AM Antenna Broadbanding

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Abstract

As implementation of an in-band-on-channel (IBOC) digital transmission standard for AM approaches, broadcast engineers are giving more and more thought to the bandwidth requirements of a digital transmission scheme. Many current AM antenna systems are bandwidth limited because of poor design, improper adjustment and other factors. While achieving broad impedance bandwidth in AM antenna systems is most always a challenge, there are steps that can be taken and techniques that can be used to improve impedance bandwidth. The purpose of this paper is to give engineers facing bandwidth problems with their antenna systems some tools to use to make improvements now in preparation for the digital medium. Immediate rewards will be realized as fidelity and efficiency are improved.

1.0 Antenna Bandwidth Factors

There are many factors that enter into the bandwidth of an AM antenna. In fact, there are several different criteria for defining bandwidth.

In a directional array, the phase shift characteristics of transmission lines and L-C networks vary across the passband of the channel on which the station operates. This results in a change in the pattern shape between carrier and upper/lower sidebands. How well a directional pattern holds its shape across the passband defines the *pattern bandwidth*.

Another such criteria, the one which is the focus of this paper, is the *impedance bandwidth*. This term describes the degree of constancy of an antenna's input impedance across the range of a transmitter's sideband frequencies. In the case of modern analog AM stations employing NRSC preemphasis and filtering, this range is most accurately described as carrier ±10 kHz. With IBOC transmissions producing sideband energy within the NRSC RF mask out to 40 kHz, this definition may need to be revised.

1.1 Bandwidth as a Function of Frequency

Consider that at AM frequencies, the bandwidth is a significant portion of the frequency. In that sense, AM bandwidth requirements are more difficult to achieve than those of VHF NTSC TV. For example, the 20 kHz (carrier ±10 kHz) bandwidth of a station operating on 540 kHz represents about 4% of the frequency. That is a greater ratio than for an NTSC TV signal on channel 7.

1.2 Component Bandwidth Effects

An ideal antenna would present a purely resistive and constant load across the entire passband, from lower sideband to upper. In the real world, however, the radiating element itself will have a varying resistance and reactance across the passband. Coils and capacitors which are used to phase, distribute and match the RF energy to the antenna likewise have varying reactances across the passband. It doesn't take much imagination to visualize how these factors can compound to produce unacceptable impedances at the sideband frequencies.

1.3 Bandwidth Objectives

Design engineers generally have two goals for impedance bandwidth. The first is low sideband VSWR. The other is load symmetry.

Sideband VSWR values of 1.2:1 or less generally produce good results with regard to audio response. Higher values will work, but there is a performance penalty. In any case, if at all possible, values of 1.5:1 or less should be the minimum performance objective.

Load symmetry is sometimes overlooked but it is just as important as sideband VSWR, particularly where sideband VSWR is high. Asymmetrical load conditions can produce high-frequency distortion and all sorts of other objectionable transmitted products. With the IBOC system, different information is transmitted in the upper and lower sidebands. In this system, load symmetry becomes even more important.

2.0 Antenna Considerations

An ideal antenna would present a purely resistive load across the entire passband. In the real world, the impedance versus electrical height plots as a pair of discrete curves. Resistance increases with increasing height up to about 140 degrees above which it begins to drop. Reactance is capacitive up to about 80 degrees, which tends to be a resonant point. Above that it is inductive up to about 140 degrees, another resonant point. Above 140 degrees the reactance tends to be capacitive out to about 240 degrees.

2.1 Impedance and Resonance

Since antennas do have a complex impedance which varies with frequency, the best compromise the design engineer can make is to start at a resonant point with a reasonable (i.e. 25 to 75 ohm) resistance. For a uniform cross-section guyed tower, this combination exists at about 80 degrees where the impedance, depending on tower cross section and environmental factors, tends to be about 30 ohms non-reactive.

Starting with an antenna impedance as such does two things. First, it eliminates a series-resonant condition wherein a component is used to cancel or series resonate the antenna reactance. Second, it eliminates high-reactance network components necessary to match a high or low resistance to a nominal 50-ohm transmission line. Both these factors have a significant effect on bandwidth.

2.2 Skirted Towers

Despite claims of improved bandwidth from the folded monopole and other wire skirt antennas, such antennas (depending on installation and configuration) tend to have a relatively high Q. A typical installation on a uniform-cross-section tower will exhibit a Q of 5 or more.

A common practice with such antennas is to place the shorting stub at a location that produces a feed point resistance of 50 ohms. The reactance in such cases tends to be 250 ohms or more (inductive in cases where the skirt is less than 90 degrees). Matching the antenna to the transmission line becomes a simple matter of installing a vacuum variable capacitor (or fixed capacitor/coil combination) in series to cancel out the high inductive reactance. While this is a simple, reliable, low-component-count method of matching a skirt antenna, it creates a bandwidth bottleneck. The skirt reactance in series with the canceling reactance creates a series-resonant circuit which limits bandwidth.

Other simple methods, such as Lnetworks, can be used to match a skirt-fed antenna, but the common theme seems to be that a high reactance exists in the feed point impedance and a high opposite reactance component must be used to cancel it.

A better method of matching such an antenna starts with selecting a shorting stub location for best bandwidth. To determine this, the tower rigger uses a temporary stub with jumper-cable clamps on each end. Starting just above the mid-point of the skirt, he sets the stub and an impedance measurement sweep is made of the feed point. Moving up the tower in five-foot increments the process is repeated. Plotting all the sweeps on a Smith chart, it should be relatively easy to find the optimum location.

A tee-network is a good choice to match a skirt. It does have more components than an L-network or single component match but it also gives complete control of R, X and phase shift. Phase shift of the matching network is adjusted to produce the best load symmetry.

3.0 Matching/Tuning Network Considerations

One of the best ways to improve overall system bandwidth is to get rid of non-beneficial reactances, starting at the antenna. In the matching/tuning network(s) of a non-directional or directional system, the objective is to present a non-reactive load to the transmission line while achieving the desired phase shift. Quite often (and particularly in older directional systems), there is a significant amount of reactance at the transmission line output. This results in a standing wave on the transmission line and has some detrimental effect on bandwidth as well. Properly adjusting matching networks to present a non-reactive load of the proper resistance (nominally 50 ohms) to the transmission line is fundamental.

3.1 Directional Matching Networks

In some cases, matching networks are designed to accommodate a wide range of antenna impedances. This is particularly true in directional systems where the exact driving point impedances were not known at design time. As a result, large-reactance components are sometimes used to provide a wide range of adjustment. An example would be a low-value capacitor in the output leg with a large-inductance coil in series to cancel out most of the reactance. This provides a lot of adjustment range but it also produces a bandwidth bottleneck. Now that the driving point impedance can be measured, corrections can be made. Increasing the capacitor value to reduce the reactance and using a smaller-value coil in series will quite often improve the bandwidth of a matching network.

This is not universally true, however. A better approach would be to look at the driving point impedance over the entire passband. The output leg of the network could then be optimized to better match the impedance slope of the driving point. This would result in a much greater improvement in network bandwidth than simply reducing individual component reactances.

3.2 Non-Directional Networks

In non-directional systems, not only can the network design be optimized to the slope of the antenna impedance but the phase shift of the network can be altered to produce the best load symmetry. In a non-directional system the value of the network phase shift is not particularly important. However, the phase shift quite often does have a significant effect on symmetry. While the phase shift in a directional network must be set to achieve the proper relative phase from the tower which it feeds, in a non-directional system the full range of phase adjustment (typically ±20 degrees) is available to optimize symmetry.

4.0 Phasors and Power Dividers

In directional systems, some method of dividing the power between the various towers in the system and setting the relative phase for each tower must be provided. This is typically done in a device called a phasor.

A well-designed phasor will be a matched system. In other words, the transmitter output will be matched to the common point bus impedance, the power divider output impedances will be matched to the phase shifter inputs and the phase shifter outputs will be matched to the transmission line inputs. Every effort will have been made to eliminate non-beneficial and stray reactances within the system.

Older and "economy" systems may not have many of the design features that eliminate mismatches and unwanted reactances. In many such cases it may not be economically or mechanically feasible to upgrade an existing system. For example, a system that uses a single variable component to trim the phase to each tower has no means of presenting a constant impedance back to the power divider or forward to the transmission line. There is not likely to be space inside the phasor cabinet to replace the single-component phase shifter with a full tee-network shifter.

The truth is that many things can be done at design time to improve the impedance bandwidth of a phasor. In some extreme cases it may be necessary to start from scratch with a new phasor or entire phasing and coupling system.

4.1 Phase Shifter Considerations

Again, a well-designed phasor will be impedance matched at every point. Tee-network phase shift networks are a critical point in the system where gains can be made in bandwidth by impedance matching and elimination of unwanted reactances.

In addition to providing a variable amount of phase shift, a phase shift network can also function as a matching network. The network should be designed to match the predicted impedance at the output of the power divider for a particular tower on one side to the 50-ohm non-reactive transmission line input impedance on the other. This is easy to do at design time.

During construction, the input, output and shunt legs are set to their calculated values, then the variable input and output legs are coupled together to create a ganged coil. Adjusting the phase shift network moves both input and output legs together, changing the phase shift without appreciably changing the impedance transformation properties of the network.

4.2 Power Divider Considerations

All sorts of power divider schemes have been used over the years in phasing and coupling systems. Some offer low component count and high-reliability at the expense of adjustability. Others offer adjustment range at the expense of component count and reliability.

Tank-type power dividers are among the worst for bandwidth. The power divider circuit is, as its name implies, itself a tank circuit that stores energy. As with any parallel-resonant circuit, the slopes are steep on either side of resonance and this has a very detrimental effect on the sideband impedances.

The tee-network power divider/phase shifter combination offers a lower component count and adjustability with good adjustability, but it operates on the principal of an impedance mismatch. While bandwidth is generally acceptable, there are unwanted reactances in such a system.

The shunt-type (sometimes called "Ohm's Law") power divider is probably the best choice for providing adjustability and producing optimum bandwidth.

4.3 Common Point Networks

The common point, in essence the power divider bus, is the last point in a directional antenna system after the transmitter that is common to all towers. The impedance at that point is the conjugate parallel impedance of all the power divider taps connected to the bus. Unless it is treated somehow (such as by parallel resonating the residual reactance) to raise the impedance, it usually exhibits a relatively low impedance. To match this to the 50-ohm transmission line coming from the transmitter, a matching network must be used.

The common point network is the one point in which the greatest gains in bandwidth improvement can often be made. All of the principles discussed above regarding matching networks also apply to common point networks. A well-designed network at the common point can do a great deal to optimize the load as seen by the transmitter. By using a tee network with carefully chosen components to match the slope of the impedance on the bus and by selecting a phase shift that produces symmetrical response, the transmitter load can often be just short of ideal.

This is not always the case, however. In some arrays, the slope of the impedance on the common point bus may be such that sideband VSWR at the transmitter output is excessive despite the best efforts of the designer. In such cases, a broadbanding network can sometimes be inserted that will correct some of the problem. For such a network to be effective, the load impedance must be inductive at the lower sideband and capacitive at the upper. A series LC circuit, resonant on carrier, is inserted on one side or the other of the common point matching network (depending on where it would be the most beneficial). This network will be capacitive below carrier and inductive above.

Ideally, component values will be selected so that the residual reactances cancel at the sideband frequencies, leaving a purely resistive load across the passband. This is seldom achievable in practice, however. Still, a good deal of improvement is possible using such a circuit where the criteria for its use exists.

5.0 Diplexed Antennas

Stations that share their antennas with other stations face a whole new set of bandwidth challenges. In addition to the impedance slope of the tower itself, the series and parallel tuned circuits in the diplexer add bottlenecks and impedance bumps of their own that must be overcome. While an in-depth discussion of diplexer circuit design is beyond the scope of this paper, there are some techniques of which broadcast engineers should be aware that can be employed to minimize the negative impact a diplexer has on impedance bandwidth.

5.1 Prematch

One technique to improve both bandwidth and isolation is to employ a pre-match between the diplexer and antenna. This is a circuit that transforms the antenna impedance on both frequencies to one that is more desirable, usually eliminating most of the reactive component. Keep in mind that reducing non-useful reactances throughout the system will benefit impedance bandwidth.

5.2 Q-Matching

The other technique worth mentioning is Q-matching. Most diplexer designs are made using what is referred to as the “standard design.” In this case, the value of the capacitor in each trap is selected so that its loaded Q is roughly the same on both the low and high frequencies. While this is a generally acceptable technique, it does not result in optimum impedance bandwidth.

In a Q-matched design the capacitor in the main trap is selected for a lower Q_H (Q on the high or pass frequency) than would be called for in the standard design, and the components in the auxiliary trap are chosen to match the loaded Q of the main trap.

Using a Q-matched design, the main trap will have a higher Q and the reject resistance will thus be larger. This results in improved isolation (usually by 20 dB or more), and the reduced Q_E (equivalent Q) results in greatly improved impedance bandwidth for the system.

6.0 Other Tricks of the Trade

There are instances where an antenna or array are inherently narrowband and all the designer’s best efforts produce only marginally acceptable impedance bandwidth. While the causes can be myriad, they most often result from very short radiators and poorly-designed directional patterns.

6.1 Short Radiators

In the case of short radiators (which exhibit low resistance, high loss and high reactance with a steep slope), the only way to improve bandwidth may be to add electrical length to the antenna. This can be done by extending the tower or top-loading.

Extending the tower is the best option from an engineering perspective but it is also the most expensive and may not be possible because of FAA or zoning restrictions. Still, it would be worthwhile to at least make a run at a taller height with the regulatory agencies. It could well be that the circumstances which originally prohibited a greater height no longer exist.

Top loading can be achieved by means of a top-hat or by shorting the top section of each top guy wire to the tower. Sometimes the ends of these top guy sections are joined just above the insulators that mechanically join them to the next segment down the guy. Top loading changes the current distribution on the tower and has a beneficial effect on both the impedance and efficiency of short radiators.

By increasing efficiency, either through increased height or top loading, chances are that a power reduction will be required to maintain contours at their present locations. Nighttime operation can be a complex situation that should be carefully examined before such a project is undertaken. With increased efficiency, there will be no net loss of coverage even with a power reduction, making the project worthwhile for the net gain in bandwidth.

6.2 Negative Power Flow Towers

In many directional antennas, one or more towers are parasitic, meaning that they draw power from the other towers and feed it back down the transmission line to the phasor.

As long as the negative power flow is substantial, negative towers are not a problem. In fact, in a well-designed array, a negative tower will be very stable, following the other towers in locked phase and current ratio like a caboose on a train. In some circumstances, however, the negative tower is just barely negative with a driving point resistance of just a couple of ohms negative.

On sideband frequencies the tower will often be more negative or will flip over to positive. With modulation, the tower alternately pulls power from and supplies power to the common point bus. The result many times is a common point impedance that changes dramatically from one sideband to the other.

Depending on many factors such as power level, driving point impedance of the negative tower and overall measured system RMS, it may be possible to remedy the bandwidth problem caused by the very low impedance tower. This is done by disconnecting the tower from the common point bus and connecting it instead to a load resistor. With this mechanism in place, the only effect the low impedance tower has on the common point is through the mutual coupling between towers.

This technique cannot be used if the power in the negative tower is substantial (although if the power is substantial, the impedance is probably high enough so that it does not cause adverse effects at the common point). It also cannot be used if the measured RMS is marginal (i.e. just barely above 85% of standard pattern RMS). Removing the power delivered back to the common point and dissipating it in a load may well reduce the RMS sufficiently that the array no longer meets the 85% minimum.

Still, it is a technique worth looking at in those circumstances where a low-impedance negative-power-flow tower is creating a bandwidth problem. Keep in mind that phase control of the tower will be mostly at the antenna tuning unit (tower base). Current can be controlled to some degree by using a sliding tap on the load resistor.

7.0 Conclusion

There is no hard and fast rule or sure-fire technique that will produce a wide impedance bandwidth in an AM directional or non-directional antenna system. Each situation is different with many variables, including radiator height, impedance, impedance slope, directional pattern and phasing/coupling system design and construction. Achieving a good impedance bandwidth starts with optimizing the radiating element itself and working back toward the transmitter. It is an exercise of degrees, making small improvements throughout the system to achieve a significant improvement at the transmitter output.

With the IBOC digital hybrid mode and its requisite broader bandwidth on the horizon, AM broadcasters should be taking steps now to prepare their antenna systems. Those building new systems or making site moves have the advantage in that they can start from scratch with optimized impedance bandwidth as a goal. The rest of us have to work with what we have, but in most cases considerable improvement can be made by paying attention to impedance matching and slope correction. As for how well even the best antenna systems respond to the IBOC envelope, that remains to be seen.