WILKINSON POWER DIVIDER

Kabato Burka

FUNDAMENTALS

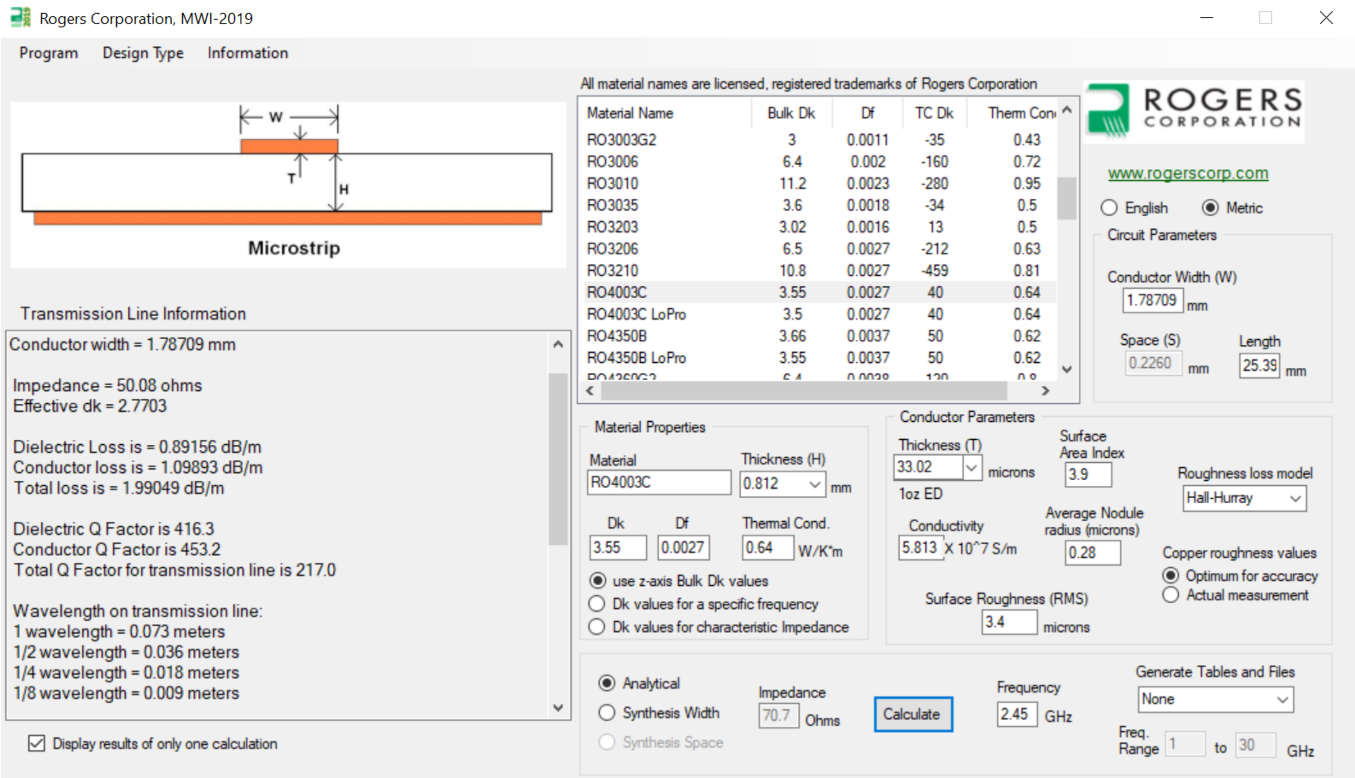
- Three-port networks must have one of:
  - lossy
  - non-reciprocal
  - not matched
- *An N-Way Hybrid Power Divider,* E.J. Wilkinson '60
  - No dissipated power w/ matched external loads
  - Isolation between output ports
  - Internal loads require crossover for n > 2
- Microstrip line schematic for 2-way Wilkinson
  - Initial simulations for design with center frequency ~2.45 GHz
  - Selection of substrate and layout

FINAL APPROACH

- Iterative approach: Using RO4003C substrate (dk = 3.55), Keysight Genesys circuit, layout, then Ansys HFSS model of 2-way 2.45 GHz WPD
  - For circuit: do linear analysis simulation then tune
  - For layout simulation: do method and moments simulation then tune
  - For HFSS Ansys: do 3D analysis simulation then tune
- Create Gerber file from layout file to mill in LPKF
- Mill on LPKF
- Solder surface mount resistor and SMA ports
- Test and record S-parameters on VNA

STARTING RANGES

- Roger's Microwave Impedance Matching Calculator for starting parameters
  - Provided starting range for quarter wavelength width and length and characteristic impedance width

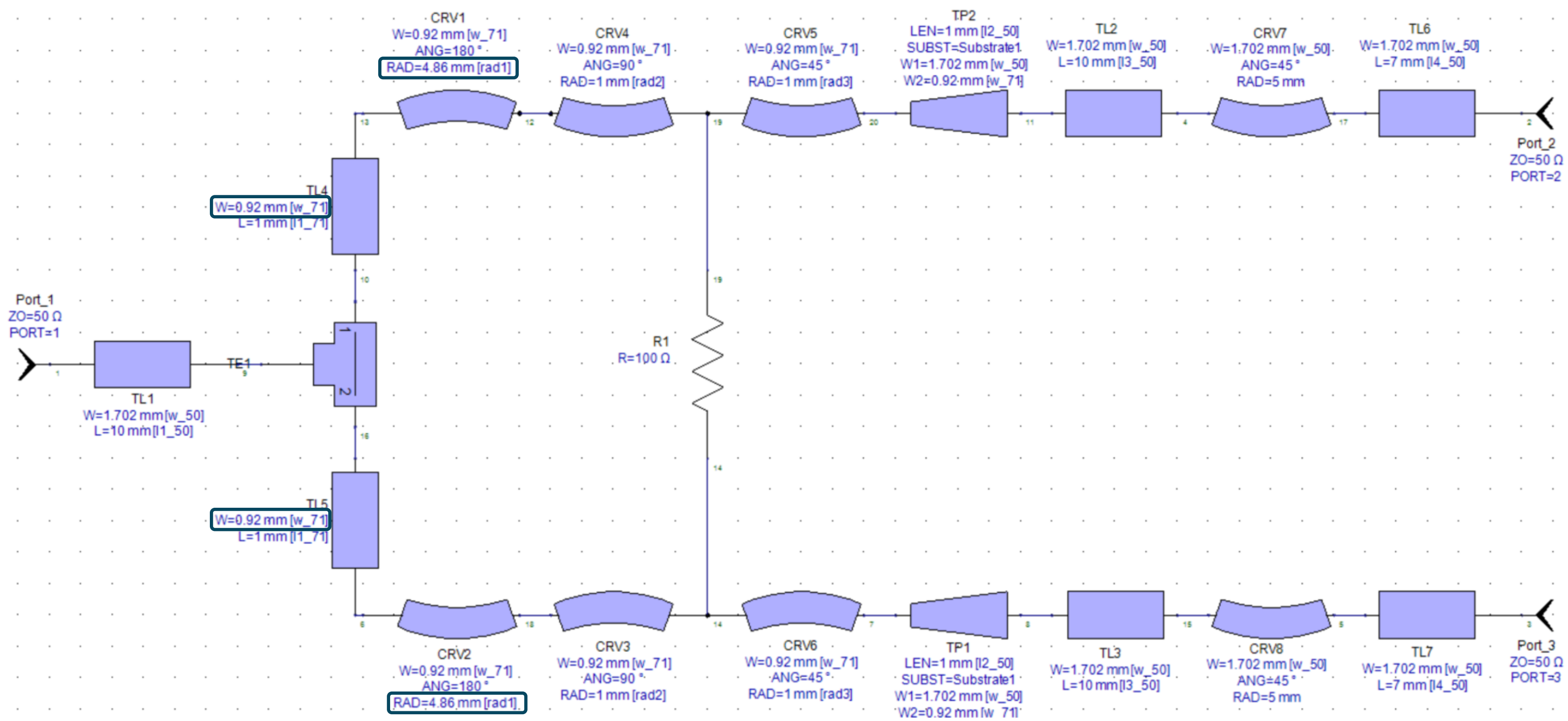


CIRCUIT SCHEMATIC

- Keysight Genesys 1:2 WPD circuit design

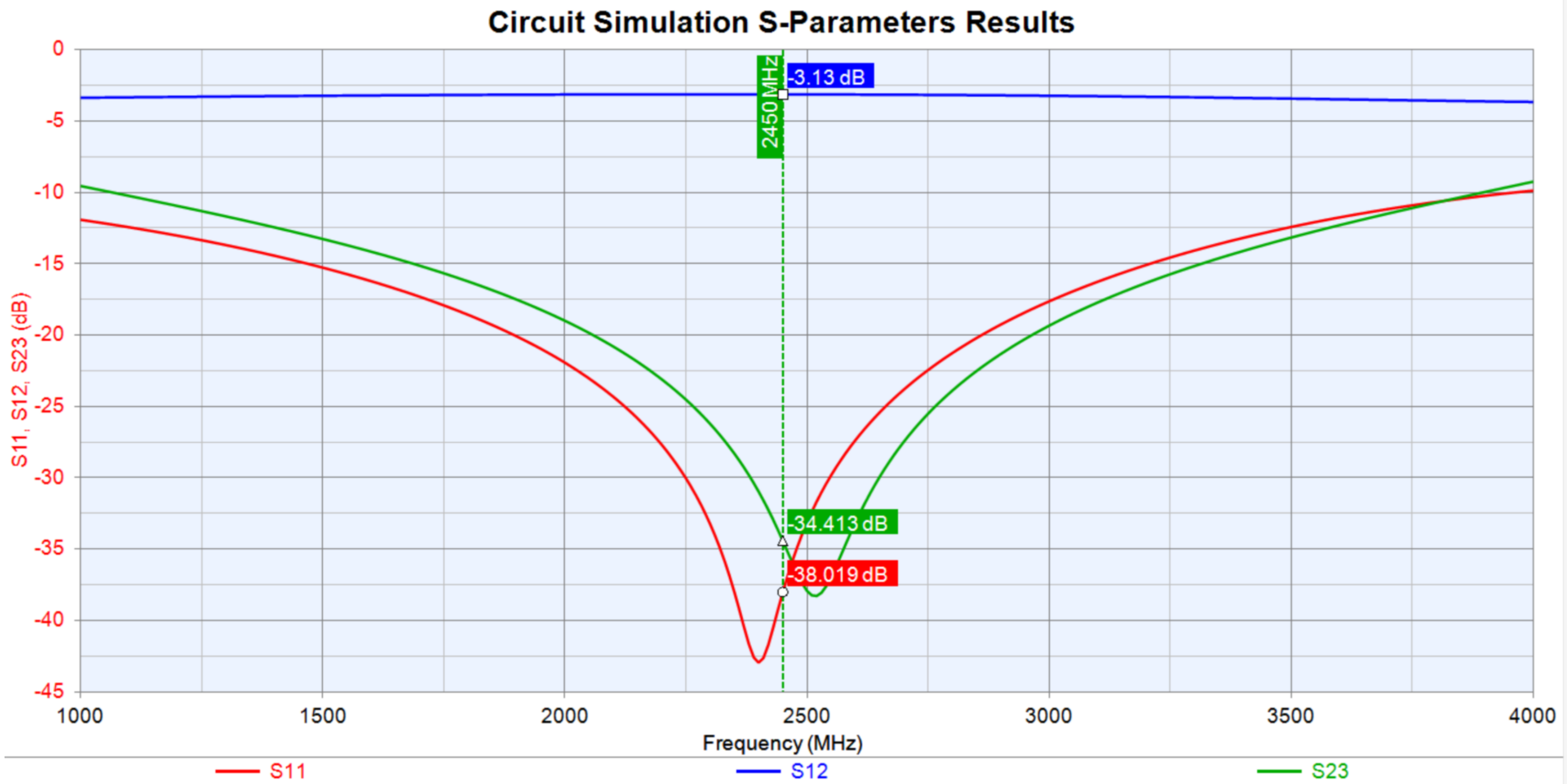
Tune Window

Variable	Value
Percentage	5%
Equation.l1_50	10
Equation.l1_71	1
Equation.l2_50	1
Equation.l2_71	0.9
Equation.l3_50	10
Equation.l4_50	7
Equation.rad1	4.86
Equation.rad2	1
Equation.rad3	1
Equation.w_50	1.702
Equation.w_71	0.92



CIRCUIT SIMULATION

- Keysight Genesys 1:2 WPD circuit simulation results

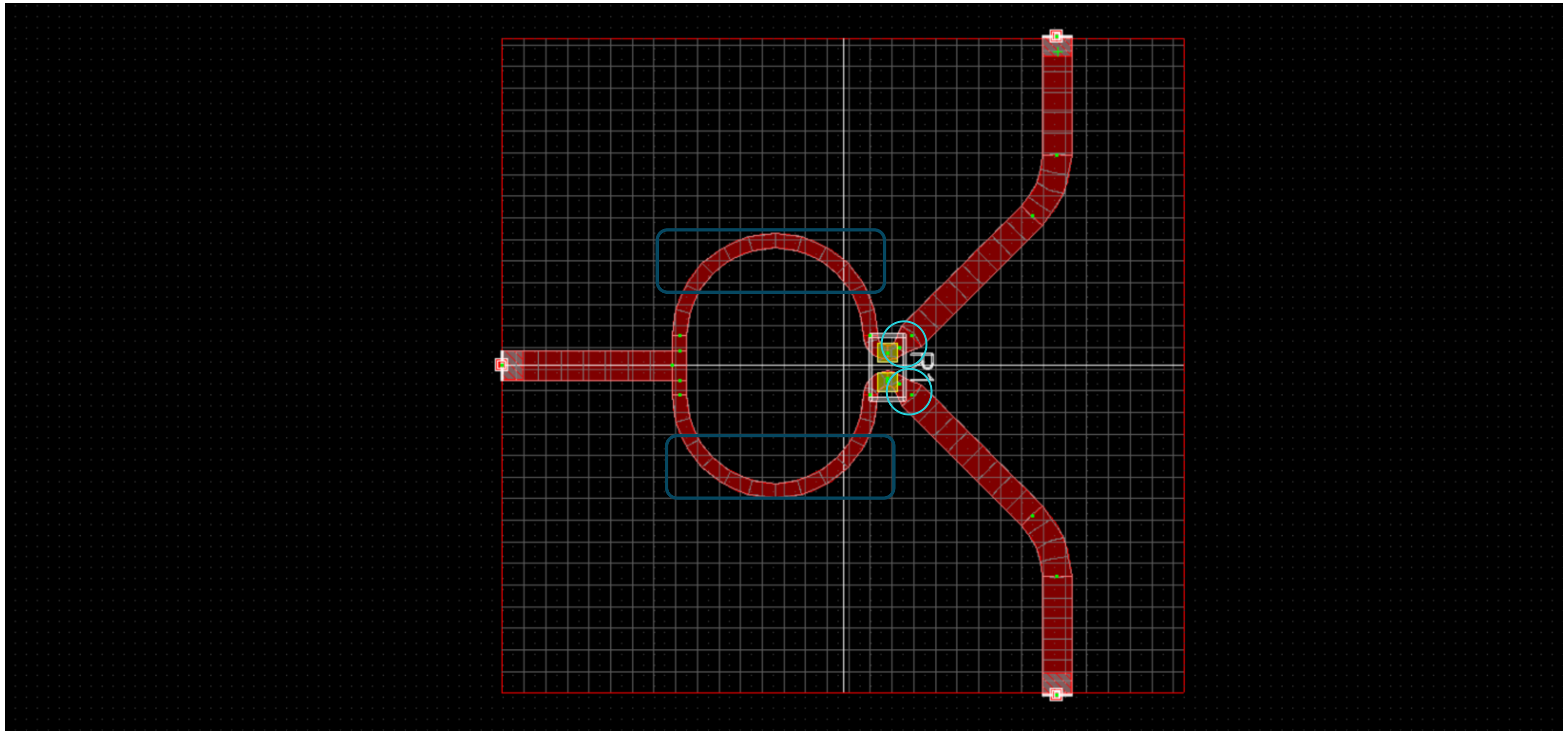


CIRCUIT LAYOUT

- Keysight Genesys 1:2 WPD layout design

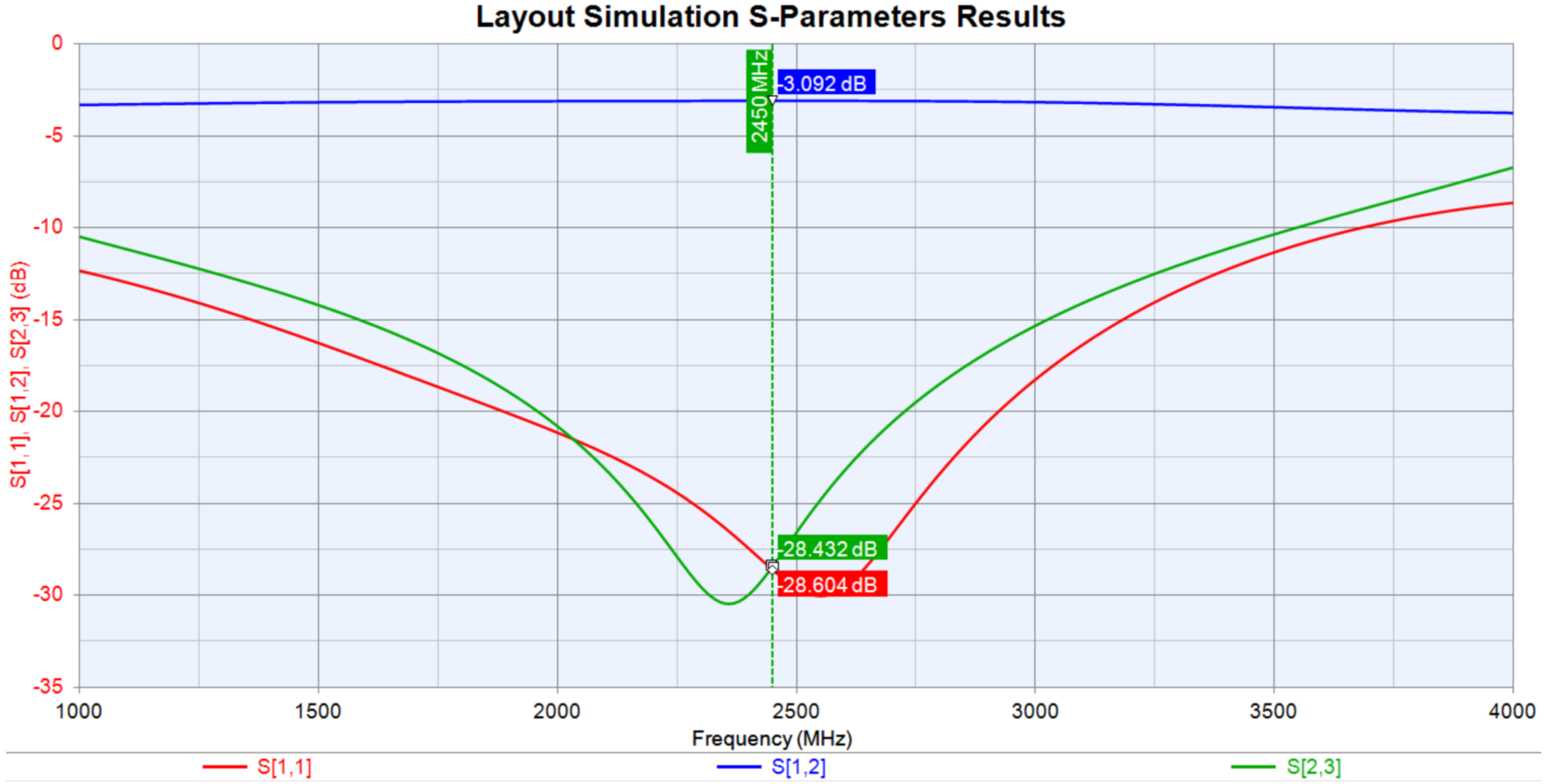
Tune Window

Variable	Value
Percentage	5%
Equation.l1_50	10
Equation.l1_71	0.9
Equation.l2_50	1
Equation.l2_71	0.9
Equation.l3_50	10
Equation.l4_50	7
Equation.rad1	5.6
Equation.rad2	1
Equation.rad3	1
Equation.w_50	1.702
Equation.w_71	0.85



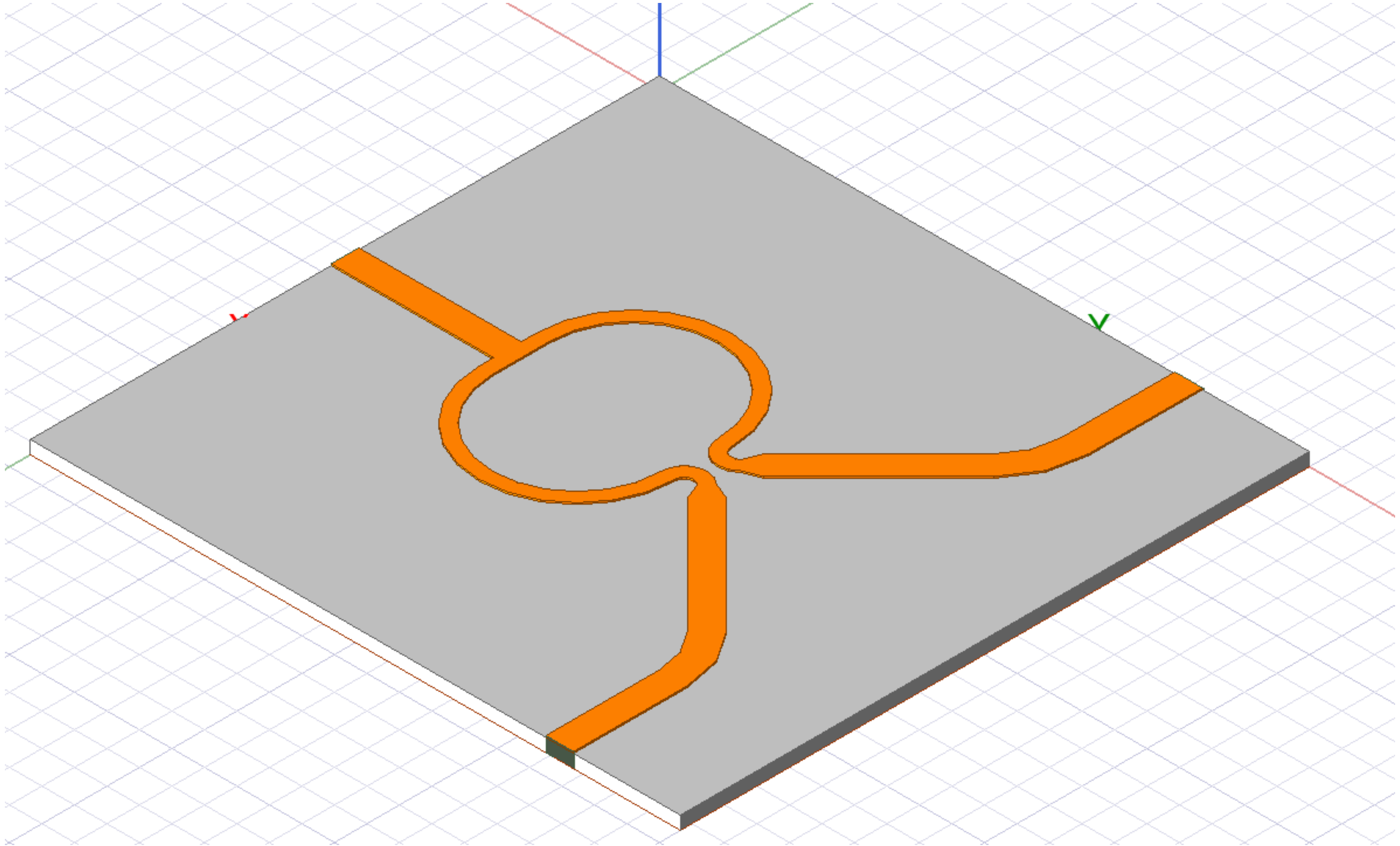
MOMENTUM GXF (METHOD OF MOMENTS)

- Keysight Genesys 1:2 WPD layout simulation results



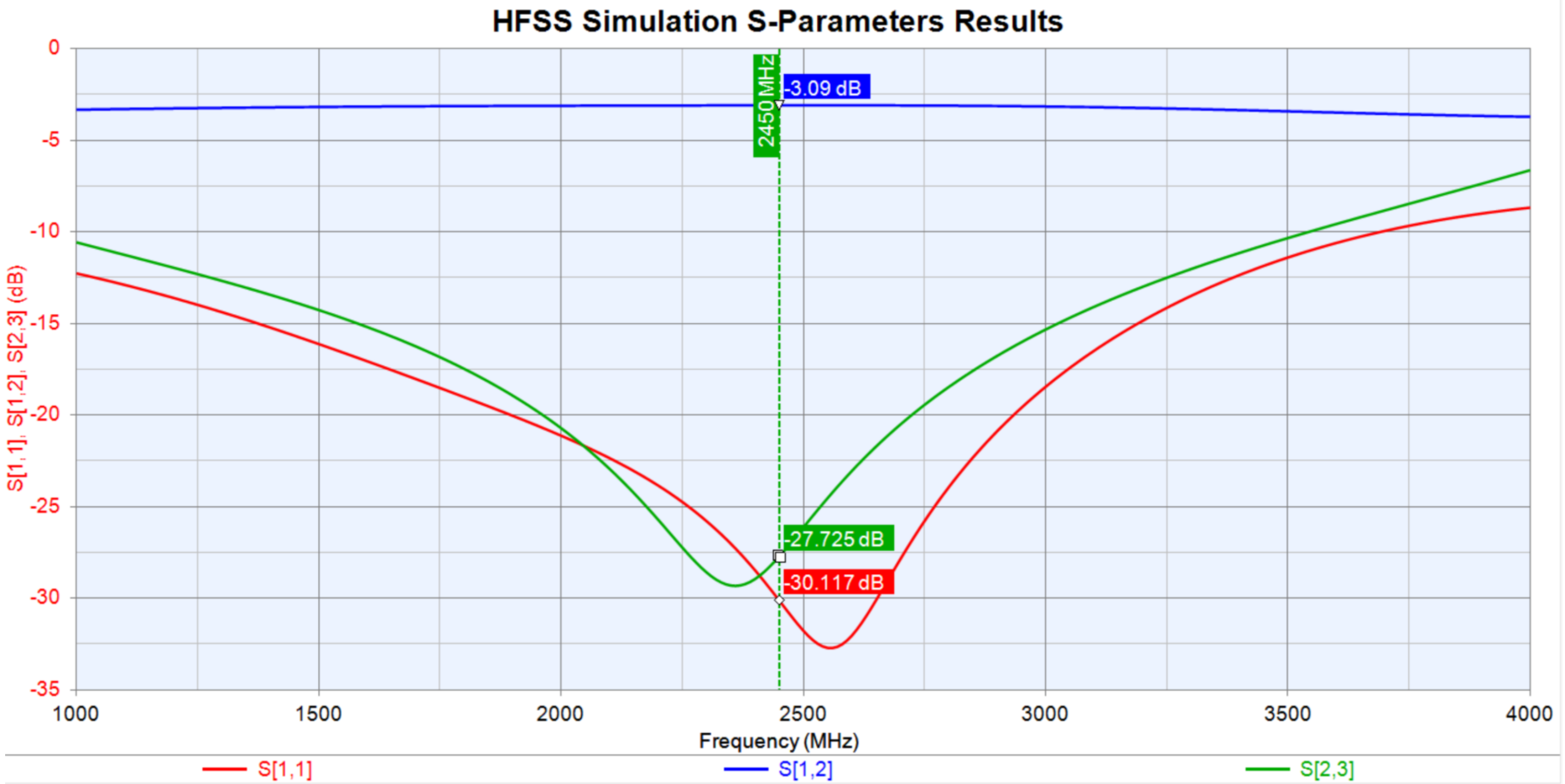
3D SIMULATION DESIGN OF LAYOUT

- Ansys HFSS 1:2 WPD 3D design



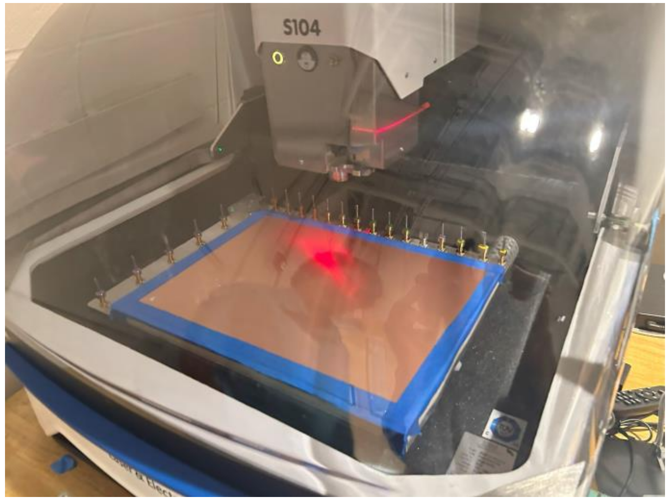
ANSYS HIGH FREQUENCY SIMULATION SOFTWARE

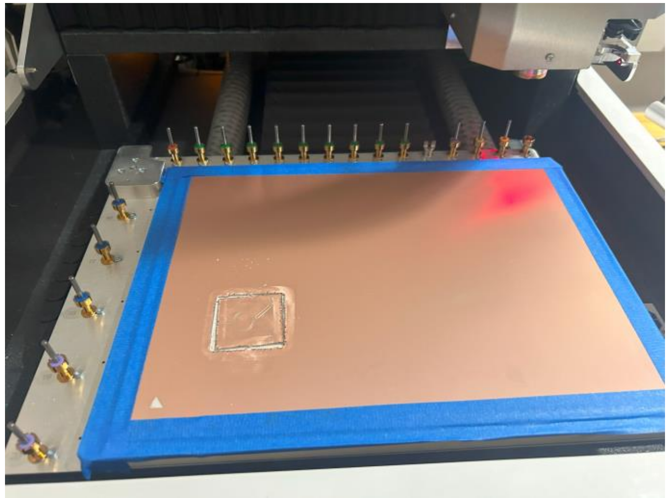
- Ansys HFSS (similar to CST)1:2 WPD 3D analysis simulation results



MILLING PROCESS WITH LPKF

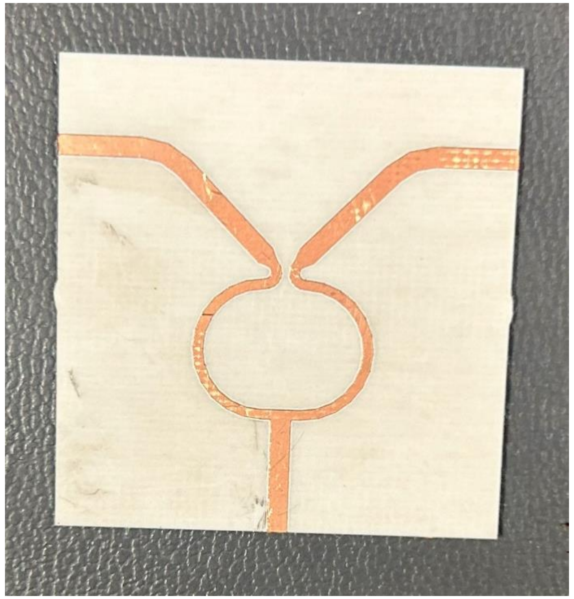
- Activate Air Compressor connected to LPKF
- Add RO4003C substrate onto mat
- Follow user friendly LPKF CircuitPro PM software to set up system
- Transfer Gerber file from final design consisting of board outline then mill

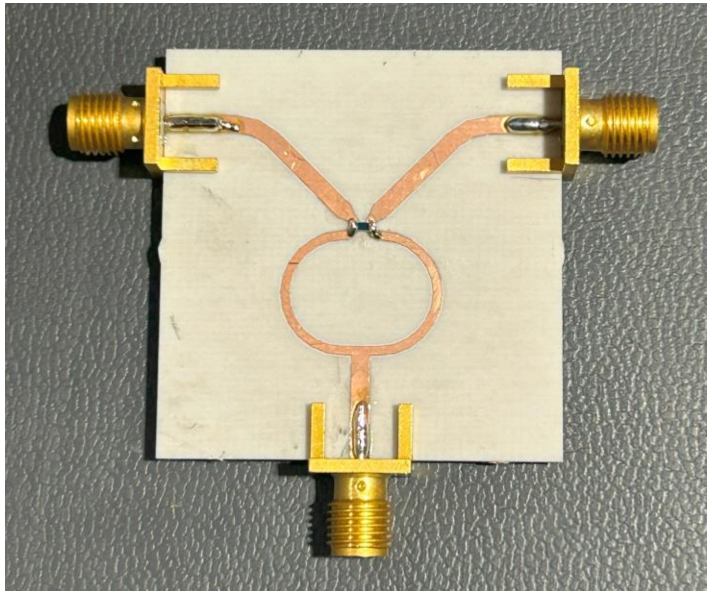


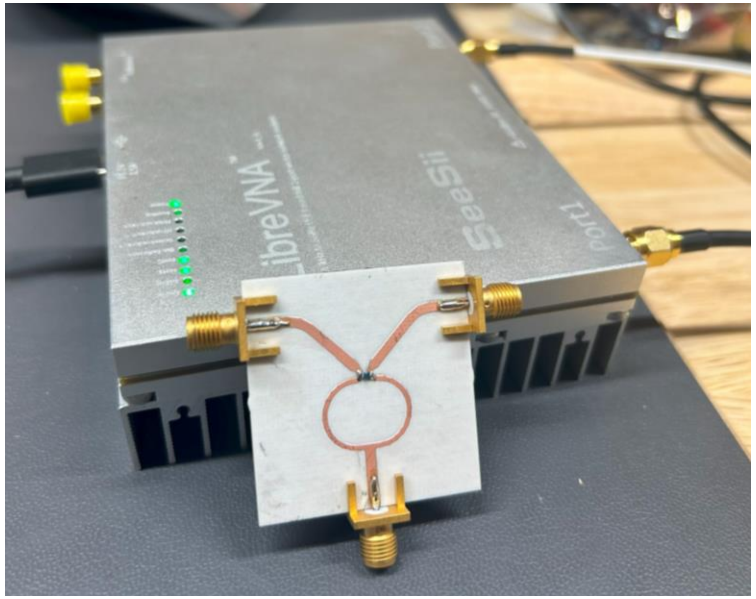



CONSTRUCTING WPD

- Peel excess conducting strip
- Solder 0603 resistor and SMA female launch end connector
- Collect VNA (LibreVNA), SMA Cables, and 50-ohm termination for measuring

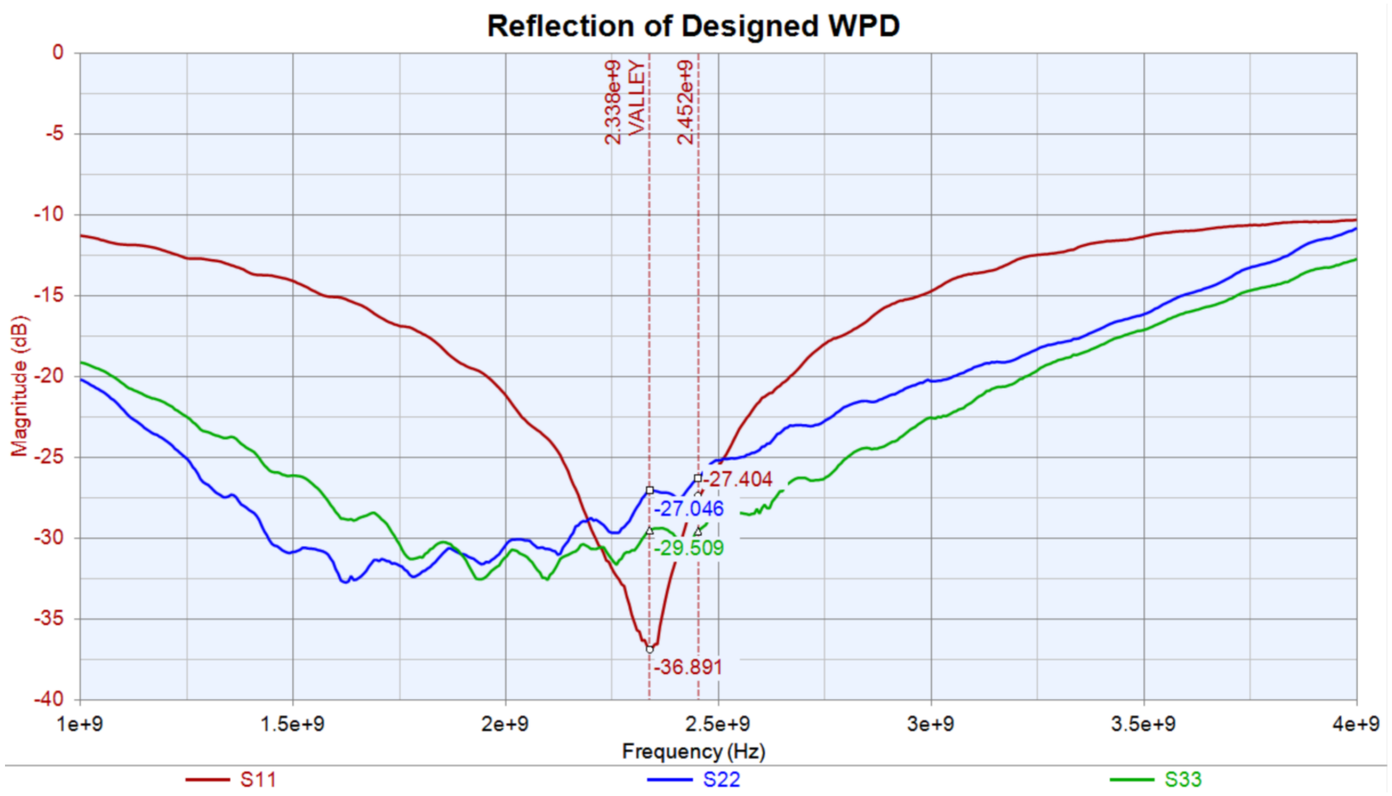






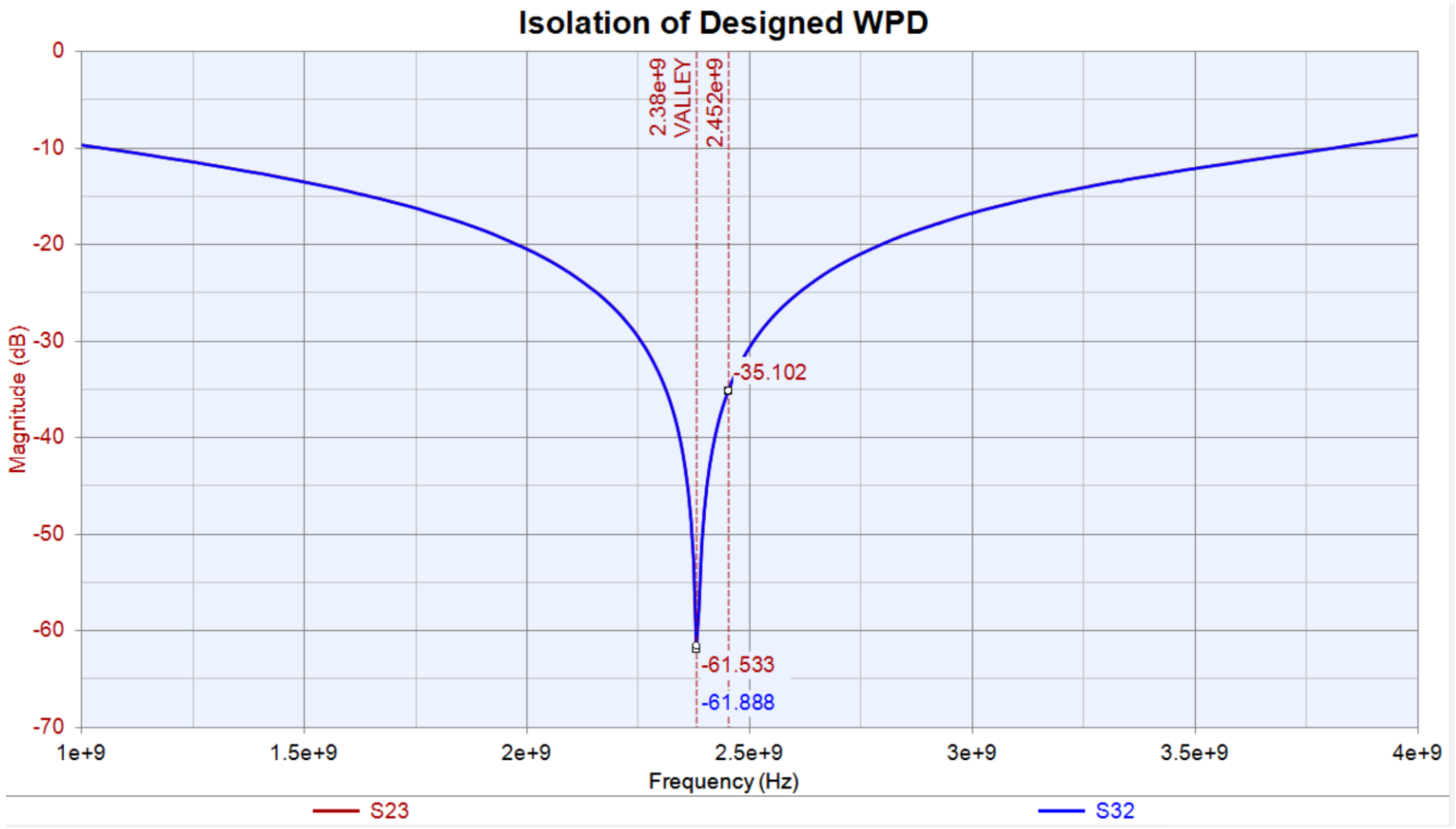
RESULT (REFLECTION)

- S11 resonance roughly at 2.338 GHz but -27.4 dB at 2.45 GHz



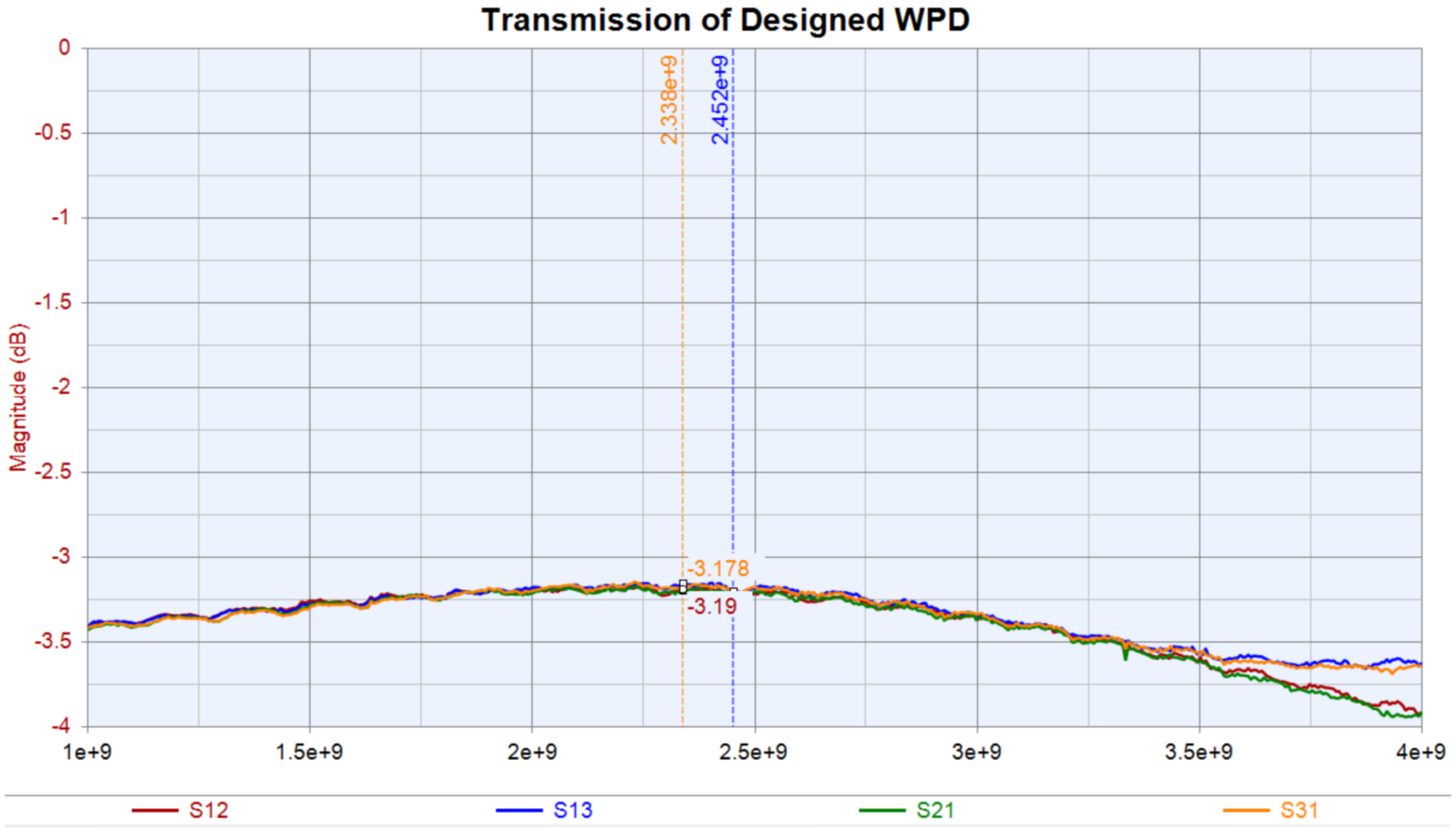
RESULT (ISOLATION)

- S23 and S32 roughly at 2.338 GHz resonance and -35.1 dB at 2.45 GHz

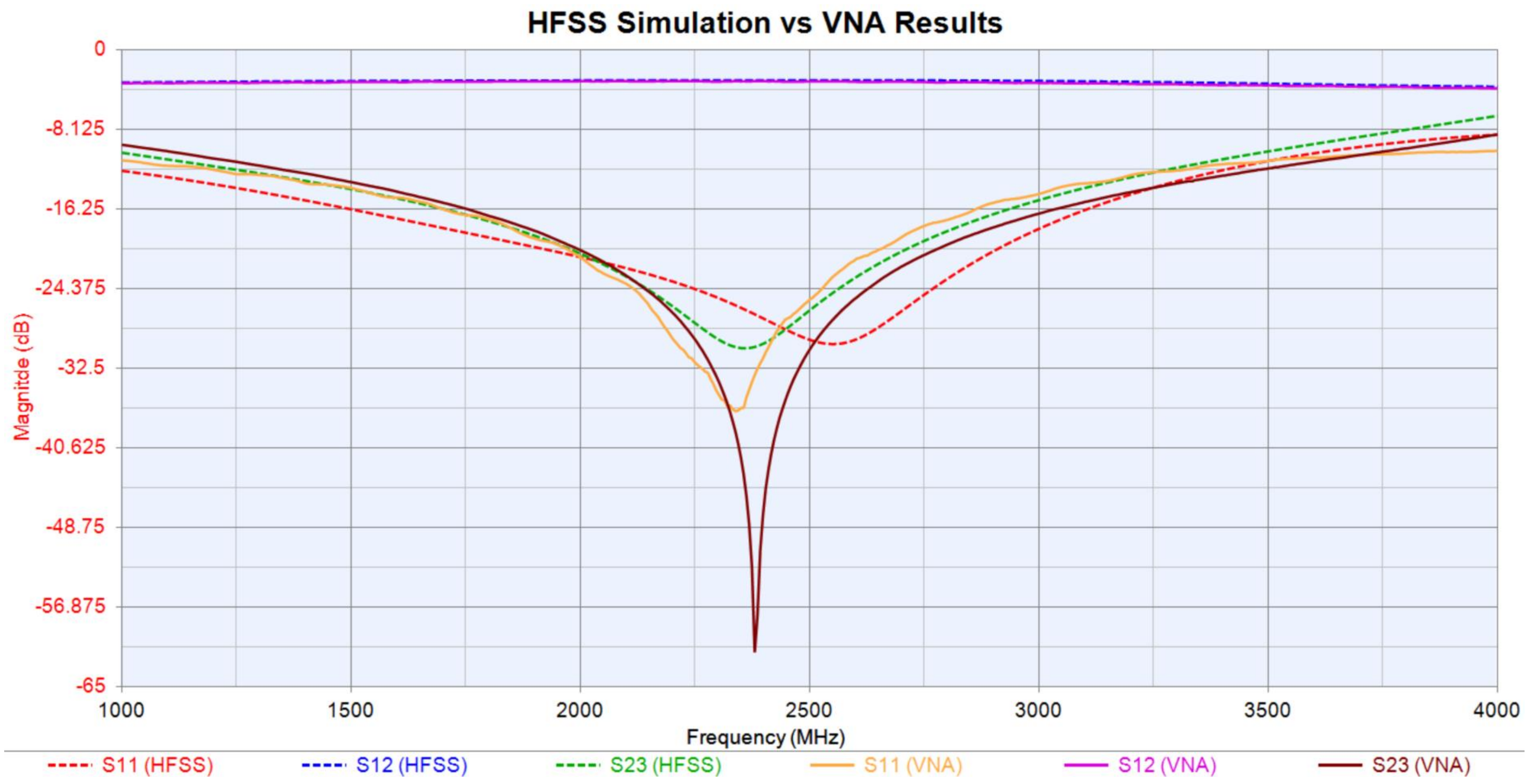


RESULT (TRANSMISSION)

- Roughly half power (i.e. -3dB)



HFSS VS VNA RESULT



POSSIBLE IMPROVEMENTS

- Coupling issues from taper in design
- Drum off quarter wavelength to match 2.45 more closely

FURTHER DEVELOPMENTS

- Power Capabilities
  - *N-Way Power Divider/Combiner Suitable for High-Power Applications*, U.H. Gysel '75
- Increased Bandwidth
  - *Design of an Ultra-wideband Wilkinson Power Divider*, B.Mishra '07
- High Frequency Applications
  - *Modified Wilkinson Power Dividers for Millimeter Wave Integrated Circuits*, S. Horst…

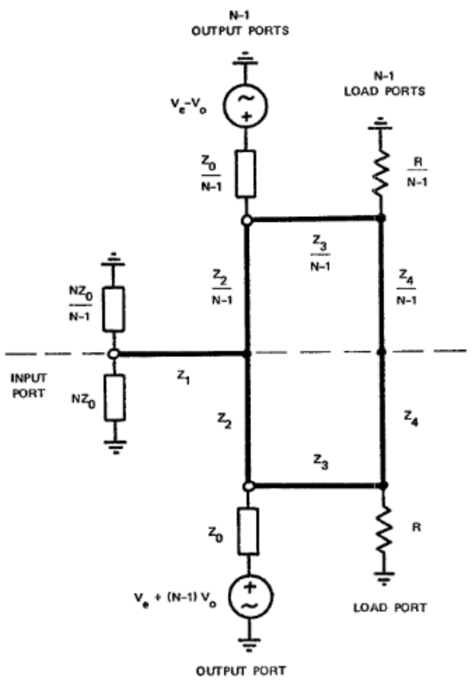
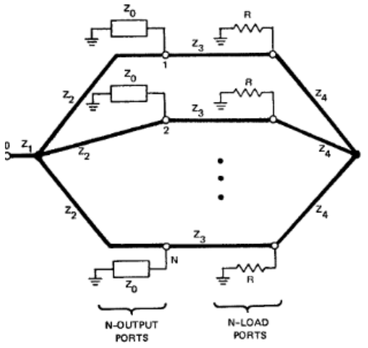


FIGURE 2 EQUIVALENT FOUR-PORT FOR THE N-WAY COMBINER



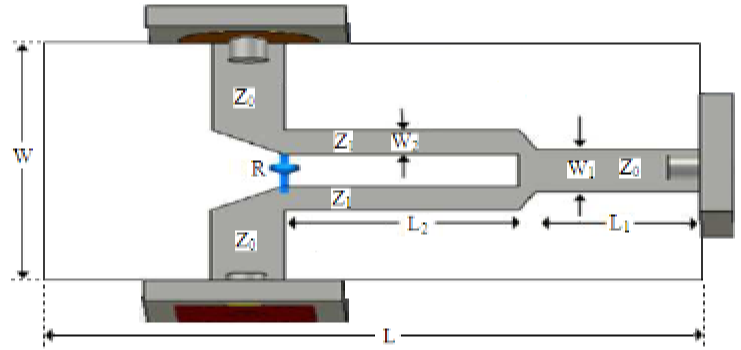
1 HIGH-POWER N-WAY DIVIDER/COMBINER (all transmission lines are a quarter-wavelength long at midband)

INCREASED POWER

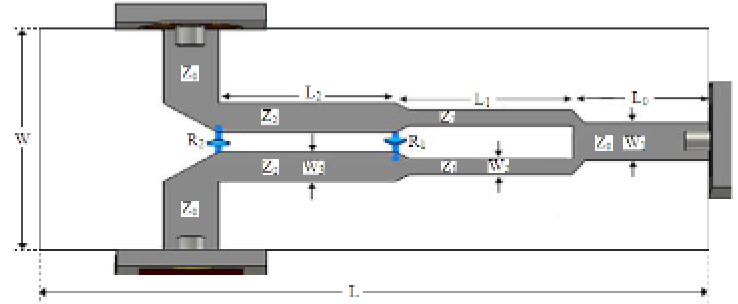
- Wilkinsons Design:
  - Low insertion loss, high isolation, matched conditions
  - Power handling limited by internal loads
- Shunt connected loads
  - Loads are external, can use high-power elements
- Power-handling limited by:
  - Breakdown voltage of TL
  - Heat-dissipation capacity
- Realizable in miscrostrip

INCREASED BANDWIDTH

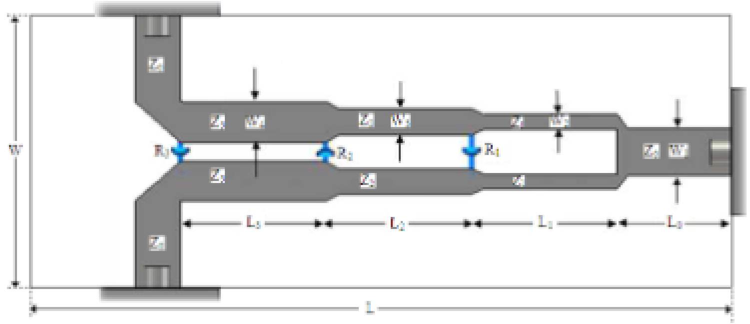
- Wilkinson's Design:
  - 20 percent band
- Binomial multi-section matching transformer
- Ultra-wideband
  - 3.1 - 10.6 GHz
- Isolation between outputs greatly improved vs. WPD
- Generally, the number of sections is given by:
  - ratio of low end of frequency range to center



(a) W_1 = 2.204 mm, W_2 = 1.254 mm, L_1 = 5 mm, L_2 = 7. 0675 mm, W = 13 mm, L = 20 mm, R= 100 Ω



(b) W_1 = 2.204 mm, W_2 = 0.9 mm, W_3 = 1.682 mm, L_0 = 5 mm, L_1 = L_2 = 7. 0675 mm, W = 13 mm, L = 24 mm, R_1= 100 Ω, R_2= 184 Ω



(c) W_1 = 2.204 mm, W_2 = 0.75 mm, W_3 = 1.254 mm, W_4 = 1.932 mm, L_0 = 5 mm, L_1 = L_2= L_3=7. 0675 mm, W = 13 mm, L = 32 mm, R_1 = 100 Ω, R_2 = 184 Ω, R_3 = 145 Ω

Fig. 3 Geometry of the microstrip WPD using (a) single (b) two and (c) three sections

INCREASED CENTER FREQUENCY

- Wilkinsons Design:
  - Low insertion loss, high isolation, matched conditions
  - Center frequency ~500 MHz
- Originally designed for shielded coax systems
  - Parasitic effects of geometric inconsistencies negligible
- RF and mmWave designs require precision layouts
- Additional TL elements Increases spacing reduce coupling
- Standard Wilkinson divider good below 10 GHz
- Underdetermined system of equations gives range of solutions

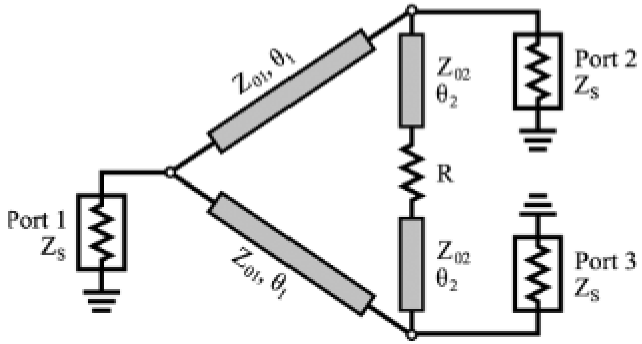


Fig. 2. Proposed modification of the Wilkinson design.

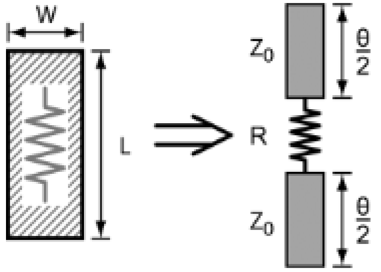


Fig. 5. Equivalent high-frequency model of an integrated resistor used in the proposed design.

$$z_{01} = z_{02}$$

$$r = z_{02}^2$$

$$\theta_2 = \tan^{-1}\left(\sqrt{1 - \frac{r}{2}}\right)$$

$$\theta_1 = \frac{\pi}{2} + \theta_2.$$

RESOURCES

- [1] D. M. Pozar, *Microwave engineering*. Hoboken, Nj: Wiley, 2012.
- [2] E. J. Wilkinson, "An N-Way Hybrid Power Divider," in IRE Transactions on Microwave Theory and Techniques, vol. 8, no. 1, pp. 116-118, January 1960, doi: 10.1109/TMTT.1960.1124668.
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- [7] S. Horst, R. Bairavasubramanian, M. M. Tentzeris and J. Papapolymerou, "Modified Wilkinson Power Dividers for Millimeter-Wave Integrated Circuits," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 55, no. 11, pp. 2439-2446, Nov. 2007