Improving FM Combiner/Filter Efficiency and Size Using Non-Conventional Coupling

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Sr. RF Engineer

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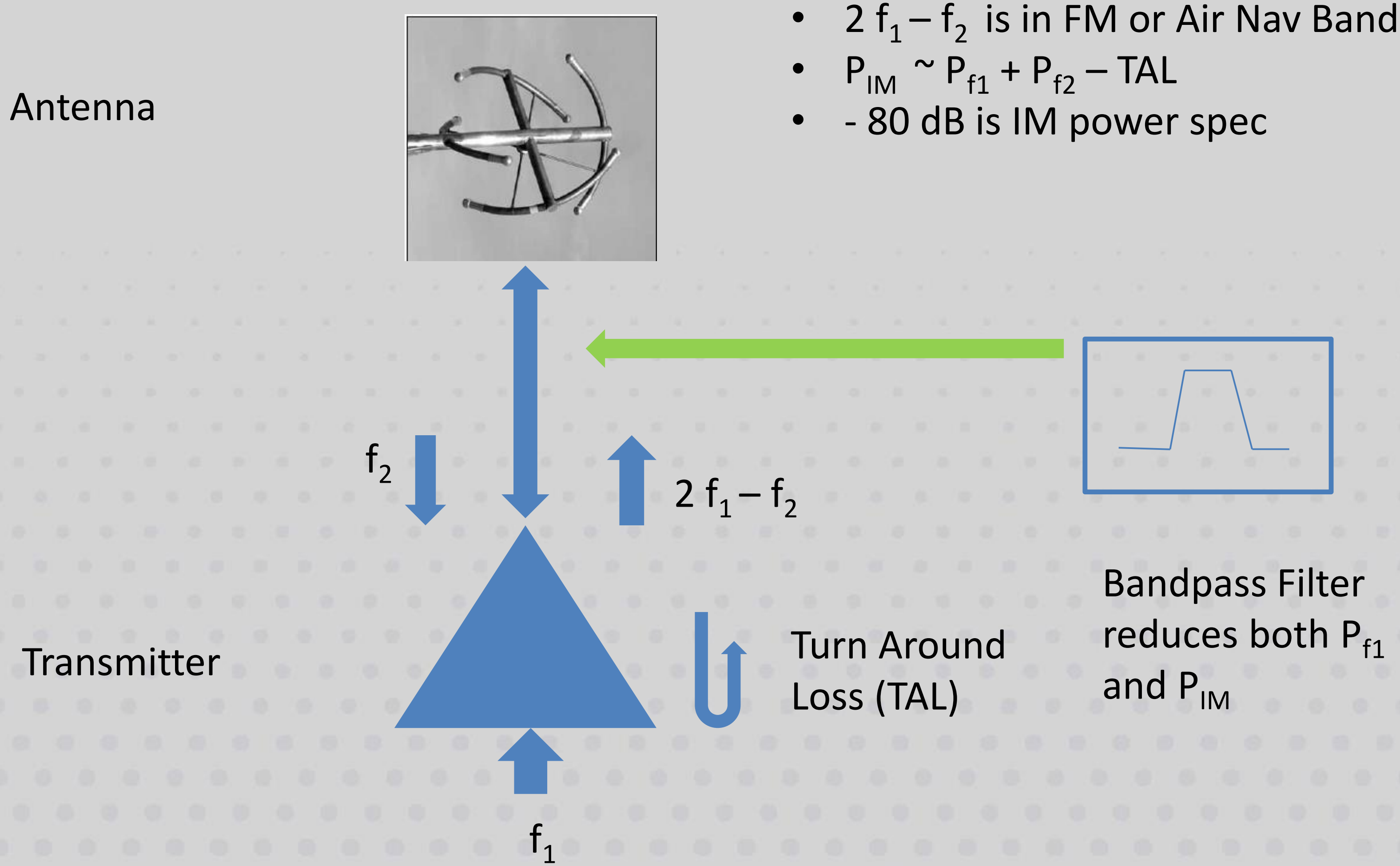
AGENDA

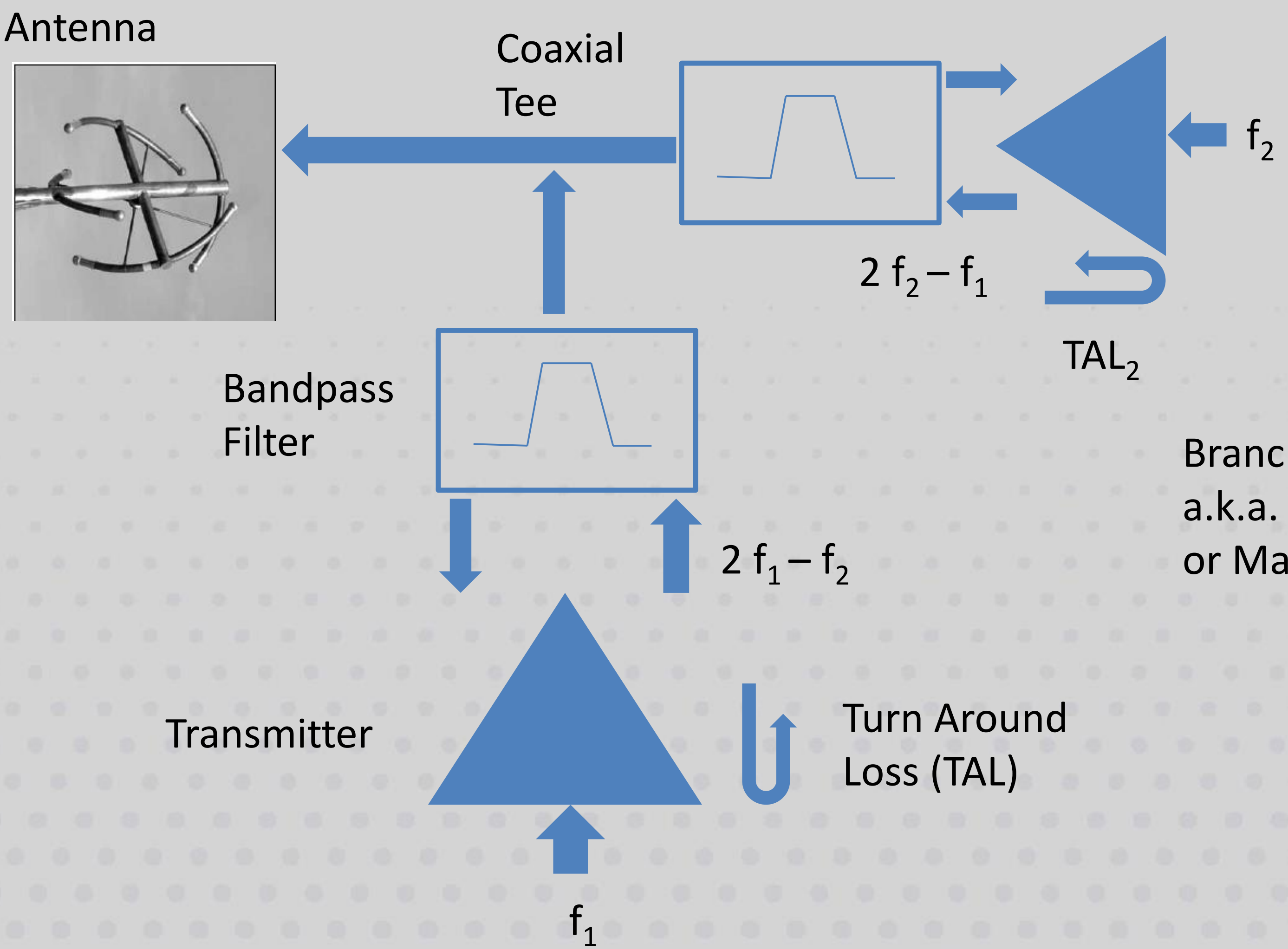
- FM Combining Basics
  - Transmitter Intermodulation
  - Constant impedance filter(CIF) and Brach Combiners
- Efficiency for Chebychev and Cross-Coupled Filters
- Source / Load Coupling
- Relative advantages and dis-advantages of CIF and Manifold Combining

Intermodulation Generation – Co-site Interference

- $2\ f_1 - f_2$ is in FM or Air Nav Band
- $P_{IM} \sim P_{f1} + P_{f2} - TAL$
- - 80 dB is IM power spec



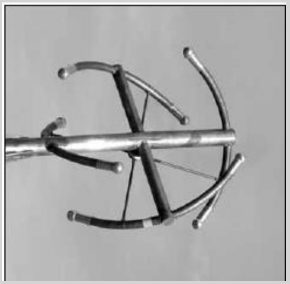
Intermodulation Generation – Channel Combining



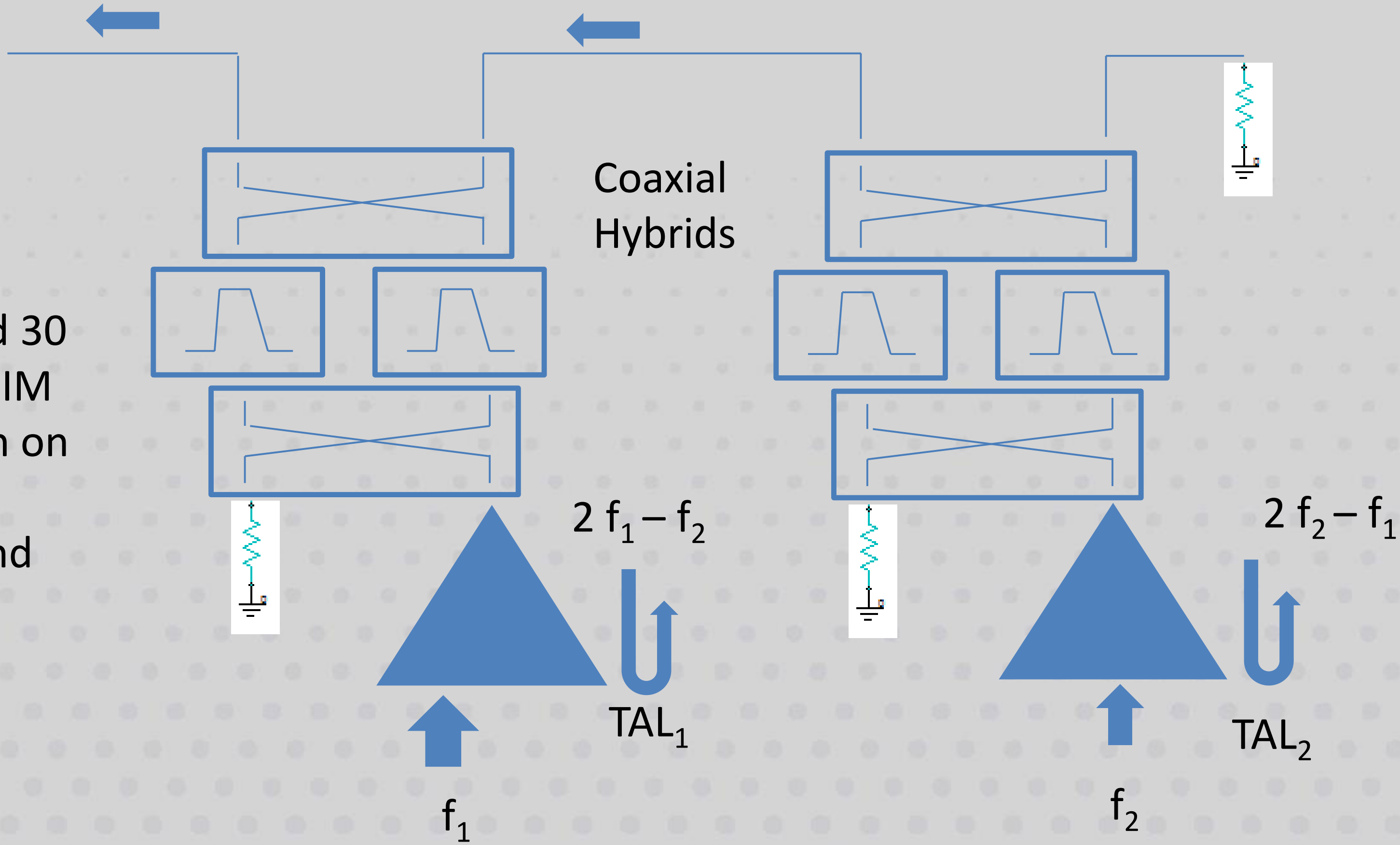
Branch Topology
a.k.a. Star Point
or Manifold

Intermodulation Generation – Channel Combining

Antenna



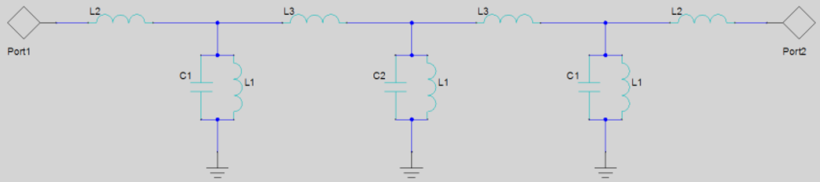
Constant Impedance Filter (CIF) Topology
a.k.a. Balanced or Directional Filter



Hybrids add 30 to 35 dB of IM suppression on top of filter rejection and TAL

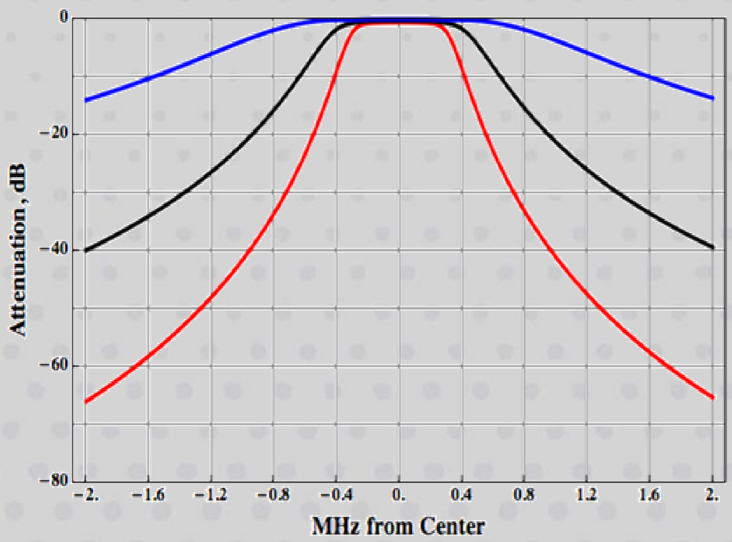
Chebyshev Filters

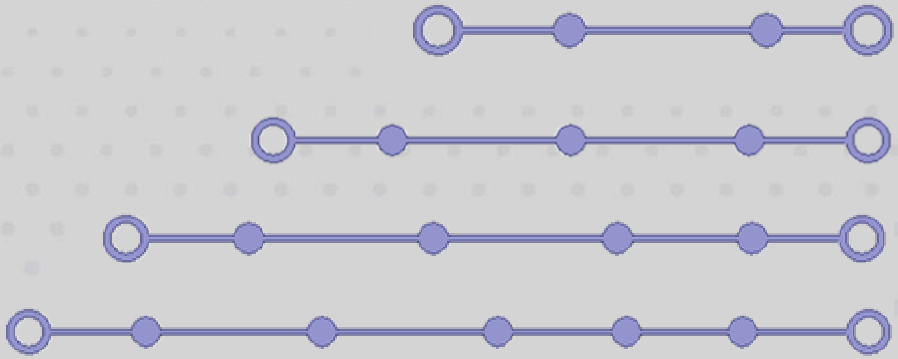
Sequentially coupled from input to output



Lump element inductively coupled filter

Coupling routing diagram





Two - Five Pole are used in FM Combining

Chebyshev Filters -
Channel Spacing and Efficiency

Minimum Channel Spacing
to get -80 dB IM Suppression

# of	spacing in MHz	
poles	CIF	manifold
2	4.4	10.2
3	1.6	2.6
4	0.8	1.6
5	any	0.8

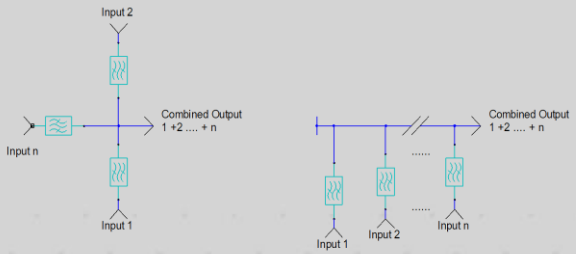
Efficiency vs. # of poles vs. Cavity size

# of poles	24" cavity	14" cavity	6" cavity
2	97.7%	96.6%	95.5%
3	96.6%	94.4%	91.6%
4	94.4%	92.2%	85.5%
5	92.2%	88.1%	77.6%

Efficiency ∝ Insertion Loss ∝ Cavity Size

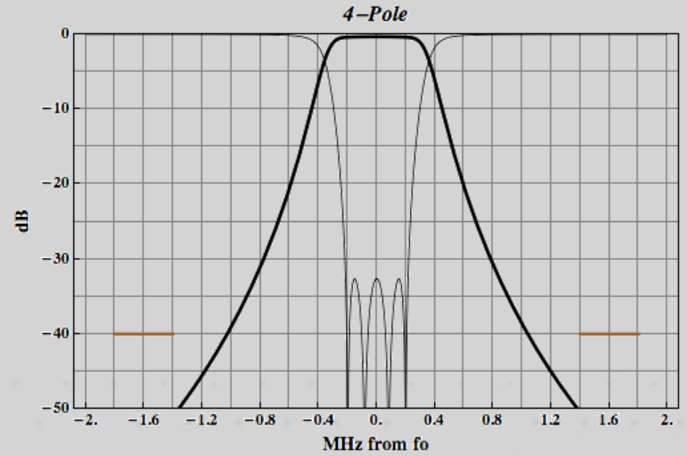
Combining Requirements

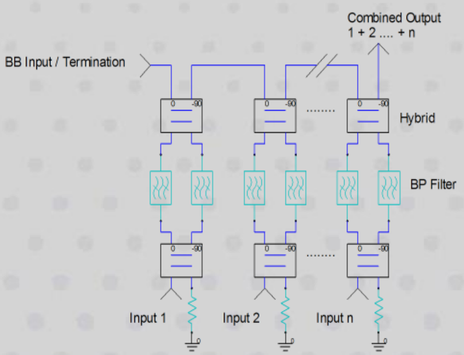
1.6 MHz Spacing Example



Junction Combiner

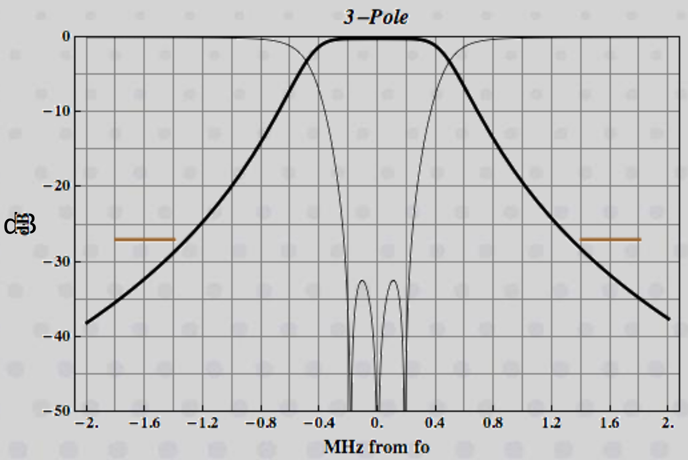
- Isolation entirely dependent on filter
- ∴ 40 dB min filter rejection
- 4-pole required for 1.6 MHz spacing





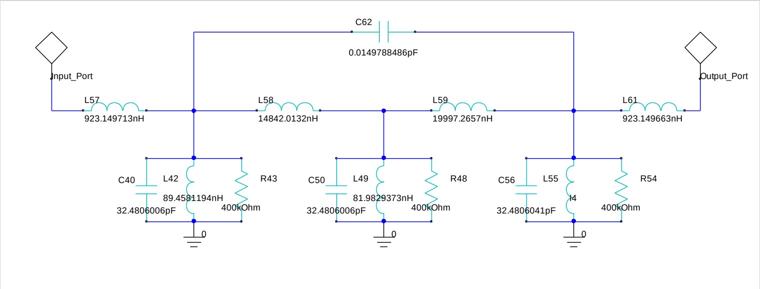
Directional Combiner

- Hybrids provide directionality (isolation), ~ 30 dB
- ∴ 27-30 dB min filter rejection
- 3-pole required for 1.6 MHz spacing

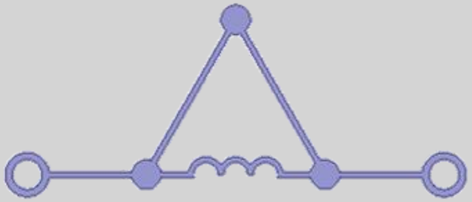


Cross Coupled Filters; Tri-Circuit

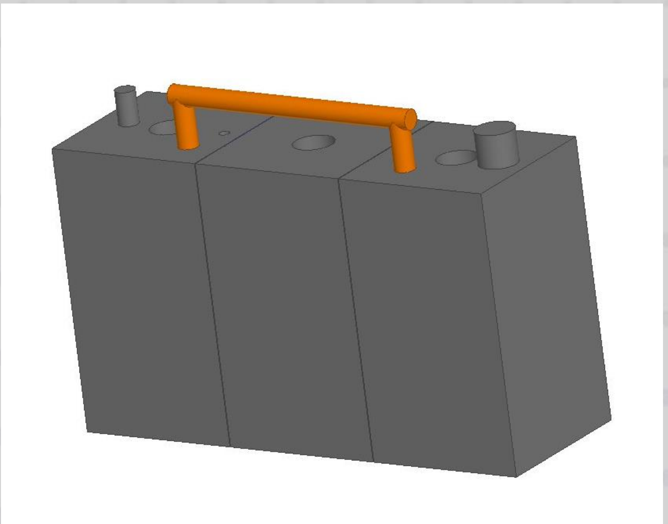
Coupling Introduced between Non-Adjacent Resonators

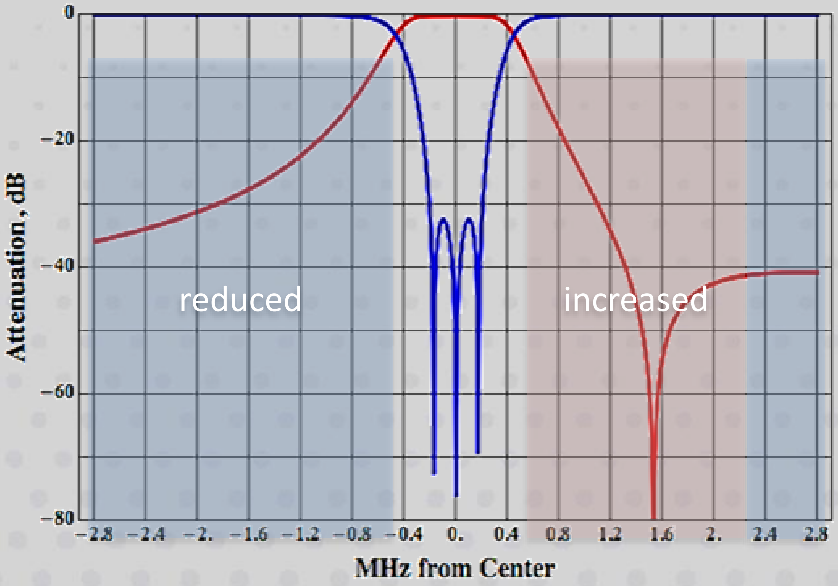


Lump element inductively coupled filter



Coupling routing diagram

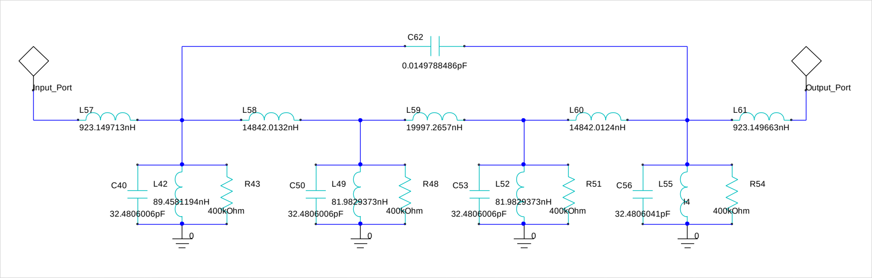




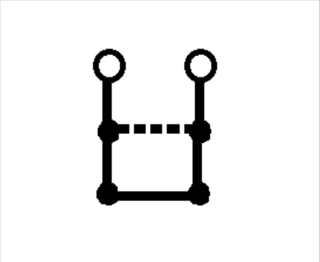
Allows for closer channel combining but no significant increase in IM suppression

Cross Coupled Filters; Quad-Circuit

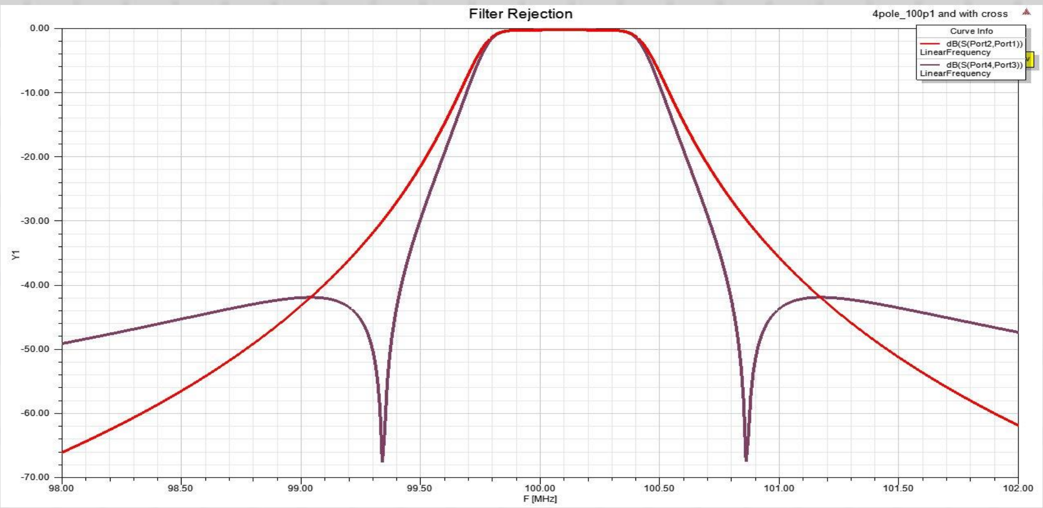
Coupling Introduced between Non-Adjacent Resonators



Lump element inductively coupled filter

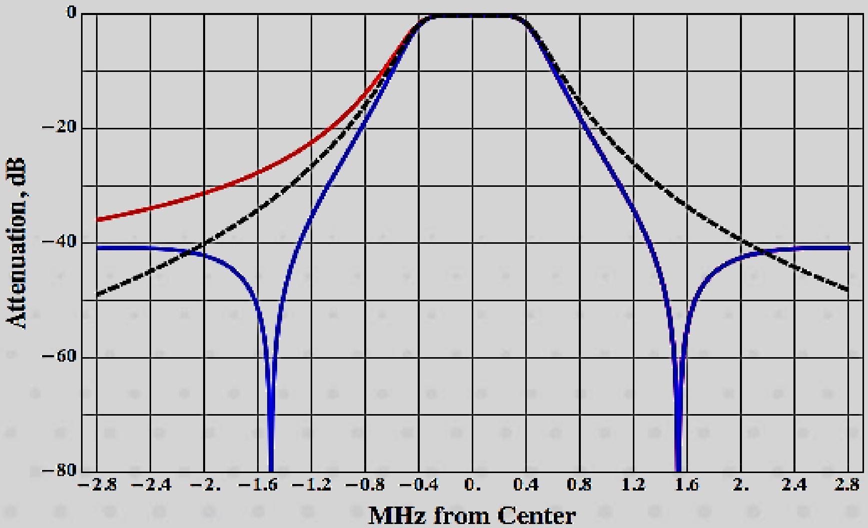


Coupling routing diagram



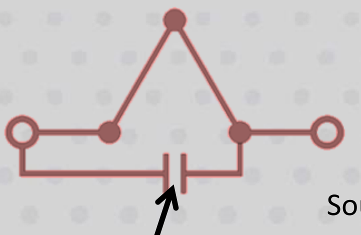
Allows 4 pole to be used for 800 kHz and greater spacing in manifold combiner

New Cross Coupled Filter – Source to Resonator Three Coupling

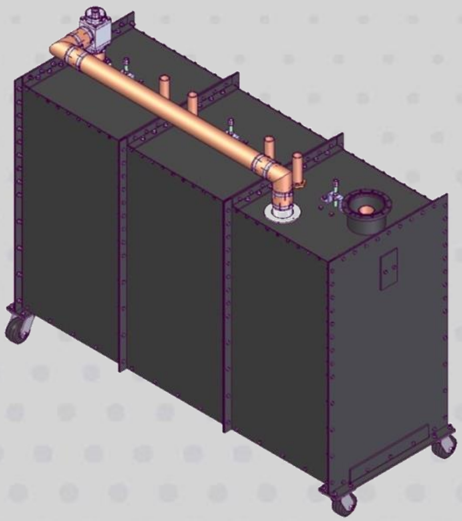


Implemented with:

- Coaxial Tee at Input
- “Towel Rack” to Resonator Three
- Proper Coupling Structure in Resonator Three



Source multi-resonator coupling provides 2 transmission zeros



New Cross Coupled Filter – Source to Resonator Three Coupling

Minimum Channel Spacing
to get -80 dB IM Suppression

# of	spacing in MHz	
poles	CIF	manifold
2 cheb	4.4	10.2
3 cheb	1.6	2.6
3 w/ s-3 X	1.2*	1.6
4 cheb	0.8	1.6
4 w/ 1-4 X	any	0.8
5 cheb	any	0.8

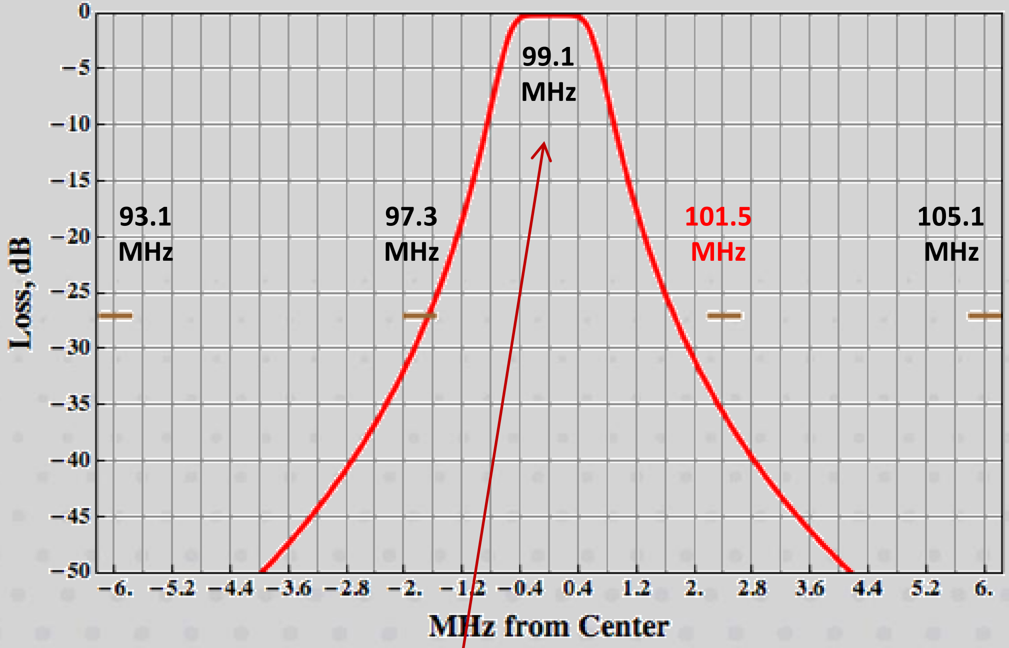
* 0.8 MHz if TAL is included

Cross coupled filters offer higher rejection without increased insertion loss

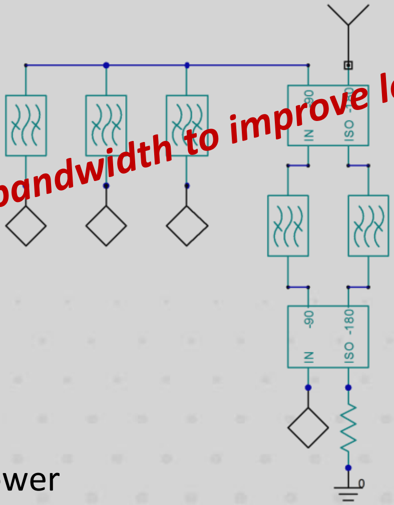
- Lower Loss
- Lower Group Delay
- Smaller Size

New Source/Load Multi-Resonator Coupling

Solution for an Efficiency Problem



n = 3
VSWR = 1.05
BW_r = 550kHz
$Loss_{fo}$ = **.128 dB**



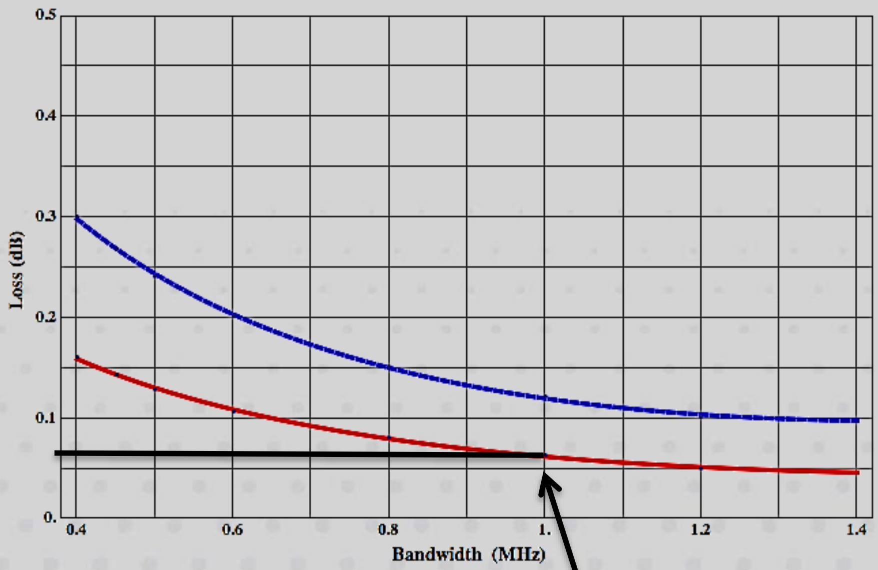
How far can I open bandwidth to improve loss?

- 99.1 MHz, high power
  - No Tx headroom
  - 3-pole filters to minimize loss
  - ***< .1 dB loss required***
- 101.5 MHz may come in later

New Source/Load Multi-Resonator Coupling

Loss vs Bandwidth

Loss vs BW_r

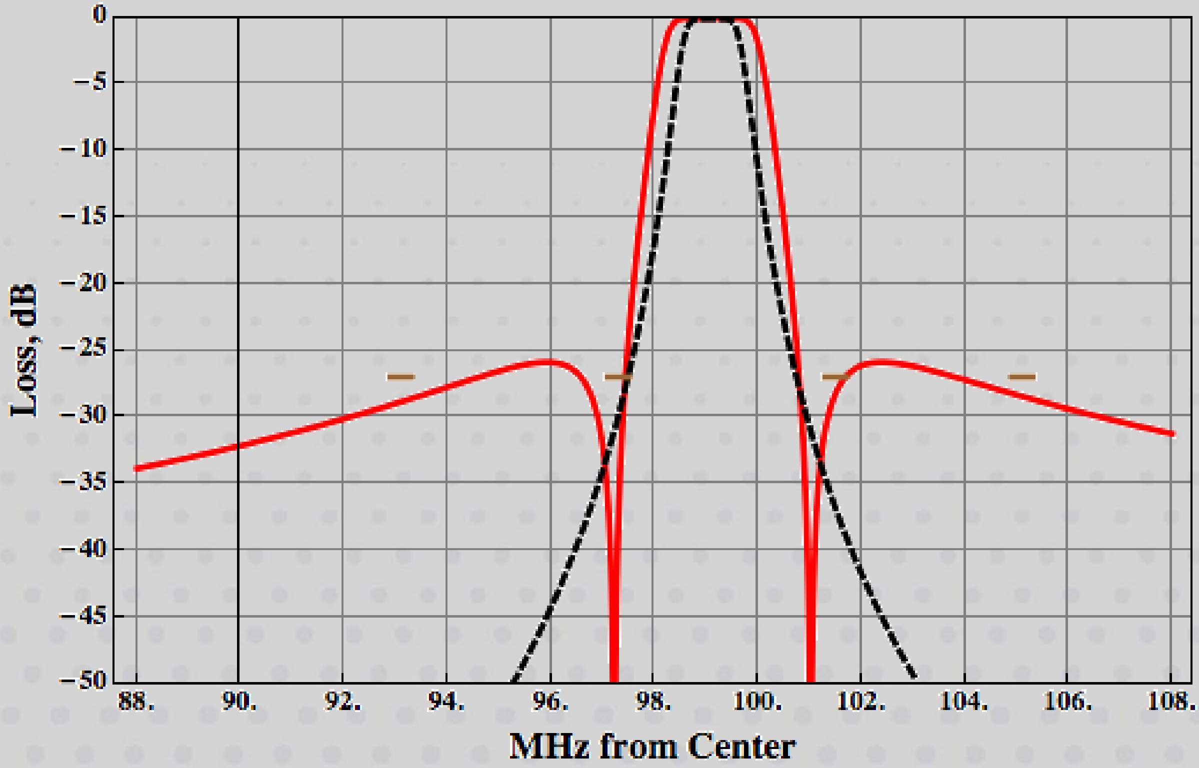


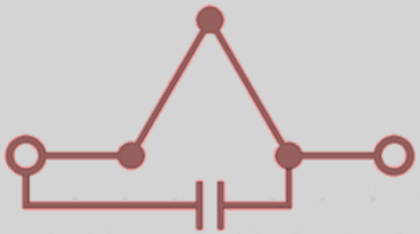
Need ≈ 1 MHz BW_r

- 24” Cavity
- 3-pole red
- 4-pole blue

New Source/Load Multi-Resonator Coupling

SOLUTION to an Efficiency Problem





n = 3

VSWR = 1.12

BW_r = 1150kHz

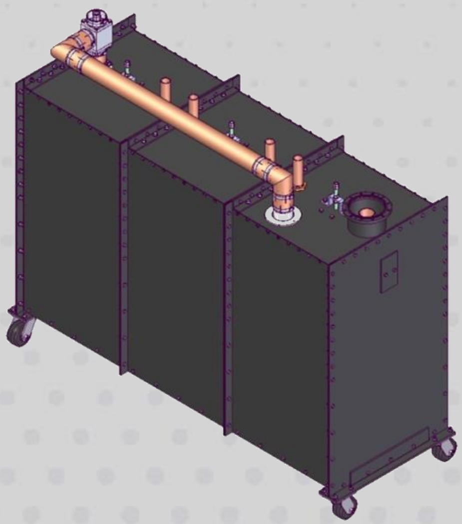
$Loss_{fo}$ = .06 dB

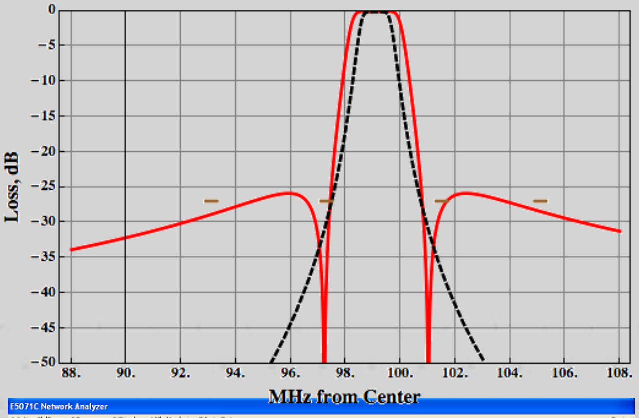
New Source/Load Multi-Resonator Coupling

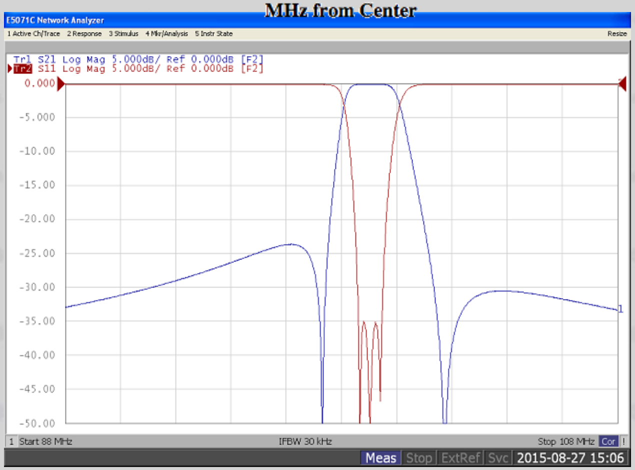
SOLUTION to an Efficiency Problem

- Source to three used on a 3-pole filter
  - Provide transmission zeros
  - Increase efficiency with wider bandwidth

- Filter loss:
  - < .16 dB w/o X-coupling
  - < .06 dB with X-coupling

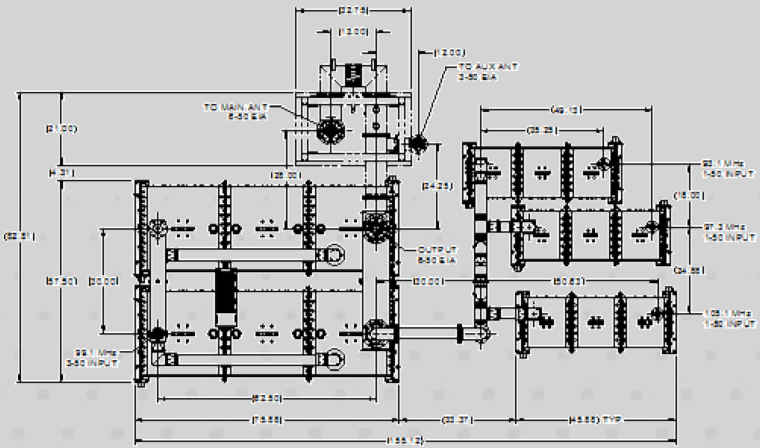


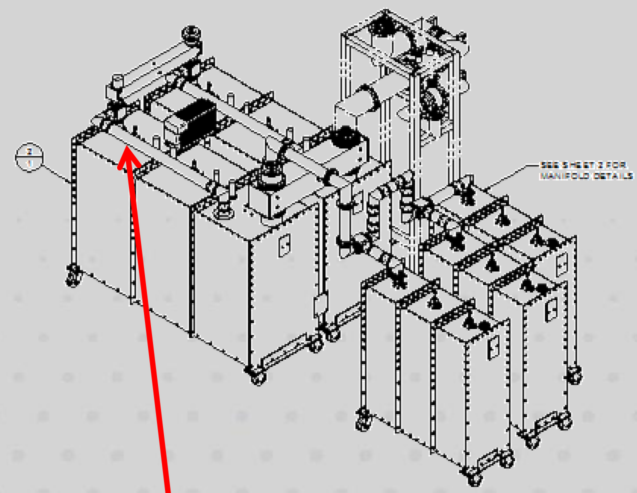




New Source/Load Multi-Resonator Coupling

SOLUTION to an Efficiency Problem

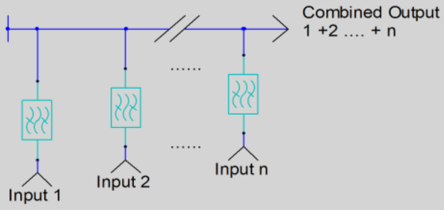


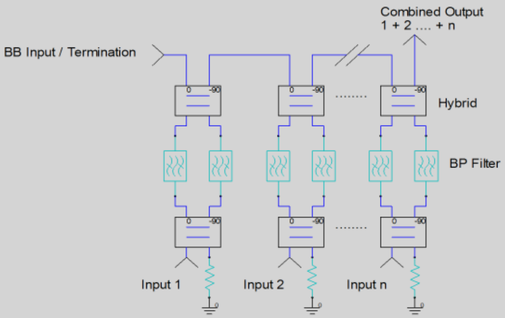


Multi-channel site in Miami

- Efficiency improvement with wider bandwidth
- Source multiple coupled MODULE loss: **.08dB**

Efficiency Manifold or Directional





Manifold

- More efficient
- All channels same VSWR
- All channels same loss
- Mainline offers higher voltage safety margin
- Compact, light and simple
- Easy to assemble
- Easy to test
- Easily maintainable
- Lower cost (by 60%)
- Simple module design and installation

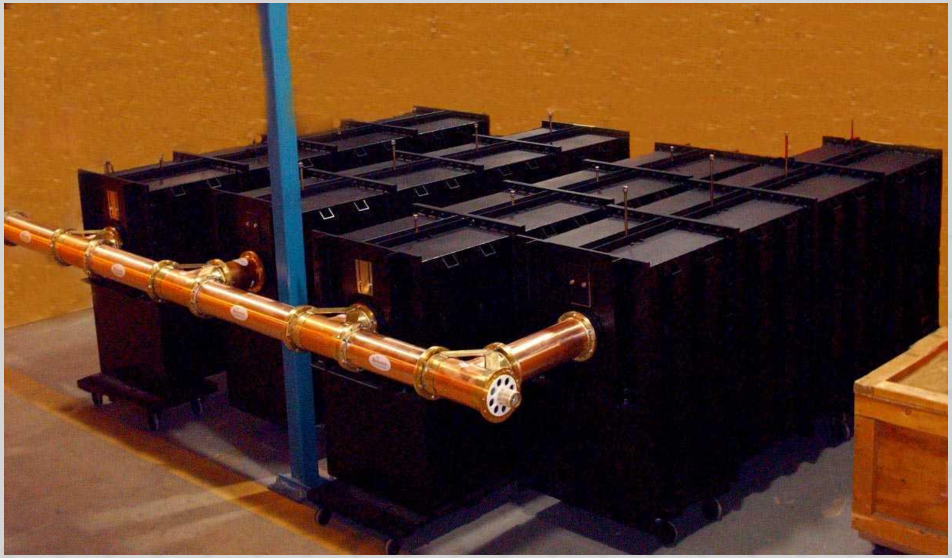
- Non – Expandable
- Power Limited
- Need to be properly phased with tube transmitters

Directional

- Less efficient
- VSWR degrades with distance
- Loss degrades with distance
- Hybrids limit voltage safety margin
- Large, heavy and complex
- Difficult to assemble
- Difficult to test
- Difficult to maintain
- Higher cost
- Part intense module design

- Expandable
- Doubles Filter Power
- Works well with tube transmitters

Manifold Combiner



4-Channel Manifold

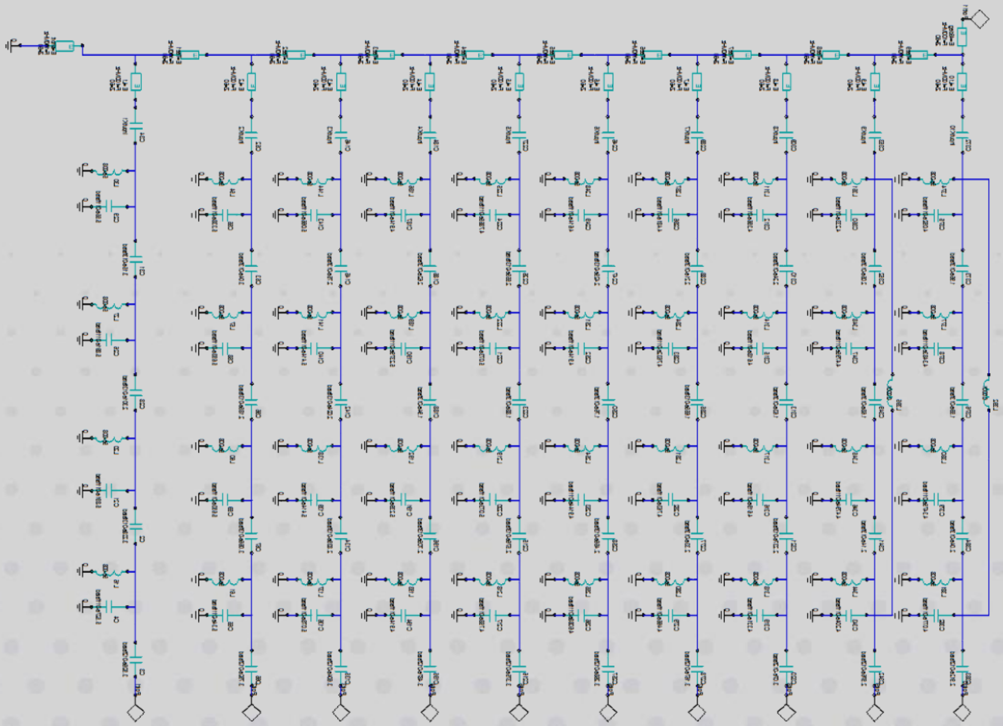
- Band pass filter, tee, delay line
- Tees spaced ≈ $n\ \lambda/2$
- Traditionally limited to 6 channels or less due to difficulty of cut and try design method

Manifold Combiner

Modern CAD tools make manifold design more predictable

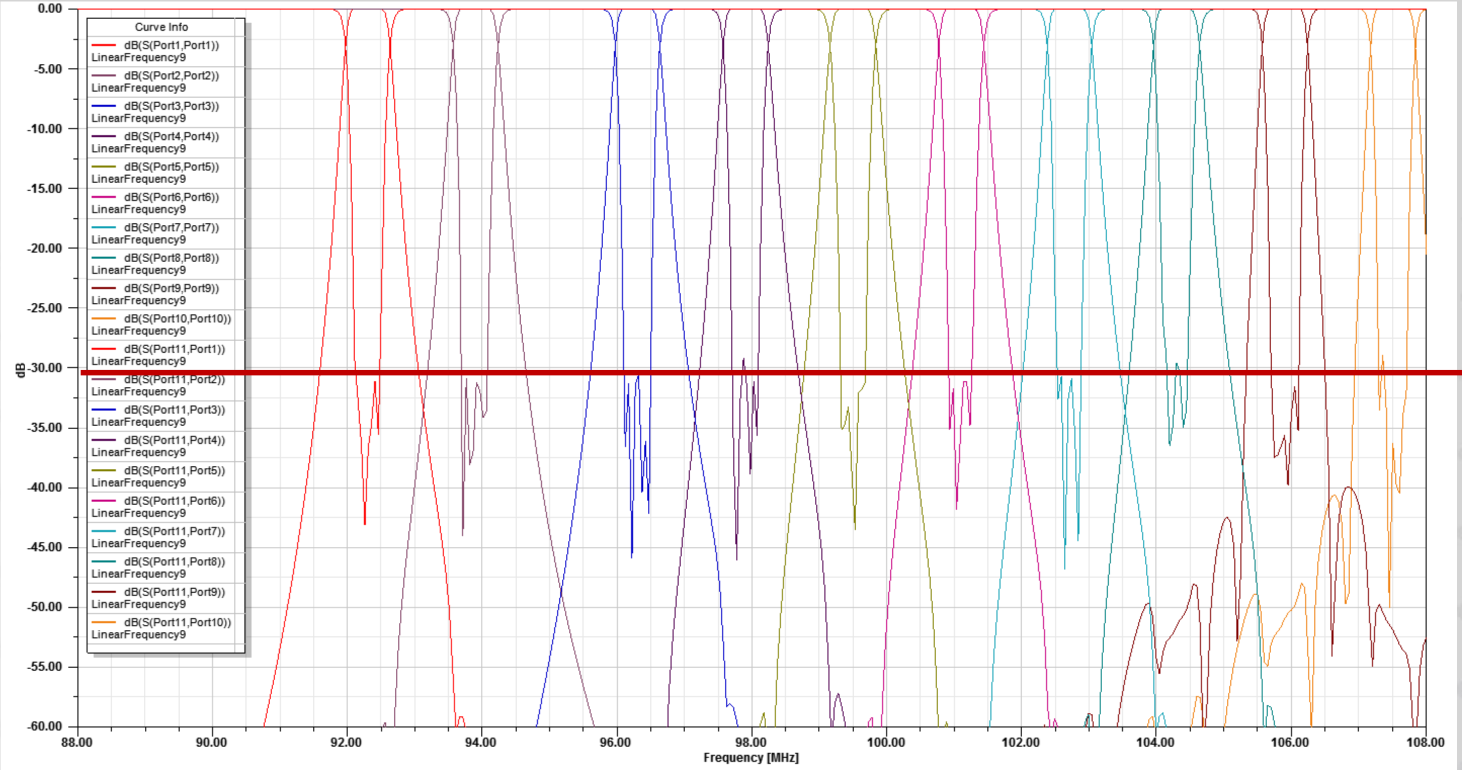
Site requires 10 channel manifold

Decided to design and build using 6” cavity filters



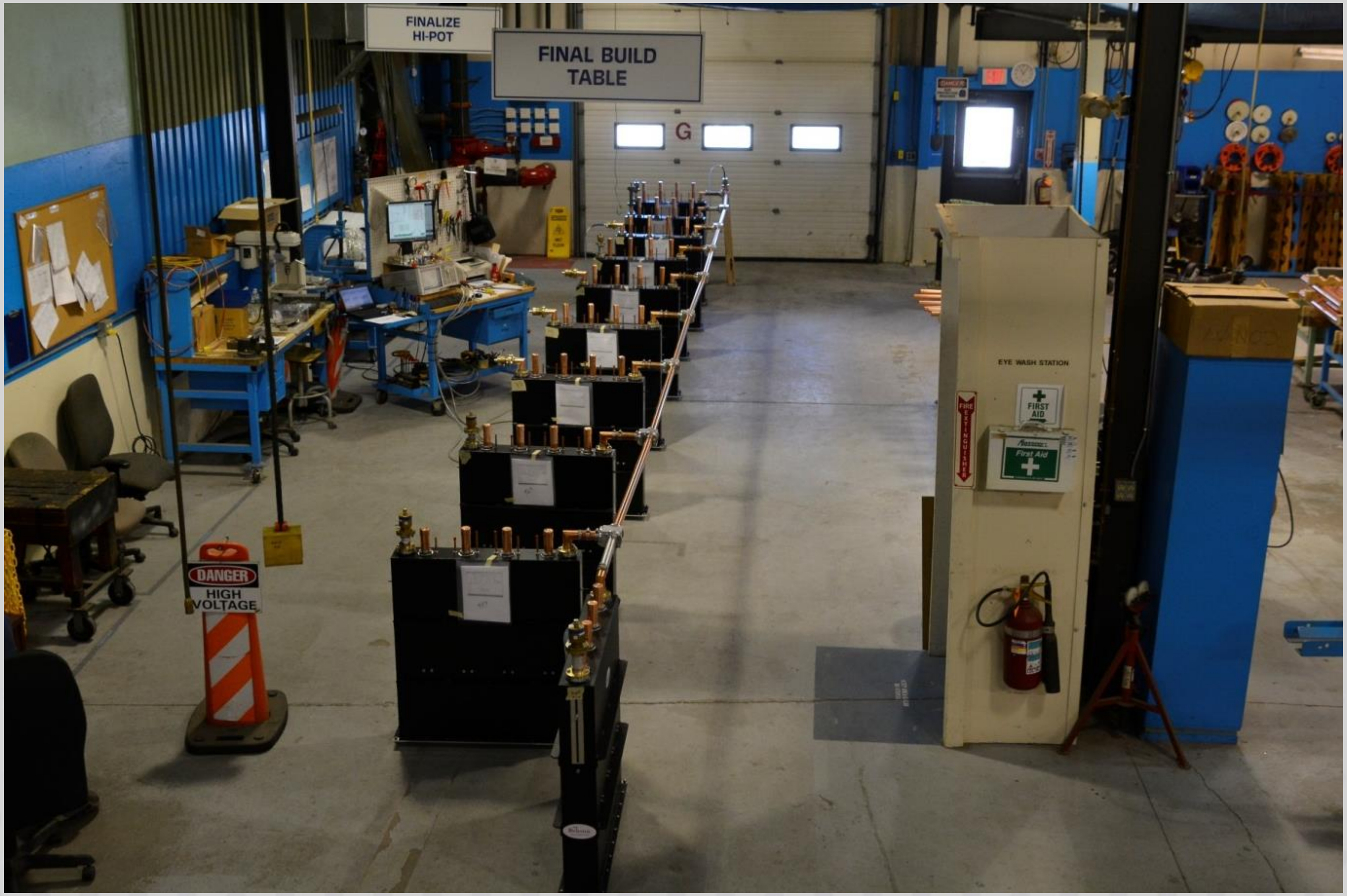
Manifold Combiner Lumped Element Model

Optimized Results



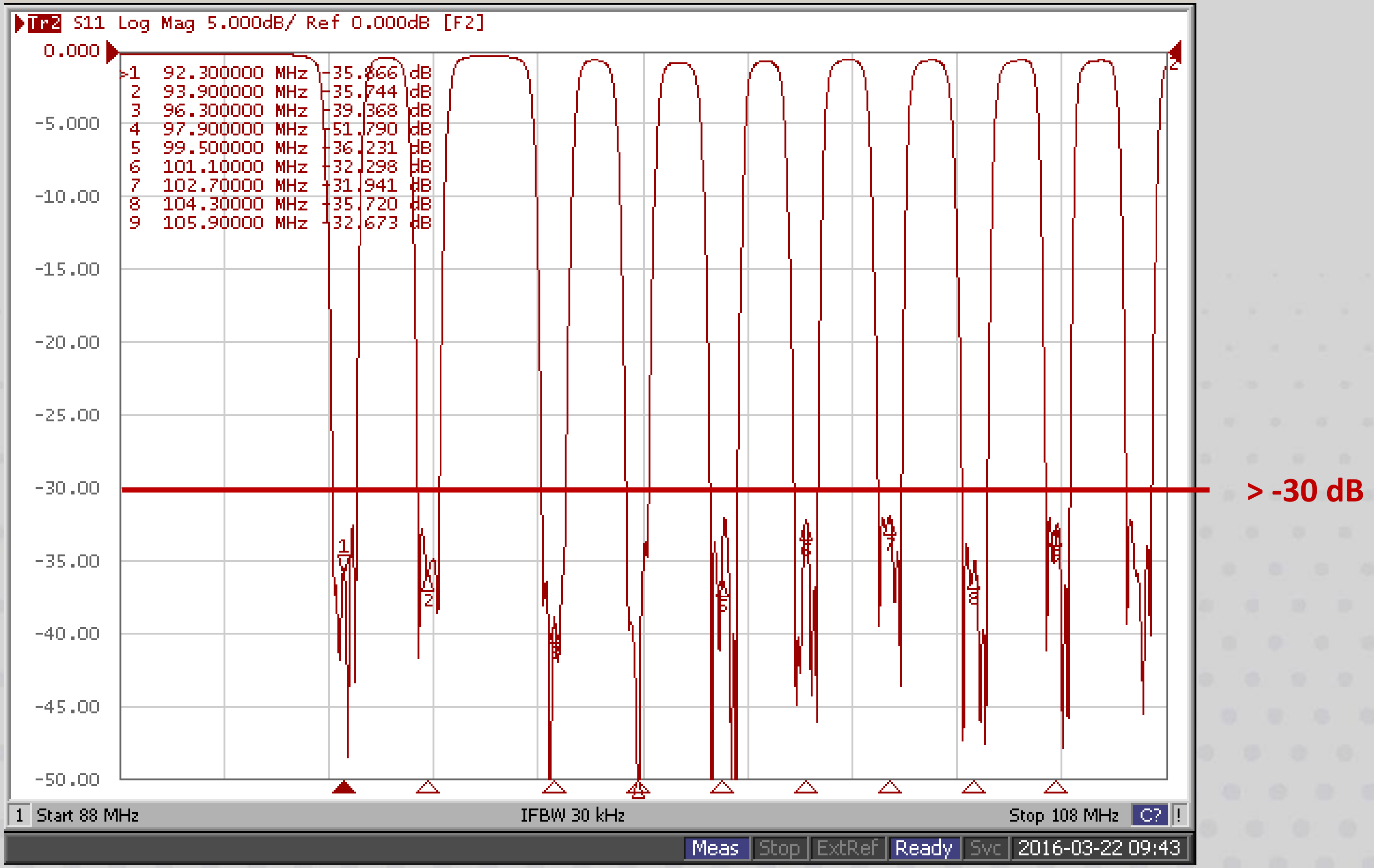
-30 dB

10 Channel LPFM Combiner
In line configuration



10 Channel LPFM Combiner

Actual Data, Post Optimization Return Loss



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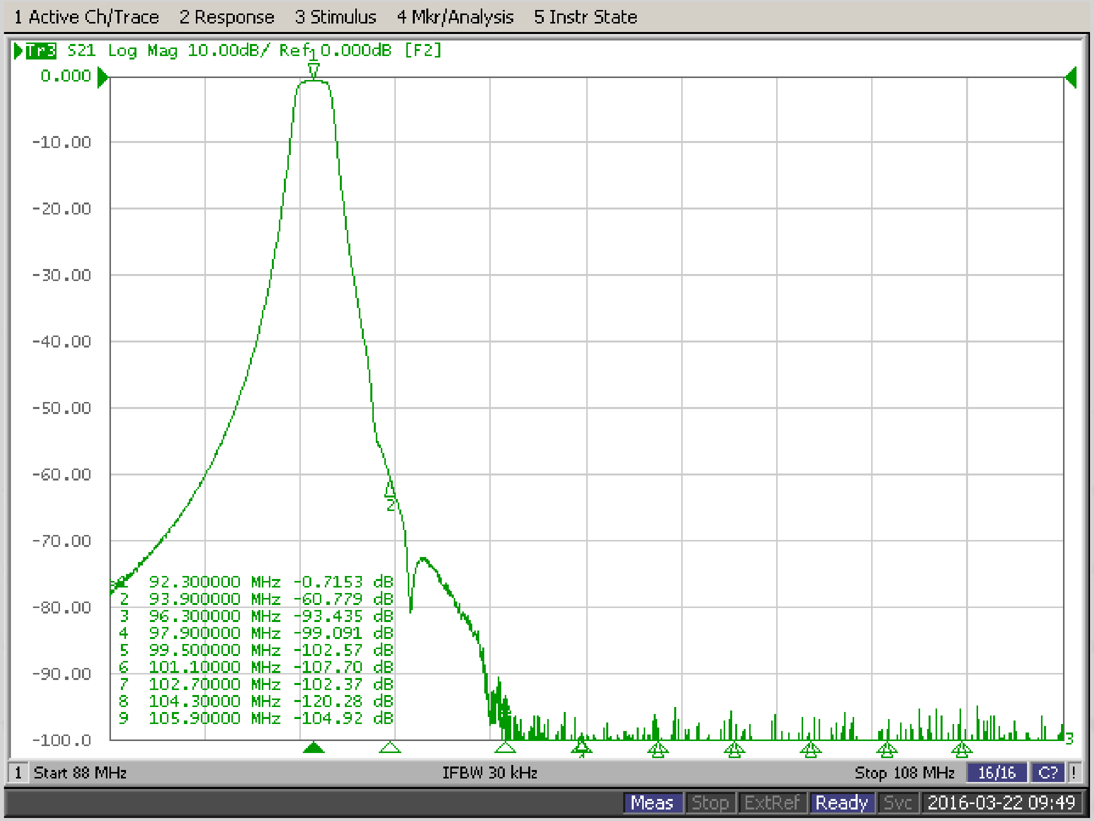
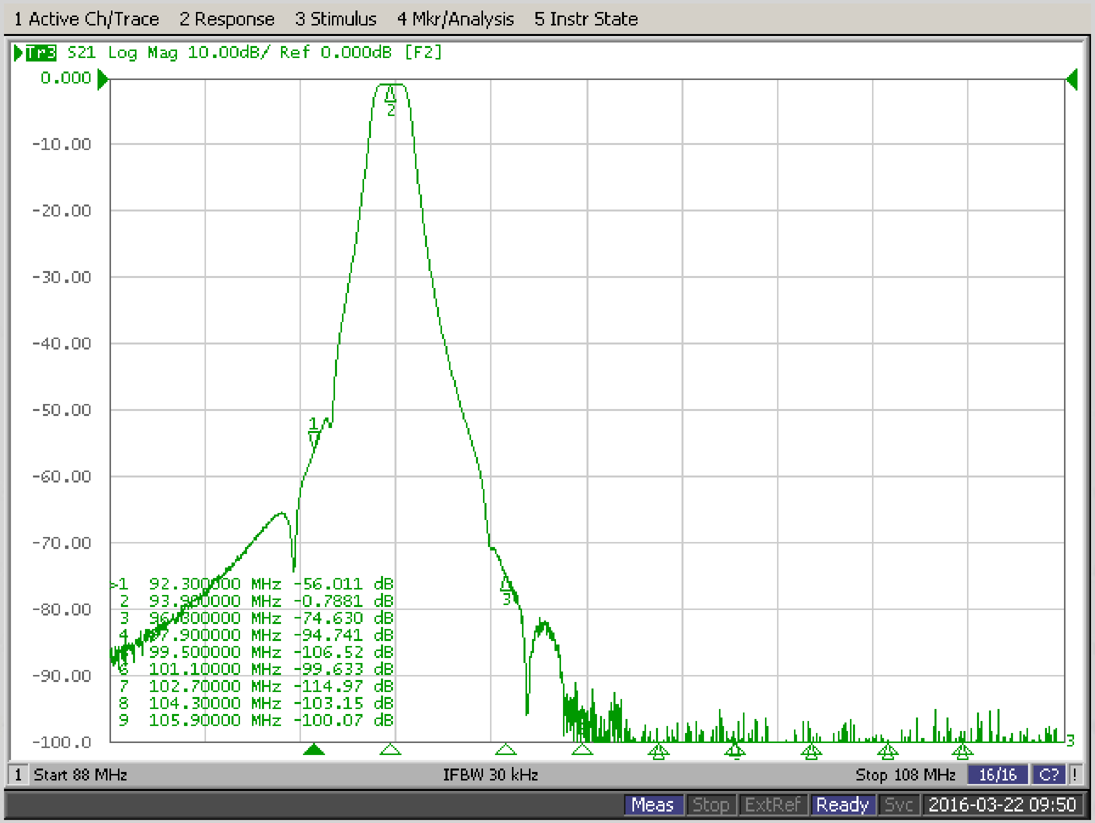
10 Channel LPFM Combiner
Actual Data, Post Optimization



Channel	Combiner Loss
92.3MHz	.72dB

10 Channel LPFM Combiner

Actual Data, Post Optimization



Channel	Combiner Loss
92.3MHz	.72dB
93.9MHz	.79dB

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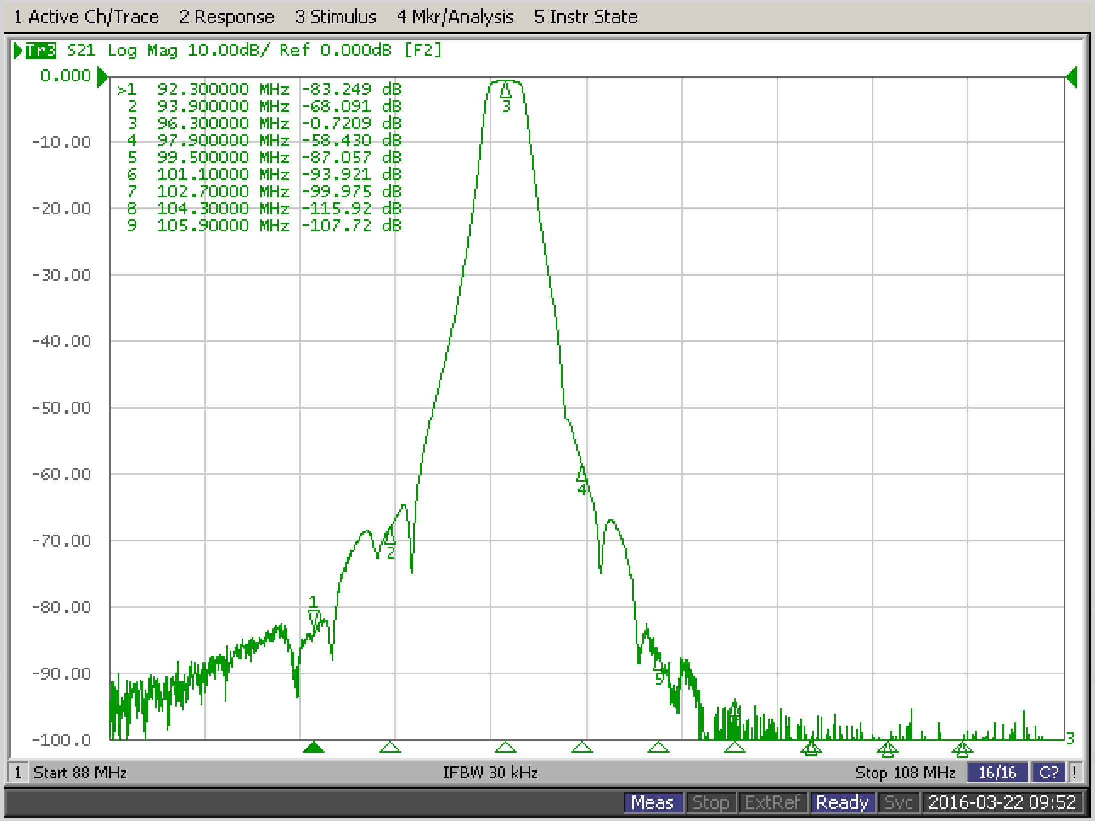
10 Channel LPFM Combiner

Actual Data, Post Optimization



Channel	Combiner Loss
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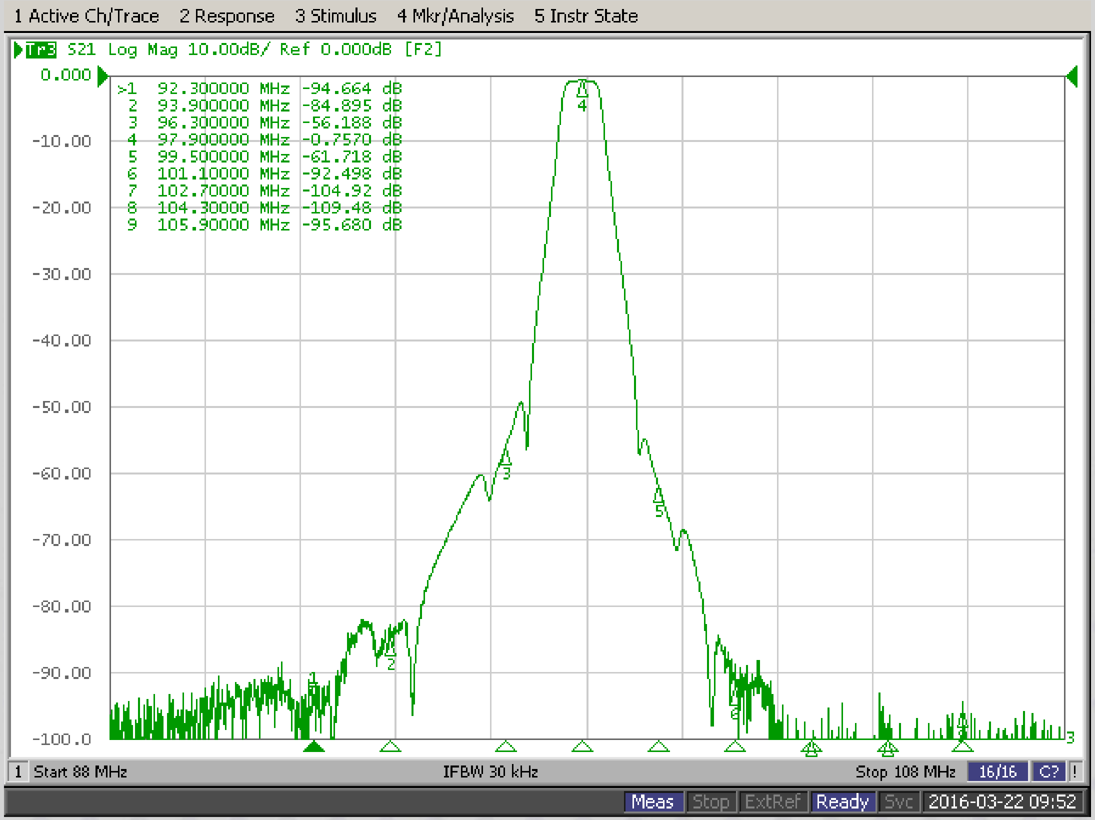
93.9MHz	.79dB
96.3MHz	.72dB

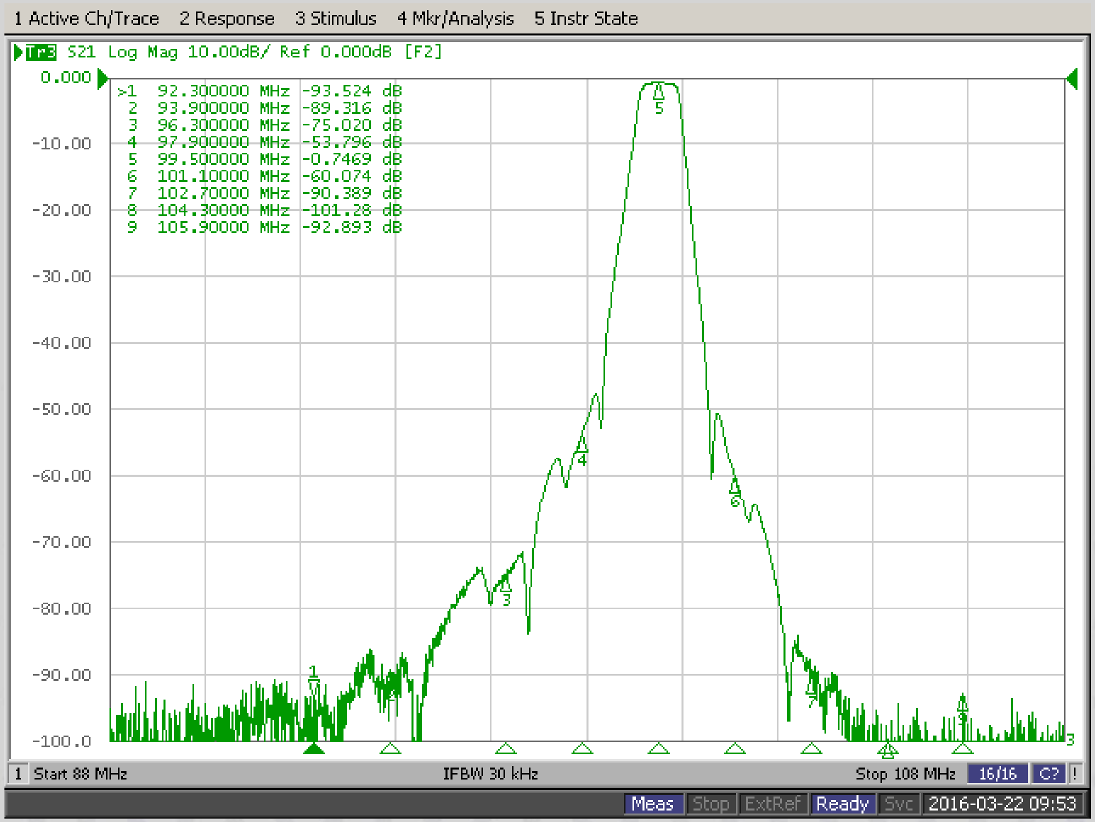
10 Channel LPFM Combiner
Actual Data, Post Optimization



Channel	Combiner Loss
92.3MHz	.72dB
93.9MHz	.79dB
96.3MHz	.72dB
97.9MHz	.76dB

10 Channel LPFM Combiner

Actual Data, Post Optimization



Channel	Combiner Loss
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93.9MHz	.79dB
96.3MHz	.72dB
97.9MHz	.76dB
99.5MHz	.75dB

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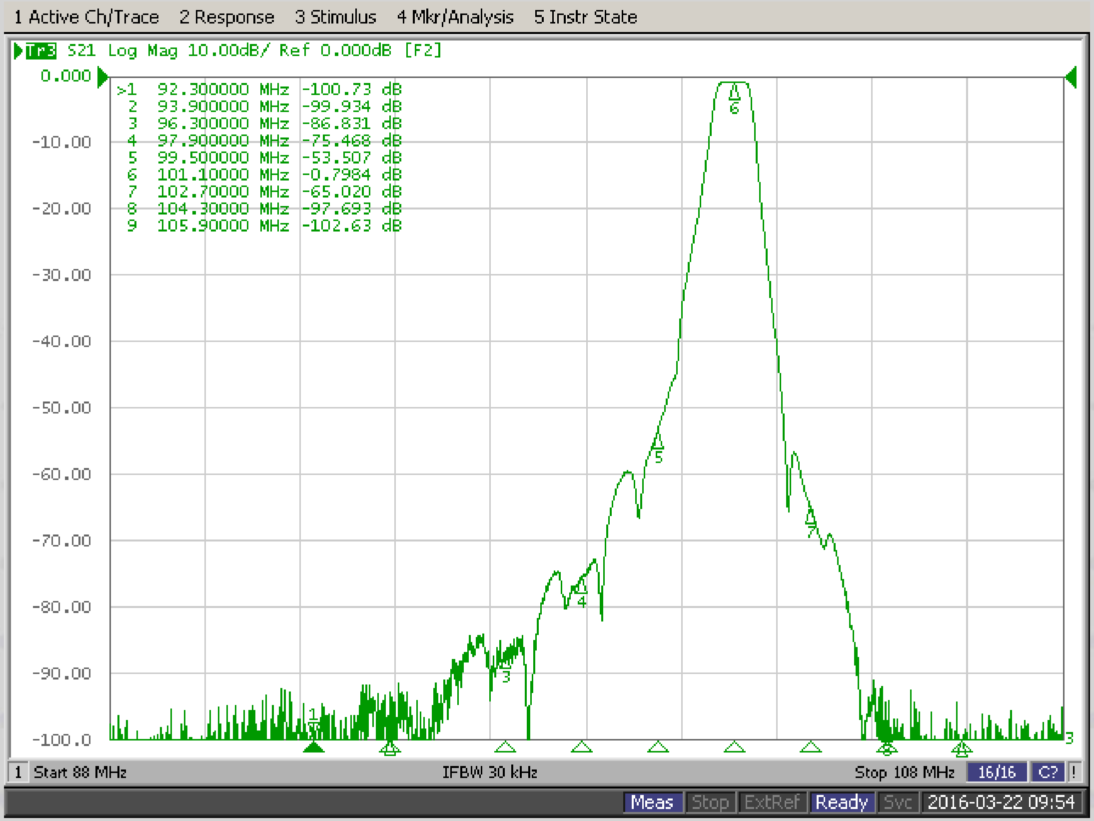
Actual Data, Post Optimization



Channel	Combiner Loss
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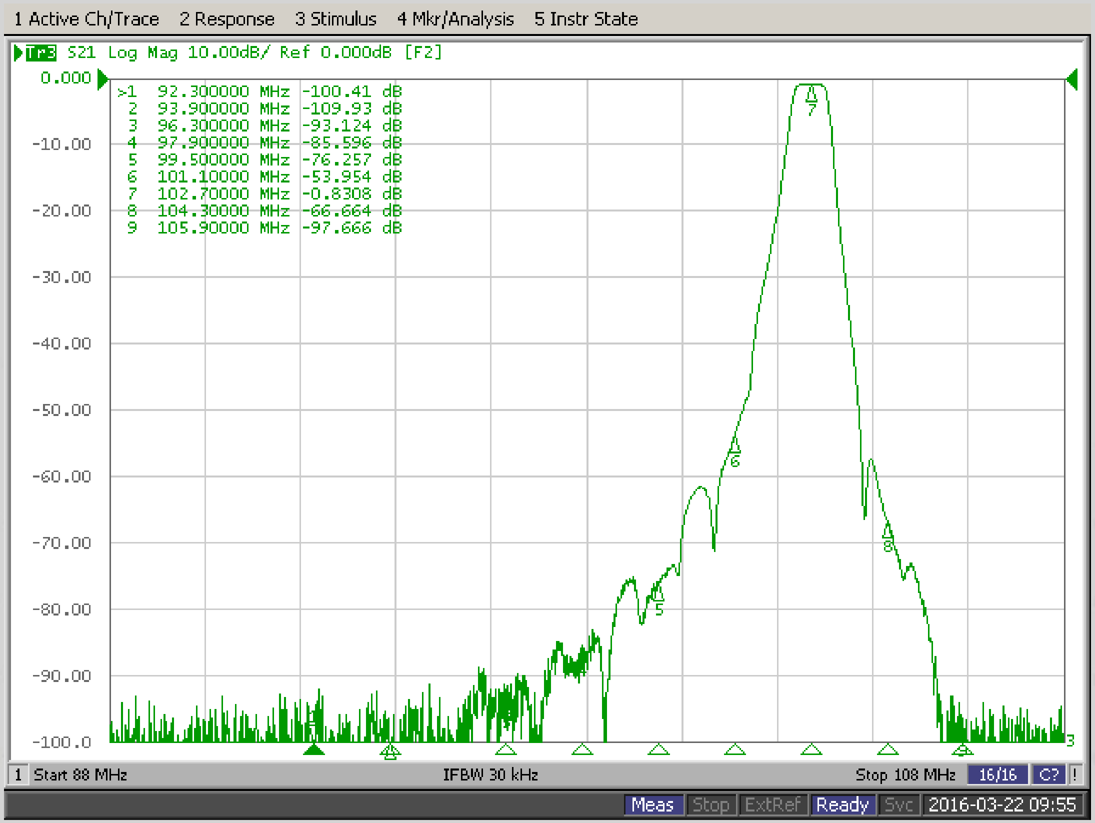
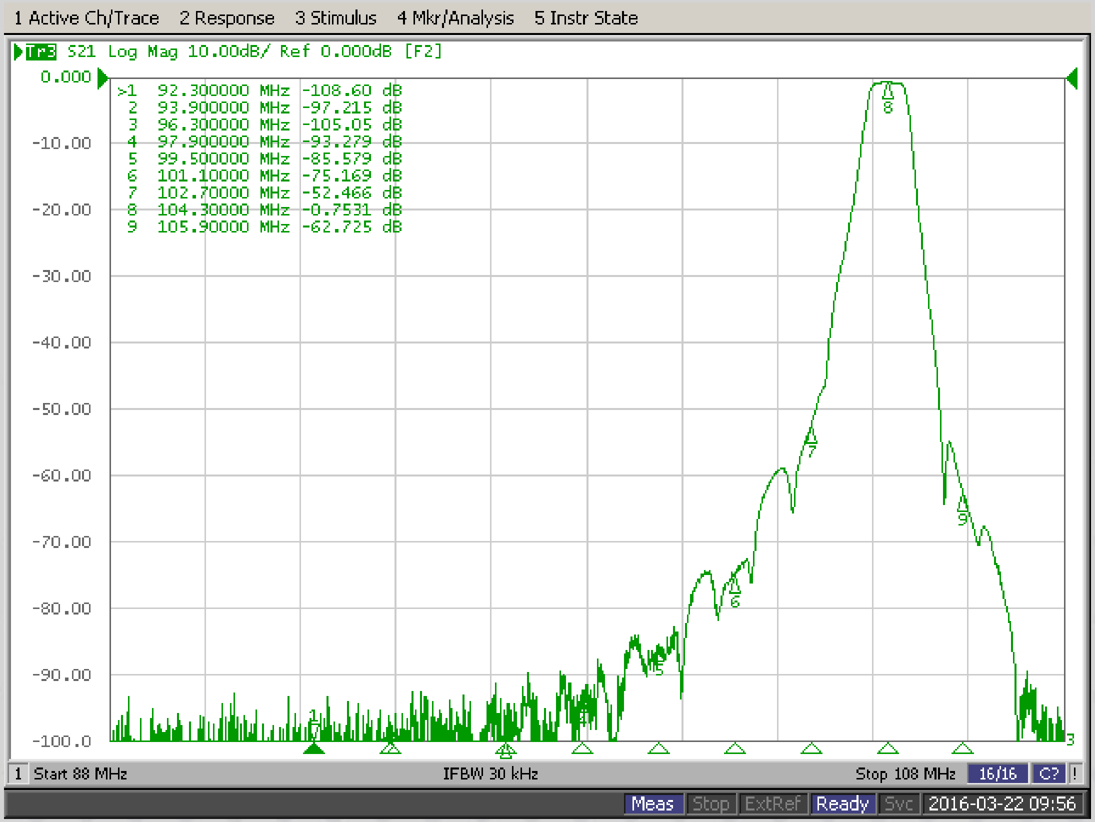
93.9MHz	.79dB
96.3MHz	.72dB
97.9MHz	.76dB
99.5MHz	.75dB
101.1MHz	.80dB

10 Channel LPFM Combiner
Actual Data, Post Optimization



Channel	***Combiner Loss***
92.3MHz	.72dB
93.9MHz	.79dB
96.3MHz	.72dB
97.9MHz	.76dB
99.5MHz	.75dB
101.1MHz	.80dB
102.7MHz	.83dB

10 Channel LPFM Combiner
Actual Data, Post Optimization



Channel	***Combiner Loss***
92.3MHz	.72dB
93.9MHz	.79dB
96.3MHz	.72dB
97.9MHz	.76dB
99.5MHz	.75dB
101.1MHz	.80dB
102.7MHz	.83dB
104.3MHz	.75dB

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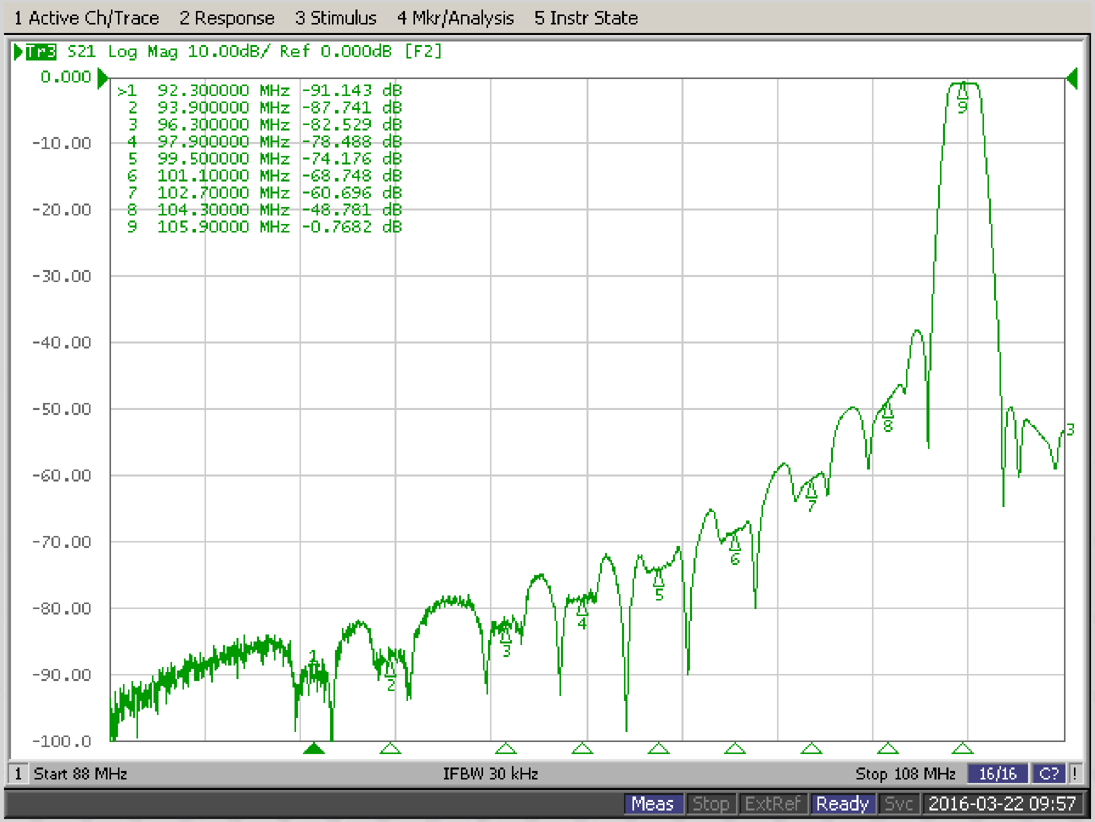
10 Channel LPFM Combiner

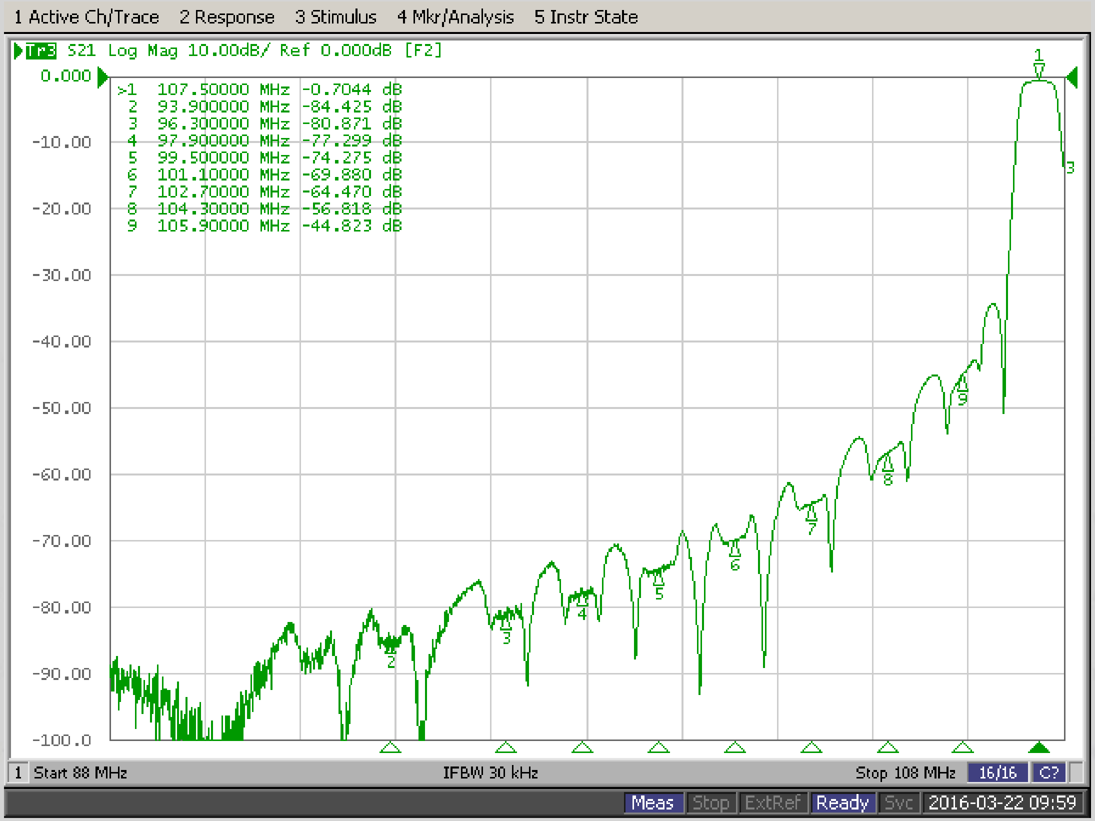
Actual Data, Post Optimization



Channel	Combiner Loss
92.3MHz	.72dB
93.9MHz	.79dB
96.3MHz	.72dB
97.9MHz	.76dB
99.5MHz	.75dB
101.1MHz	.80dB
102.7MHz	.83dB
104.3MHz	.75dB
105.9MHz	.77dB

10 Channel LPFM Combiner

Actual Data, Post Optimization



Channel	***Combiner Loss***
92.3MHz	.72dB
93.9MHz	.79dB
96.3MHz	.72dB
97.9MHz	.76dB
99.5MHz	.75dB
101.1MHz	.80dB
102.7MHz	.83dB
104.3MHz	.75dB
105.9MHz	.77dB
107.5MHz	.70dB

10 Channel LPFM Combiner
Design/Optimization Time

Actual Duration Times:

- Lumped element design in ANSYS – 2 days
- Mechanical design – 1 day
- Manufacturing – 10 days
- Individual filter tuning – 0.5 days
- 10 channel manifold assembly/test – 0.5 day

Manifold Combiner Benefits

- Better impedance for transmitters at ALL channels
- Higher efficiency for ALL broadcasters
- Lower initial cost
- Lower operating cost
- Design/component simplicity
- Reduced size

Cross coupled filters allow lower order filters in manifold combiners!

Specification	Manifold	CIF (# of modules from output)
VSWR	< 1.06:1	< 1.1;1 (1st , takes a beating for others) < 1.16:1 (10th, pays dearly for position)
Loss, f_0	< .35 dB	< .35 dB (1st and keeping quite about it) < .95 dB (10th no beer money left)

THANKS FOR YOUR TIME!
ANY QUESTIONS?

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