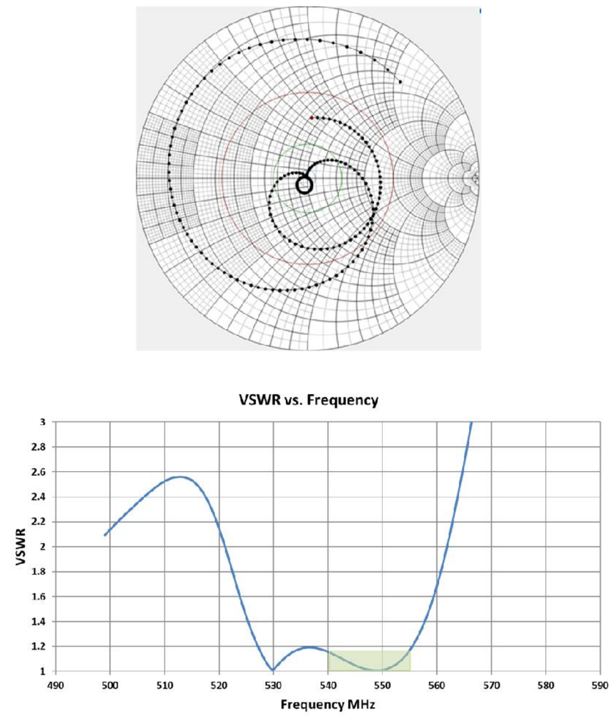
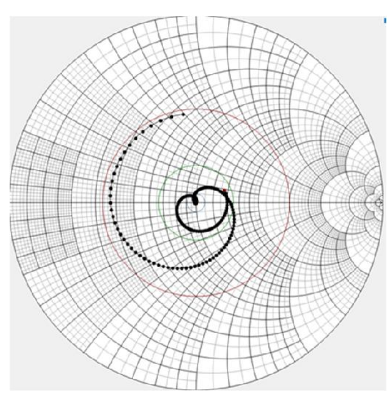


Figure 7: Calculated impedance – VSWR response at points B in Figure 4.

The calculated effect of the impedance summation given the 35 degree offset results in a bandwidth increased to 2.6% for the same allowable VSWR of 1.15:1. Although far from optimal (90 degree offset), this first level of cancellation begins to shrink the impedance spread. Level 2 of cancellation in the example provides 85 degrees of offset. The calculated resulting impedance at point C in Figure 4 is shown in Figure 8.



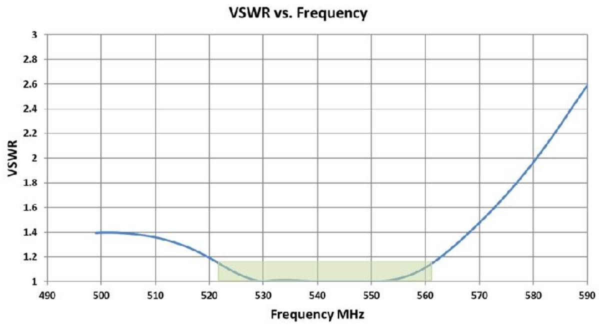


Figure 8: Calculated impedance – VSWR response at points B in Figure 4.

As can be seen, since the 85 degree offset is nearly optimal (90 degrees for two loads as given by equation 3) the usable bandwidth for an allowable VSWR of 1.15:1 has increase to 7.2% for the entire antenna array.

THEORECTICAL VS. PRACTICAL APPLICATION OF PHASE CANCELLATION

It must be noted that the above example provides a theoretical maximum bandwidth. It has assumed that the impedances at points A are all identical. This of course is not realistic since no material or manufacturing tolerances have been accounted for and the power splitting points are assumed to have no impedance contribution. Top mounted pylon broadcast antennas are constructed from steel pipe which is at the mercy of steel tolerancing. Standard industry steel pipe which doubles as the outer conductor as well as structural backbone, typically has a tolerance of 12% for the wall thickness. Depending on pipe size, a 12% variation on the outer conductor of a coaxial line will create a compounding 1.05:1 to 1.2:1 VSWR offset at each layer in the antenna. Therefore, the impedances at points C in the example will not be the same and the actual product bandwidth will be reduced from the theoretical maximum.

REAL DATA - FULL ANTENNA USING TWO LEVEL CANCELLATION

The cited example has been implemented into a high power top mounted pylon antenna design manufactured for channels 26 and 29 combined service in Omaha Nebraska. The 32 layer design used the phasing offset described in Figure 4. Dual feeds are used to center feed the bottom half of the antenna from the bottom and center feed the top half of the antenna from the top. Each feed uses layered inner conductors called a triax. The triax's inner conductor becomes the antenna inner for one half and the outer becomes the antenna inner for the opposite half. Refer to figure 9.

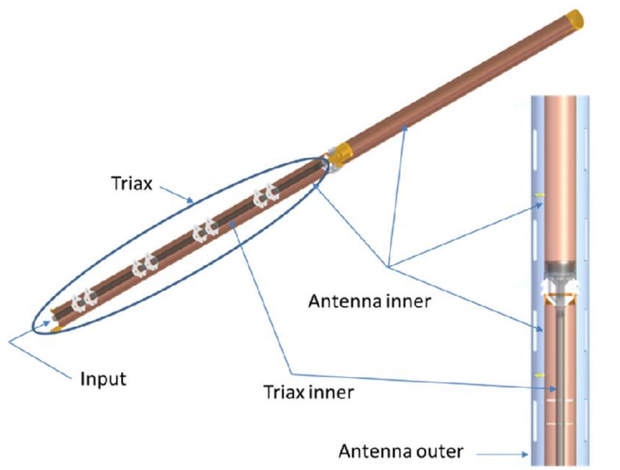


Figure 9: Center feeding a slotted coaxial antenna with layered inner conductors called a triax

The full antenna design is shown in Figure 10 and pictures of the design before shipment in Figure 11.

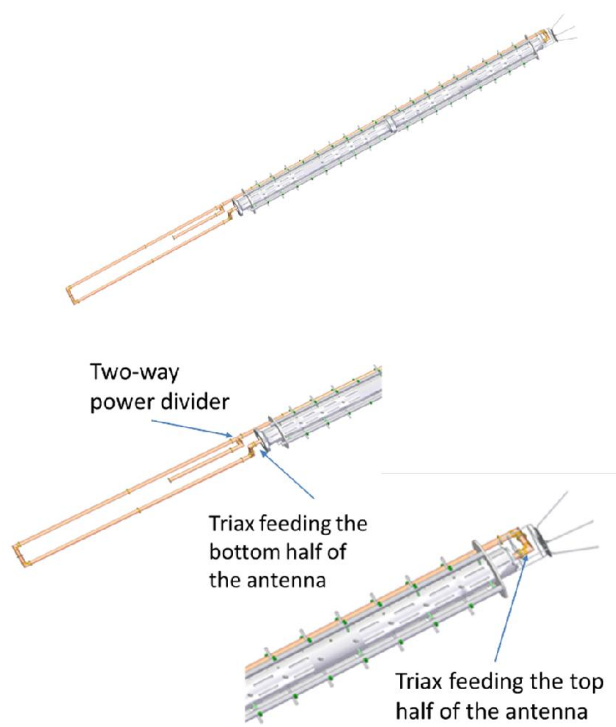


Figure 10: Full antenna design manufactured for Omaha utilizing the phase cancellation scheme shown in Figure 4.

Figure 10: Full antenna design manufactured for Omaha utilizing the phase cancellation scheme shown in Figure 4.

The Omaha antenna was tested in October of 2021 proving broadband performance. The measured VSWR vs. frequency is shown in Figure 11.

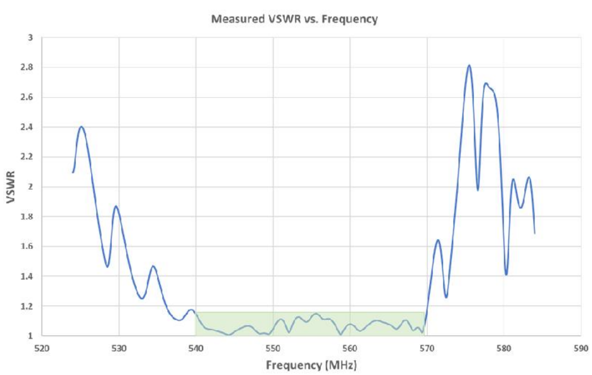


Figure 11: Measured VSWR vs. frequency. Omaha antenna based on phase cancellation scheme shown in Figure 4.

The usable measured bandwidth for a maximum allowable VSWR of 1.15 is found to be 5.4%. This value is 75% of the theoretical maximum calculated earlier. The reduction is to be expected and the 75% value would appear to be a good rule of thumb for practical designing.

AZIMUTH PATTERN CIRCULARITY

Top mounted dual channel operation has historically been accomplished by structurally stacking two single channel antennas on top of each other such as the stack shown in Figure 12. A disadvantage of this technique could be the effect of the top antenna's feedline has on the circularity of the bottom antenna. Depending on the power level, which dictates the transmission line size, and the shape of the azimuth pattern, the circularity of the lower antenna could be compromised on the order of one to two decibels.

Figure 12: Stacked UHF antenna configuration.

If the antenna is circularity or elliptically polarized, the vertical components circularity is typically worse due to the fact that the transmission line is placed in the vertical plane. A typical set of elliptically polarized omni / omni stacked antenna patterns at UHF usually look similar to Figure 13.

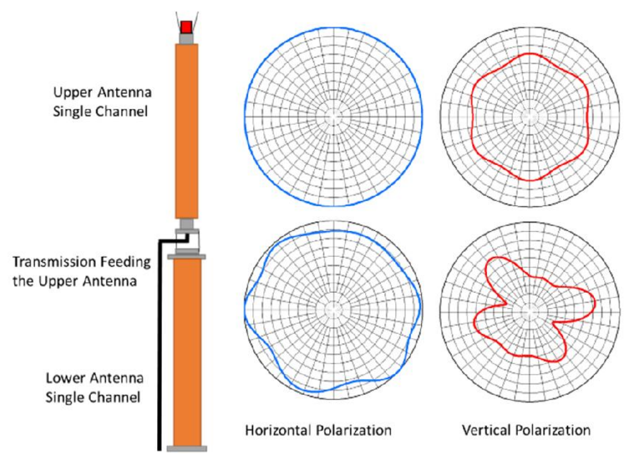


Figure 13: Stacked UHF antenna azimuth patterns. Note the bottom antenna's circularity is affected by the transmission line running up the side of the antenna to feed the upper antenna.

Another disadvantage of the stack configuration is the extra weight and windload of the second antenna. The development of a new approach has led to improving the circularity of an omni UHF slotted coaxial when transmission lines are placed in its aperture. This is especially true for the vertical polarization. This is accomplished by placing four symmetrical cylindrical lines around the aperture instead of one. The new approach also accommodates more than one channel thus not needing the second antenna of a stack. This technique was used in Omaha Nebraska and utilized the antenna design described in the previous section. Since only a single feed was necessary to run through the aperture to the upper feed point, three "dummy" parasitic lines are used in conjunction to the live line. This is shown in Figure 14.

Figure 14: Live and dummy transmission lines placed around the antenna aperture to improve the circularity.

A comparison of the azimuth patterns with only the one single active transmission line verses the addition of three parasitic dummy lines are shown in Figure 15.

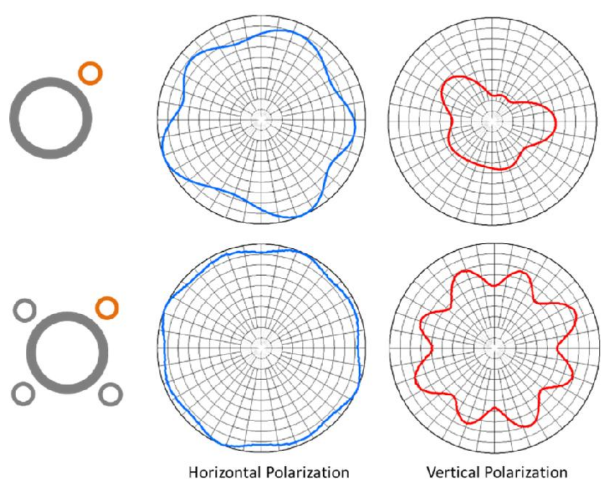


Figure 15: Comparison of the Omaha azimuth patterns with a single transmission line verses the addition of 3 extra dummy lines.

EXPANDING PATTERN CIRCULARITITY IMPROVEMENT TECHNIQUE TO BROADER BAND APPLICATIONS

In the previous design scheme, only one of the four lines running through the aperture serves a feed purpose. If the other three were used as transmission lines instead of dummy parasitics, then more feed point could be added to the array. As previously discussed, if more feed points are added, then the operating bandwidth can be increased using phase cancellation. In a 32 layer design similar to the Omaha design, each of the four lines can be used to center feed four sections of 8 layers. This doubles the number of load sections shown in Figure 4. The phase offsets used in this new design are shown in Figure 16. The elevation pattern produced by the phase cancellation scheme shown in Figure 16 has the same electrical characteristics (beam tilt, null fill and gain) as that shown in Figure 5. Figure 17 depicts the full antenna design utilizing the phase cancellation scheme shown in Figure 16.

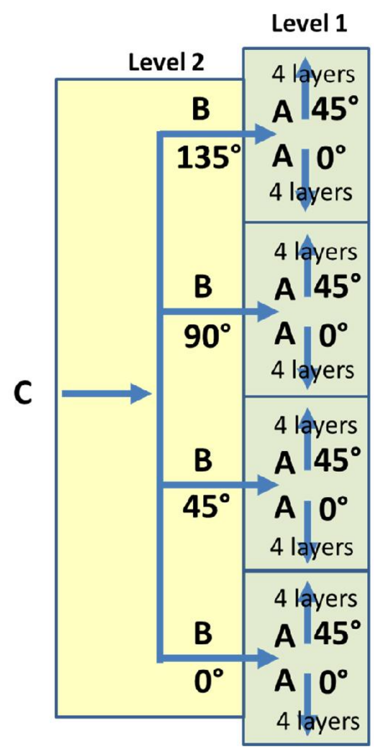


Figure 16: Phase offsets incorporated into a 32 layer coaxial antenna design to provide more operating bandwidth then the scheme shown in Figure 4.

To analyze the maximum increase in expected bandwidth the quad-feed phase cancellation design can provide, we again can use the typical slotted coaxial antenna impedance shown in Figure 6 as our load impedances at points A in Figure 16. Again, note this typical response has 2.0% bandwidth at a maximum allowable VSWR of 1.15:1. The impedance at points B in Figure 16 with level 1 cancellation of 45 degree offset is shown in Figure 18.

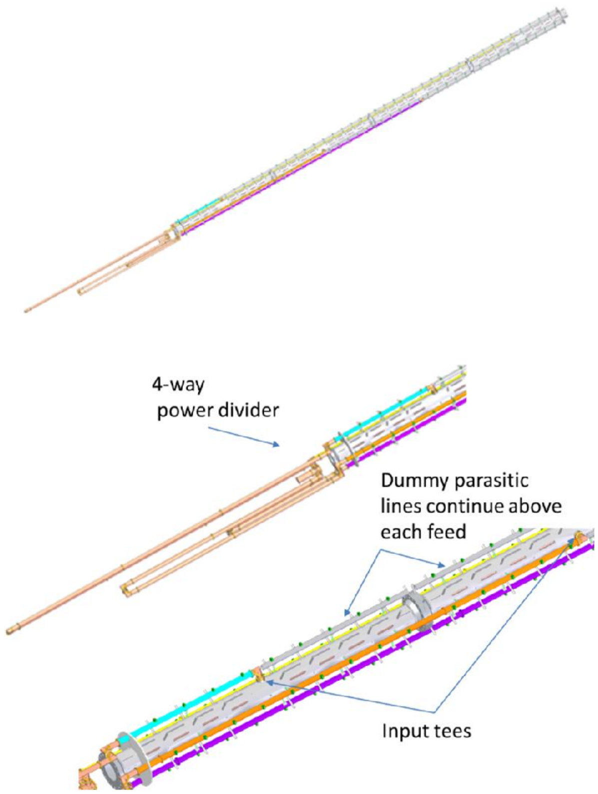
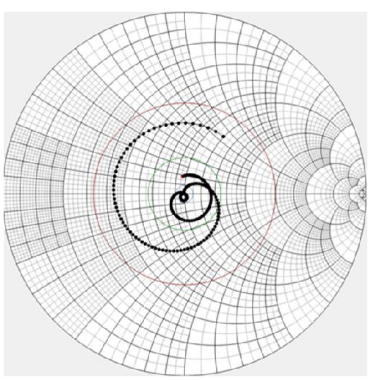


Figure 17: Full antenna design utilizing four tee feeds for the phase cancellation scheme shown in Figure 16.



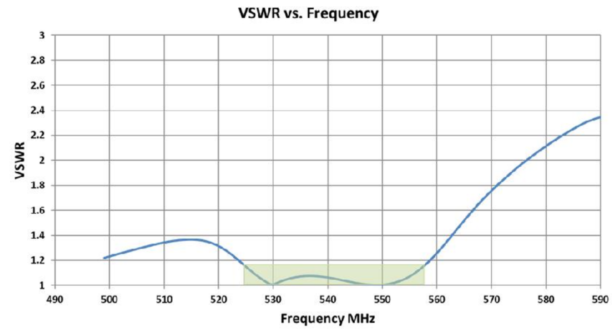


Figure 18: Calculated impedance – VSWR response at points B in Figure 16.

The calculated effect of the impedance summation in this case, given the 45 degree offset, results in a bandwidth increase to 5.8% for the same allowable VSWR of 1.15:1. As seen again, this first level of cancellation shrinks the impedance spread. Level 2 of cancellation for the four feed design uses a 0,45,90,135 degree phase offset. Referring to equation 3, this is optimal. The calculated resulting impedance at point C in Figure 16 is shown in Figure 19.

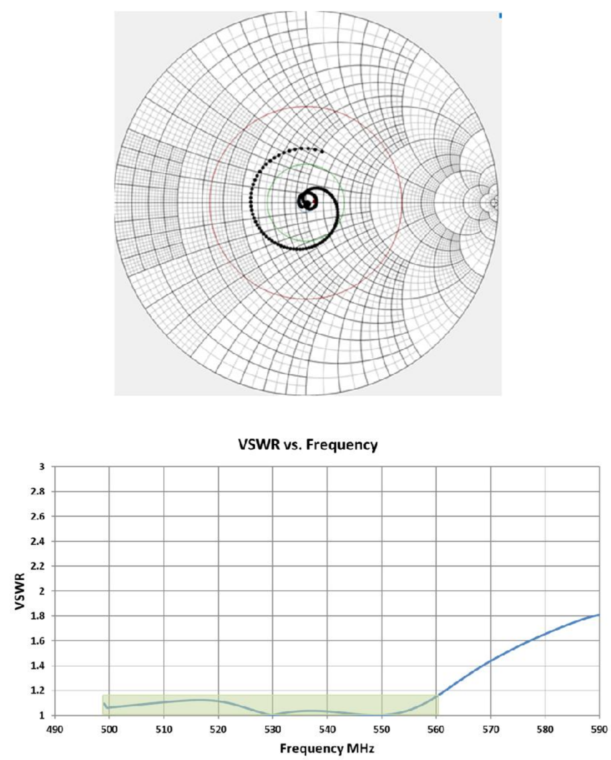


Figure 19: Calculated impedance – VSWR response at point C in Figure 16.

The usable bandwidth for an allowable VSWR of 1.15:1 has increase to 11.8% for the entire antenna array. This is substantially higher than the dual triax design discussed earlier. If the 75% rule of thumb is applied to the quad tee design, the overall expected operating bandwidth is 8.9% which can effectively cover eight UHF channels.

CONCLUSION

It has been shown that high power top mounted slotted coaxial broadcast antennas can be used for broadband multi-channel applications. The new technology provides a lower cost, lower windload and more reliable alternative to panel antennas. This is done by applying phase cancelation through multiple feeds. The effect external transmission lines, used for the multiple feeds, has on the circularity of the azimuth pattern can be greatly minimized through the use of parasitic tubes near the surface of the aperture.

REFERENCES

[1] John L. Schadler, "Broadband Slotted Coaxial Broadcast Antenna Technology", White Paper, www.dielectric.com, 2014

[2] Warren L. Stutzman, Gary A Thiele, "Antenna Theory and Design" John Wiley & Sons, 1981