Reconfigurable Manifold Combiner

2023 BEITC Proceedings
Dielectric
Raymond, ME.

Abstract–Traditionally, when looking at expanding a filter system for the addition of new channels, the use of a Constant Impedance Module (CIF) would be used. This paper will examine a new combiner technology that allows for expansion without the use of the CIF and showcases additional attributes that make it a viable solution for broadcasters moving forward. The groundbreaking technology helps pave the path for future channel combiners, especially when space and economics demand something other than the CIF.

Introduction

The new technology being introduced incorporates a Manifold combiner, which is not new to the industry. However, the combination of features added to the Manifold, and described in this paper, make it a more economical option moving forward for systems requiring expandability and less floor space in the transmitter building. Manifold combiners have one filter per channel and are combined/phased on a coaxial Manifold to provide enhanced electrical characteristics for each channel but lack flexibility in expansion for additional channels. Directional filter modules, or constant impedance filter modules, CIF's, are cascaded and easily expandable due to the constant impedance seen at each module output. CIF modules are less efficient, significantly more expensive and require more space due to the extra components within the modules. Tube transmitters prefer constant impedance modules to operate properly making CIF combiners popular. Today's new solid-state transmitters are smaller, more efficient, and easily operate into bandpass filters with high out-of-band reflection making smaller, more efficient Manifold combining more beneficial for the broadcaster's budget.

Reconfigurable Manifold Description:

Introducing the addition of unused ports on the Manifold spline allows for future expansion. This in combination with an analysis to compute the line lengths for the output spline (all while keeping the I/O's in the same location) is what makes this package unique. One benefit of a typical Manifold combiner is that the overall footprint is much smaller than the CIF. The Manifold allows for the most compact configurations, which is beneficial given each transmitter building is unique and space is often a limiting factor. The Manifold has advanced electrical characteristics over the CIF. By eliminating the hybrids, the peak power rating can be increased. These advantages will be discussed in more detail further in this paper.

Mechanical Advantages

The reconfigurable Manifold combiner incorporates a streamline design with a footprint that is half the size of an equivalent CIF. A Manifold has 60% fewer components than the CIF. The reduction of components equates to better reliability as shown in the following failure rate formula:

$$\lambda = \sum_{i=1}^{n} N_i \lambda_i \pi_{Qi} \qquad (1)$$

Where n is the number of part categories, N_i represents the quantity of the i^{th} part, λ_i is the failure rate of the i^{th} part and π_{Qi} is the quality factor of i^{th} part [1]. From equation (1), we conclude that reliability is directly proportional to component count. The simplicity of the Manifold inherently makes it more reliable than other complicated combiner styles. A comparison between a Manifold and equivalent CIF is shown in Figure 1.

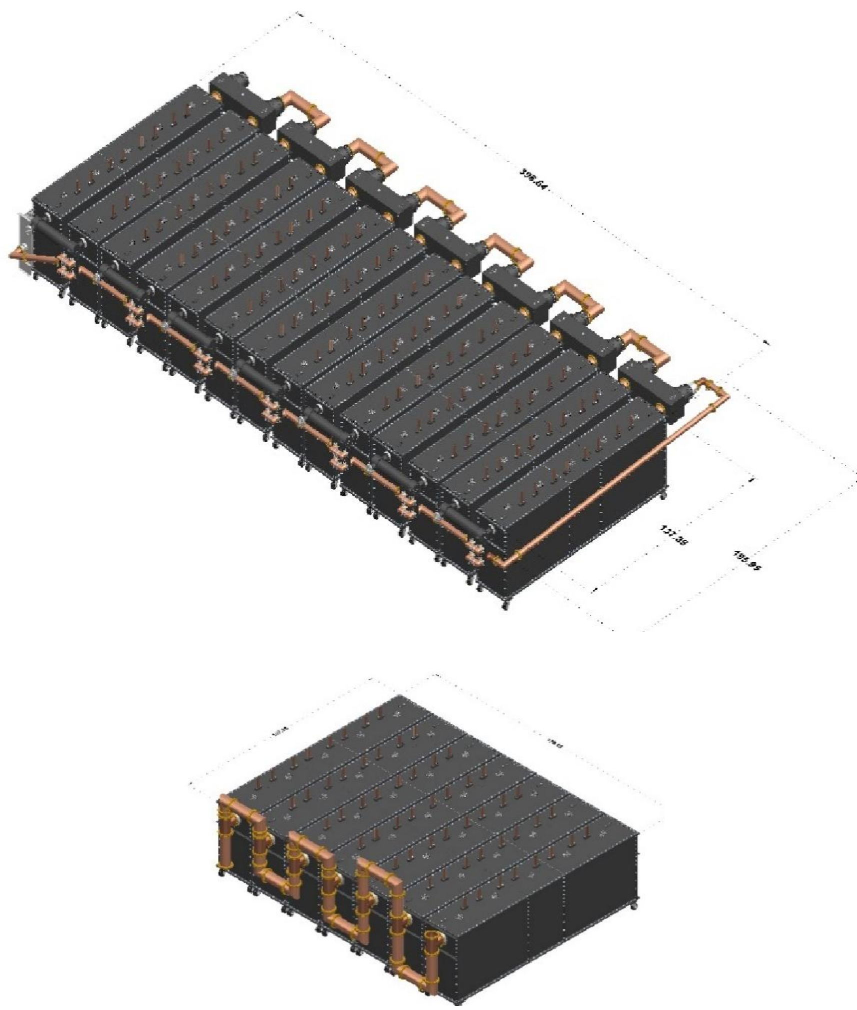

FIGURE 1: CIF (TOP) VERSUS MANIFOLD (BOTTOM).

The unique output U-links on the Manifold have a significant advantage as new channels are added into the system. It allows for easy removal of the spline to make phase modifications without disrupting the physical location of the existing filter inputs. Thereby eliminating the cumbersome rerouting of the transmission line inputs when new stations are added. When new channels are added to the Manifold design, it is simply a matter of verifying electrical data of the system. Figure 2 below depicts how the output U-links are configured to keep the footprint as small as possible while leaving the input ports in the same location.

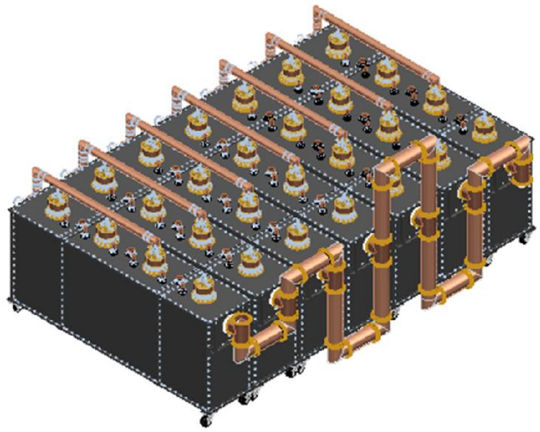

FIGURE 2: OUTPUT U-LINKS DESIGNED TO KEEP INPUTS IN SAME LOCATION.

Each channel requires a filter module whereas a CIF requires an input and output hybrid and a second bank of filters. In addition, the Manifold combiner does not utilize any reject loads or a ballast load for the combined system output.

Once the number of stations to be combined is defined the overall footprint of the Manifold remains constant after installation. In contrast, with a CIF filter, space needs to be planned and reserved for future expansion. Any future expansions of a CIF system will take considerably longer than the Manifold design.

Ports for Future Channels

The example being used for this paper is a 7-channel Manifold combiner. Five of the channels are defined and two open ports are dedicated for future channel expansion. Reference Figure 3.

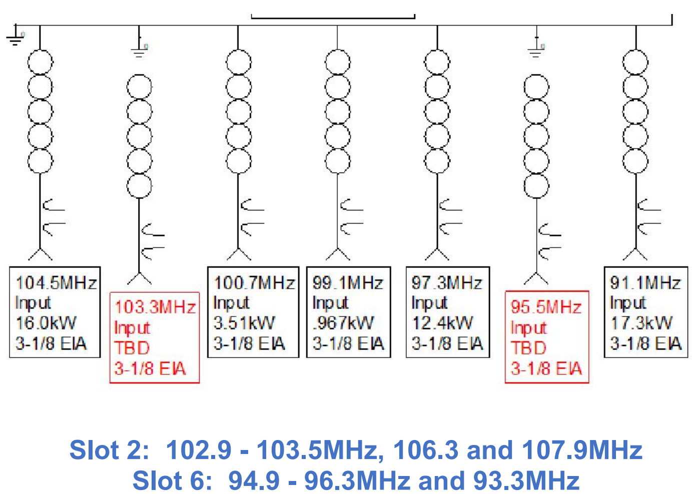

FIGURE 3: FIVE CHANNEL MANIFOLD WITH THE FUTURE EXPANSION OF TWO CHANNELS SHOWN IN RED BOXES. FREQUENCIES THAT CAN BE ADDED FOR THIS EXAMPLE SHOWN IN BLUE.

Spare Filters

When manufacturing and testing the system all 7 filters are incorporated. The frequency matrix, based on the anticipation of future channels, is confirmed using 3-dimensional electromagnetic simulation software (HFSS) and circuit simulation. The two additional filters are delivered to site and utilized for the future channels or as backup filters. A field technician can tune the two spare filters to the required new channels and place them in line by removing the shorting cap and adding the new channel. If a new channel is being added, the Manifold spline will need to be adjusted and retuned before going back into operation. This procedure is relatively simple and typically takes less than 4 hours to complete. This approach is notably quicker than adding a new CIF module to an existing CIF combiner system.

Or in the rare event a filter requires maintenance, the filter can be removed, and the spare put in its place. If a spare filter is utilized to replace a failed main filter, the damaged filter should be visually inspected for issues while spare parts are ordered to get the original filter back in operation. The repaired filter can continue to be utilized as a spare or to be used as a new station in the system in the future. Spares are a fraction of the overall costs when compared to today's CIF topology. The Manifold concept equips the station for all future scenarios, whereas CIF systems simply are not equipped with spare parts or expedient, economic expansion capability.

Electrical Shorts for Unused Ports

Continuing with the 7-channel system with 5 defined channels example, the unused ports are capped with an electrical short that have the equivalent short distance as the filter itself. The output spline is defined for each filter configuration. To accomplish this, a channel matrix is defined. The filter configurations are defined by the broadcaster in advance of the combiner production. Alternately, a new channel can be defined and added after shipment. Analysis of the new spline is completed using HFSS and circuit simulation. See Figure 4 showing the two blank locations where the future channels will be added to the Manifold.

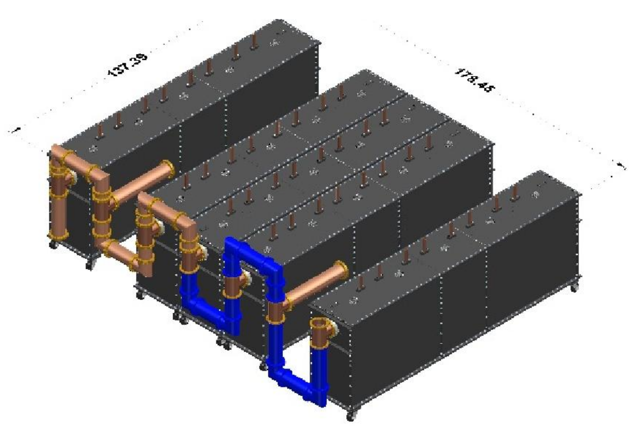

FIGURE 4: FIVE CHANNEL MANIFOLD SHOWING TWO SLOTS FOR FUTURE STATIONS. TWO SLOTS WILL BE ELECTRICALLY SHORTED AND USED IN FUTURE WHEN STATIONS ARE DEFINED.

Electrical Characteristics of Spline Defined in HFSS

At time of order the HFSS tool defines the S-parameters of each tuned filter. In addition, S-parameter data is taken on the elbows and tees in the output spline. This data is then entered into a circuit simulator to calculate the line lengths for each configuration. Figure 5 shows the possible changes to output U-links. Depending on the scenario, changes to a few or all U-links may be necessary.

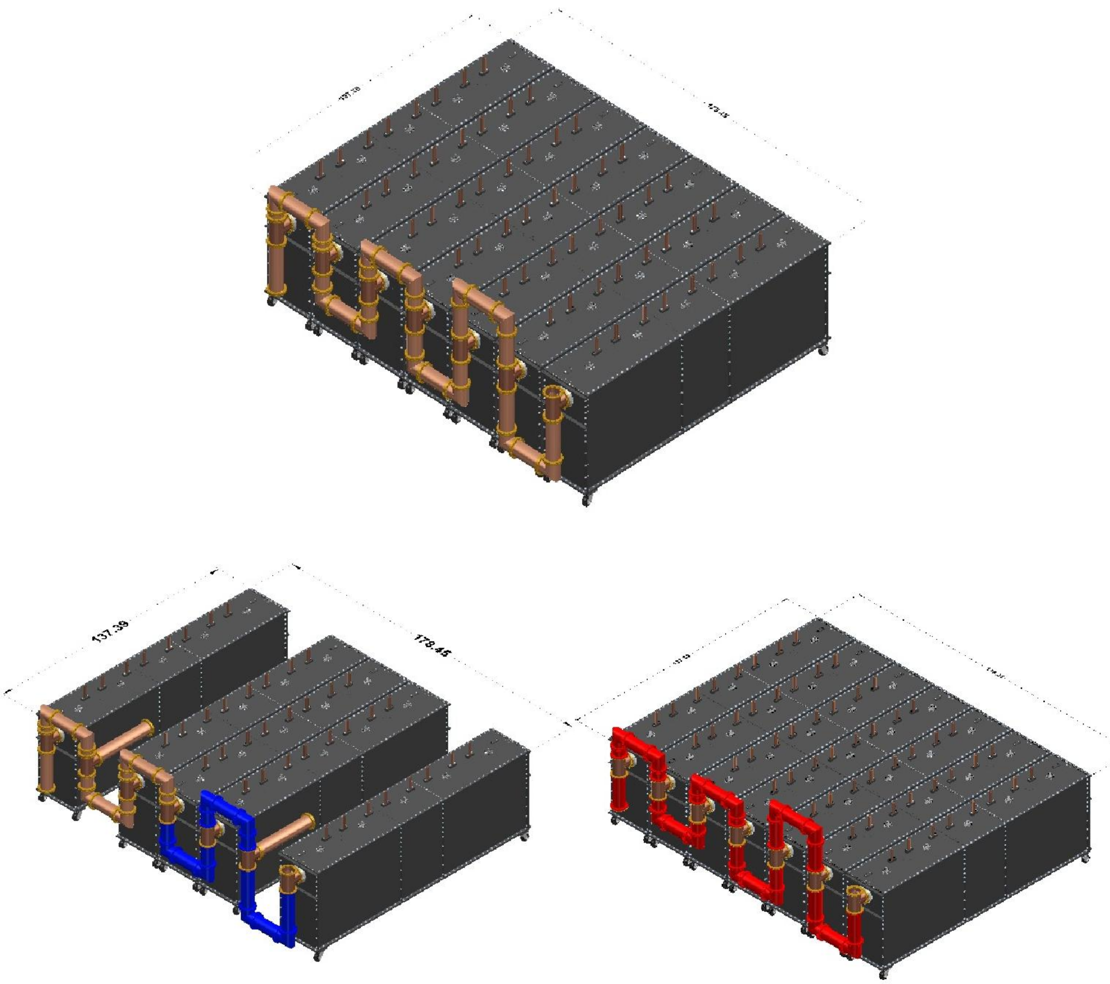

FIGURE 5: SHOWS ORIGINAL SPLINE VERSUS TWO SCENARIOS OF ADDING NEW CHANNELS. OUTPUT SPLINE CHANGE COULD BE PARTIAL U-LINKS AS SHOWN IN BLUE OR ALL U-LINKS SHOWN IN RED.

HFSS is a powerful tool that has advanced technology for Broadcasters. Time to market and implementation costs are minimized by the advancements with HFSS or other 3D electromagnetic programs. Obviously, these programs can only be managed by subject matter experts.

Manifold Enhanced Electrical Characteristics

The Manifold combiner has enhanced electrical characteristics over the CIF. The 7 channel CIF combiner will have increased loss in the chain further away from the antenna. Typically, the station at the ballast load end of the chain will experience a degradation in performance over the other channels in the system. The optimum location is at antenna side due to the degradation in electrical specifications as you get farther away from the antenna. This is an advantage of the Manifold design, there are no compromised positions in the chain. All channels have similar loss, VSWR, and group delay characteristics. The loss tables in Figure 6 illustrate the loss/efficiency between Manifold and CIF.

Manifold Combiner			
Station	Freq, MHz	Loss, dB	Eff, %
1	104.5	0.43	0.91
2	TBD		
3	100.7	0.41	0.91
4	99.1	0.4	0.91
5	97.3	0.39	0.91
6	TBD		
7	91.1	0.36	0.92

CIF Combiner			
Station	Freq, MHz	Loss, dB	Eff, %
1	104.5	0.5	0.89
2	100.7	0.55	0.88
3	99.1	0.61	0.87
4	97.3	0.67	0.86
5	91.1	0.71	0.85
6	TBD		
7	TBD		

FIGURE 6: MANIFOLD AND CIF INSERTION LOSS COMPARISON

VSWR in a Manifold combiner is also improved over a CIF combiner. Each station in the Manifold can easily be tuned to under a 1.06:1 VSWR, regardless of the station's location in the chain. A CIF has higher VSWR closer to the load side due to the addition of the output hybrids. Low VSWR is a desired specification in any system as it results in a more efficient system. Having a system with equivalent specifications for all channels and an advantage for all the tenants in the master system.

Hybrids on the output side of a CIF module are the weakest voltage link in the system. Hybrids inherently require a large capacitance at the coupled strip junctions. This junction capacitance must be carefully constructed to maximize peak power rating of the hybrid. The Manifold combiner can take advantage of system peak power rating since hybrids are eliminated from the system. Of course, the power ratings of the filters will be burdened since only one is used as opposed to two in a CIF, however, with proper sizing of the I/O's and filter the burden is easily reduced.

Intermodulation Suppression (IM)

The prime function of a channel combiner is to combine power from multiple transmitters into a single transmission line for broadcasting on a common antenna. A secondary but important function is to suppress 3rd and higher order intermodulation byproducts generated in the high-power amplifier of each transmitter. Figure 7 shows the generation of a third order intermodulation product from a high-power amplifier. F1 is the frequency of the amplified channel and f2 is the frequency of power applied to the output of the amplifier due to lack of perfect isolation. The frequency assignments of FM broadcast are such that the intermodulation products can fall on other FM frequencies, causing interference, or more significantly on airport communications and radar frequencies that can cause life critical interference. The FCC mandates the IM suppression from a high-power FM transmitter be -80 dB below the carrier in the FM band.

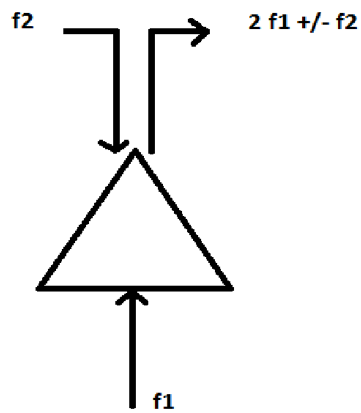

FIGURE 7: IMD PRODUCT GENERATION.

Figure 8 shows filter rejection at 800kHz for the 4-pole cross-coupled filter used in the Manifold combiner. Looking at the 3rd IMD product, f2 is reduced by:

- 35dB passing through CH filter to transmitter
- 24dB transmitter turn around loss (Solid State Transmitter)
- 3rd IMD reduced another 35dB passing through CH filter

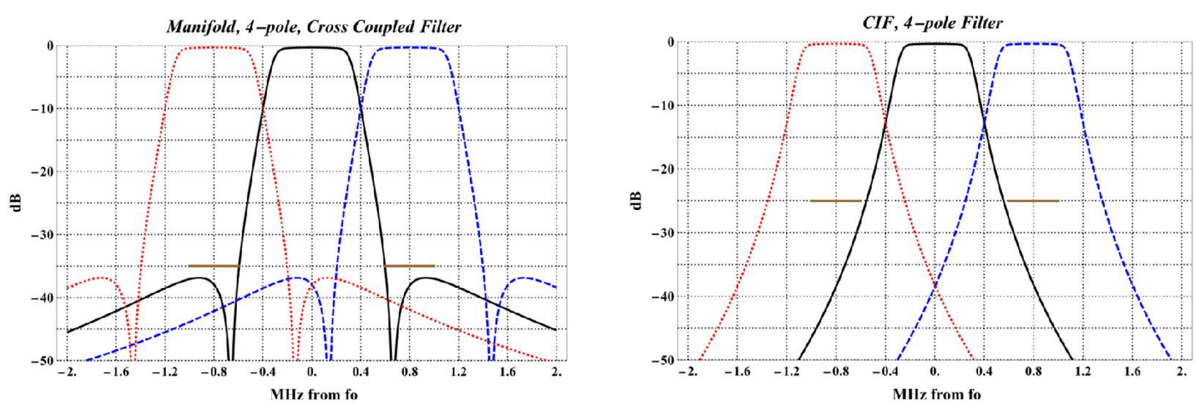

FIGURE 8: MANIFOLD AND CIF FILTER FREQUENCY RESPONSE.

Total IMD reduction in the Manifold combiner design is 94dB, well below the 80dB specification. The total IMD shown above is for closely spaced channels and will improve with larger the channel spacing. Additionally, 5 pole filters with cross coupling would increase the IMD reduction and gain headroom on the FCC -80 dB specification. If ample IMD headroom is achieved, you can consider reducing the number of poles within the filter and or remove cross coupling to widen the filter response. Note: The wider the filter the better the insertion loss.

Market Analysis

In reviewing how complex the solve matrix is for any site, we start with identifying there are 100 stations on the FM spectrum. Even though the analysis is simplified and optimized with software it can still be daunting to consider the possibilities that must be solved. However, knowing that the minimum spacing for stations is 800 kHz the potential for the maximum stations in one market can be defined by (2),

$$\frac{F(t)}{F(e)} \tag{2}$$

Where F(t) is total number of stations available on the FM dial or 100 and F(e) is the number of stations eliminated each time one is selected due to 800 kHz spacing, or 4.

This suggests that the market maximum potential size is 25. For example, the Boston market has 21 stations. Once low power stations (less than 4kW ERP) and directional patterns are eliminated only 9 stations remain. See Figure 9.

Status	Calls	Freq	Power	City	State
LIC	WERS(FM)	88.9	4	Boston	MA
LIC	WGBH(FM)	89.7	100	Boston	MA
LIC	WJMN(FM)	94.5	9.2	Boston	MA
LIC	WBQT(FM)	96.9	22.5	Boston	MA
LIC	WBZ-FM	98.5	9	Boston	MA
LIC	WZLX(FM)	100.7	21.5	Boston	MA
LIC	WBGB(FM)	103.3	8.7	Boston	MA
LIC	WWBX(FM)	104.1	21	Boston	MA
LIC	WMJX(FM)	106.7	21.5	Boston	MA

FIGURE 9: HIGH POWER OMNI BOSTON CALLS.

When breaking down the Boston market the possibilities of an Aux or Main site with multiple different stations is quickly minimized. The stations in conjunction with their vertical real estate organization can analyze the Manifold combiner design and available ports for future stations. As an example, assume 5 out of the 9 stations in Figure 9 incorporate into a shared antenna system for economic purposes, while taking advantage of expandability with spare parts, the end user may decide to build a 7 channel Manifold giving two of the 4 remaining stations the ability to join the system. If the 4 stations not going into the system are A, B, C & D then solutions are needed to solve the following spline scenarios:

- 5 known stations with A & B
- 5 known stations with A & C

- 5 Known stations with A & D
- 5 known stations with B & C
- 5 known stations with B & D
- 5 known stations with C & D

The total possible combinations would be defined by (3):

$$C(n,r) = n!/[r! * (n-r)!] \quad (3)$$

Where n is number of stations not included in the Manifold, for Boston that is 4. And r is number of spare ports going into the Manifold, for Boston that is 2.

The solve for the output spline and validation at time of test would be minimized to the 6 possible solutions for the Boston market, the point here is the analysis is simplified when you break down the possibilities by market.

Another example is the St. Louis market.

See Figure 10:

Status	Calls	Freq	Power	City	State
LIC	KDHX(FM)	88.1	42	St. Louis	MO
LIC	KWMU(FM)	90.7	100	St. Louis	MO
LIC	KSIV-FM	91.5	85	St. Louis	MO
LIC	WIL-FM	92.3	100	St. Louis	MO
LIC	KSD(FM)	93.7	74	St. Louis	MO
LIC	WFUN-FM	96.3	92	St. Louis	MO
LIC	KYKY(FM)	98.1	90	St. Louis	MO
LIC	KEZK-FM	102.5	100	St. Louis	MO
LIC	KLOU(FM)	103.3	90	St. Louis	MO
LIC	KSLZ(FM)	107.7	100	St. Louis	MO

FIGURE 10: ST. LOUIS HIGH POWER OMNI ANTENNAS.

When breaking down St. Louis, the possibilities of an Aux or Main site with multiple different stations is again quickly minimized. The stations or vertical real estate companies can then analyze the Manifold combiner design and how many unused ports for future stations should be in the said design. Again, as an example, assume 4 of the stations above agree to go on a shared antenna system. Like Boston, the end users in St Louis may decide to also build a 7 channel Manifold giving three of the six remaining stations the ability to jump into the system. If there are 6 unknown stations and three possibilities going into Manifold, using (2), gives a total of 20 iterations that need to be solved.

The solve for the Manifold output spline and validation at time of test would be minimized to the 20 possible solutions for the St. Louis market. The point to be made is it is still a simple engineering analysis.

Another scenario may be that over time this Manifold configuration gets completely occupied and an 8th station needs to be added. A new analysis that includes an 8th channel into the system can be done. In this case additional space would be needed to make it happen, but still can be designed so all existing I/O's remain in the same location.

Note: When looking at any potential market it is key to get an FM consultant involved to make sure the market is analyzed to its fullest. Other factors like HAAT, station moves, ERP changes, etc. should be considered and may give more options than examples in this paper. The key here in this paper's analysis is that the number of possible stations on any one master combiner is not significant when you start looking at site specific data. A Reconfigurable Manifold with all the benefits listed in this paper should be considered at sites where a CIF combiner would have been traditionally used.

Conclusion

Historically, typical channel expansions of multiple channel configurations utilize the CIF combiner. However, with the advancements in simulation software in combination with other construction techniques, the Manifold provides a viable alternative to the CIF. The Manifold is known for its equality in electrical specifications for all stations and the considerably smaller footprint, but until now was not expandable. When future master sites are being built, the Manifold provides a superior, economical solution to other traditional systems.

This groundbreaking technological advancement will give future multi-station systems a better choice moving forward. As technology continues to evolve, the choice between a Manifold over a CIF system may become even more clear.

This paper covers an example at the FM frequency band, the technology discussed can also be deployed for UHF television channels.

References

[1] MIL-217 Standard.

[2] Small, D. J., "Technical Proposal for FM Channel Combiner", RF TP_083022, August 2022.

[3] Schadler, J. L., "Changing the Landscape of FM Broadcast Antenna Technology", BEITC Proceedings 2022.