



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

Rogers Corporation, MWI-2019

Program Design Type Information

All material names are licensed, registered trademarks of Rogers Corporation

Material Name	Bulk Dk	Df	TC Dk	Therm Con
RO3003G2	3	0.0011	-35	0.43
RO3006	6.4	0.002	-160	0.72
RO3010	11.2	0.0023	-280	0.95
RO3035	3.6	0.0018	-34	0.5
RO3203	3.02	0.0016	13	0.5
RO3206	6.5	0.0027	-212	0.63
RO3210	10.8	0.0027	-459	0.81
RO4003C	3.55	0.0027	40	0.64
RO4003C LoPro	3.5	0.0027	40	0.64
RO4350B	3.66	0.0037	50	0.62
RO4350B LoPro	3.55	0.0037	50	0.62

ROGERS CORPORATION
www.rogerscorp.com
English Metric

Circuit Parameters

Conductor Width (W) 1.78709 mm

Space (S) 0.2260 mm Length 25.39 mm

Material Properties

Material: RO4003C Thickness (H) 0.812 mm

Dk 3.55 Df 0.0027 Thermal Cond. 0.64 W/K*m

Conductor Parameters

Thickness (T) 33.02 microns Surface Area Index 3.9

1oz ED Conductivity 5.813 X 10⁷ S/m Average Nodule radius (microns) 0.28

Surface Roughness (RMS) 3.4 microns

Dielectric Loss is = 0.89156 dB/m
Conductor loss is = 1.09893 dB/m
Total loss is = 1.99049 dB/m

Dielectric Q Factor is 416.3
Conductor Q Factor is 453.2
Total Q Factor for transmission line is 217.0

Wavelength on transmission line:
1 wavelength = 0.073 meters
1/2 wavelength = 0.036 meters
1/4 wavelength = 0.018 meters
1/8 wavelength = 0.009 meters

Transmission Line Information

Conductor width = 1.78709 mm

Impedance = 50.08 ohms
Effective dk = 2.7703

Impedance 70.7 Ohms Frequency 2.45 GHz

Calculate

Generate Tables and Files None

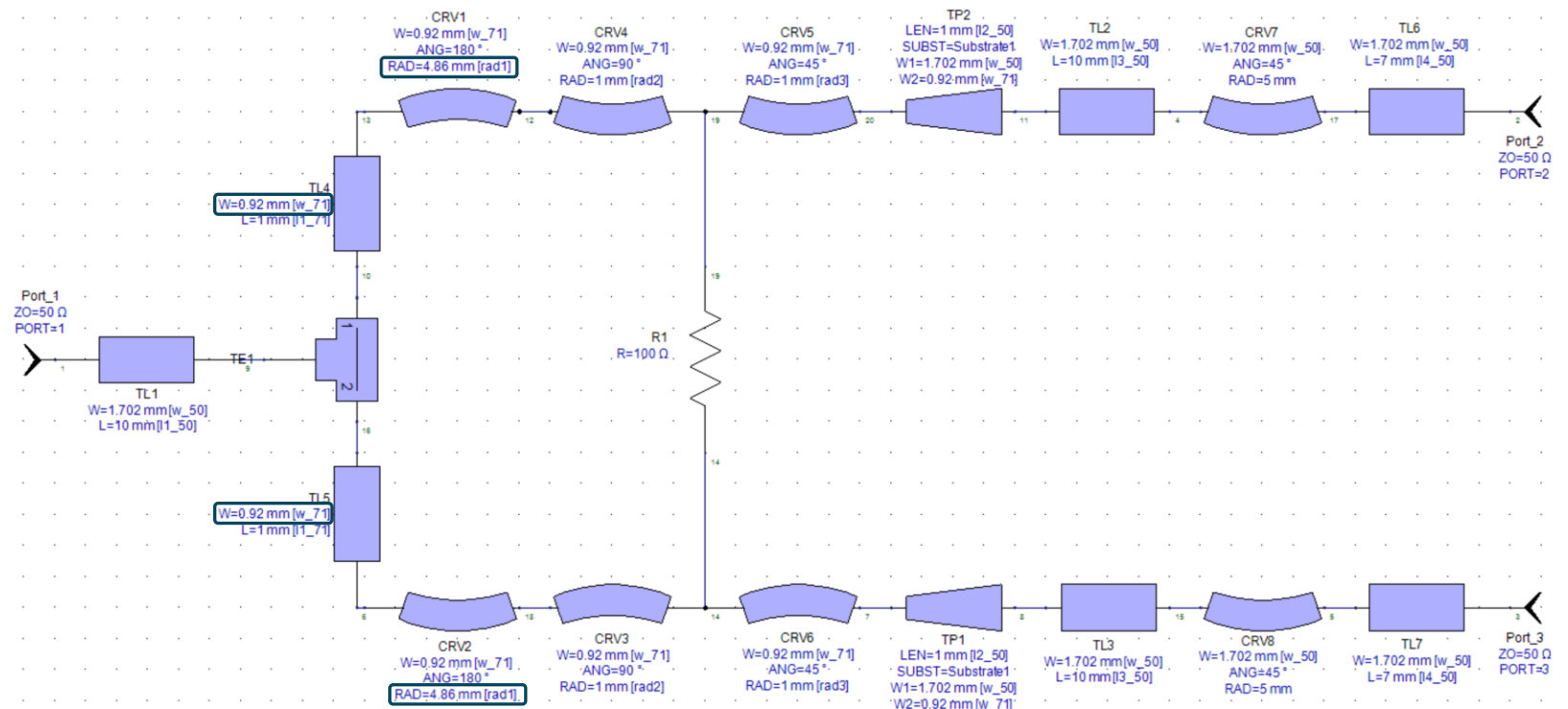
Freq. Range 1 to 30 GHz

Display results of only one calculation

CIRCUIT SCHEMATIC

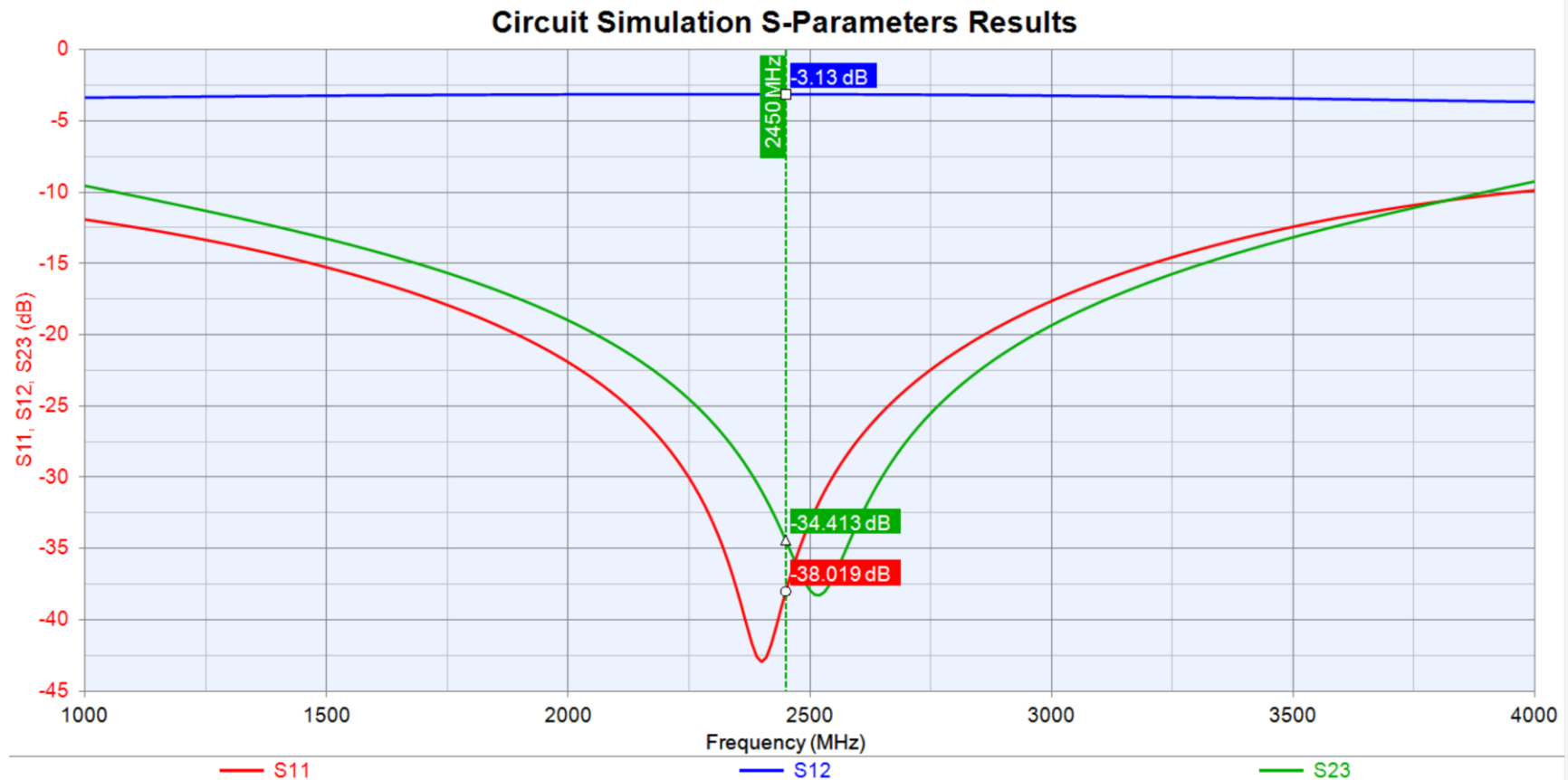
- Keysight Genesys 1:2 WPD circuit design

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

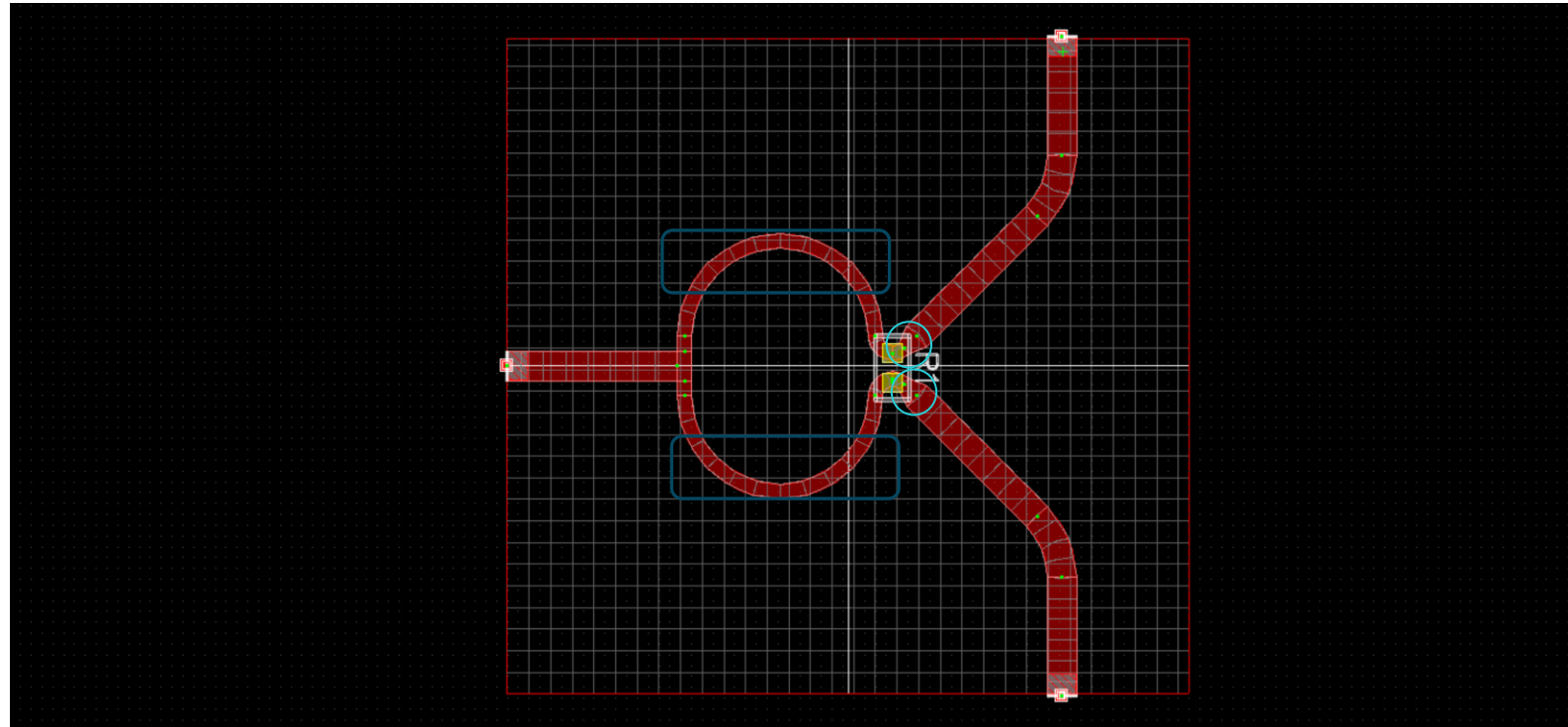


CIRCUIT LAYOUT

- Keysight Genesys 1:2 WPD layout design

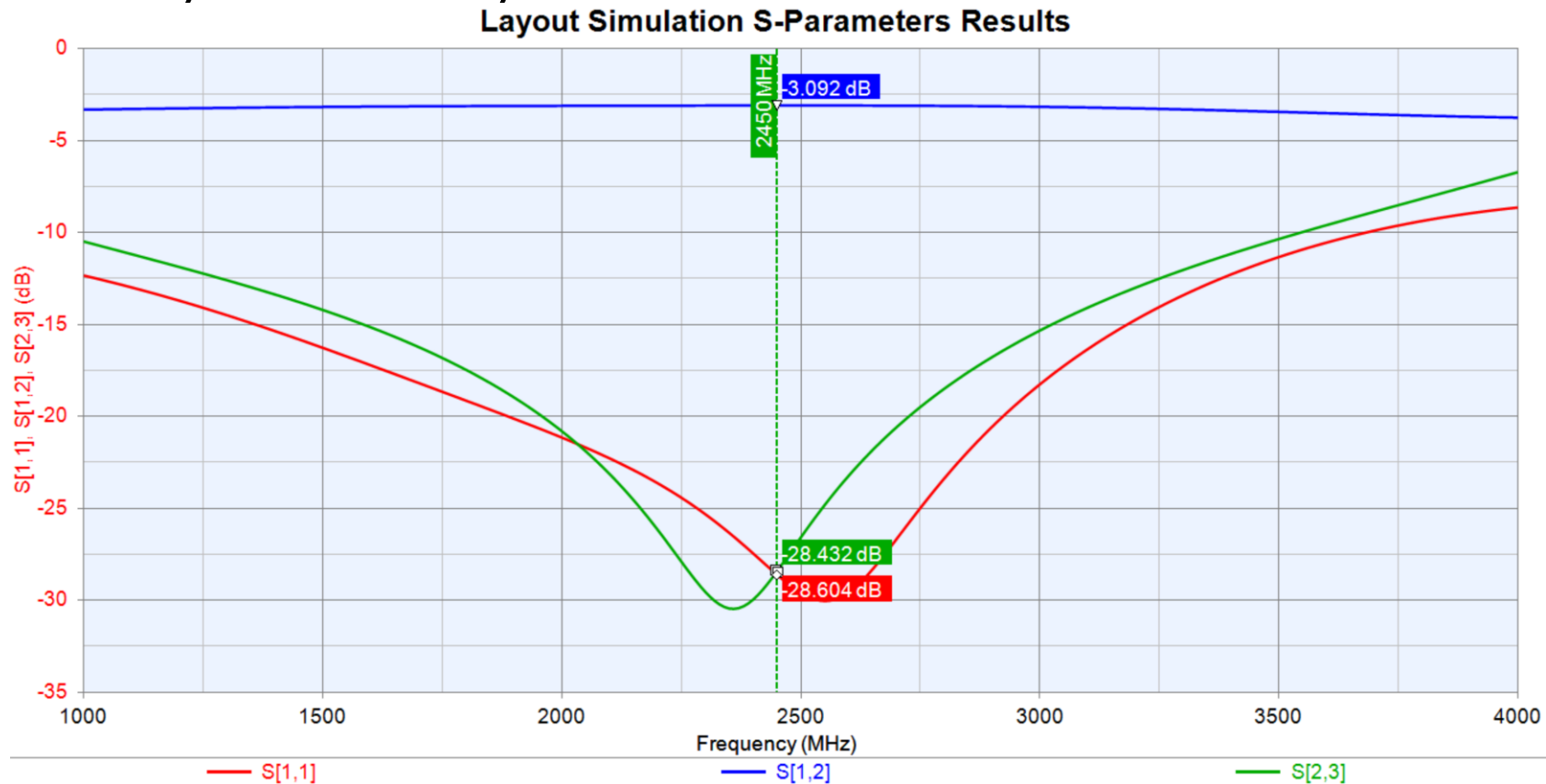
Tune Window

Variable	Value
Percentage	5%
Equation.I1_50	10
Equation.I1_71	0.9
Equation.I2_50	1
Equation.I2_71	0.9
Equation.I3_50	10
Equation.I4_50	7
Equation.rad1	5.6
Equation.rad2	1
Equation.rad3	1
Equation.w_50	1.702
Equation.w_71	0.85



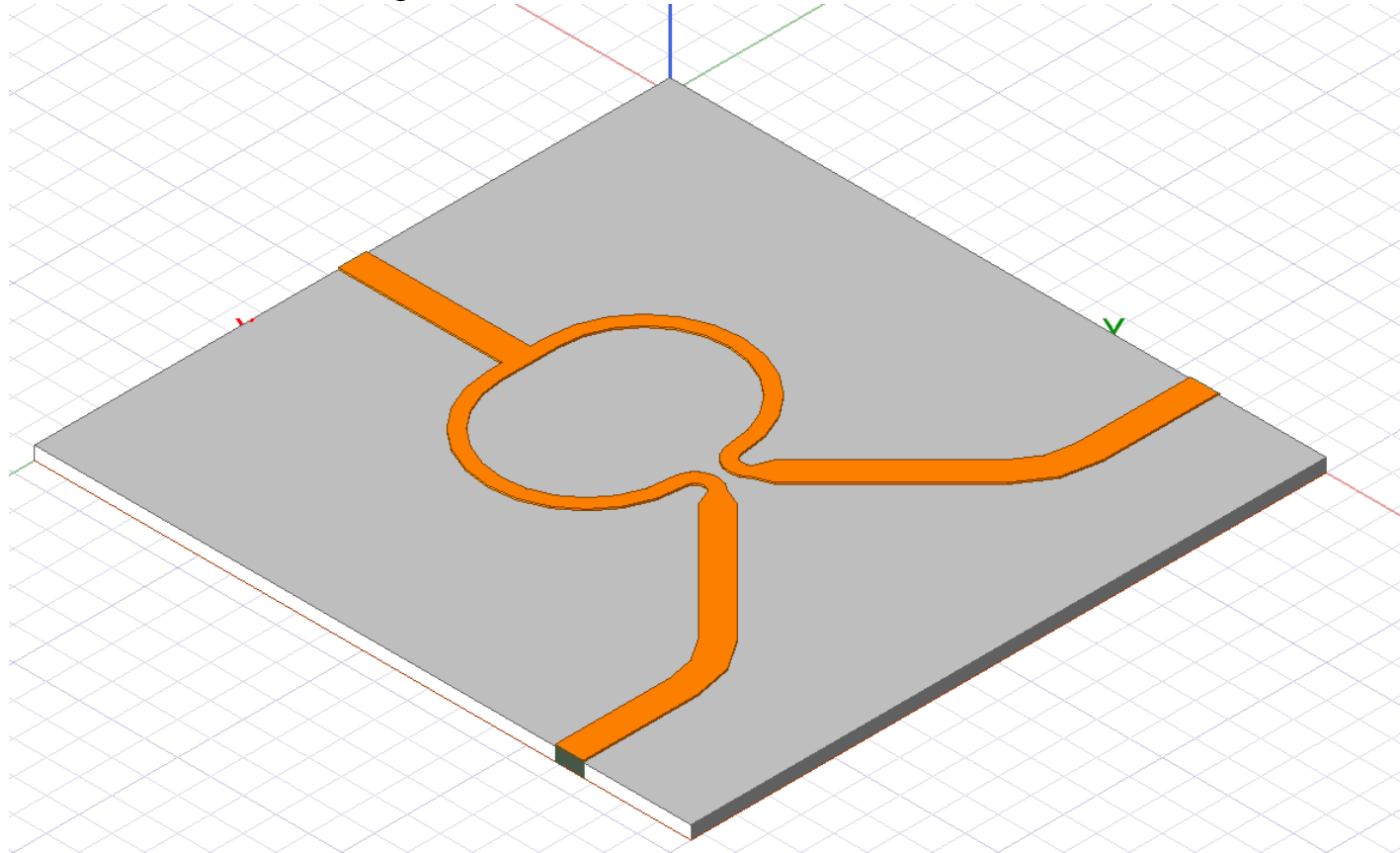
MOMENTUM GXF (METHOD OF MOMENTS)

- Keysight Genesys 1:2 WPD layout simulation results



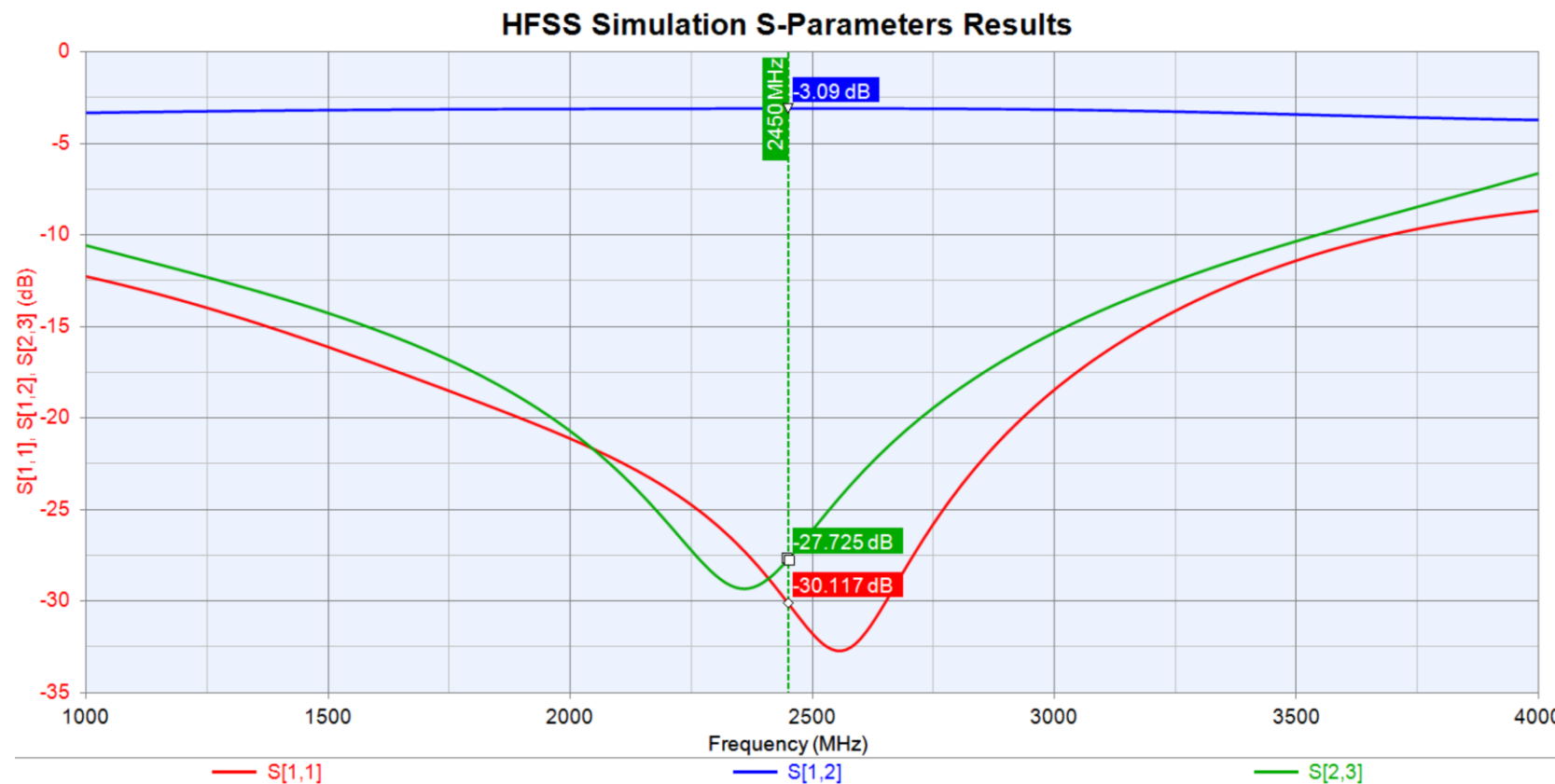
3D SIMULATION DESIGN OF LAYOUT

- Ansys HFSS 1:2 WPD 3D design



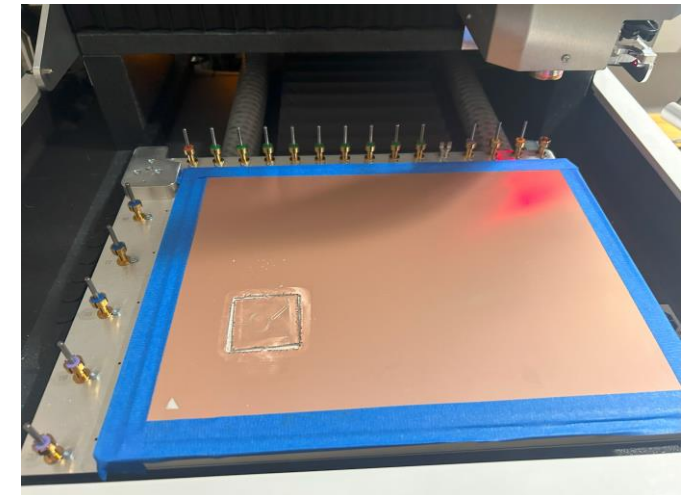
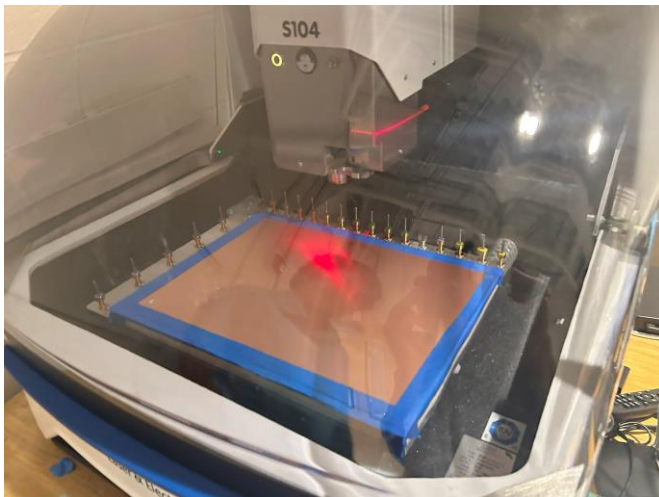
ANSYS HIGH FREQUENCY SIMULATION SOFTWARE

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



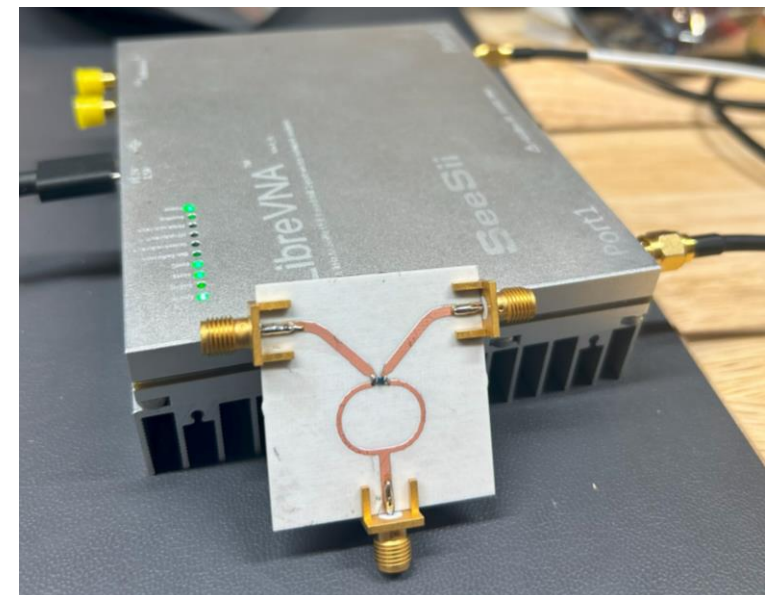
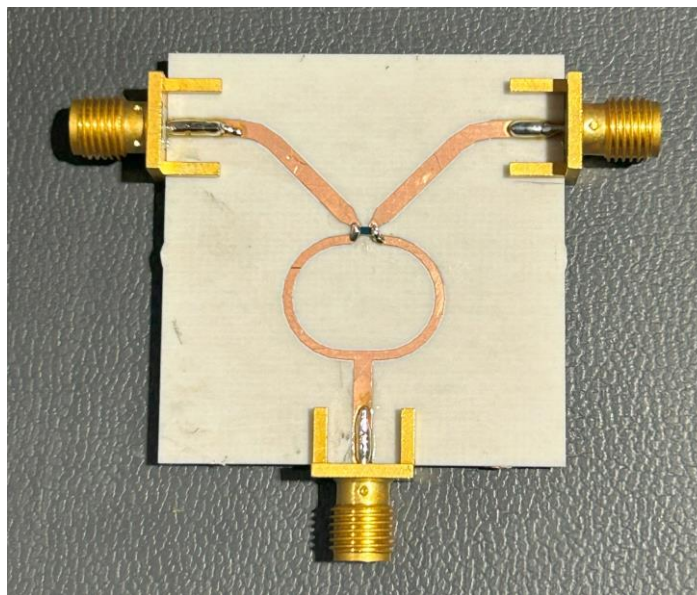
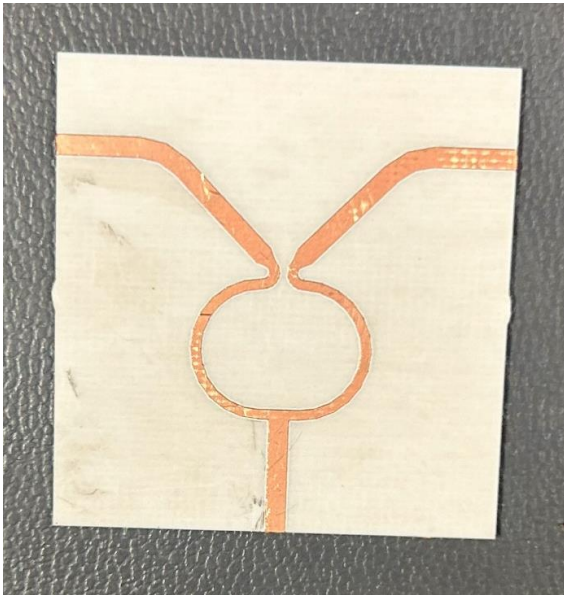
MILLING PROCESS WITH LPKF

- 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



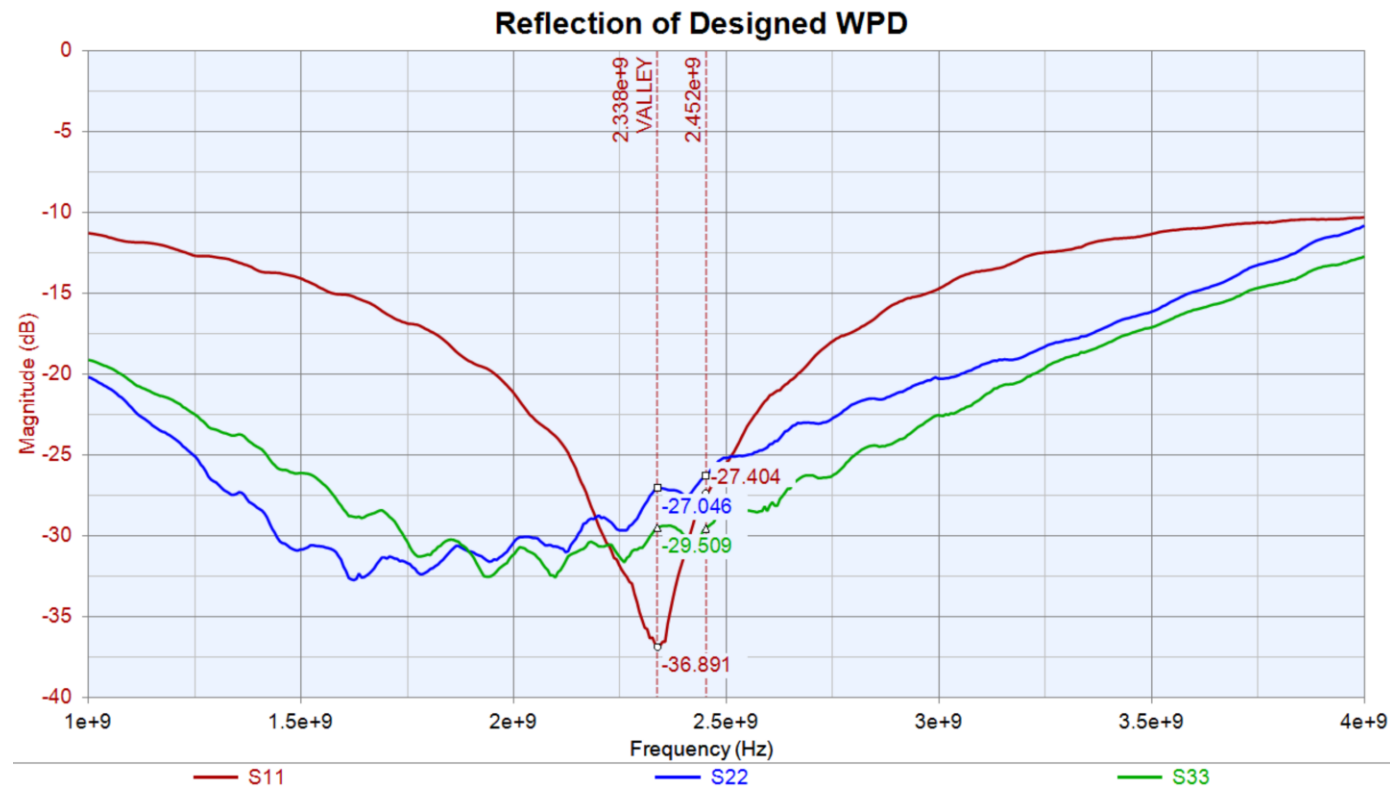
CONSTRUCTING WPD

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



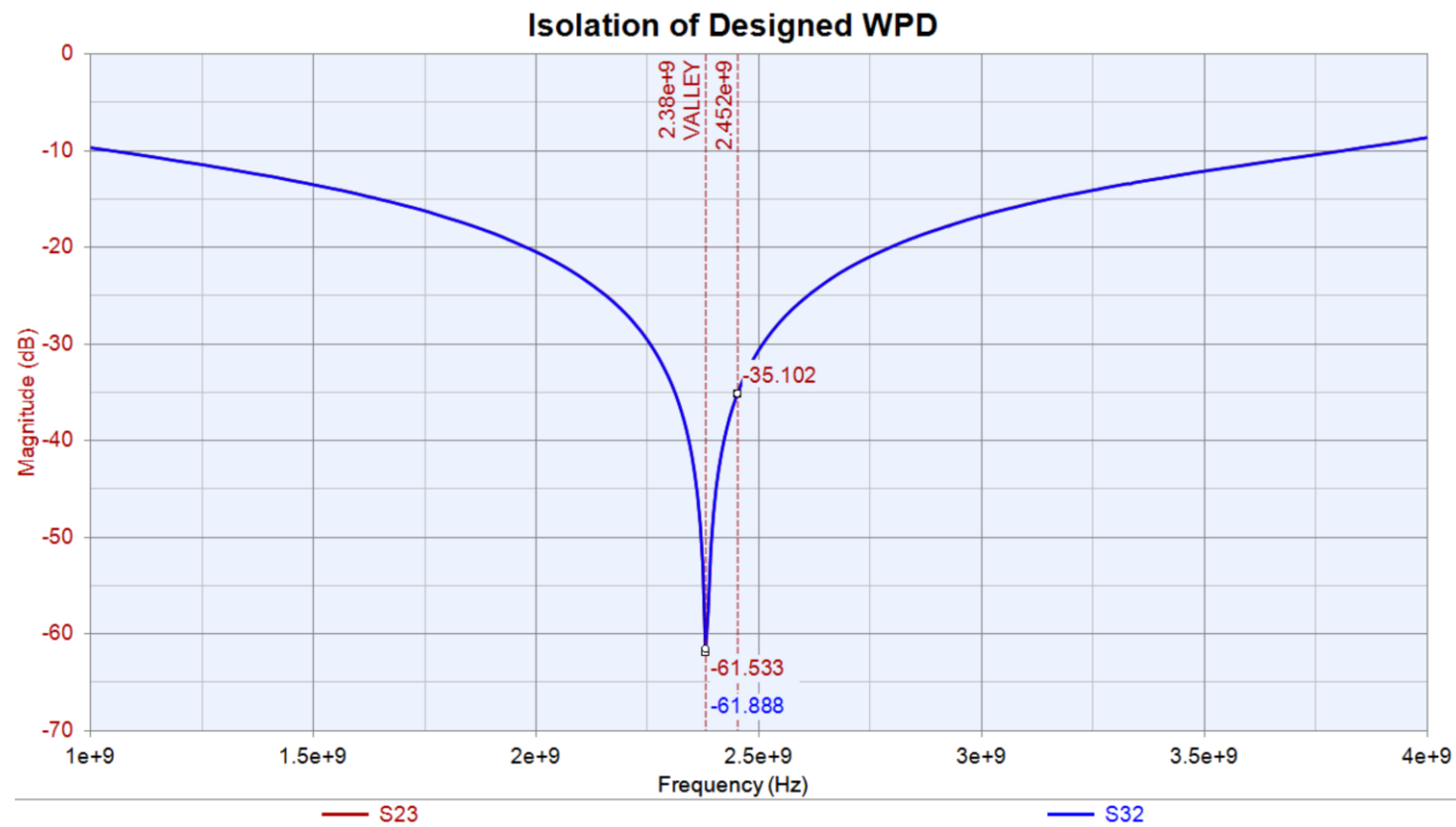
RESULT (REFLECTION)

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



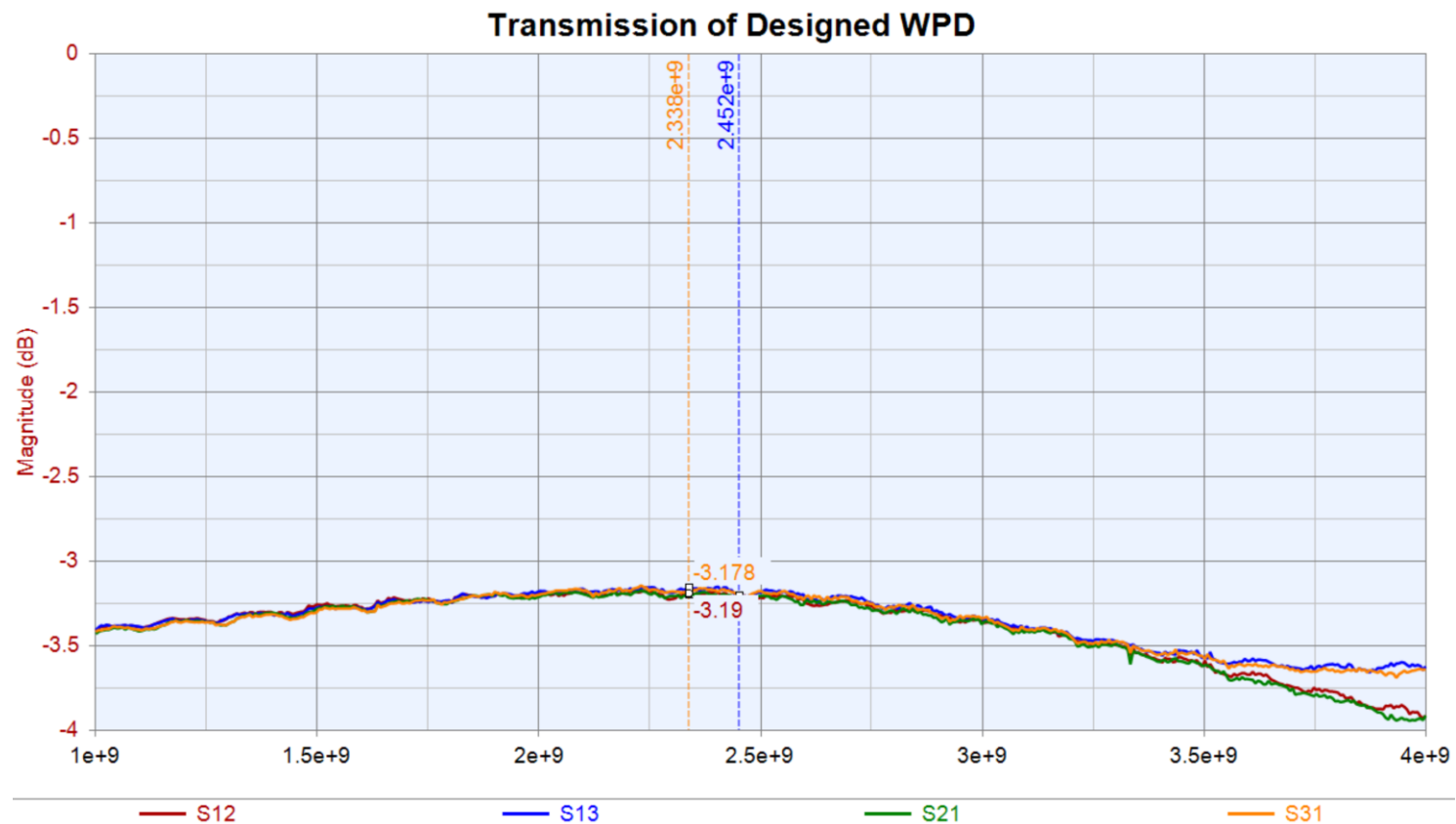
RESULT (ISOLATION)

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

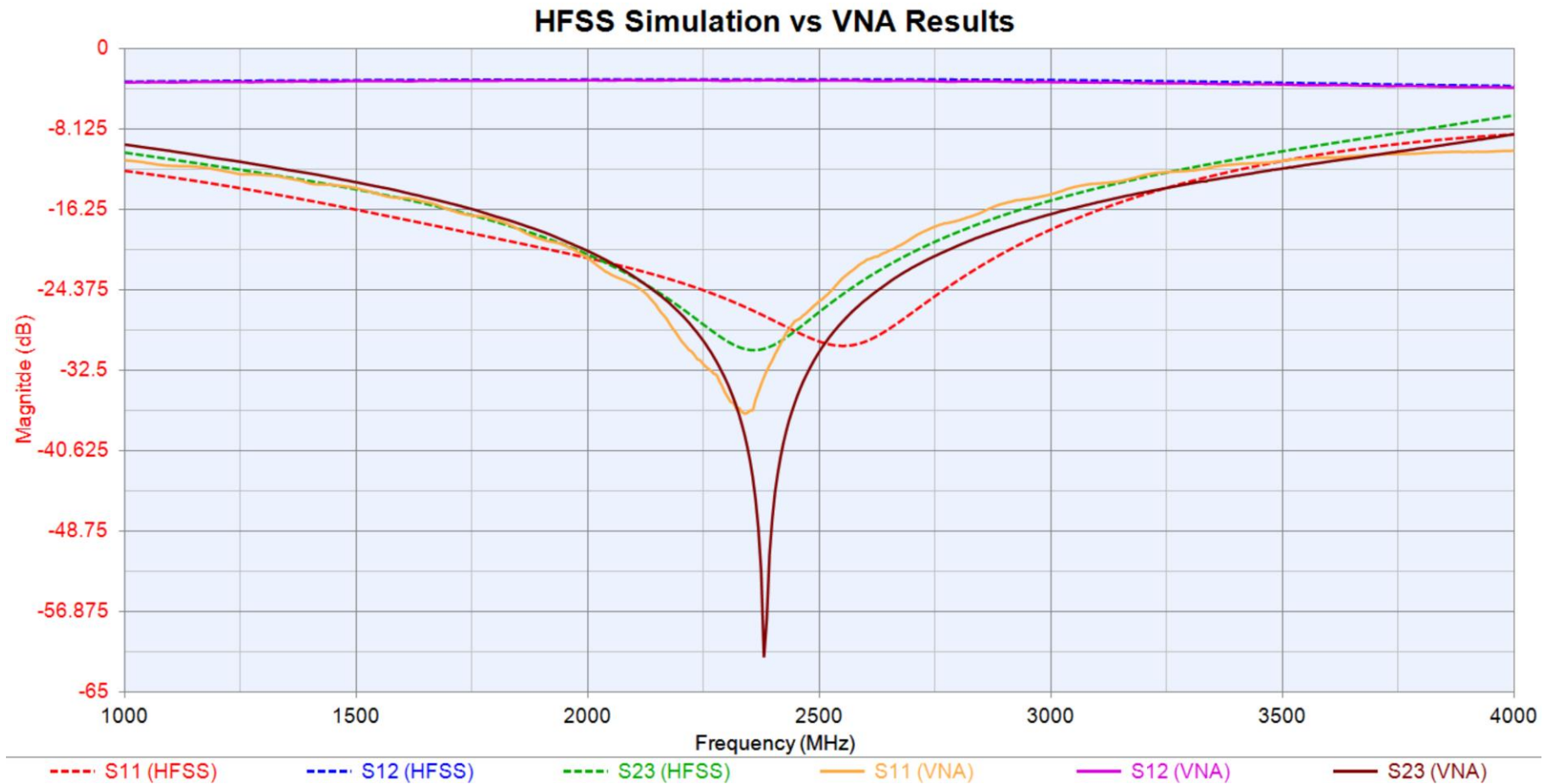


RESULT (TRANSMISSION)

- 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...

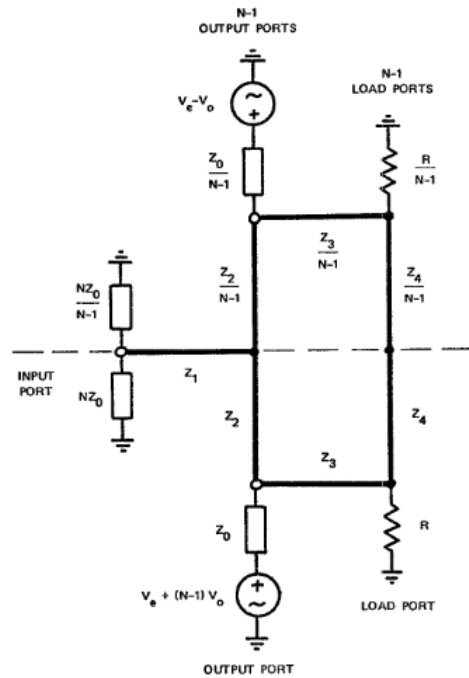


FIGURE 2 EQUIVALENT FOUR-PORT FOR THE N-WAY COMBINER

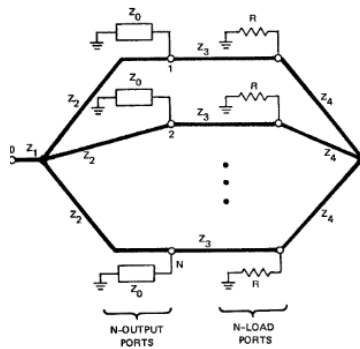


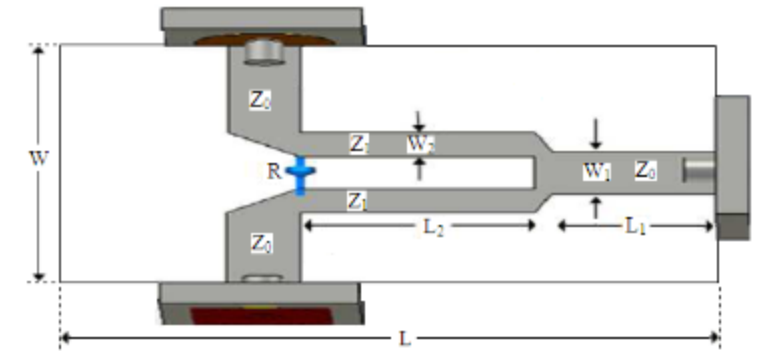
FIGURE 3 HIGH-POWER N-WAY DIVIDER/COMBINER
(all transmission lines are a quarter-wavelength long at midband)

INCREASED POWER

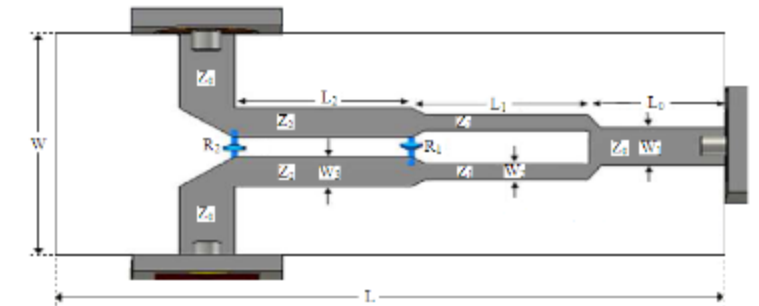
- Wilkinsons Design:
 - Low insertion loss, high isolation, matched conditions
 - Power handling limited by internal loads
- Shunt connected loads
 - Loads are external, can use high-power elements
- Power-handling limited by:
 - Breakdown voltage of TL
 - Heat-dissipation capacity
- Realizable in microstrip

INCREASED BANDWIDTH

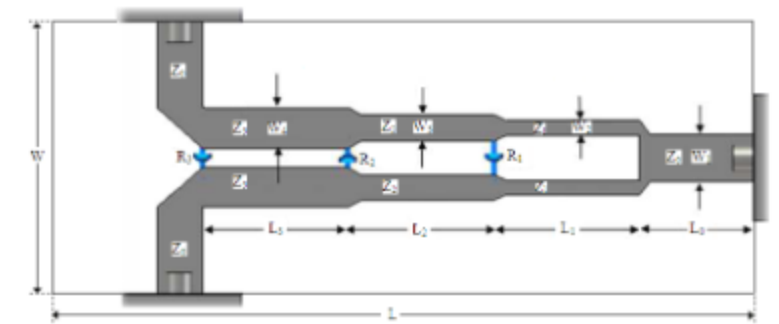
- Wilkinson's Design:
 - 20 percent band
- Binomial multi-section matching transformer
- Ultra-wideband
 - 3.1 - 10.6 GHz
- Isolation between outputs greatly improved vs. WPD
- Generally, the number of sections is given by:
 - ratio of low end of frequency range to center



(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, $R = 100 \Omega$



(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, $R_1 = 100 \Omega$, $R_2 = 184 \Omega$



(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, $R_1 = 100 \Omega$, $R_2 = 184 \Omega$, $R_3 = 145 \Omega$

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

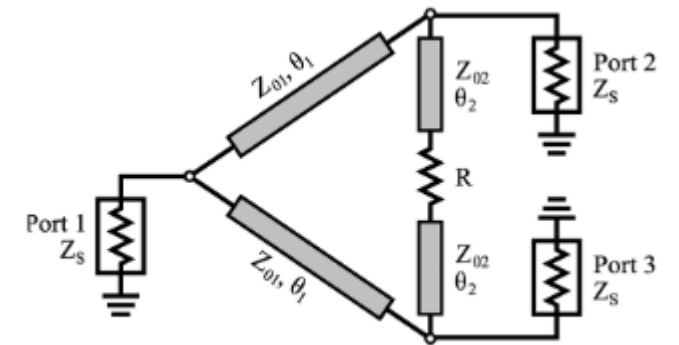


Fig. 2. Proposed modification of the Wilkinson design.

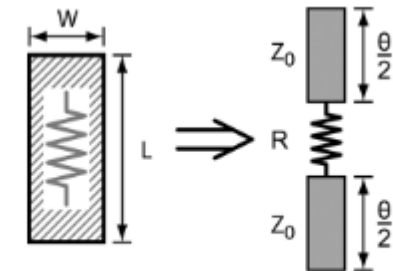


Fig. 5. Equivalent high-frequency model of an integrated resistor used in the proposed design.

$$\begin{aligned}
 z_{01} &= z_{02} \\
 r &= z_{02}^2 \\
 \theta_2 &= \tan^{-1} \left(\sqrt{1 - \frac{r}{2}} \right) \\
 \theta_1 &= \frac{\pi}{2} + \theta_2.
 \end{aligned}$$

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.
- [3] "Microwaves101 | Circulators," *Microwaves101.com*, 2024.
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- [4] R. F. Harrington and IEEE Antennas And Propagation Society, *Field computation by moment methods*. Piscataway, Nj: IEEE Press, 1993.
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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