Wilkinson Power Combiners for Axion Detection

T. Alamin, P. M. Harrington, J. Buckley, E. Henriksen, & K. W. Murch

Washington University, St. Louis

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Why use power combiners?

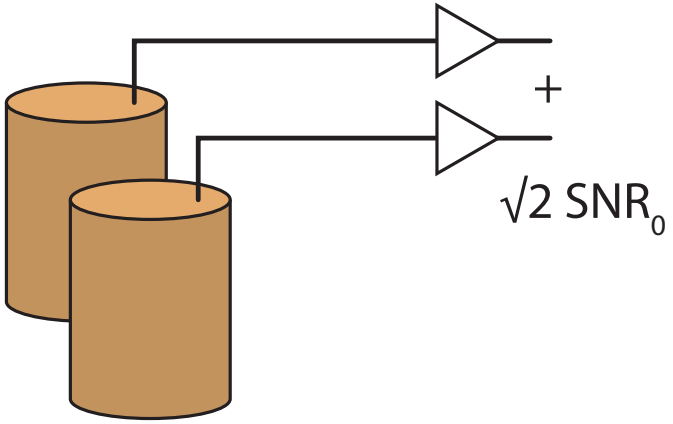
- TEM010 frequency $\propto 1/R$
- SNR scales with volume

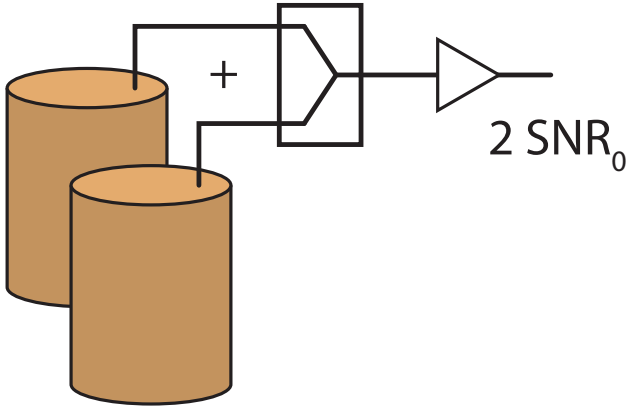
$$\mathrm{SNR} \propto V \propto R^2 \propto 1/f^2$$

- N separate cavities:
  - SNR goes like √N
- The axion signal is coherent:

$$\lambda \sim 10\text{-}10000\ \mathrm{m}$$

- N coherently added cavities:
  - SNR goes like N
- Scan rate ~ SNR²
  - N times faster than uncombined cavities



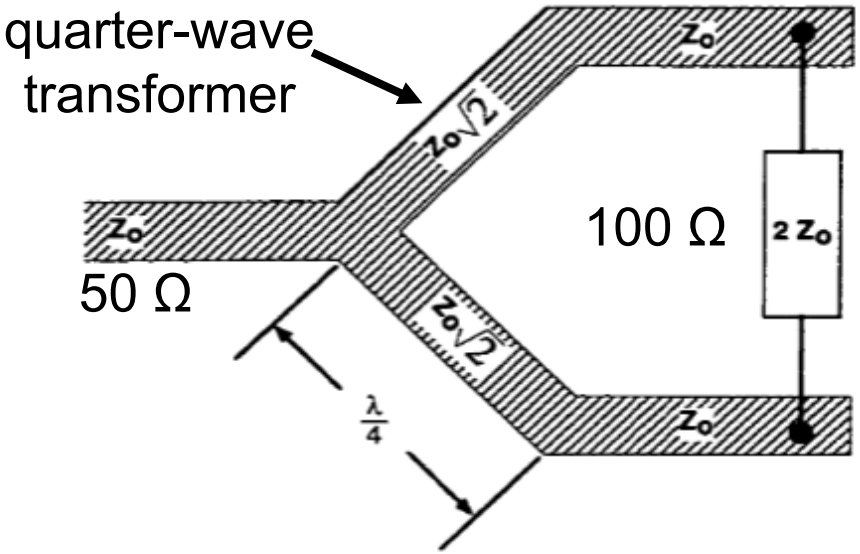


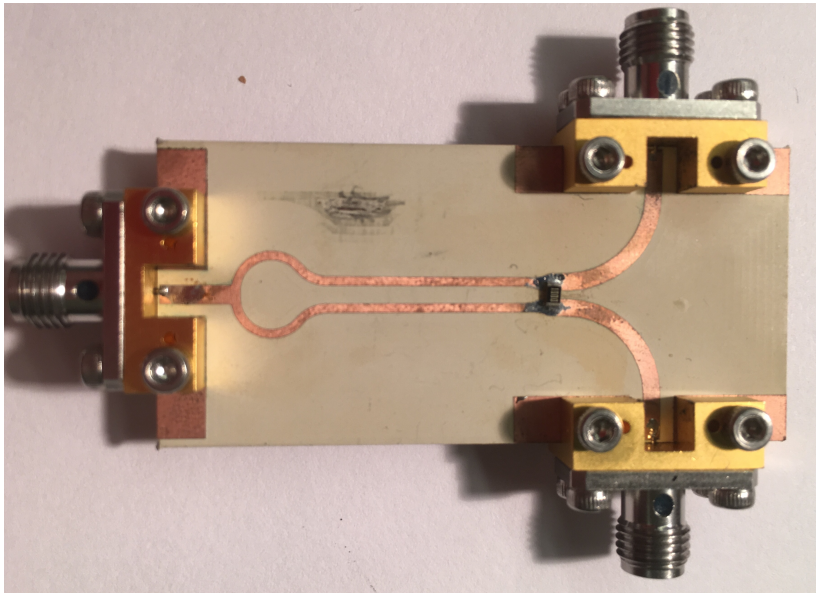
ADMX power combiner requirements

- Project goals:
  - Meet combiner requirements with a 2-to-1 device
  - Design and create a 4-to-1 combiner from cascaded 2-to-1's
  - Optimize packaging and consider size constraints
- Requirements:
  - Low loss (<1 dB)
  - Phase matching (20 degrees)
  - Isolation between ports (< ~15 dB)

Custom design

- Wilkinson power divider
  - Pros: simplicity, easy to design & fabricate
  - Cons: limited bandwidth





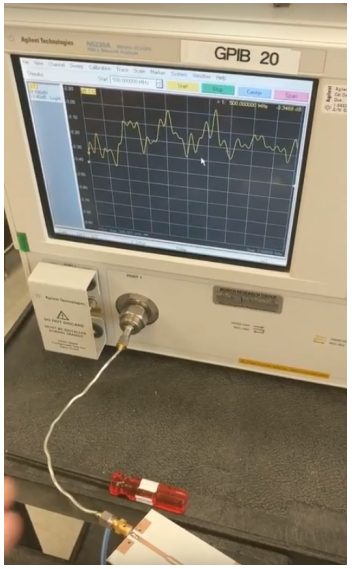
D. Kinion. Thesis, 1994

Device development workflow

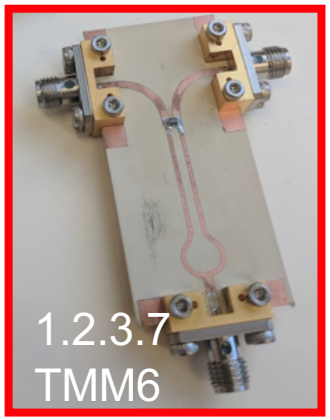
- Design: AWR Microwave Office

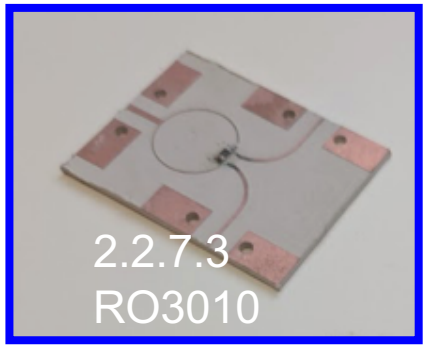
- Prototype: CNC micro mill devices with LPFK

- Measurement: Calibrated VNA measurements, cryo measurements



Old Designs



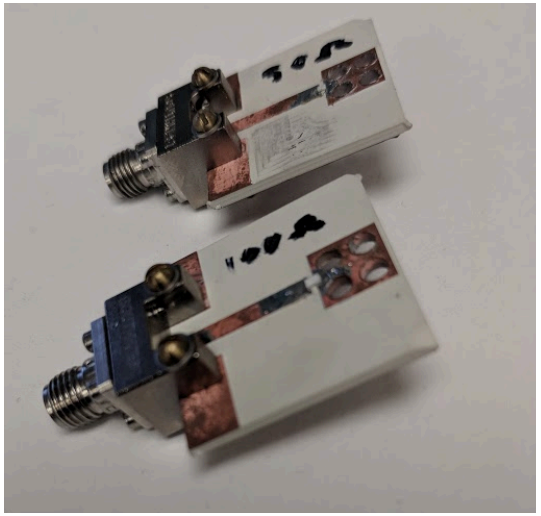


Issues we encountered

- Dielectric constant thermal dependence
- Launch-PCB impedance mismatch
- Resistor's frequency dependence

High frequency resistors

- Vishay thin film NbCr resistors
  - short effective electrical length
  - thermally stable down mK temperatures
  - Performance at cryo temperatures verified with termination tests at WashU



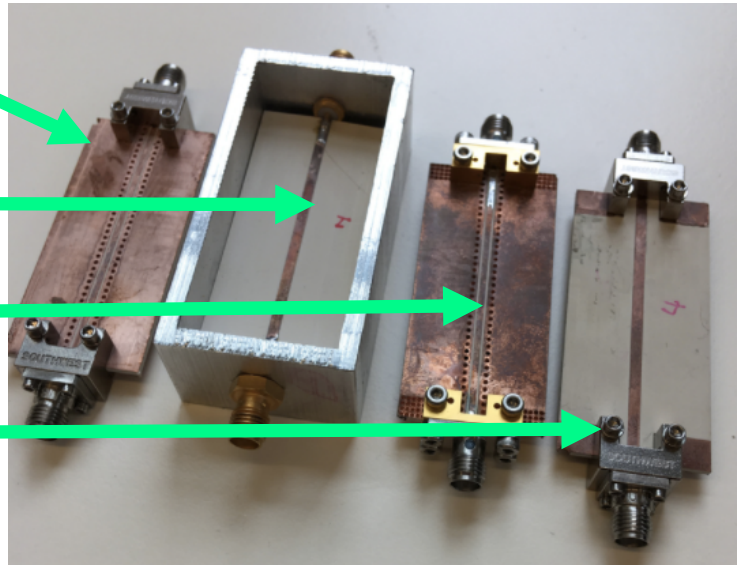
Microwave packaging and connector tests

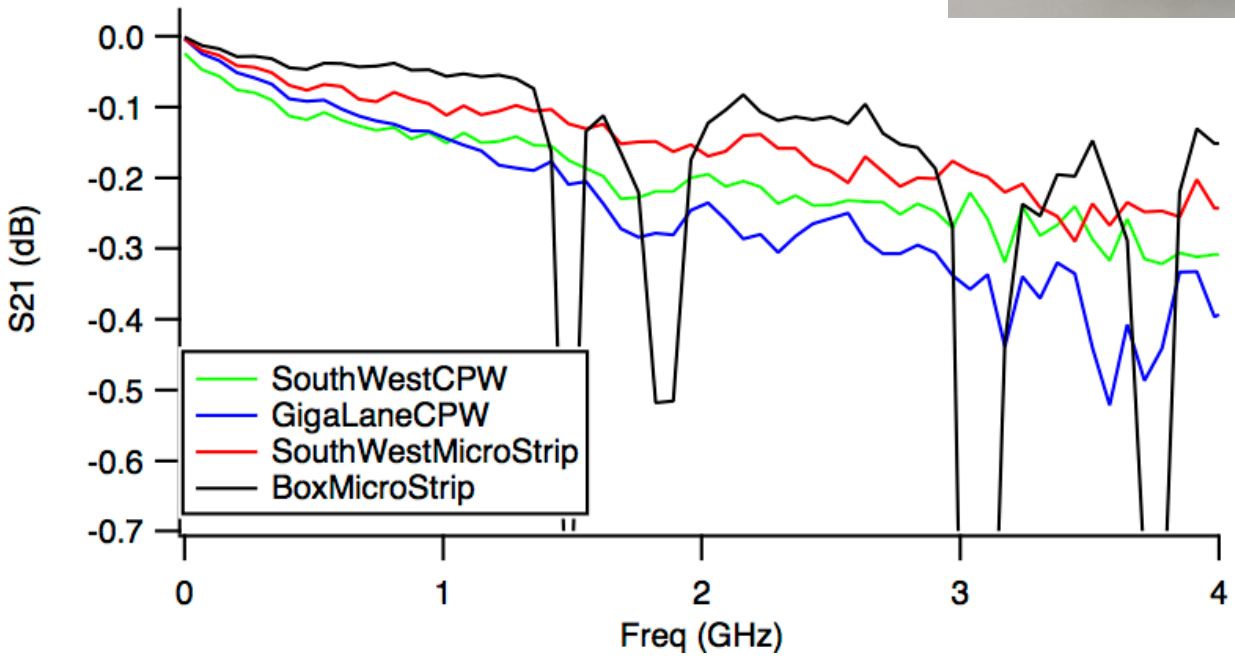
Southwest Microwave connectors + CPW

“Box design” (adapted from Minicircuits)

Gigalane connectors + CPW

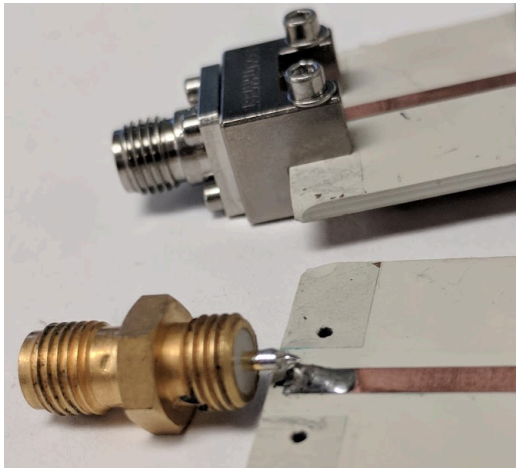
Southwest + Microstrip



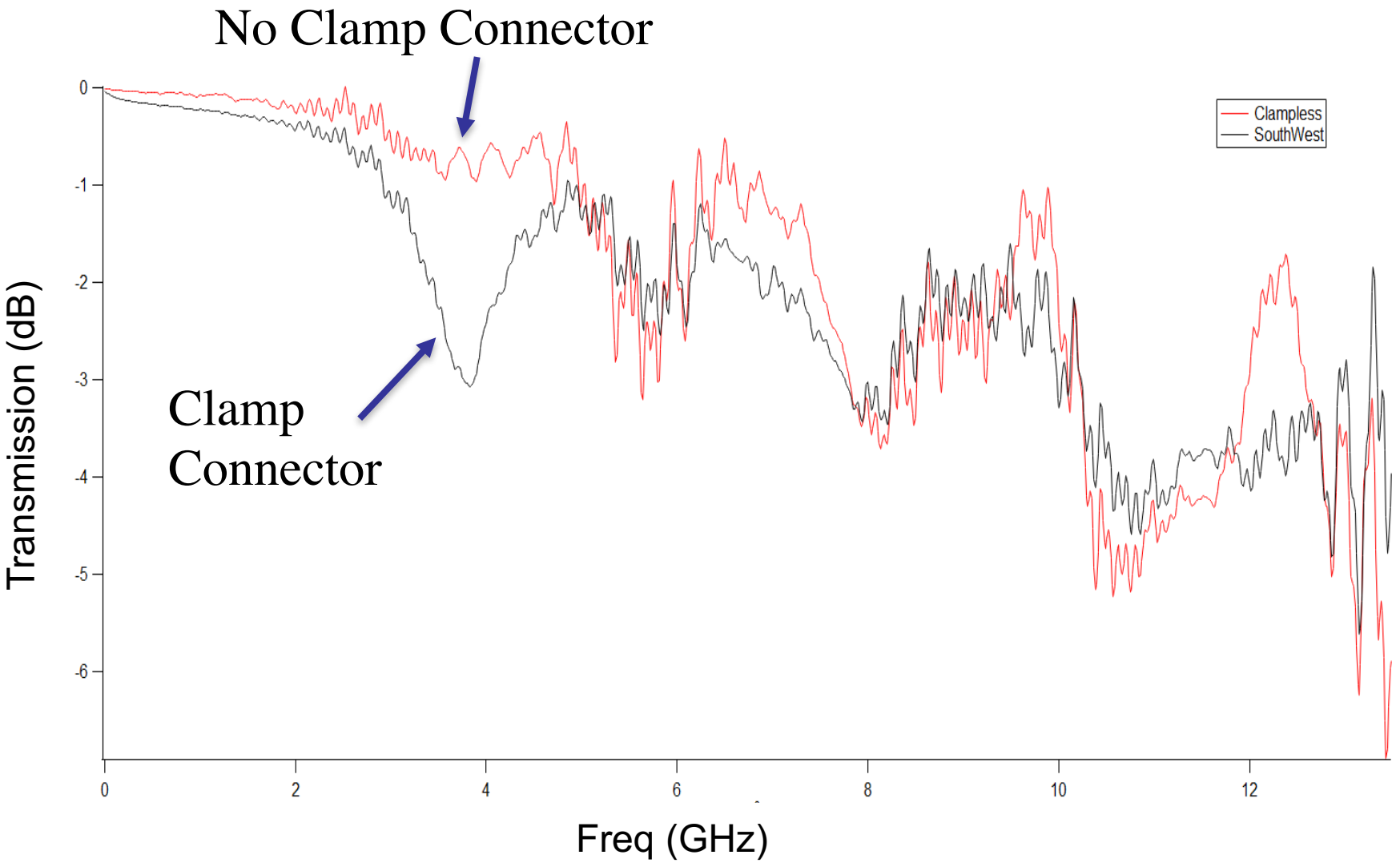


SMA Connectors

- Clamped vs clampless connectors
  - Performed tests by coupling to 50 Ohm microstrip transmission lines

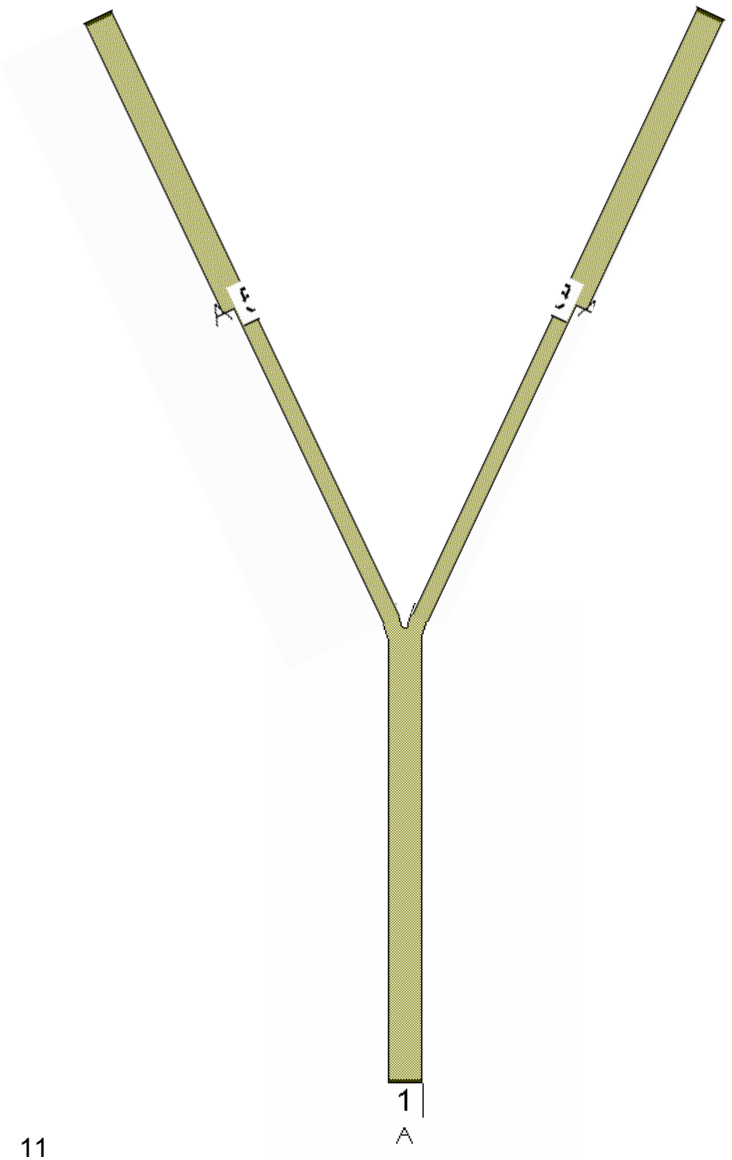


Microstrip Transmission Line Tests



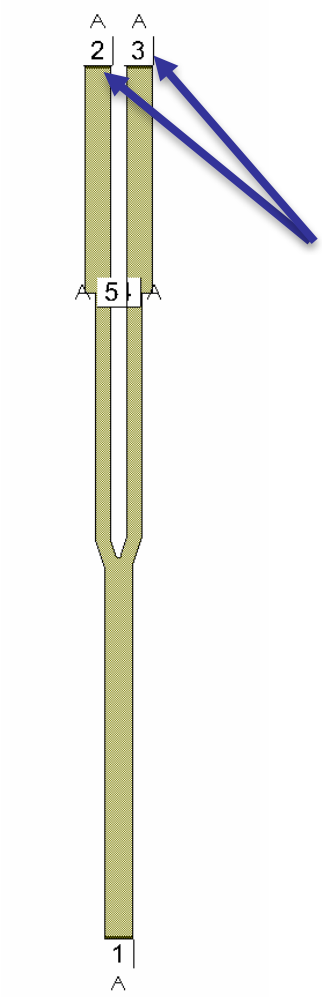
ADMX range is approximately 1 to 2.5 GHz

Minimal Curvature Concept

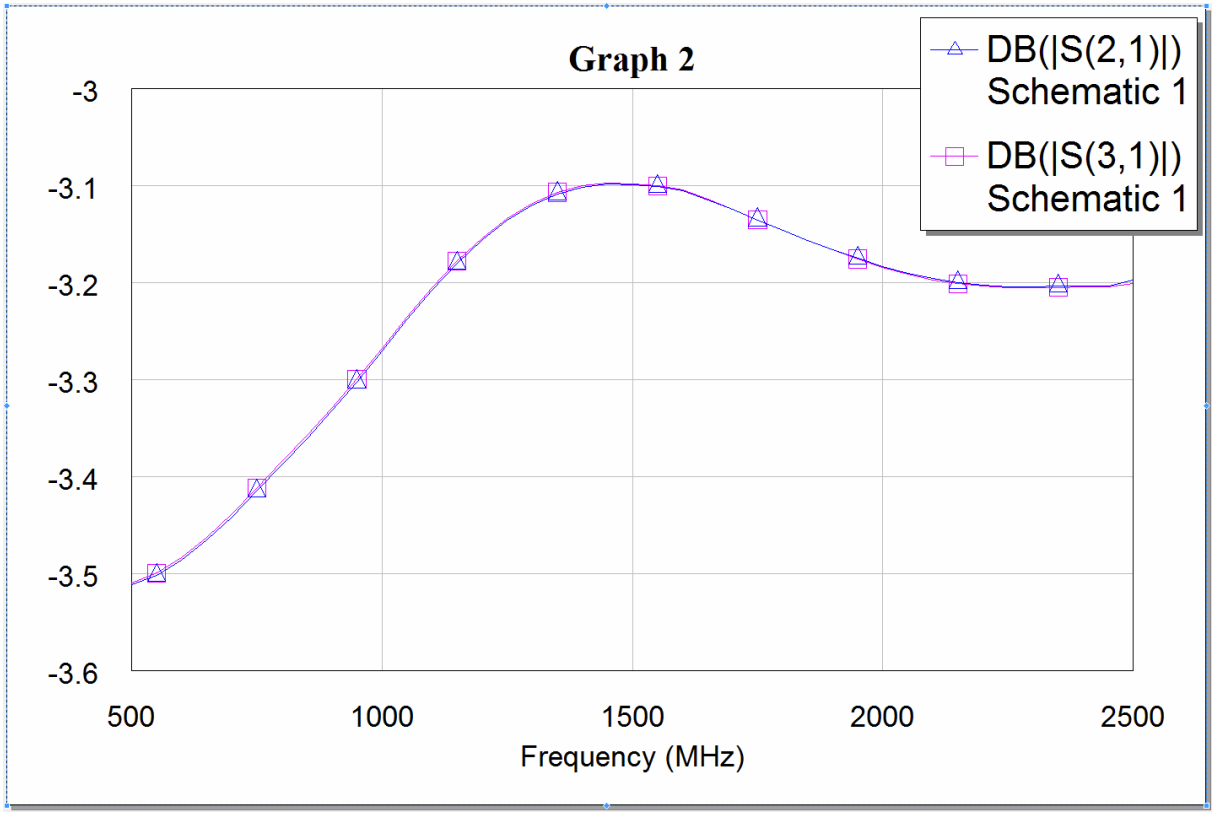


- All previous designs utilized gradual curves to lessen curve tightness
  - We suspected extra curvature may contribute to reflection
- Initial design was not physical due to wide resistor gap

Minimal Curvature Concept



- More Physical device
- Ports too close to fit physical connectors

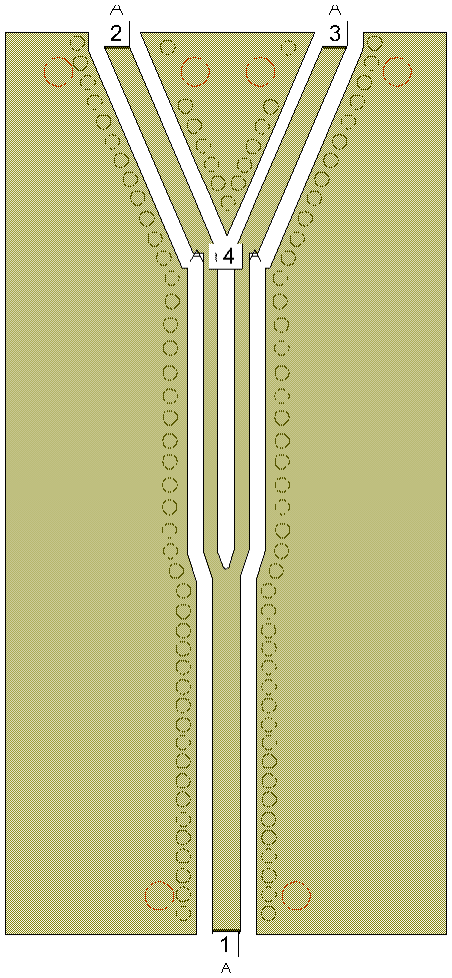


Testing method

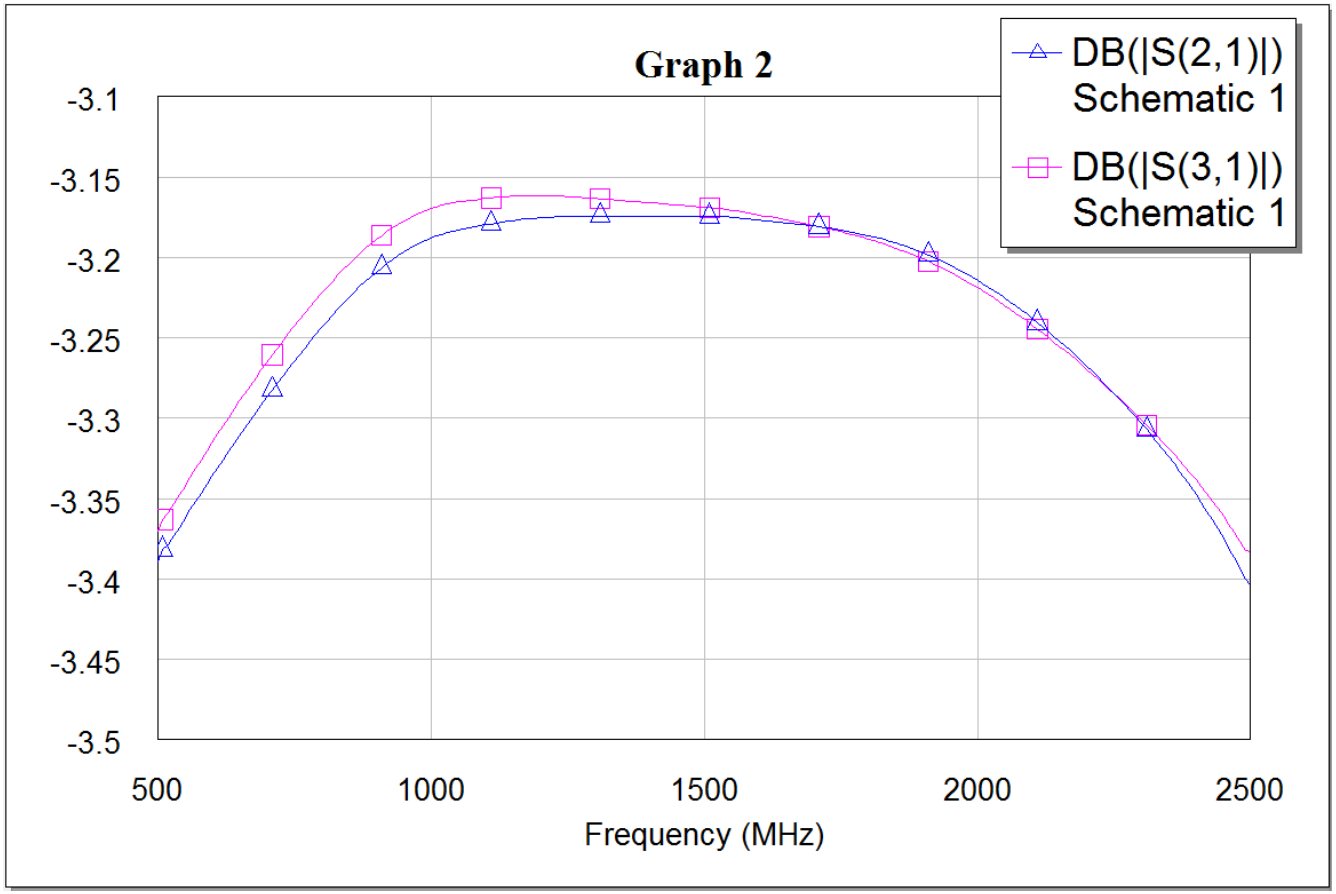
Output

- Measurements of S21 & S31
  - Wilkinson symmetry
- Characterizes insertion loss by resistor loss & impedances matching

Coplanar Version

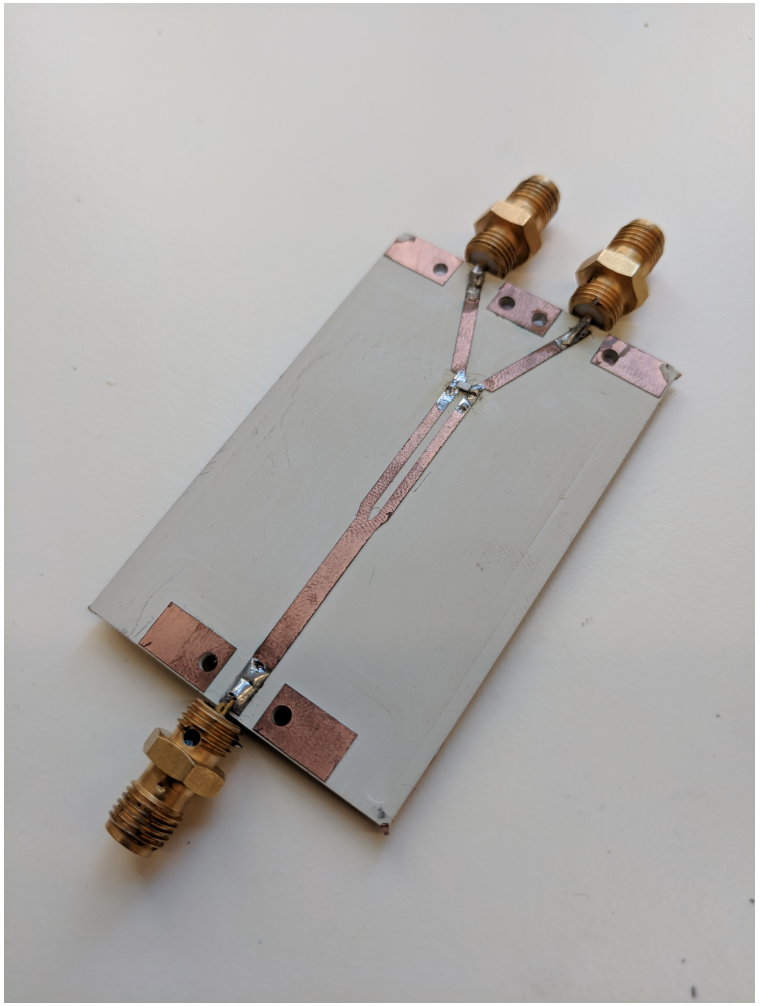


- This device layout is physical

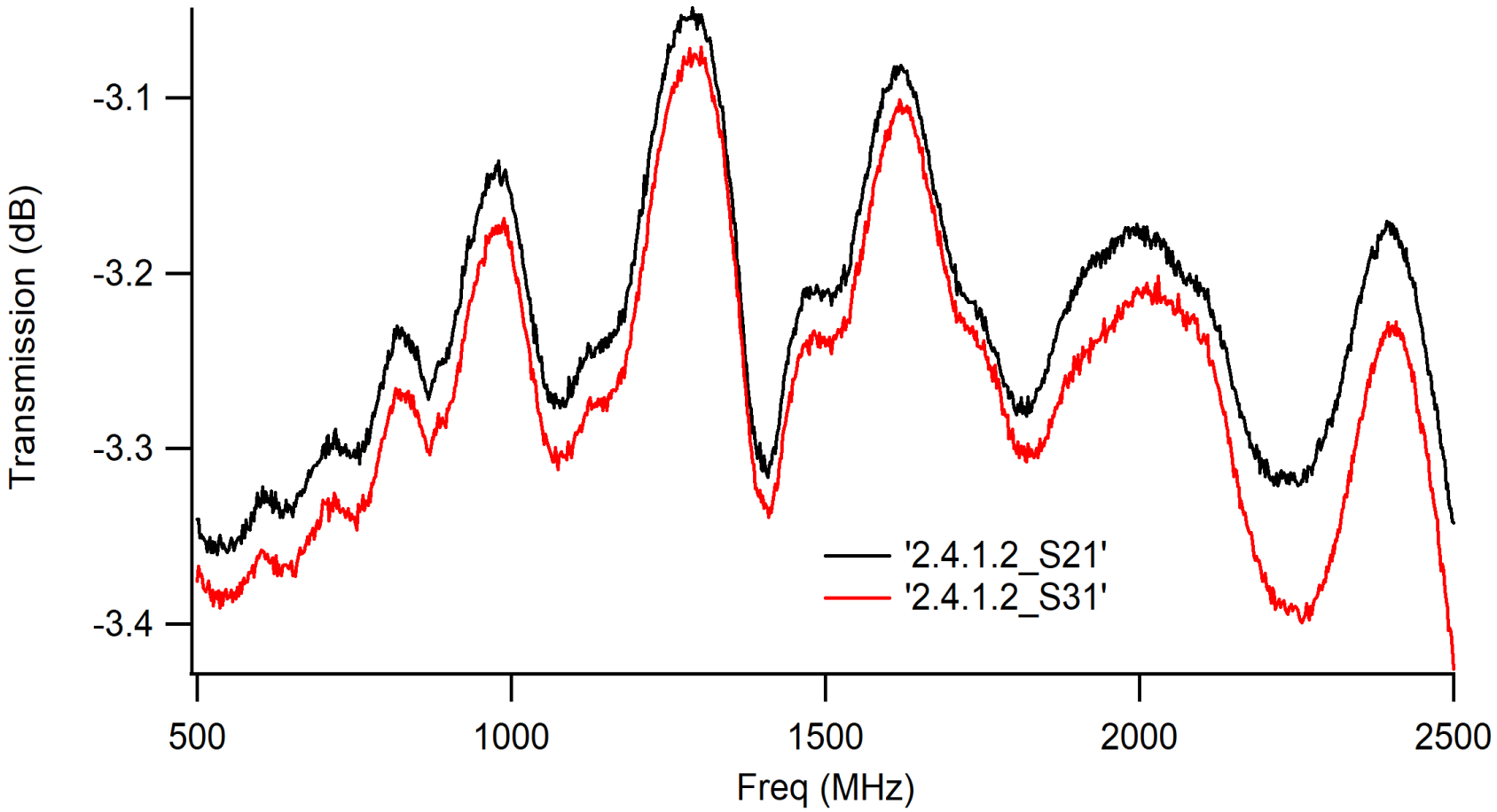


Wilkinson power combiner: 2-to-1

- Clampless connectors
- Low curvature
  - No gradual curves
  - Sharp bends
- Simple geometry
  - Easy to optimize
  - Low spatial footprint

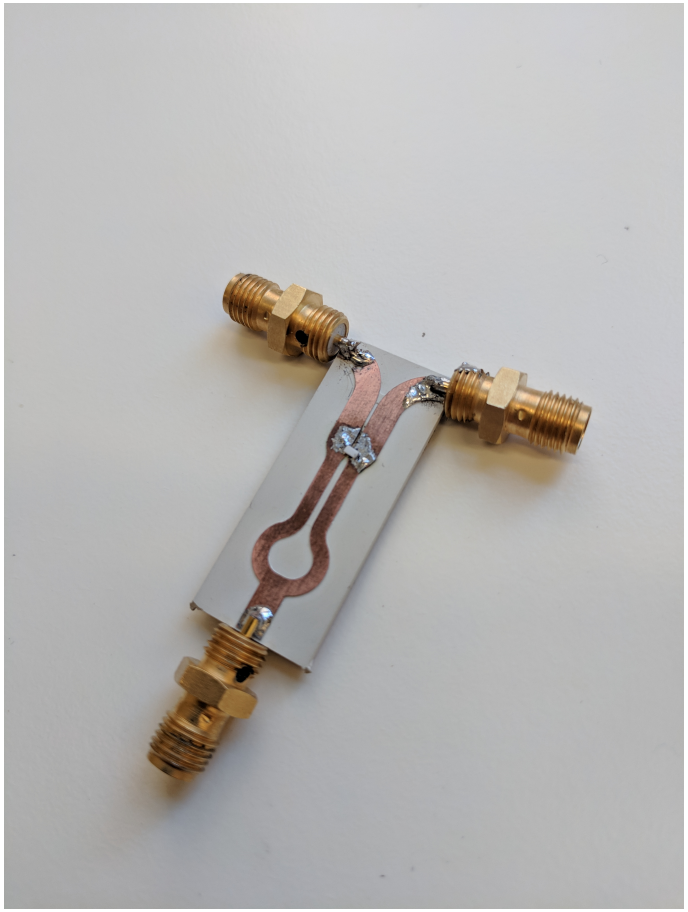


Wilkinson power combiner: 2-to-1

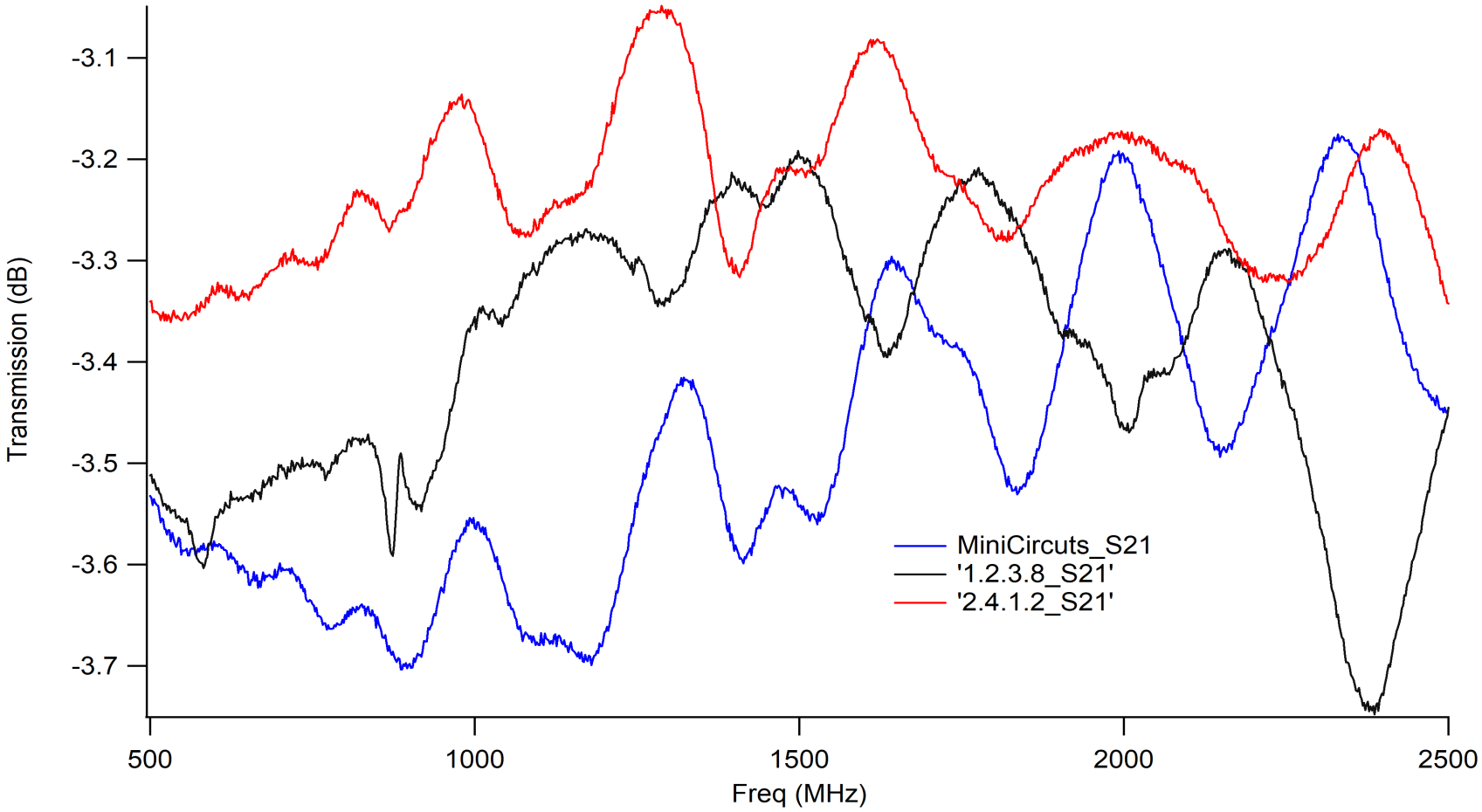


Next iteration of design

- Minimizing area (1x1.5in)
  - Non quarter wave branch lengths
- Still utilizes curved design
  - Smaller capacitive impedance



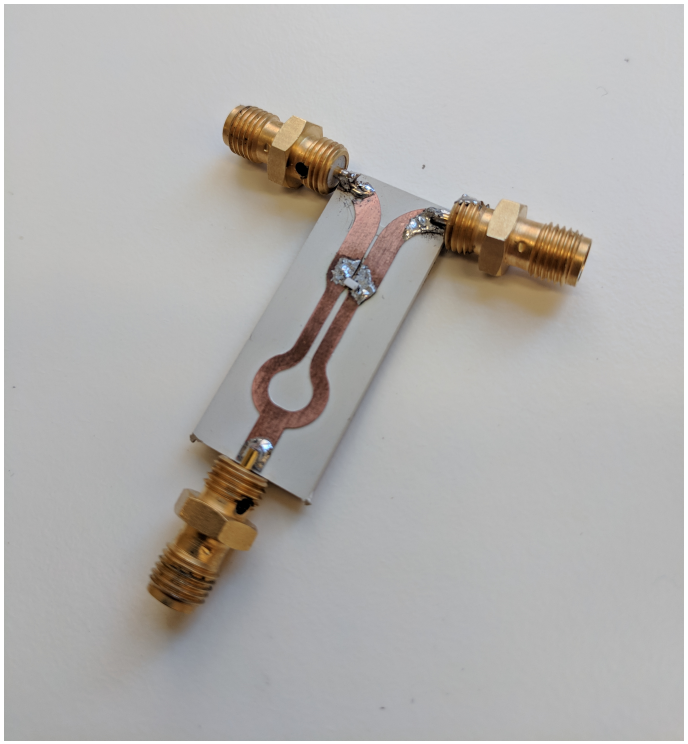
Comparison of prototypes & commerical



What we learned

- Simple design with parallel branches are better than curved
  - Can accommodate for capacitive coupling between branches
  - Curvature is directly related to reflection
- Smallest practical board size is 1.75x1.25 in with this dielectric (for a 2 to 1)
- Enclosure is required for signal stability

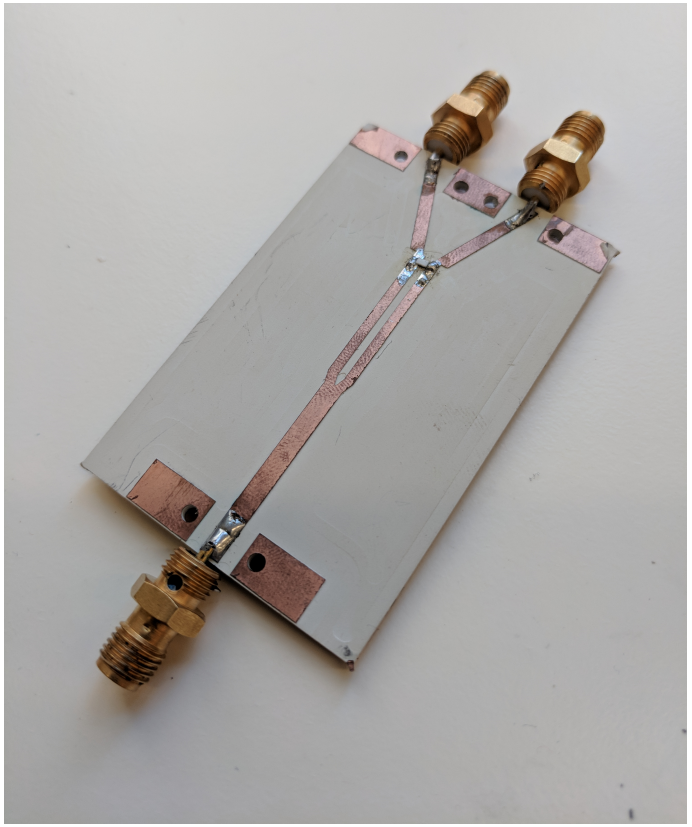
Which design to pursue: Pros and Cons



1.2.3.8

- Smallest Design ☺
- Extra curvature ☹
- Less Capacitive coupling ☺
- Very Fragile 😐
- Transmission (meets 1dB loss goal) 😐

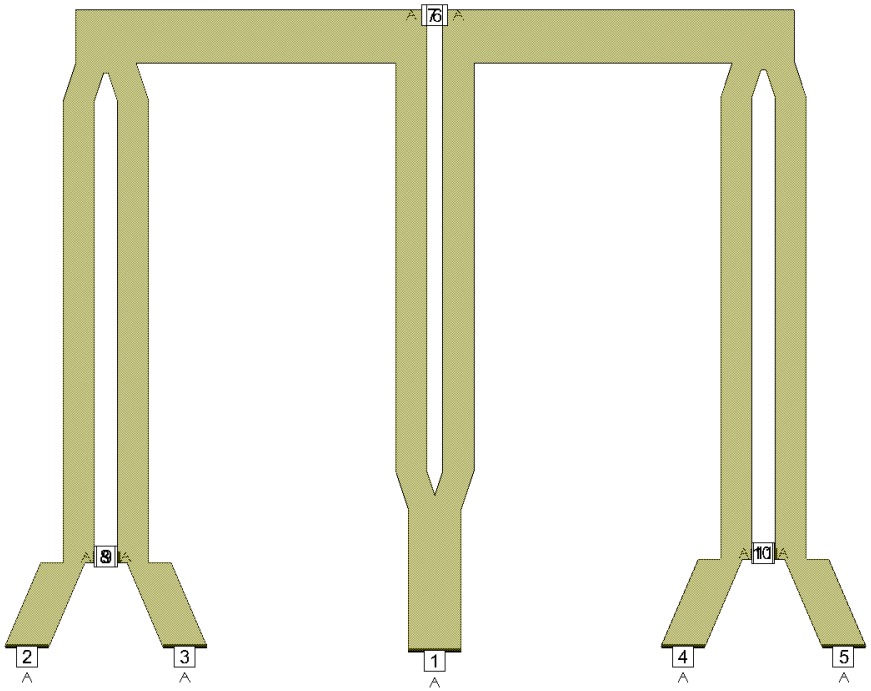
Which design to persue: Pros and Cons

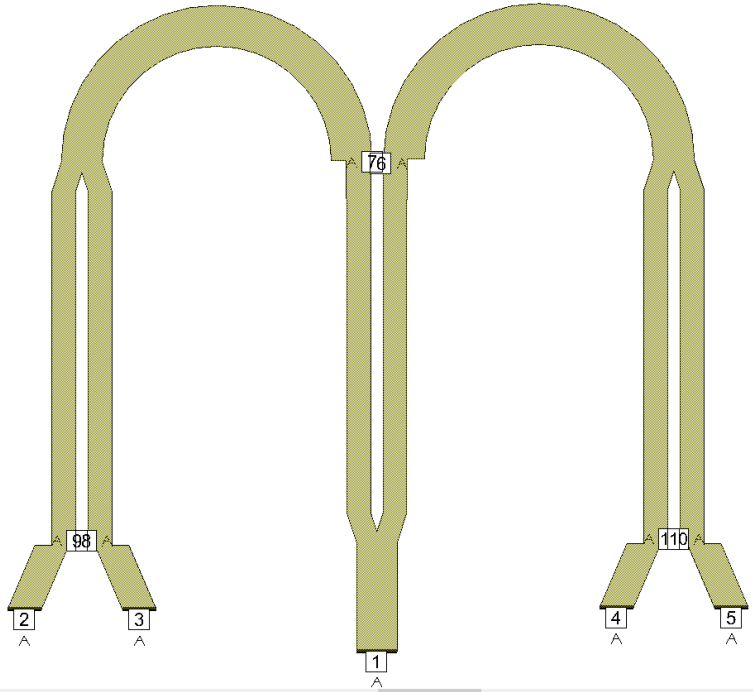


2.4.1

- Larger Design 😐
- Minor Curvature ☺
- Significant Capacitive coupling 😐
- Less Fragile ☺
- Transmission (exceeds 1dB goal and is so far) ☺☺

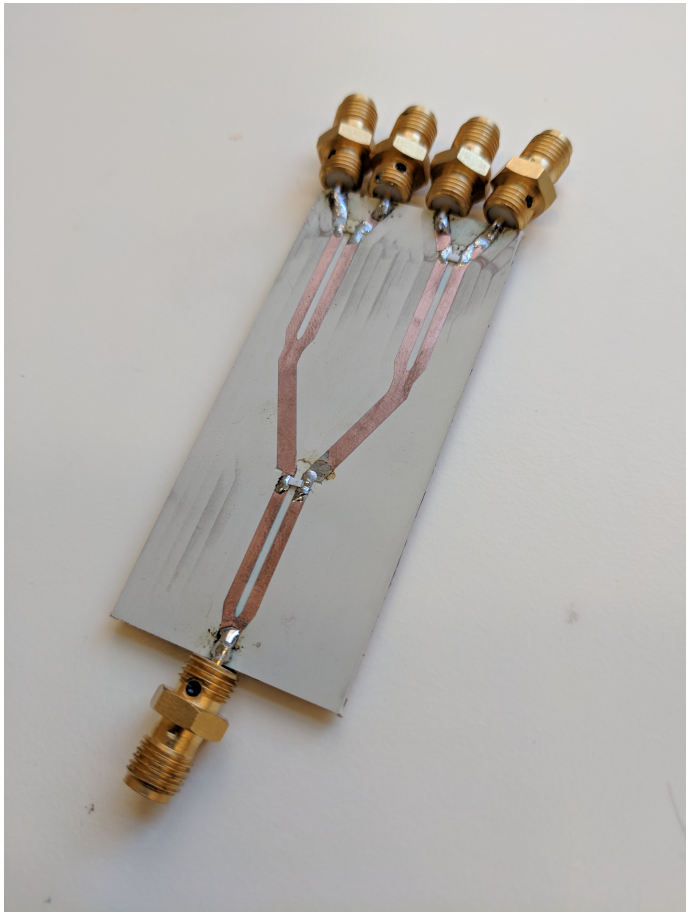
4-to-1 Wilkinson Power Combiners



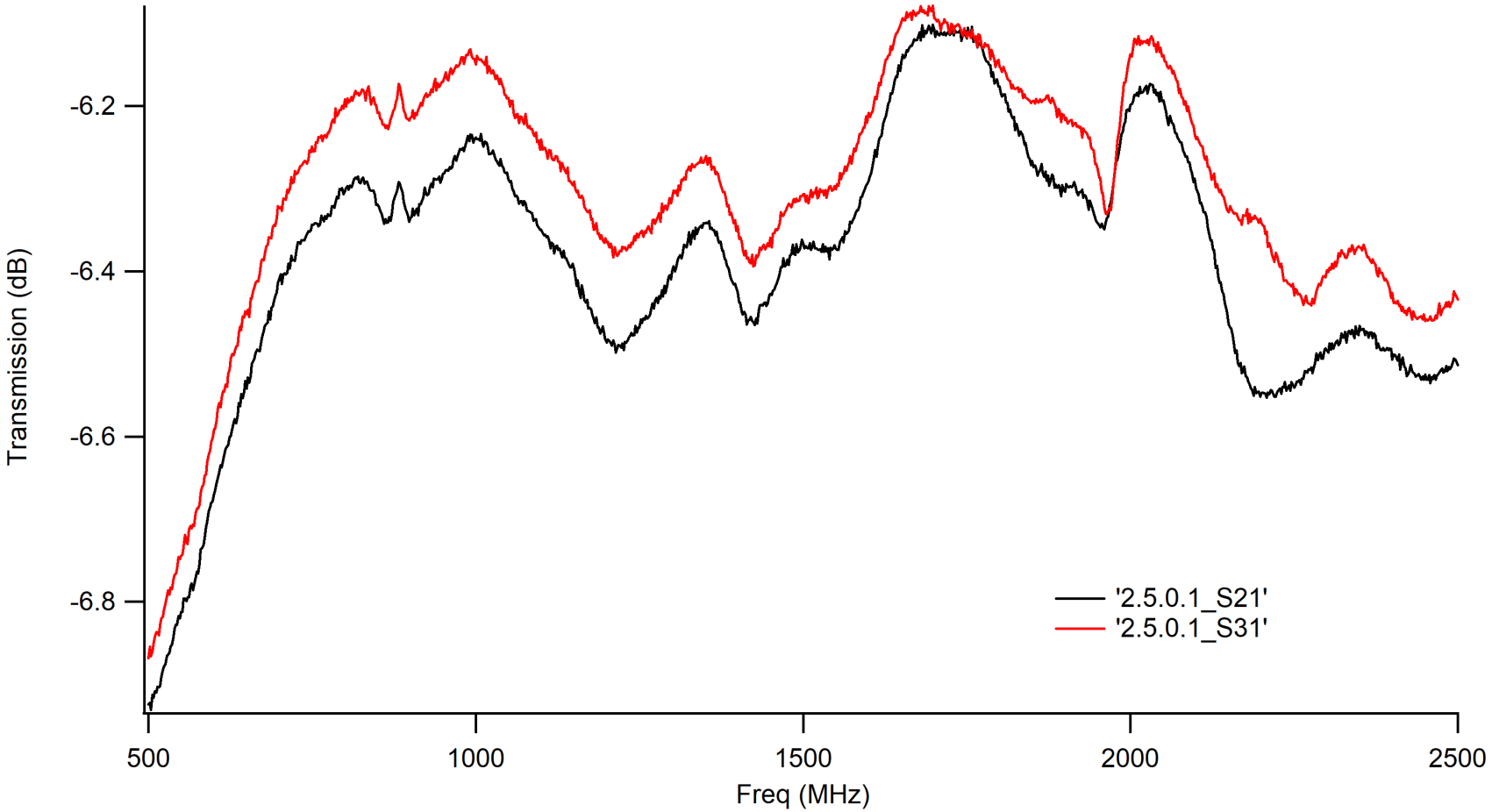


4-to-1 Wilkinson Power Combiners

- Cascaded shortened 2-to-1 combiners
- Crowded Design
- Low curvature cascade
  - Less is possible



4-to-1 Wilkinson Power Combiners



Packaging & Enclosure

- Devices are sensitive to external interference
- Devices are fragile and easily break
- May address the differing capacitances seen in the inner and outer branch lines of the 4 to 1 splitter
  - We plan on adding ‘walls’ suspended form the lid so each branch splitter would have its own ‘room’

Summary

- Project goals achieved
  - 2-to-1 combiner
  - 4-to-1 combiner
- In the next design...
  - Full enclosure
  - High isolation (minimal S23/S32)
  - Smaller spatial footprint
  - Coherent combining efficiency measurements