NEW DEVELOPMENTS IN MASTER FM ANTENNA SYSTEMS

Keith Pelletier
Dielectric, Raymond, ME
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ABSTRACT

As more and more FM stations consider consolidation on a common site to lower expenses, or look to upgrade present systems for improved performance, the design of Master FM Antenna Systems continues to evolve. New systems recently installed in the United States and Brazil have unique features for broadcasters, including power levels, coverage, introduction of digital transmission, auxiliary capabilities and installation requirements. This paper will describe how these requirements are addressed and the subsequent development of hardware (antenna components) and antenna systems to produce the desired results. Actual installations will be used as case studies for demonstrating the implementation and final performance of the design solutions.

In addition, this paper will describe how the increase in IBOC (In Band On Channel) power levels from -20 dB to -14 dB or -10 dB has dramatically changed the design philosophy in these Master FM Systems. The technology and specifications required will be covered to demonstrate why the increase in IBOC power has fundamentally changed the designs and Engineering behind the scenes.

Key Design Criteria for Master FM Sites

EACH SITE HAS A UNIQUE DESIGN SOLUTION FOR OPTIMAL PERFORMANCE

A great deal of consideration must be given by broadcasters when selecting a new Master FM antenna system, including the following parameters:

-Pattern Circularity

-Axial Ratio or VP vs. HP Tracking

-VSWR Specification

-Tower Loading

-Costs

-Vertical Pattern Shaping

-Prior Product Performance History

-Power Handling

With the addition of digital signals come new design elements that were not present just 8 years ago.

-Total IBOC Power Levels

-Isolation Between Analog and Digital Signals

The IBOC considerations are very critical in the decision making of the new FM site, especially since the IBOC power levels can now be raised to as high as -10 dB versus the original standard of -20 dB. This paper will cover multiple scenarios and sites, and tie them back to the key design points noted above, as well as review the decision points needed to optimize a given solution.

Top Mount Master FM Site Utilizing Single Input Port

Top mount antennas used for Master FM installations typically are cross dipole antennas covering the entire FM band. The single-input varieties of these antennas are produced for either analog or digital signals only. Typically, these antenna types are used when the broadcaster will be using a separate antenna for IBOC needs, or the IBOC power will be injected using common amplification.

The key for the broadcaster, if utilizing two antennas, is to determine the differences in patterns (elevation and azimuth) and determine if it is beneficial to take this approach. To maintain the same coverage, it is recommended that antennas maintaining the same patterns and yielding adequately high isolation to meet the mask requirement be used. When utilizing separate antennas, the isolation required to meet the mask is the same as the isolation needed between the analog and digital ports of a dual input master antenna (see below).

A measure of this isolation is the level of so-called Spectral Re-growth (SR), which is defined as follows:

Spectral Re-growth = A/D ratio + Antenna Isolation + Transmitter-Turn Around Loss (TAL),

where A/D ratio is defined by Ibiquity as follows:

-10 dB IBOC = -31.4 dB

-14 dB IBOC = -35.4 dB

-20 dB IBOC = -41.4 dB

TAL typically is defined as -6 to -10 dB for tube transmitters and -16 to -20 dB for solid state transmitters. For examples used in this paper, we will use -6 dB for tubes and -16 dB for solid state.

Since the mask requires SR to be below the -74.4 dB level, and the variables above are fixed, the isolation needed to meet this requirement can be quickly calculated.

We will assume -10 dB IBOC injection levels for this example and analyze both paths, i.e., analog to digital and digital to analog. We will also assume high power analog services with a tube type transmitter and a solid state digital transmitter.

SR (A to D) = A/D ratio + Ant Isolation + TAL

-74.4 dB = -31.4 dB + Ant Isolation + -16 dB

Ant Isolation = -27 dB Minimum

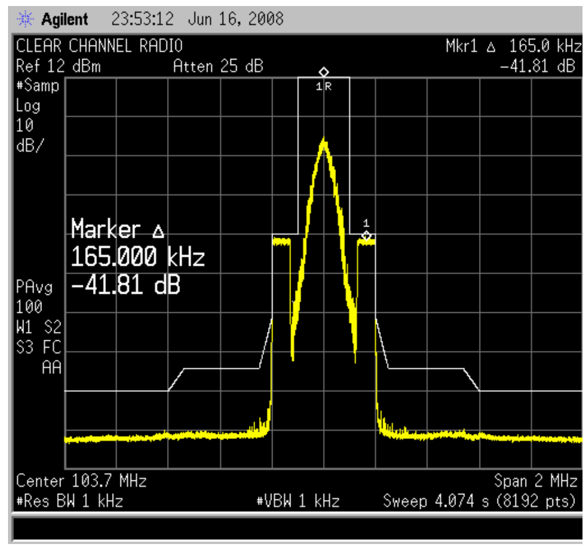
SR (D to A) = A/D ratio + Ant Isolation + TAL

-74.4 dB = -31.4 dB + Ant Isolation + -6 dB

Ant Isolation = -37 dB

The example above illustrates that the digital to analog path is the most important to consider with IBOC power levels at -10 dB. The isolation required from digital to analog is 10 dB higher than that of the analog to digital. In the early days of IBOC, at the -20 dB injection levels, the thought was that poor antenna isolation could be masked with a low power digital circulator. Clearly, since the most critical path is the digital to analog, the use of high power circulators becomes problematic. A high power circulator is expensive, very large, has many connections which can contribute to decreased reliability, and represents an inefficient use of power, given the amount of energy being directed to the dummy load. The latter will show up as increased operating expenses (OPEX) each month, which all station owners are diligently working to reduce. It is strongly recommended that additional headroom be added to the minimum isolation value of -37 dB to account for fluctuations within the system caused by rain, snow, VSWR changes, etc.

Also note that for each dB in IBOC power increase, there is a corresponding increase in isolation required – the relationship is always one for one.



Typical response of a system having superior isolation. Spectral re-growth levels are well below the mask. System shown had -43 dB of antenna isolation and -20 dB of TAL from solid state transmitters. (Courtesy of Clear Channel)

In cases where single-input cross dipole designs are considered, the following key criteria are driving the decision:

-Tower Loading

-Circularity

-Total IBOC Power Levels (Low)

-Prior Product Performance History

In general, the efficiency of most transmitters decreases at higher power levels, and they will often have difficulty handling power levels at -14 dB and -10 dB in the common amplification mode. This has a direct impact on broadcasters who need a solution for carrying the IBOC signal. If utilizing two antennas, it is recommended that the analog and digital antenna system be ordered from the same manufacturer, so they can analyze the isolation between the two antennas and deliver the required

-40 dB. The isolation design between two closely spaced antennas is no small engineering feat, and requires a strong technical background with careful manufacturing processes and understanding of the interaction between different elements.

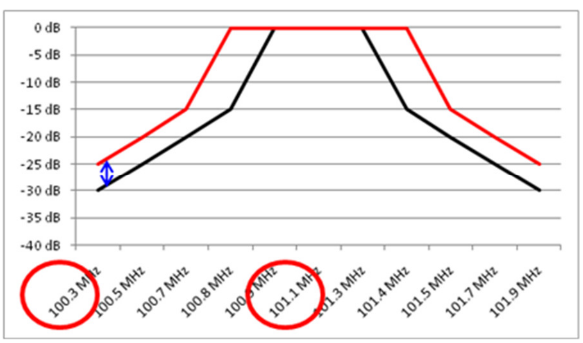
Note: Whether the antenna has dual inputs (i.e., analog and digital signals share a common radiator) or two antennas operate separately, the same isolation is required to meet the Spectral Re-Growth value.

I recommend separate combiners be used from the analog Constant Impedance Filter (CIF) to ensure adequate antenna isolation is realized. If we reverse-fed the combiner into the digital antenna (assuming the antenna had -40 dB of isolation), then the isolation realized would only be as good as the input hybrid to the CIF. Given that hybrid isolation is -35 to -37 dB with perfect loads (i.e., excellent VSWR matching), this method is not recommended for two reasons.

1. The filter's match is not perfect

2. If you drive the filter match down it widens the filter, so input A-D isolation improves but A-A and D-D on close-spaced stations decreases (see chart below).

In other words, there is no free lunch, and to make it work makes other system sacrifices and the A-D isolation within the channel would be border line at best. The use of a digital branch combiner can be used for this situation when considering costs, size, and IBOC power levels.



Widening of filter causes loss of channel-to-channel isolation which could be detrimental in close spacing Master FM sites.

Interleaved Solutions

Interleaved Systems have been deployed with isolations levels exceeding -40dB. Dual-channel, close–spaced, interleaved systems have been deployed with superior isolation and VSWR performance. In one recent case, two stations on a combiner were only separated by 800 kHz, and due to the IBOC sidebands they were even closer in frequency. The stations involved were interested in getting a space combined system with high isolation, however tower loading and costs were a deciding factor. The station wanted to keep the monthly operating costs down and space combining the antennas was the most efficient method to produce the desired result. The Interleaved solution met all their requirements and provided the necessary isolation to stay within the mask specification. To recap, the key criteria for this solution included:

-Tower Loading

-Cost

-Isolation Between Analog and Digital Signals

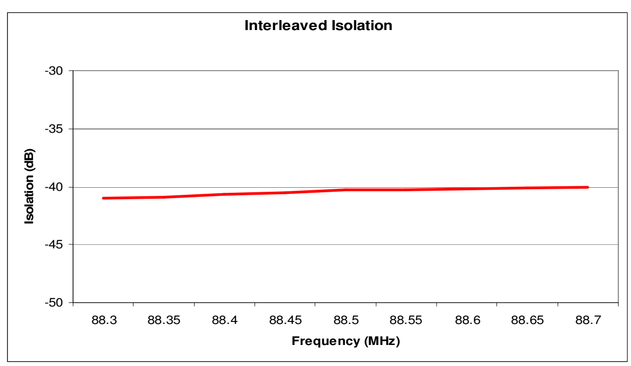
-Total IBOC Power Levels

-Prior Product Performance History

This system was deployed and achieved -43dB of antenna isolation between the analog and digital antennas. This site is currently running the existing CIF combiner for analog services and will install a new CIF combiner for the digital services in order to maintain the high antenna isolation as a means to stay well within the mask requirements.

Interleaved arrays have been successful in the field and have a proven track record with approximately 20 systems installed with greater than -40 dB of antenna isolation. These systems have been designed to yield the same azimuth and elevation patterns between the analog and digital antennas.

Note: Antenna isolation does not include the use of a circulator.



Typical isolation of SPX Communication Technology interleaved antennas

Panel Systems Installed on Existing Towers with Low IBOC Power Applications

Single-input panel antenna systems have been deployed to yield higher reliability. The advantage of this style of antenna is the single input, which reduces feed system components by ½ over the traditional dual-input panel antennas. The single-input panel antenna is quoted when the broadcasters choose to use common amplification at low IBOC injection levels or combine on the ground with a coupler at -20 dB IBOC.

The single-input antenna significantly increases reliability since the feed system of the panel is half that of typical broadband FM panels. The single-input antenna is an economical choice for single channel or two channel operation at low power levels. This antenna goes through the same peak power calculations in order to maintain high safety margins on the input and feed jumper.

To recap the key criteria for this solution we have:

-Circularity

-VSWR Specification

-Tower Loading

-Cost

-Vertical Pattern Shaping

-Prior Product Performance History

-Total IBOC Power Levels

Antenna Systems for Single Carrier Use – Side Mounted

Antenna manufacturers must design antennas to handle the peak power of multiple signals. In addition to the peak power design criteria, these antennas can be also used for a high power single channel operation. The antenna design includes a robust antenna element and large inter-bay feed system. The key design criteria for the high power requirements:

-Power Handling

-Tower Loading (Space)

-Cost

Antennas have long been developed to enable side mounting master antennas with bandwidths covering multiple megahertz. In addition with the Peak to Average Power Ratio (PAPR) on the IBOC signals and the IBOC signals at -10 dB the IBOC voltage is essentially the same as the analog voltage. For example, if there are six class C stations with IBOC at -10 dB on each station, it is similar to having 12 class C analog stations. See equations and example below:

Power = 90 kW

Z = 50 Ohm

X = Number of Stations

PAPR = 6.3 (8 dB)

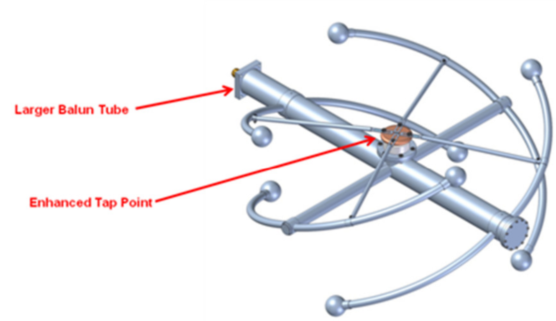
Analog Voltage = $\sqrt{\left(2 * \frac{Power}{X} * Z * 1000\right)}$ *X

Analog Voltage = $\sqrt{\left(2 * \frac{90}{1} * 50 * 1000\right)}$ *1 = 3000 Volts

IBOC Voltage (-10 dB) = $\sqrt{2 * \frac{Power*.1}{1} * PAPR * Z * 1000}$ *X

IBOC Voltage (-10 dB) = $\sqrt{2 * \frac{90*.1}{1} * 6.3 * 50 * 1000}$ *1 = 2381 Volts

As you can see it is very important to have a robust antenna design that can incorporate these peak powers (voltages) with sufficient safety margin. One example of the more robust antenna design from SPX Communication Technology is shown below. SPX developed this antenna from their standard product but enhanced the tap point and made the balun tube larger.



DCRS Bay Showing Enhanced Features over DCRM

Although the DCRS was designed for higher peak powers with IBOC in mind, it was also a perfect fit for the high-power, single-channel applications that are limited to using fewer bays. Typically, the power levels on single-channel FMs in parts of South America will run at 70 to 80 kW of antenna input power. These high power requirements need a robust antenna design.

Side Mount Broadband Antennas

Antenna systems from some manufacturers at ½ wave spacing can cover most of the FM band. The broadband nature of this design along with the robust design for peak power concerns makes these antennas an excellent choice for multi-station, side-mount master FMs. An upcoming installation will feature a four-station analog system with the IBOC rated at -10 dB. This system covers a 14 MHz-wide band (93.3 – 107.3 MHz). The key design criteria included:

-VSWR Specification

-Tower Loading

-Cost

-Vertical Pattern Shaping

-Prior Product Performance History

-Power Handling

Another added benefit of the side-mount, shunt-fed design is the increased reliability that comes along with a decrease in the number of connections when compared to existing branch fed panel antennas. The system also is designed with a 6” input and is rated for 80 kW plus 8 kW IBOC power (4 stations analog plus 4 digital, IBOC at -10 dB).

In addition, the increased IBOC power levels on this antenna will be accomplished by the transmitter as the antenna has a single input. The key in this design is verification that the antenna delivers high safety factors due to the high peak powers. The following equations were completed to see if the safety factors where indeed in place. I typically strive for a high voltage safety factor due to changes that can occur in VSWR once the antenna is introduced to the elements.

Power = 80 kW Total, 5 kW per Bay

IBOC Power = 8 kW Total, 0.5 kW per Bay

Stations = 4 Analog and 4 Digital

Impedance of Bay (Z) = 100 Ohm

X = Number of Stations

PAPR = 6.3 (8 dB)

Y = Bay VSWR (Assume 3:1 for this exercise)

Analog Voltage at Each Bay $= \sqrt{2*\frac{\text{Power Per Bay}}{\text{X}}*\text{Z}*1000}$ *X * (Y*2) / (Y+1)

Analog Voltage = $\sqrt{2*\frac{5}{4}*100*1000}$ *4 * (3*2) / (3+1) = 3000 Volts per Bay

IBOC Voltage (-10 dB) = $\sqrt{2*\frac{\text{Power Per Bay*0.1}}{\text{X}}*\text{Z*PAPR}*1000}$ *X * (Y*2) / (Y+1)

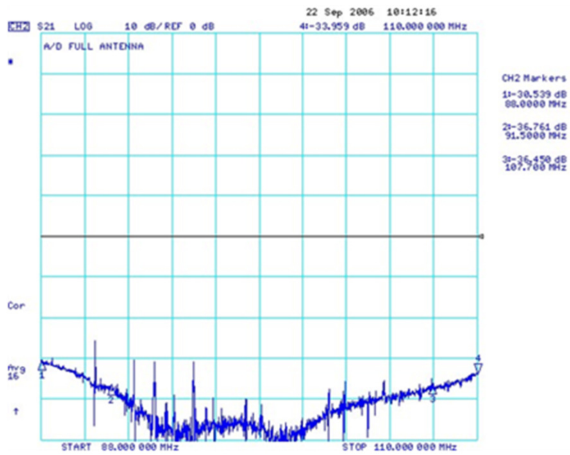
IBOC Voltage (-10 dB) = $\sqrt{2*\frac{0.5}{4}*100*6.3*1000}$ *4 * (3*2) / (3+1) = 2381 Volts per Bay

Note additional stations and changes in power need to be reviewed prior to any changes at the site

It is very critical to understand the performance of each bay and the calculations that go into its design to insure appropriate safety factors are applied to each multi-station application. This becomes particularly important at the higher IBOC power levels. As illustrated above, the voltage due to the IBOC power is almost equivalent to the analog voltage at -10 dB, and improper calculation or misunderstanding could result in a catastrophic error at the master FM site.

Top Mount Master FM Site Utilizing Dual Input Ports for IBOC and Analog

It is still recommended that use of an antenna system like the HD-FMV or HD-DCBR and space combining the analog and IBOC signals when possible. This is the most efficient method of getting your two signals on the air with the same electrical performance. The key when looking at this design is to verify the manufacturer’s isolation between the analog and digital ports. See typical SPX Communication isolation plot below.



Field measured isolation > 30 dB
without the use of a circulator

System Upgrades for Power Increases – Peak Power Concerns

Another frequent request we receive is to increase the IBOC power on existing systems built with -20 dB IBOC power levels. This situation needs to be analyzed from the combiner through the antenna. As stated above the voltages begin to stack up quickly at the -14 dB and -10 dB power levels. The best approach is to break down the entire system design, calculate the voltages and evaluate for the proper safety factors. The following equations are used:

Analog Voltage = $\sqrt{2*\frac{\text{Power}}{\text{X}}*\text{Z}*1000}$ *X * (Y*2) / (Y+1)

IBOC Voltage (-10 dB) =
$\sqrt{2*\frac{\text{Power}*0.1}{\text{X}}*\text{Z}*\text{PAPR}*1000}$ *X * (Y*2) / (Y+1)

Many large systems such as St. Louis HD-FMV, Birmingham FMV, and New Orleans FMV have undergone this level of analysis and successful solutions were provided to many other sites where increased power levels were desirable. The recommendations made included but were not limited to:

-Upgraded Power Splitter

-Addition of Second Transmission Line

-Upgraded Digital Feed System

-Upgraded CIF TL Interlinks

-Upgraded CIF Hybrids (input and output)

-Addition of a Separate Digital Antenna

Each new Master FM site should receive this type of analysis, and typically the new sites consider the higher IBOC injection levels. Thus it is crucial to the antenna design that these parameters are carefully scrutinized before providing the customer with the technical solution.

CONCLUSION

With the increase in IBOC power, it is clear that solid engineering work is required prior to providing a solution to the customer. The existing platform on how decisions are made for each site is more dynamic than in years past and the added value of the Engineering should be taken into consideration and it should not be a bottom line only decision. These sites are complicated in nature and the last thing the broadcaster or manufacturer wants is a site to fail.

The most critical design criteria are isolation and power handling. The isolation is heavily dependent on the individual antenna design as well as their respective location. To be successful in delivering isolation levels mentioned above, one antenna supplier is preferred as they can carefully design each antenna to maximize the isolation levels.

The multi-station antennas have to handle not only average powers but very high peak powers. Special skill with regards to design, manufacturing and quality control are key when it comes to producing antennas that are capable of handling these high powers, and with sufficient safety margin. These are skills that few manufacturers have. SPX Communication Technology can not only deliver antennas that will handle the powers, but can do so while providing great isolation. This is essential to delivering an efficient site to the customer as well as provides the best quality of both HD and analog signals in the entire coverage area.

The site complications due to the high peak HD signals drive design safety margins. Once these signals are multicast with their corresponding analog signals it highlights the tremendous need for analysis. Proper design criteria are developed by experience with implementations and a strong technical background. The manufacturing and quality process is equally as critical to design the product to yield the optimal performance and ensuring the product meets the specifications. The quality process within the manufacturer’s four walls should verify that the high safety margins are realized at the time of installation.