

AM ANTENNA SYSTEM CASE STUDIES FOR DRM AND IBOC DAB

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ABSTRACT

In preparing for the arrival of DRM and IBOC for AM broadcast, it is important to consider the bandwidth performance of a station's antenna system. This paper seeks to present an overview of broadband design techniques and tools that may be employed when designing AM broadcast antenna systems. Antenna system parameters will be weighed for their bandwidth significance. Methods for enhancing the bandwidth of an antenna system will be explored. Case studies including moment method modeling, advanced circuit design tools, multiplexing considerations, and system tuning will demonstrate the results.

INTRODUCTION

For a non-directional AM broadcast station the term "antenna system" refers to the radiating tower, the associated antenna tuning unit and the coaxial feed line from the transmitter. For a directional station, the term refers to the array of towers, their tuning units and coaxial feed lines, and the phasor, which consists of the power dividing and phasing networks, and the final common point network. For cases where more than one station share a site, filter networks may also be present.

An antenna system should be designed to efficiently transform the power from the transmitter into radiated energy. In order to do so, the design of the antenna system must take impedance bandwidth into consideration. In the case of directional arrays, pattern bandwidth must also be carefully considered. For most modern transmitters, the antenna system must present a $50 + j 0 \Omega$ match to the transmitter on carrier to be properly matched. The impedance bandwidth of an antenna system refers to the amount of variation from $50 + j 0 \Omega$ that the antenna system exhibits over a frequency band centered about the carrier frequency. In this paper, the most critical +/- 15 kHz frequency band about carrier frequency will be addressed.

The impedance bandwidth presented to the transmitter will be evaluated in terms of VSWR. The exact VSWR requirements for DRM and IBOC DAB are still evolving. However, it appears that the bandwidth requirements are similar to those for AM stereo.¹ Experiments at Nautel have indicated that the sideband VSWR should be kept symmetric about carrier and below approximately 1.2/1 at 10 kHz and 1.4/1 at 15 kHz from carrier.² However, the lower the VSWR, the better the overall quality of performance the system will deliver.

Cases 1A through 1F will demonstrate the effect of the antenna design and the ATU design for a non-directional case. Cases 2A through 2E will then illustrate for a diplexing system several bandwidth enhancing design techniques that have resulted from many years of experience at Kintronic labs in the design of AM antenna systems. Finally, cases 3A through 3C will demonstrate methods of improving the bandwidth performance of a directional antenna system.

THE SINGLE FREQUENCY, NON-DIRECTIONAL CASE

The most simple case to begin with is the case of a single tower operation with only one station involved (i.e. no filter networks involved). For this case the main parameters are the antenna design and the antenna tuning unit (ATU) design. AM stations most commonly use vertical radiators. The radiator may be a series fed tower (base insulated) or a shunt fed tower (grounded base). The choice of tower height and construction will often be driven by economics or local building regulations. Tower height is generally dictated by allowable radiating efficiency constrains and/or Federal Aviation Administration (FAA) regulations. However, it is worth noting that the construction of the tower will have a large bearing on the impedance bandwidth of the antenna system.

In general, excessively short towers should be avoided. Towers below 50 electrical degrees in height may pose bandwidth problems for the ATU designer. Towers above 225 electrical degrees are avoided due to increased skywave radiation and diminished groundwave radiation. Larger cross section antennas, such as self supporting towers and skirt fed towers generally present better bandwidth performance than narrow cross section radiators. These factors should be considered when planning for a new tower installation.

To demonstrate these basic principles, a single tower 170 feet tall with a uniform, 12" triangular cross section will be used as the radiator for a station operating on 1070 kHz. At this frequency the electrical tower height (in wavelengths at 1070 kHz) is approximately 66.5 degrees. This tower will be fed in several different ways. In case 1A the tower will simply be base insulated and series fed. In case 1B the tower will be grounded at the base and fed with a common 3-wire folded unipole antenna with 30 inch leg standoff insulators and no shorting stub. In case 1C, a shorting stub set for 50 ohms resistance will be added to the case 1B scenario. Case 1D will use a 3-wire folded unipole antenna with longer 72 inch leg standoff insulators and no shorting stub. Case 1E will ground the bottom of the 72 inch radius unipole skirt to the tower above the base insulator and drive the skirted tower in a series fed configuration. Lastly, case 1F will use a grounded base and an unconventional 4-wire flared skirt. In each of these five cases the impedance bandwidth of the antenna itself will be evaluated via a figure of merit similar to VSWR in order to account for both the resistance and the reactance variation of the antenna impedance with frequency.³ This figure of merit is computed by normalizing the impedance values to the carrier impedance and then computing VSWR in the normal fashion where the antenna resistance at carrier is used in place of characteristic impedance in the VSWR formula. This figure of merit normalized to carrier we'll refer to as VSWR (NTC). Then for each case basic T-network tuning unit designs with and without slope-correcting measures will be considered.

Case 1A, Basic Series Fed Tower

In this case the 170 foot tower is simply series fed. The NEC-4 moment method modeling program is used to compute the predicted antenna impedance versus frequency.⁴ Using a

wire model that approximates the lattice structure of the tower is not really necessary for such a simple structure. However, since a lattice model is important to accurately model the skirted cases that will follow, the same lattice model will be used in all cases for consistency. A perfect electric conducting (PEC) ground is used in each model as well. The model is illustrated in Figure 1 below. The resulting antenna impedance bandwidth is given in Table 1.



Figure 1 Wire Model of Series Fed Tower

Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,055	18.6 - j 85.0	1.377/1
1,060	18.9 - j 83.0	1.236/1
1,065	19.1 - j 81.0	1.111/1
1,070	19.4 - j 79.0	1.000/1
1,075	19.6 - j 77.0	1.109/1
1,080	19.9 - j 75.0	1.229/1
1,085	20.1 - j 73.0	1.358/1

Table 1 Base Impedance of Case 1A, the 66.5 Degree Series Fed Tower

A standard lagging T-network is now designed to transform the antenna impedance to $50 + j 0 \Omega$ at 1070 kHz. In this and all cases the phase shift of the network is selected to roughly balance the resulting sideband reactances when possible. The capacitor selection for the basic T-network design is based on the standard ATU design practices that are employed at Kintronic Laboratories, using the largest standard capacitor values while allowing for variation in the antenna resistance and variation in phase shift for

the network. The resistance variation allows for a margin of error in the computer prediction of the antenna impedance as well as for variations in the actual impedance due to unforeseen conditions near the base of the antenna that may transform the antenna impedance (the ATU cabinet stray capacitance to ground, a metal fence or isocoupler, an older ground system, etc.). The phase shift variation allows for some margin of error for the antenna reactance and also allows for fine tuning of the sideband match to improve the rotation of the load for the transmitter. When reliable measured antenna base impedance data is available, these margins of variation may be reduced in order to reduce the cost of the ATU and to prevent unnecessary harm to the bandwidth performance of the ATU by using excessively small capacitance values.

Note that in cases 1A-1F only matching T-networks are presented. However, pi-networks, L-networks, and various combinations of networks can be used for the ATU matching network. The simple T-network may not be the optimum design choice, so various designs should always be considered. Since the purpose of these example cases is to demonstrate the effect of changing the antenna design, the ATU design is chosen to be a basic T-network, which is by far the most commonly used matching network design.

Table 2 illustrates the results for matching with a standard T-network with -83 degree phase shift, a 5000 pF input branch capacitor, no output branch capacitor, and a 2500 pF shunt branch capacitor.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	41.9 + j 16.6	1.493/1
1,060	46.1 + j 12.4	1.309/1
1,065	49.0 + j 6.6	1.145/1
1,070	50.0 + j 0.0	1.000/1
1,075	48.8 - j 6.7	1.148/1
1,080	45.6 - j 12.5	1.319/1
1,085	41.0 - j 16.7	1.516/1

Table 2 Standard T-Network Results for Case 1A, the 66.5 Degree Series Fed Tower

Note that using a capacitor in the output branch and/or reducing the value of the capacitor in the shunt branch does not improve the performance of the matching network in this case. However, by reducing the value of the input branch capacitor and correspondingly increasing the size

of the input branch inductor, the reactance variation with frequency seen at the input of the T-network can be reduced significantly. This is a commonly known technique known as slope correction. To implement this technique properly, the phase shift of the T-network is chosen to result in sideband resistance values that are symmetric about carrier and sideband reactance values that are symmetric in magnitude about carrier but opposite in sign. This type of symmetry is exhibited in Table 2.

An appropriate phase shift through the matching network can be found by normalizing the antenna impedance sweep to the value on carrier, plotting the normalized sweep on a Smith chart and rotating the resulting cusp through an angle on the chart that will result in the cusp being directed either toward 3:00 o'clock or 9:00 o'clock on the chart. The amount of rotation of the cusp required to give this orientation is the amount of phase shift that should first be tried for the matching network. Rotation on the chart toward the generator (clock-wise) results in a lagging network and the opposite direction results in a leading network. The phase shift for a standard T-network should fall roughly between +/- (60 to 100) degrees to yield a network with reasonably sized components.

Applying this technique in Case 1A requires using an input branch capacitor of 250 pF and results in the final input sweep illustrated in Table 3 below.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	41.9 + j 0.6	1.194/1
1,060	46.1 + j 1.7	1.094/1
1,065	49.0 + j 1.4	1.035/1
1,070	50.0 + j 0.0	1.000/1
1,075	48.8 - j 1.4	1.039/1
1,080	45.6 - j 2.0	1.107/1
1,085	41.0 - j 1.0	1.220/1

Table 3 Slope Corrected T-Network Results for Case 1A, the 66.5 Degree Series Fed Tower

Note that for case 1A the standard T-network design does not quite give acceptable VSWR levels. The case with slope correction gives a much flatter impedance sweep. Note also that lesser degrees of slope correction can be used to give a compromise design between the standard design and the fully slope corrected design. The advantage of an intermediate design would be lower input branch voltages, less sensitive tuning

of the ATU, and less costly components in the input branch. The disadvantage would be reduced bandwidth performance.

Case 1B, 3-Wire Folded Unipole With 30 Inch Leg Standoff Insulators and No Shorting Stub

In this case the 170 foot tower is grounded at the base and is outfitted with a full length folded unipole skirt. The skirt wires are spaced from the legs with 30 inch insulators. Each skirt wire is grounded to the tower at the 170 foot level. A commoning ring is installed at the base of the skirt at the 10 foot level above ground. This commoning ring has a single drop wire to ground that is driven by the ATU. The model is illustrated in Figure 2 below. The resulting antenna impedance bandwidth is given in Table 4 below. Notice that the impedance bandwidth of the folded unipole is slightly better than that of the simple series tower case. This subtle improvement is primarily due to the larger diameter of the antenna when the wire skirt is present. This has been shown previously and will be demonstrated again in case 1E.³

A standard T-network design with -92 degree phase shift, no input or output branch capacitors, and a 1000 pF shunt branch capacitor gives results shown in Table 5 below.



Figure 2 Wire Model of Case 1B

Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,055	167.8 - j 317.8	1.350/1
1,060	162.1 - j 301.8	1.219/1
1,065	156.9 - j 286.6	1.103/1
1,070	152.2 - j 272.2	1.000/1
1,075	147.9 - j 258.6	1.100/1
1,080	144.0 - j 245.6	1.207/1
1,085	140.4 - j 233.3	1.319/1

Table 4 Base Impedance of Case 1B, Folded Unipole With 30" Standoffs, No Shorting Stub

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	44.8 + j 10.4	1.278/1
1,060	47.6 + j 7.6	1.179/1
1,065	49.4 + j 4.1	1.086/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.3 - j 4.1	1.086/1
1,080	47.4 - j 7.7	1.182/1
1,085	44.5 - j 10.7	1.288/1

Table 5 Standard T-Network Results for Case 1B, the Folded Unipole with 30" Standoff Insulators and No Shorting Stub

Note that the antenna's bandwidth is improved in this case by the standard ATU design. Once again applying slope correction to the tuning network can further improve the impedance bandwidth performance. Using an input branch capacitor of 350 pF results in the final input sweep illustrated in Table 6 below.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	44.8 - j 1.6	1.121/1
1,060	47.6 - j 0.3	1.052/1
1,065	49.4 + j 0.1	1.013/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.3 - j 0.1	1.014/1
1,080	47.4 + j 0.2	1.055/1
1,085	44.5 + j 1.2	1.126/1

Table 6 Slope Corrected T-Network Results for Case 1B, the Folded Unipole with 30" Standoff Insulators and No Shorting Stub

Case 1C, 3-Wire Folded Unipole With 30 Inch Leg Standoff Insulators and With a Shorting Stub Set to Approx. 50 Ω Antenna Resistance

This case is identical to Case 1B with the exception that a shorting stub grounding the skirt wires to the tower is now installed on the folded unipole and is set for approximately the 50 ohm antenna resistance point. This is a common practice, but one that does not always improve the impedance bandwidth performance of the antenna. In this case, the shorting stub is placed

at approximately 62 feet above ground level. The resulting antenna impedance bandwidth is given in Table 7 below.

Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,055	36.3 + j 192.6	1.408/1
1,060	39.9 + j 195.3	1.253/1
1,065	43.8 + j 198.1	1.118/1
1,070	48.2 + j 200.7	1.000/1
1,075	53.1 + j 203.1	1.114/1
1,080	58.4 + j 205.3	1.234/1
1,085	64.2 + j 207.2	1.362/1

Table 7 Base Impedance of Case 1C, the Folded Unipole with 30" Standoff Insulators and 50 Ω Shorting Stub

Note that the addition of the shorting stub degraded the inherent impedance bandwidth of the antenna in this case. Transforming this impedance sweep through a -60.6 degree standard T-network design with a 5000 pF input branch capacitor, a 750 pF output branch capacitor, and a 1000 pF shunt branch capacitor results in the input impedance sweep of Table 8.

Application of slope correction to the T-Network by changing the input branch capacitor from 5000 pF to 250 pF enhances the bandwidth as shown in Table 9 below. Note that in this and in all the cases attempts were made to enhance the bandwidth by iteratively varying the values of the capacitors in all branches of the T-network. In each case, the largest values possible of output branch capacitor and shunt branch capacitor resulted in the best impedance bandwidth. Only reducing the value of the input branch capacitor gave effective slope correction. Note that this will not always be the case. One should always investigate the effects of varying the capacitor

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	42.2 + j 15.9	1.466/1
1,060	46.4 + j 11.7	1.288/1
1,065	49.2 + j 6.2	1.134/1
1,070	50.0 + j 0.0	1.000/1
1,075	48.6 - j 6.0	1.132/1
1,080	45.7 - j 10.9	1.276/1
1,085	41.7 - j 14.4	1.435/1

Table 8 Standard T-Network Results for Case 1C, the Folded Unipole with 30" Standoff Insulators and 50 Ω Shorting Stub

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	42.2 - j 0.1	1.184/1
1,060	46.4 + j 1.1	1.082/1
1,065	49.2 + j 0.9	1.024/1
1,070	50.0 + j 0.0	1.000/1
1,075	48.6 - j 0.7	1.031/1
1,080	45.7 - j 0.3	1.095/1
1,085	41.7 + j 1.4	1.202/1

Table 9 Slope Corrected T-Network Results for Case 1C, the Folded Unipole with 30" Standoff Insulators and 50 Ω Shorting Stub

values in each branch of the matching network while still allowing for variations in the antenna impedance as necessary. This will ensure that a good design is being used.

Note that the impedance bandwidth for case 1C was made reasonably flat with slope correction, but that the results are still not as good as those for case 1B when no shorting stub was used on the folded unipole antenna. It is worth noting too that the number of capacitors necessary to design the ATU for case 1C was also greater, needing 3 capacitors for the standard T-Network versus 1 for case 1B. In general case 1B is preferable over case 1C. This illustrates that when using a folded unipole antenna, the placement of the shorting stub should not be chosen based on the general 50 Ω rule of thumb. Nor should one always omit the shorting stub. Each situation needs to be evaluated individually either via computer modeling or by actual on-site measurements to ensure that the shorting stub setting is one that will get the best possible impedance bandwidth out of the antenna system.

Case 1D, 3-Wire Folded Unipole With 72 Inch Leg Standoff Insulators and No Shorting Stub

To illustrate that the diameter of the antenna influences its bandwidth, case 1B is repeated with 72" long leg standoff insulators. The impedance of the antenna is shown in Table 10 below.

Comparison of Table 4 with Table 10 shows that the larger diameter skirt kit on the tower reduces the VSWR noticeably. Transforming this impedance sweep through a standard -83 degree T-Network design with no input and output branch capacitors and a 1,000 pF shunt branch capacitor results in the input impedance sweep shown in Table 11 below.

Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,055	89.7 - j 169.3	1.271/1
1,060	89.0 - j 162.0	1.172/1
1,065	88.4 - j 154.9	1.082/1
1,070	87.9 - j 148.0	1.000/1
1,075	87.4 - j 141.3	1.080/1
1,080	87.0 - j 134.8	1.163/1
1,085	86.6 - j 128.5	1.250/1

Table 10 Base Impedance of Case 1D, the Folded Unipole with 72" Standoff Insulators and No Shorting Stub

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	46.3 + j 9.5	1.235/1
1,060	48.3 + j 6.8	1.153/1
1,065	49.6 + j 3.6	1.075/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.4 - j 3.6	1.077/1
1,080	47.8 - j 7.0	1.161/1
1,085	45.4 - j 9.8	1.255/1

Table 11 Standard T-Network Results for Case 1D, the Folded Unipole with 72" Standoff Insulators and No Shorting Stub

Application of slope correction to this T-Network requires using a 400 pF input branch capacitor. Note that this is less sharp than the 250 pF capacitor that was required for the 30" wire cage of Case 1B. The resulting bandwidth is shown in Table 12 below. This is the best bandwidth of all the cases thus far.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	46.3 - j 1.0	1.083/1
1,060	48.3 - j 0.2	1.034/1
1,065	49.6 + j 0.1	1.007/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.4 - j 0.1	1.013/1
1,080	47.8 - j 0.1	1.047/1
1,085	45.4 + j 0.5	1.103/1

Table 12 Slope Corrected T-Network Results for Case 1D, the Folded Unipole with 72" Standoff Insulators and No Shorting Stub

Case 1E, Series Fed 3-Wire Skirt Kit With 72 Inch Leg Standoff Insulators

To further verify that the larger diameter of the antenna is chiefly responsible for the enhanced bandwidth of Case 1D rather than the shunt feeding, Case 1E modifies Case 1D to a series fed configuration. The commoning ring at the 10 foot level above ground is shorted to the tower, the tower is base insulated and the tower is then fed as a series fed tower. This is the same

then as case 1A with the tower "fattened" by a wire cage that is shorted to the tower at both the top and bottom ends. The impedance of the antenna is shown in Table 13 below.

Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,055	19.5 - j 47.5	1.245/1
1,060	19.7 - j 46.1	1.156/1
1,065	20.0 - j 44.7	1.074/1
1,070	20.3 - j 43.3	1.000/1
1,075	20.6 - j 41.8	1.073/1
1,080	20.9 - j 40.4	1.151/1
1,085	21.2 - j 39.0	1.232/1

Table 13 Base Impedance of Case 1E, Series Fed Large Diameter Skirted Tower

Comparing Table 13 to Table 10 shows that although the antenna's impedance is much lower for the series fed configuration, the antenna's impedance bandwidth is essentially unchanged whether or not it is series fed or shunt fed. Transforming this impedance through a standard -80 degree T-Network design with a 10,000 pF input branch capacitor, no output branch capacitor, and a 2500 pF shunt branch capacitor gives the input impedance sweep shown in Table 14 below. Applying slope correction to this case by reducing the input branch capacitor to 300 pF results in the impedance sweep shown in Table 15 below.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	45.6 + j 12.9	1.328/1
1,060	48.0 + j 9.1	1.210/1
1,065	49.5 + j 4.7	1.100/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.3 - j 4.8	1.102/1
1,080	47.6 - j 9.2	1.214/1
1,085	45.0 - j 13.0	1.340/1

Table 14 Standard T-Network Results for Case 1E, the Series Fed Large Diameter Skirted Tower

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	45.6 - j 0.7	1.097/1
1,060	48.0 + j 0.1	1.042/1
1,065	49.5 + j 0.2	1.011/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.3 - j 0.3	1.015/1
1,080	47.6 - j 0.2	1.051/1
1,085	45.0 + j 0.4	1.112/1

Table 15 Slope Corrected T-Network Results for Case 1E, the Series Fed Large Diameter Skirted Tower

Note that although the standard T-Network results are poorer for Case 1E versus case 1D, the results after slope correction were virtually the same. Both cases give excellent wide bandwidth performance, especially when slope correction is applied to the T-Network design.

Case 1F, Flared 4-Wire Skirt Kit

Although the bandwidth performances of all the cases explored thus far are adequate for DRM and IBOC DAB operation, when the ATU design uses broad-banding slope correction the very best performances shown so far have been for a large diameter skirt kit on the tower. Such a skirt kit can be constructed, but can be cumbersome to install and costly in hardware. Also, this phenomenon of better impedance with larger diameter radiator can only be carried so far before it becomes impractical to implement. Case 1F explores an alternate way to achieve a very large antenna diameter by use of an uncommon flared skirt kit. The configuration is shown in Figure 3 below.

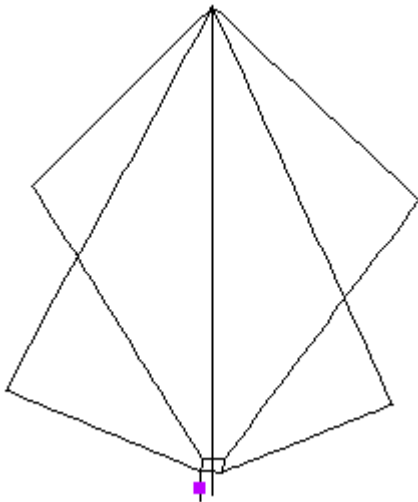


Figure 3 Flared Skirt Kit of Case 1F

In this case the tower is once again grounded at the base and shunt fed. The skirt kit consists of 4 wires that are electrically and mechanically fixed to the tower at the top. The wires are then pulled out from the tower by insulated cables at a point slightly below their midpoint. They are then pulled back in to the tower base and terminated in a commoning ring that is positioned 10 feet above ground level. Note that 3 wires could also be used for this case, but 4 wires will be used since measured data was available for this case from a successful project recently completed by Kintronic Laboratories. Just as in the case for a

folded unipole, 3, 4, 6, or more wires could be used to construct the wire cage. In general, the more the wires in the skirt cage, the better the bandwidth performance that results.

The antenna's inherent impedance bandwidth is shown in Table 16 below.

Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,055	36.5 + j 0.8	1.150/1
1,060	36.7 + j 2.7	1.091/1
1,065	36.9 + j 4.3	1.044/1
1,070	37.0 + j 5.9	1.000/1
1,075	37.3 + j 7.6	1.047/1
1,080	37.5 + j 9.3	1.097/1
1,085	37.8 + j 11.2	1.154/1

Table 16 Base Impedance of Case 1F, Shunt Fed Tower via Flared 4-Wire Skirt Kit

Note that case 1F gives the best antenna impedance bandwidth for all the antenna cases considered. This good performance carries through in the standard T-Network performance, which is shown in Table 17 below.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	48.3 + j 6.7	1.151/1
1,060	49.3 + j 4.4	1.093/1
1,065	49.8 + j 2.2	1.046/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.8 - j 2.5	1.051/1
1,080	49.2 - j 4.9	1.105/1
1,085	48.2 - j 7.5	1.169/1

Table 17 Standard T-Network Results for Case 1F, The Shunt Fed Tower via a Flared 4-Wire Skirt Kit

For the standard T-Network, a -77 degree network is used with a 10,000 pF input branch capacitor, no output branch capacitor, and a 2000 pF shunt branch capacitor. This standard T-Network gives better bandwidth performance than even the slope corrected designs of Cases 1A, 1B, and 1C. When slope correction is applied by use of a 550 pF input branch capacitor, the results are again easily the best of all the cases. The results are shown in Table 18.

Obviously impedance bandwidth performance this flat is not necessary from the antenna system. However, this is intended to demonstrate that the antenna design alone can make a substantial difference in the impedance bandwidth performance of the overall antenna system. For cases where a station may be having

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	48.3 - j 0.5	1.036/1
1,060	49.3 - j 0.4	1.017/1
1,065	49.8 - j 0.2	1.005/1
1,070	50.0 + j 0.0	1.000/1
1,075	49.8 - j 0.1	1.005/1
1,080	49.2 - j 0.1	1.017/1
1,085	48.2 - j 0.3	1.038/1

Table 18 Slope Corrected T-Network Results for Case 1F, The Shunt Fed Tower via a Flared 4-Wire Skirt Kit

difficulty with their transmitter and the antenna system is found to be the problem, not just the ATU but the antenna itself may have to be re-designed in order to achieve sufficient bandwidth performance to permit DRM or IBOC DAB operation.

A final comparison of the variations that were made on the 170 foot tall tower operating on 1070 kHz is summarized in Table 19 below.

VSWR (NTC)						
Freq. (kHz)	Case 1A	Case 1B	Case 1C	Case 1D	Case 1E	Case 1F
1,055	1.377/1	1.350/1	1.408/1	1.271/1	1.245/1	1.150/1
1,060	1.236/1	1.219/1	1.253/1	1.172/1	1.156/1	1.091/1
1,065	1.111/1	1.103/1	1.118/1	1.082/1	1.074/1	1.044/1
1,070	1.000/1	1.000/1	1.000/1	1.000/1	1.000/1	1.000/1
1,075	1.109/1	1.100/1	1.114/1	1.080/1	1.073/1	1.047/1
1,080	1.229/1	1.207/1	1.234/1	1.163/1	1.151/1	1.097/1
1,085	1.358/1	1.319/1	1.362/1	1.250/1	1.232/1	1.154/1

Table 19 Summary of The Inherent Antenna Impedance Bandwidth Independent of ATU Design For Cases 1A Through 1F

THE DIPLEXED CASE

When more than one frequency is involved, due to two or more stations multiplexing onto the same tower, or due to the necessity to filter out energy from a nearby station, the ATU will have one or more filter networks in addition to the matching network. In this case extra care needs to be taken to ensure that the bandwidth performance of the antenna system is not unnecessarily degraded by the effects of the filters. In most cases the effect of the filters will be to degrade the bandwidth performance. However, by carefully designing the system, these effects can be kept to a minimum.

The case that will be used to illustrate these design enhancements is a diplexed operation consisting of two 1 kW stations operating on a single series fed tower. Station A operates on 1290 kHz and Station B operates on 1400 kHz. The tower is relatively tall, resulting in high base impedances for both stations. Measured tower base impedance sweep data was available for both stations and is tabulated in Table 20.

Note that the tower has excellent inherent impedance bandwidth at these frequencies. Note also that the two stations are only 110 kHz apart. This is relatively close spacing for a diplexer, although not excessively close. Kintronic

Laboratories has successfully implemented diplexer designs for stations with a 50 kHz separation. A careful diplexer design for this particular scenario should result in a diplexer with good input impedance bandwidth performance for both stations. However, the close spacing of the two carrier frequencies can result in serious problems if the diplexer is not designed carefully. Such design pitfalls will now be demonstrated.

Case 2A, Standard Diplexer Design

A basic diplexer design will consist of two matching networks followed by two pass/reject filter networks. Using this basic design approach results in the system of Case 2A as shown in Figure 4 below.

The system in Case 2A uses relatively sharp filter networks, although they still do not result in sufficient port-to-port isolation between the two stations. The design would only yield isolation levels of approximately 35 to 40 dB, which would not likely be sufficient. In this case as well as in the other cases that will follow, each matching T-network will incorporate slope correction where effective to improve bandwidth performance. The input impedance sweep that results for the two stations in the design of Case 2A is shown in Table 21 below.

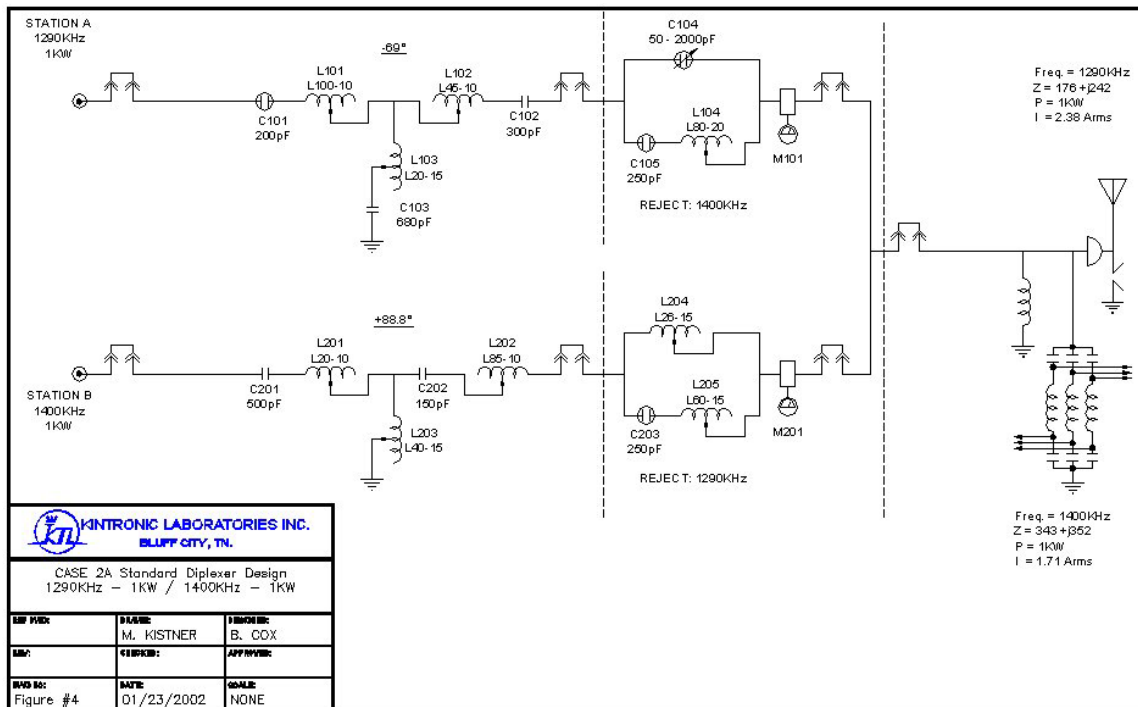


Fig. 4 Case 2A Standard Diplexer Design

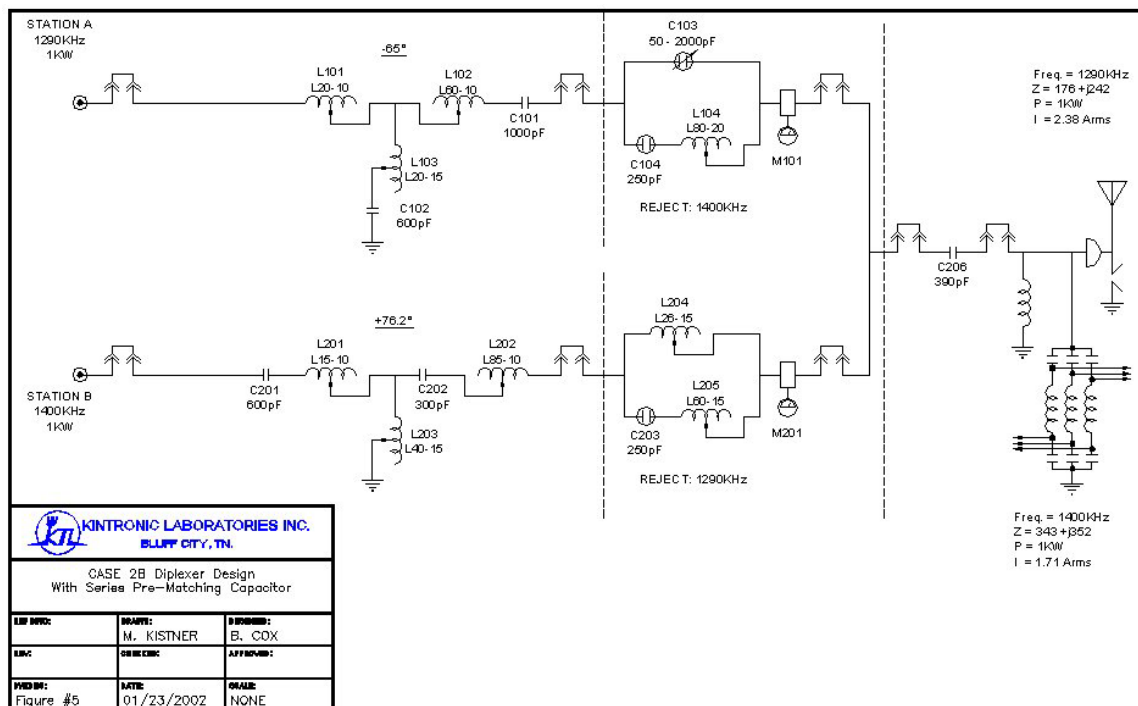


Fig. 5 Case 2B Diplexer Design with Series Pre-Matching Capacitor

Station A		
Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,275	156 + j 237	1.132/1
1,280	162 + j 240	1.087/1
1,285	170 + j 242	1.035/1
1,290	176 + j 242	1.000/1
1,295	176 + j 247	1.029/1
1,300	179 + j 250	1.049/1
1,305	184 + j 253	1.078/1
Station B		
Freq. (kHz)	Impedance Ω	VSWR (NTC)
1,385	310 + j 346	1.108/1
1,390	320 + j 347	1.074/1
1,395	330 + j 350	1.040/1
1,400	343 + j 352	1.000/1
1,405	354 + j 355	1.033/1
1,410	365 + j 356	1.065/1
1,415	380 + j 357	1.109/1

Table 20 Measured Tower Base Impedance Data For the Diplexer

Station A		
Freq. (kHz)	Impedance Ω	VSWR
1,275	16.7 + j 6.2	3.060/1
1,280	27.8 + j 18.2	2.130/1
1,285	47.7 + j 16.9	1.416/1
1,290	50.0 + j 0.0	1.000/1
1,295	39.8 - j 4.6	1.283/1
1,300	31.5 - j 0.2	1.589/1
1,305	26.5 + j 6.6	1.935/1
Station B		
Freq. (kHz)	Impedance Ω	VSWR
1,385	13.4 + j 65.4	10.29/1
1,390	64.9 + j 79.9	3.772/1
1,395	81.9 + j 14.6	1.719/1
1,400	50.0 + j 0.0	1.000/1
1,405	34.9 + j 3.6	1.447/1
1,410	27.5 + j 8.6	1.893/1
1,415	23.1 + j 13.2	2.355/1

Table 21 Diplexer Input Impedance Data For the Basic Design of Case 2A

It is clear that the excellent bandwidth of the antenna has been destroyed by the diplexer. This system would not have sufficient impedance bandwidth to function with DRM or IBOC DAB.

Case 2B, Diplexer Design With Series Pre-Matching Capacitor

One way that the design could be improved would be to use a series pre-matching element to reduce the reactive component of the antenna

impedance for each station. Case 2B demonstrates the improvement that can result from using a single 390 pF capacitor in series with the output of each unit and the tower. The schematic is shown in Figure 5. The resulting performance is tabulated in Table 22.

Station A		
Freq. (kHz)	Impedance Ω	VSWR
1,275	58.7 - j 5.9	1.214/1
1,280	55.9 - j 5.8	1.169/1
1,285	52.4 - j 4.4	1.103/1
1,290	50.0 + j 0.0	1.000/1
1,295	53.0 + j 6.0	1.139/1
1,300	59.2 + j 10.3	1.288/1
1,305	67.6 + j 9.7	1.410/1
Station B		
Freq. (kHz)	Impedance Ω	VSWR
1,385	62.7 - j 33.6	1.879/1
1,390	55.7 - j 22.6	1.550/1
1,395	51.7 - j 11.4	1.255/1
1,400	50.0 + j 0.0	1.000/1
1,405	50.6 + j 10.8	1.238/1
1,410	53.2 + j 21.2	1.511/1
1,415	56.7 + j 31.4	1.810/1

Table 22 Diplexer Input Impedance Data For the Design of Case 2B, Simple Series Pre-Matching

The results of Table 22 clearly show that the input impedance has been improved dramatically for both stations as a result of the series pre-matching capacitor. However, the input bandwidth is still not yet acceptable for station B and the port-to-port isolation is still insufficient for both stations. More must be done to improve the diplexer design.

Case 2C, Diplexer Design With Series Pre-Matching Capacitor and Shunt Filters at the T-Network Output

One method of improving the isolation between stations is to use 2-stage filtering. That is, shunt filters can be added in addition to the series filters that are already present. These filters are most commonly added between the matching network and the series filter network. This configuration is Case 2C and is illustrated in Figure 6.

The design of Figure 6 results in the input impedance performance shown in Table 23. Notice that although we should now expect to get sufficient port-to-port isolation between stations, much of the bandwidth improvement

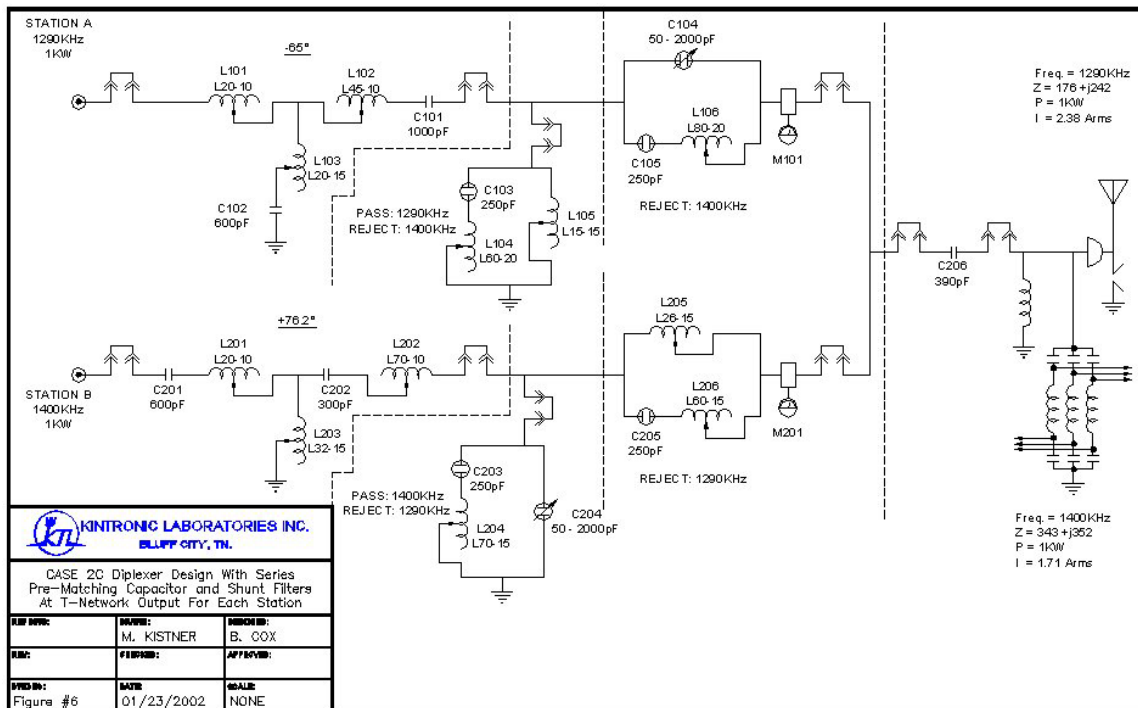


Fig. 6 Case 2C Diplexer Design with Series Pre-Matching Capacitor and Shunt Filters At T-Network Output

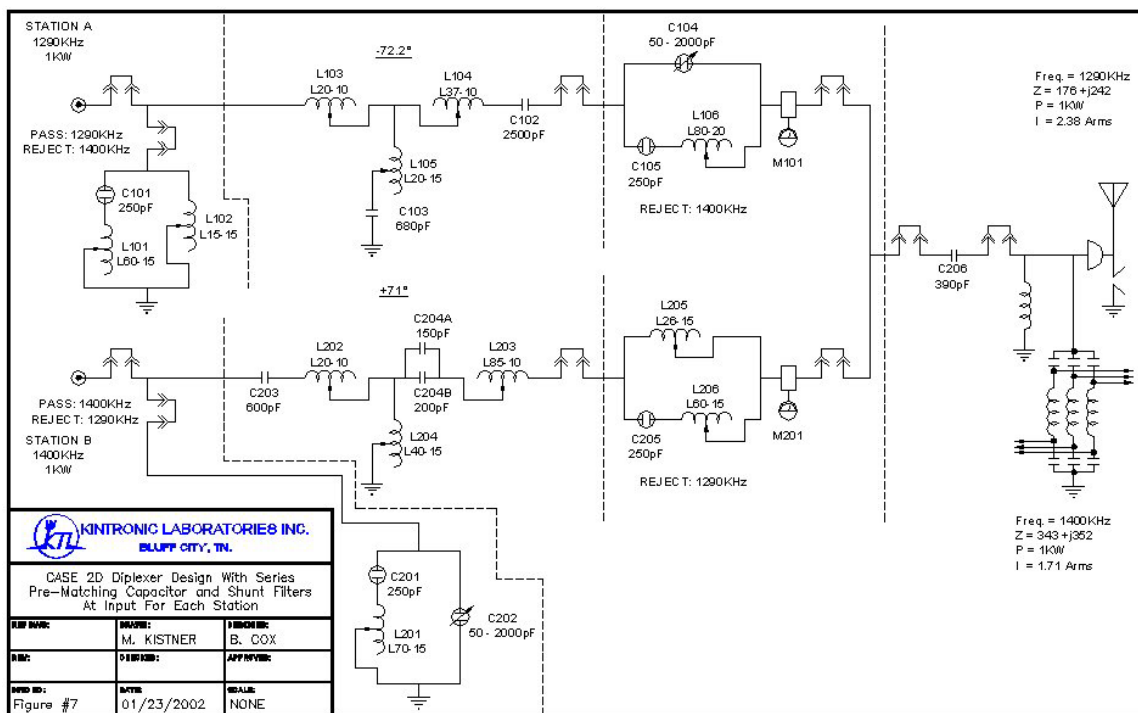


Fig. 7 Case 2D Diplexer Design with Series Pre-Matching Capacitor and Shunt Filters At Input for Each Station

that was realized in Case 2B has been lost in Case 2C. The bandwidth must be enhanced once again.

Station A		
Freq. (kHz)	Impedance Ω	VSWR
1,275	57.4 - j 32.9	1.859/1
1,280	54.8 - j 22.5	1.547/1
1,285	52.1 - j 12.1	1.270/1
1,290	50.0 + j 0.0	1.000/1
1,295	51.0 + j 13.3	1.300/1
1,300	52.2 + j 27.5	1.706/1
1,305	54.4 + j 43.6	2.265/1
Station B		
Freq. (kHz)	Impedance Ω	VSWR
1,385	51.7 - j 70.0	3.622/1
1,390	50.1 - j 44.7	2.377/1
1,395	49.7 - j 21.9	1.546/1
1,400	50.0 + j 0.0	1.000/1
1,405	51.5 + j 21.1	1.513/1
1,410	54.0 + j 42.5	2.224/1
1,415	57.1 + j 64.7	3.168/1

Table 23 Diplexer Input Impedance Data For the Design of Case 2C, Simple Series Pre-Matching and Shunt Filters at the T-Network Output

Case 2D, Diplexer Design With Series Pre-Matching Capacitor and Shunt Filters at Input For Each Station

Further improvement can be accomplished in this case by placing the shunt trap filter networks at a point where they will help rather than hurt the bandwidth performance. Placing the shunt trap filters at the input of each unit will not result in quite as much port-to-port isolation, but the level of isolation should be sufficient. This configuration is Case 2D and is shown in Figure 7. The results of placing the shunt filters at the input of each unit are shown in Table 24 below.

The results for Case 2D show that the placement of the shunt filters at the input of each stations matching network has lowered the sideband VSWR levels for this particular design. However, they are not as smooth in variation as desired. Varying of the phase shift through the matching network and attempts at slope correction gave no substantial improvement in the bandwidth. Resonances in the design are apparent and are causing the jagged VSWR performance. This type of problem can be seen

Station A		
Freq. (kHz)	Impedance Ω	VSWR
1,275	52.3 + j 2.3	1.066/1
1,280	52.0 + j 0.5	1.041/1
1,285	50.8 - j 1.1	1.028/1
1,290	50.0 + j 0.0	1.000/1
1,295	46.4 - j 33.4	1.981/1
1,300	49.1 - j 10.5	1.236/1
1,305	48.8 - j 11.3	1.257/1
Station B		
Freq. (kHz)	Impedance Ω	VSWR
1,385	60.4 - j 2.7	1.216/1
1,390	62.7 + j 12.2	1.368/1
1,395	48.3 - j 18.2	1.448/1
1,400	50.0 + j 0.0	1.000/1
1,405	51.7 + j 8.0	1.175/1
1,410	54.7 + j 15.2	1.354/1
1,415	58.9 + j 22.7	1.560/1

Table 24 Diplexer Input Impedance Data For the Design of Case 2D, Simple Series Pre-Matching and Shunt Filters at the T-Network Input

easily when factory pre-tuning a system with a network analyzer while using a driving impedance load simulator for each station at their respective carrier and sideband frequencies, which is standard procedure at Kintronic Laboratories as a result of a unique antenna load simulator developed by our engineering staff. Solving such a problem in the field could be very tricky and time consuming. This problem, however, can often be eliminated by adjustment of the filters.

Case 2E, Diplexer Design With Series Pre-Matching Capacitor, Shunt Filters at Input For Each Station, and Strategic Tuning of the Filter Networks

Case 2E illustrates the results that can be achieved when the filter networks are tuned to strategically shift their resonance points. The filter re-tuning permits the effective use of slope correction as well for both stations. The design is illustrated in Figure 8. The results for Case 2E are given in Table 25.

Case 2E shows quite dramatically the improvement in bandwidth performance that can be achieved by a carefully planned tuning of the filter networks. This diplexer design now finally exhibits sufficiently smooth impedance variation and low enough VSWR to easily operate well with DRM and IBOC DAB. The good

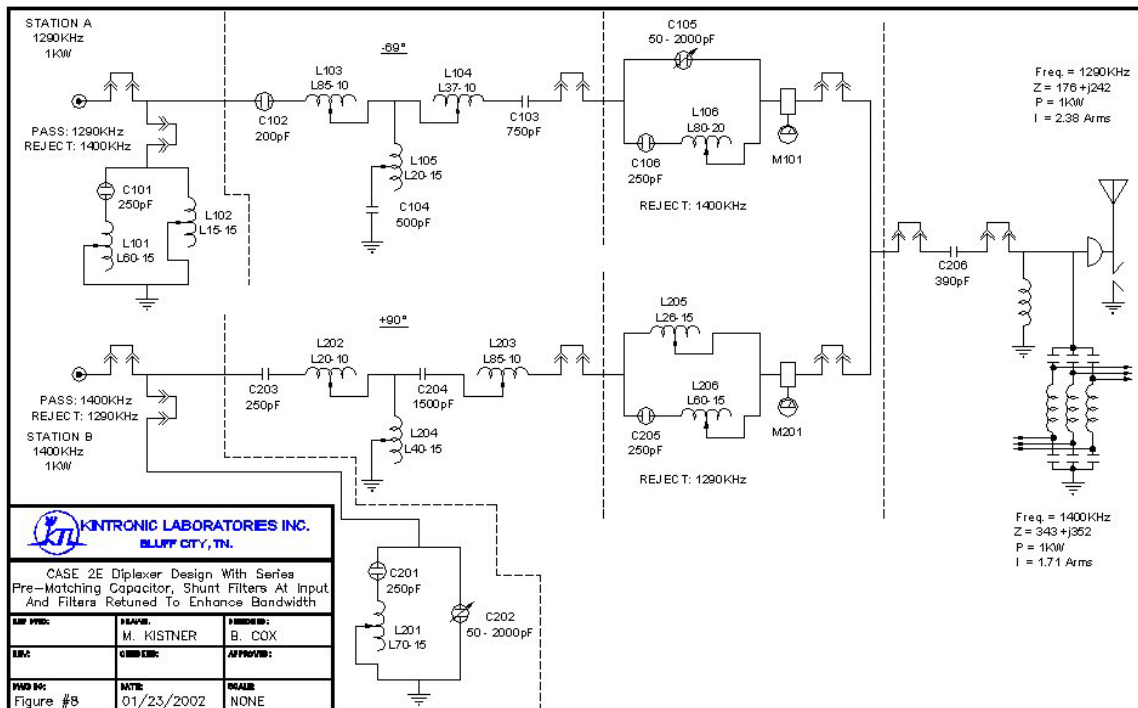


Fig. 8 Case 2E Diplexer Design with Series Pre-Matching Capacitor and Shunt Filters At Input, Filters Strategically Re-Tuned For Better Bandwidth

Station A		
Freq. (kHz)	Impedance Ω	VSWR
1,275	45.9 - j 3.1	1.112/1
1,280	48.0 - j 1.2	1.049/1
1,285	49.3 - j 0.7	1.020/1
1,290	50.0 + j 0.0	1.000/1
1,295	52.6 - j 0.4	1.052/1
1,300	53.2 - j 1.9	1.074/1
1,305	51.9 - j 3.7	1.085/1
Station B		
Freq. (kHz)	Impedance Ω	VSWR
1,385	56.0 + j 7.1	1.192/1
1,390	54.7 + j 3.0	1.113/1
1,395	52.7 + j 0.6	1.055/1
1,400	50.0 + j 0.0	1.000/1
1,405	48.0 + j 0.6	1.044/1
1,410	46.6 + j 2.4	1.089/1
1,415	45.5 + j 5.0	1.151/1

Table 25 Case 2E, Same as Case 2D with the Filters Strategically Re-Tuned

bandwidth performance of the antenna itself that was shown in Table 20 has been allowed to pass through a diplexer that does not excessively degrade its bandwidth. The filters are also

sufficient to provide high port-to-port isolation between stations.

It is worth noting that Case 2E is by no means the only diplexer design possible that would result in acceptable bandwidth. A more sophisticated pre-matching network that reduces both the resistance and reactance levels of the antenna impedance for each station could be used in this case to prevent the bandwidth perturbation that was caused by placing the shunt filter networks at the output of the matching T networks in Case 2C. This would then permit placing the shunt filter networks between the matching networks and the series trap filter networks, as shown in Fig. 6, which is in general the preferred arrangement since it gives higher port-to-port isolation between stations. However, a more sophisticated pre-matching design would add to the parts count and subsequent cost of the system, which is often a critical factor.

This series of examples has shown that a multitude of pitfalls may be present in the design of even a basic multiplexing system. Even when a good tower impedance is present for both

stations, the design of the multiplexer can substantially degrade the system performance if not approached with great care. It is recommended that the whole network be modeled with a program such as SPICE or a similar package in order to confirm that the

design yields acceptable bandwidth for each station involved.

Table 26 below summarizes the results of the diplexer design cases that were presented above.

Station A	VSWR				
Freq. (kHz)	Case 2A	Case 2B	Case 2C	Case 2D	Case 2E
1,275	3.060/1	1.214/1	1.859/1	1.066/1	1.112/1
1,280	2.130/1	1.169/1	1.547/1	1.041/1	1.049/1
1,285	1.416/1	1.103/1	1.270/1	1.028/1	1.020/1
1,290	1.000/1	1.000/1	1.000/1	1.000/1	1.000/1
1,295	1.283/1	1.139/1	1.300/1	1.981/1	1.052/1
1,300	1.589/1	1.288/1	1.706/1	1.236/1	1.074/1
1,305	1.935/1	1.410/1	2.265/1	1.257/1	1.085/1
Station B	VSWR				
Freq. (kHz)	Case 2A	Case 2B	Case 2C	Case 2D	Case 2E
1,385	10.29/1	1.879/1	3.622/1	1.216/1	1.192/1
1,390	3.772/1	1.550/1	2.377/1	1.368/1	1.113/1
1,395	1.719/1	1.255/1	1.546/1	1.448/1	1.055/1
1,400	1.000/1	1.000/1	1.000/1	1.000/1	1.000/1
1,405	1.447/1	1.238/1	1.513/1	1.175/1	1.044/1
1,410	1.893/1	1.511/1	2.224/1	1.354/1	1.089/1
1,415	2.355/1	1.810/1	3.168/1	1.560/1	1.151/1

Table 26 Summary of The Diplexer Design Cases

THE DIRECTIONAL CASE

For the case of a directional array, a multitude of variables can come into play. As with the single tower cases, both the radiating structure and the feeder system need to be accurately modeled. But with a multiple tower array, the sideband drive-point impedances change as a function of the RF feeder design. This interaction, which is due to the mutual coupling between the towers, requires that the radiating structures be included as part of the circuit in the design. The array geometry affects the overall performance of the system and needs to be taken into account, especially in a DAB design. The basic broadbanding techniques of slope correction, pre-matching, and where applicable, filter adjustment apply to directional systems as well. It is possible however for an array's geometry to dominate a broadcast system's bandwidth with only marginal improvements possible using the feeder system. Such cases need to be addressed on an individual basis and may require fairly drastic measures if they are to become DAB compatible. Changes may range from changing the feed configuration of a tower to redesigning the array itself. Fortunately though, there is

much that can be achieved by the proper design of the feeder system.

As with the single tower installations, the impedance bandwidth presented to the transmitter is an indicator of the expected quality of the DAB signal. With directional arrays, the pattern bandwidth of the system must also be taken into account. It is possible to design a phasing system to present an acceptable impedance bandwidth, yet skew the pattern as a function of frequency so as to degrade the DAB signal. It is beyond the scope of this paper to attempt to give a thorough coverage of this subject or even to describe the details of designing a particular array. Instead, the results of three case studies will be presented. Case 3A is a fairly simple, 3-tower, series-fed array with the parameters in Table 27. Case 3B presents the same array with tower 3 replaced with a unipole rather than being series fed. Arrays with at least one skirted tower are becoming more common as value of the "vertical real-estate" increases due to the demand for platforms for wireless communications. This case is presented to demonstrate the suitability of the design techniques to these more unorthodox, but

increasingly more common types of arrays. Finally Case 3C demonstrates the effect of the feed network design on pattern bandwidth.

Tower	Field Ratio/Phase	Spacing/Orientation	Tower Height
1	1 \angle 0°	0°/0°	66.5°
2	.89 \angle 93°	70°/162°	66.5°
3	1 \angle 110°	140°/203°	66.5°

Table 27 Parameters for Directional Arrays Of Cases 3A and 3B.

The Table 27 parameters correspond to the theoretical pattern shown in Figure 9. Actually three patterns are shown. The first is the theoretical pattern generated from the array parameters using the FCC method. The second pattern is the NEC 4.1 result for Case 3A and the last pattern corresponds to the NEC 4.1 result for Case 3B. The three traces coincide well enough to appear as one curve in the figure.

We take advantage of the NEC 4.1 electromagnetic modeling code's flexibility to model a wide variety of radiating structures. For a typical series fed array, the towers can be effectively modeled as cylinders to produce sufficiently accurate results. In mixed arrays with series fed and skirt fed towers, the skirted tower requires modeling with individual wires for the skirt and tower structure elements to avoid computational inaccuracies resulting from wires being too closely spaced. This constraint comes from the requirement that parallel wires be separated by several radii⁴. An accurate model cannot be maintained when using a single

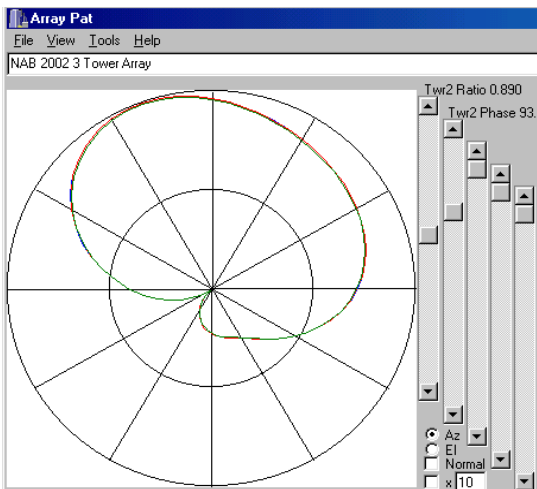


Fig. 9 Three Tower Array Pattern For Cases 3A and 3B.

large cylinder as the tower structure for the skirted tower. A series of in-house tools are used at Kintronic Labs to construct the tower structures, to retrieve the pertinent data from the NEC model, and to plot the results.

Case 3A, Series Fed Three Tower Array

An aerial view of the NEC model for the three tower series-fed array is shown in Figure 10. The towers were all modeled as lattice structures to provide for a more consistent comparison with

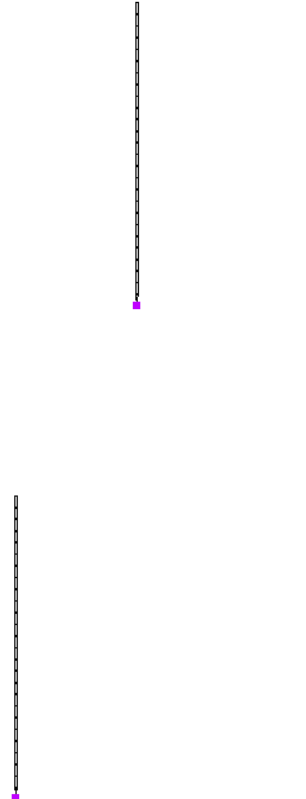


Fig. 10 NEC Model Of Series Fed Array.

the array including the unipole tower in Case 3B. The results of the common point sweep for the final design are shown in Table 28 and meet the impedance bandwidth criteria for a DAB system.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	52.1 - j 9.2	1.203/1
1,060	51.3 - j 1.0	1.033/1
1,065	49.1 - j 0.8	1.025/1
1,070	50.0 + j 0.0	1.000/1
1,075	51.7 - j 0.3	1.035/1
1,080	52.7 - j 0.5	1.083/1
1,085	45.4 - j 2.7	1.118/1

Table 28. Case 3A. Common Point Sweep

Case 3B, Three Tower Array With Single Unipole

An aerial view of the NEC model for the three tower array with tower 3 being replaced by a skirted tower is shown in Figure 11. The common point results for this directional system are presented in Table 29. The basic feed system was the same in both cases, with the primary differences being those required in the matching network to adjust for the impedance change at tower 3. Notice that the use of the unipole on tower 3 resulted in a slight improvement in the common point sweep by flattening out the VSWR at the -15 KHz sideband. The unipole was placed on the low impedance tower of the array, and the drive point impedance was transformed from $14.4-j 87.5 \Omega$ to $69.2-j190\Omega$.

Freq. (kHz)	Input Imped. Ω	Input VSWR
1,055	$54.0 - j 0.1$	1.081/1
1,060	$49.4 - j 2.8$	1.059/1
1,065	$49.3 + j 0.2$	1.015/1
1,070	$50.0 + j 0.0$	1.000/1
1,075	$51.2 + j 0.7$	1.029/1
1,080	$53.7 - j 1.9$	1.083/1
1,085	$53.7 - j 2.6$	1.092/1

Table 29. Case 3B. Common Point Sweep

The conclusion should not be that a unipole will improve DAB performance in all cases, but rather that all aspects of an array must be addressed to achieve the best DAB performance.

The drive parameters for the arrays in both Cases 3A and 3B were determined using a method based on the work presented by James Hatfield.⁵ As discussed in that reference, numerical modeling provides a powerful tool to generate an accurate design as well as to facilitate the adjustment of an array in the field. This is especially true when the tower types are mixed. Hatfield points to the utility of such methods for initially setting the array to its default parameters. In the likelihood that sampling toroids would be used on both of these arrays, the ratio of the drive currents for tower three compared to reference tower 1 is quite different in the two cases. The tower 3 base current ratios for are $1.04 \angle 108.5^\circ$ versus $.486 \angle 105.7^\circ$ for the series fed and unipole towers respectively. Using these modeled results would expedite the installation of the unipole in the existing array.

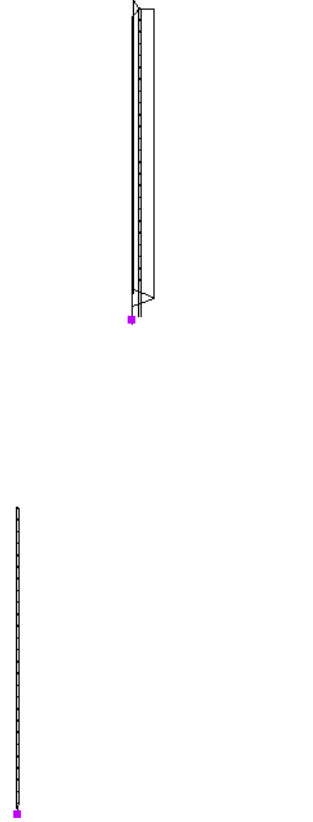


Fig. 11 NEC Model Of Array with Unipole.

Case 3C, Effect of Feed System on Pattern Bandwidth

The final case is presented to demonstrate the effect of the RF feed on pattern bandwidth. Figures 12 and 13 compare the pattern bandwidth of the Day pattern of WWJ in Detroit at two stages of the design. Figure 12 shows the pattern at carrier and the +/-10 KHz sidebands after the initial feeder design. Figure 13 shows the Day pattern after the final RF feed design for the Day pattern. It is important to note that the array and field parameters remain the same in both cases. The only difference between the two cases is the RF feed network. In both network designs, the impedance bandwidth of the array was acceptable. But in Figure 12 the field strength of the lower side band deviated by as much as 11.4 % from the field strength at carrier over the region of concern in the main lobe. In Figure 13 the sideband field strengths are within 1.4% of the field at carrier over that same region. The authors are indebted to Ron Rackley regarding his suggestions pertaining to the RF feed system on that project. The WWJ array was intentionally designed to be compatible with DAB broadcasting.

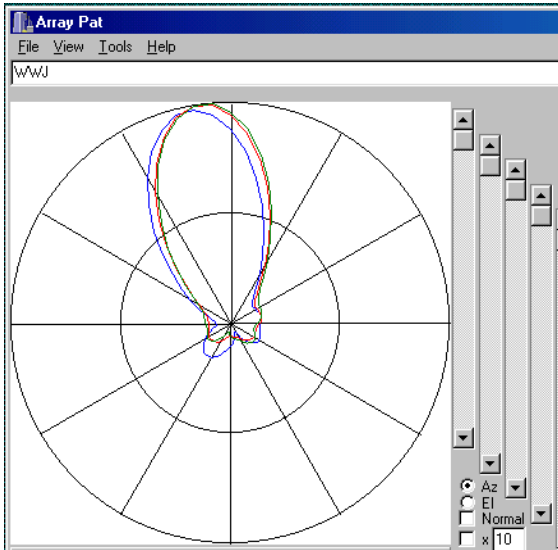


Fig. 12 Early Design With Poor Pattern Bandwidth

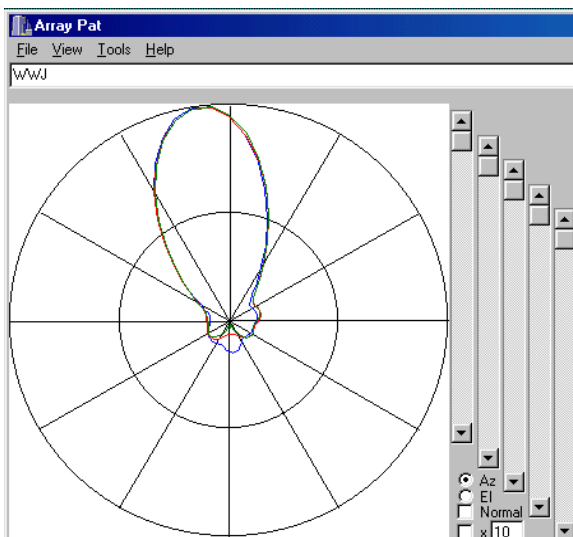


Fig. 13 Final Design With Good Main Lobe Bandwidth.

CONCLUSIONS

The single frequency, non-directional cases have demonstrated that both the antenna design and the ATU design are both critical to the impedance bandwidth that ultimately results for the antenna system of an AM broadcast station. Towers that are excessively short should be avoided. When a short tower is inevitable, improvements can still be had by increasing the cross-section of the antenna, such as through the use of the flared-skirt approach for shunt feeding the tower. Capacitive top loading, although not presented in this paper, is a commonly used

measure that can also enhance the performance of a short tower. Slope correction in the ATU design can further improve the bandwidth of the antenna system.

For cases when filter networks are present, such as when multiplexing more than one station on the same antenna system, the bandwidth impact of the filter design and placement in the system is critical. Cases 2A through 2E clearly showed that even when presented with a tower that has very good inherent impedance bandwidth, the design must be carefully carried out in order to preserve the best possible bandwidth performance. Modeling a complete multiplexed system in a circuit analysis program is highly recommended. Factory pre-tuning a new multiplexing system using antenna load simulators and a network analyzer is also recommended in order to reveal any problems that may not have been apparent in the computer simulation of the design. This can save much time and expense when the final installation and tune-up is done on site.

These same guidelines apply to directional systems, with the additional constraint of the requirements on pattern bandwidth. Because of the impact of array geometry on the overall system performance, simply choosing the array parameters which meet the coverage requirements at carrier is not sufficient to ensure a design which will be DAB compatible. Some improvement can be realized by careful design of the RF feed system, but this should not be solely relied upon for good bandwidth. Both the array details and the phasing equipment need to be carefully modeled to achieve good performance. The uniqueness of medium wave directional arrays requires this for each installation. Unfortunately there are no universal solutions to achieving DAB compatibility.

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