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Wideband Asymmetric Coupler with Optimally Positioned Capacitors for Improved Directivity

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Introduction

- Wideband Couplers have many practical applications at Microwave Frequencies
- These couplers, if realized in an inhomogeneous medium, e.g., using microstip, yield a poor directivity, which results in severe performance degradation.
- Poor directivity in inhomogeneous medium, is due to the mismatch in the odd and even mode phase velocities

Research Focus

- To Improve the Directivity of a Coupler
  - By the Implementation of Asymmetric Capacitive Compensation

- To create a coupler with the optimal Bandwidth-Directivity performance while Simultaneously maintain the Coupling and Insertion loss.

Design Criteria

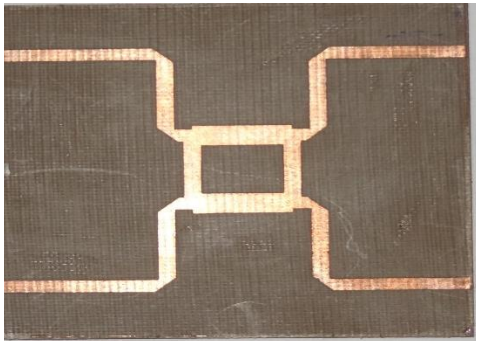
- Criteria 01: Weak Coupling (20 dB)
- Criteria 02: Wide Bandwidth (2.5 – 3.5 GHz)
- Criteria 03: High Directivity

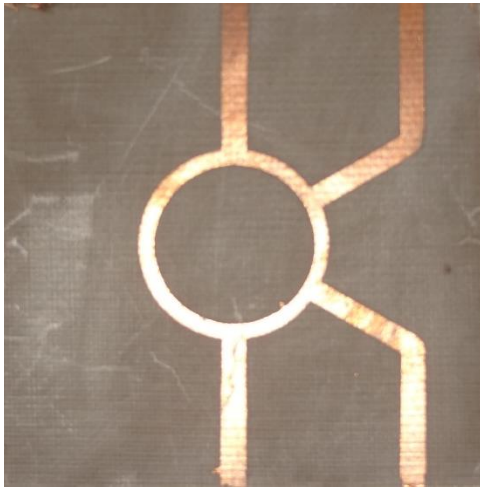
OUTLINE

- Criteria 01: The Coupled Line Coupler
- Criteria 02: The Multi-Stage Coupler
- Criteria 03: Directivity Improvements
- Fabrication & Analysis
- Design & Measurements
- Results
- Conclusion

Criteria 01: Weak Coupling

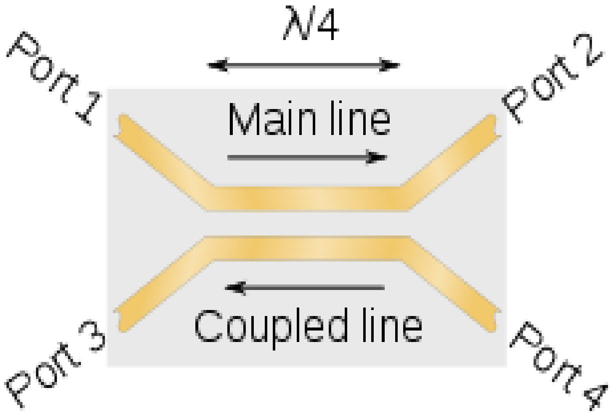
- Several types of Couplers are available:
  - Waveguide Couplers
  - Branch Line Couplers
  - Rat-Race Couplers
  - Coupled Line Couplers
  - Lange Couplers



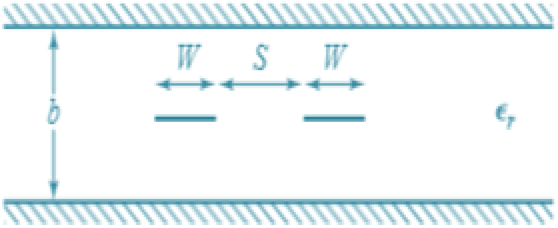


COUPLED LINE COUPLERS

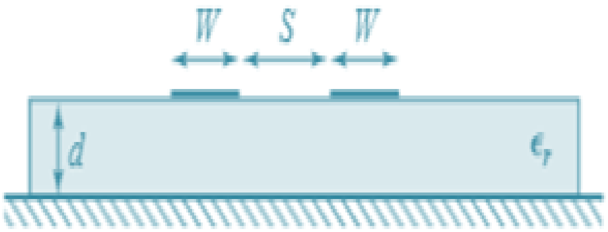
When two unshielded transmission lines are in close proximity, power can be coupled from one line to the other due to the interaction of the electromagnetic fields.



Coupled Stripline

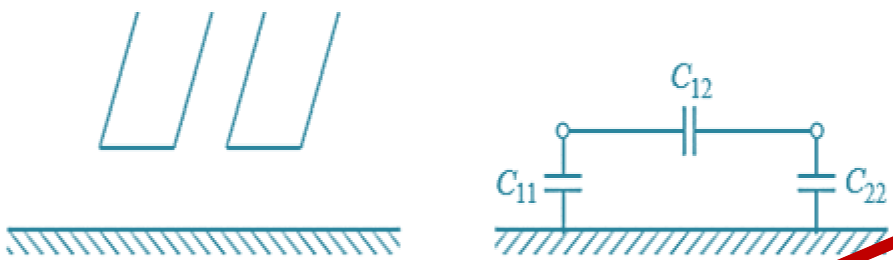


Coupled Microstrip

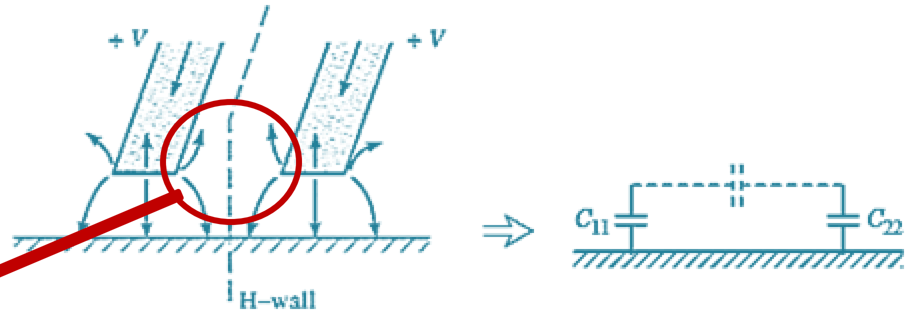


Coupled Line Theory

Equivalent Circuit of a Coupled Transmission Line



Even Mode



Fringing Fields

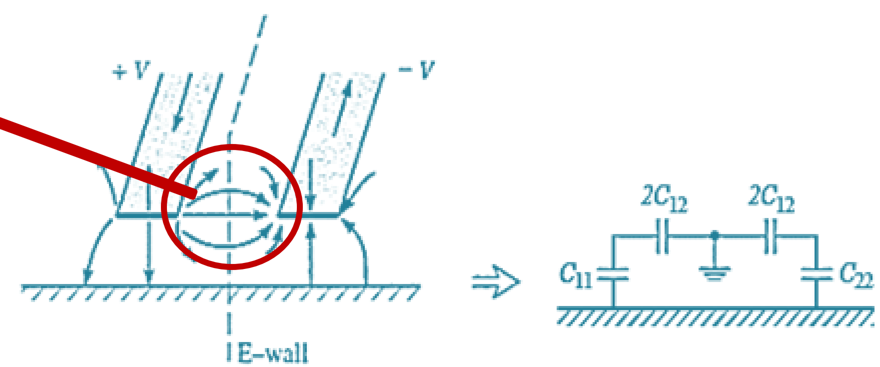
↓

Phase Velocity Mismatch

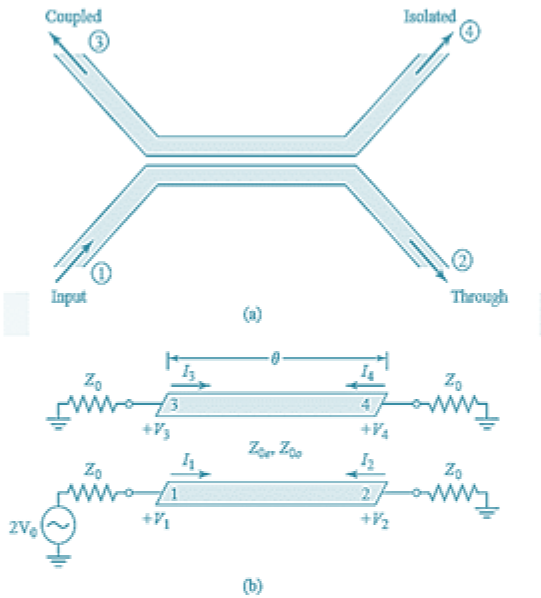
↓

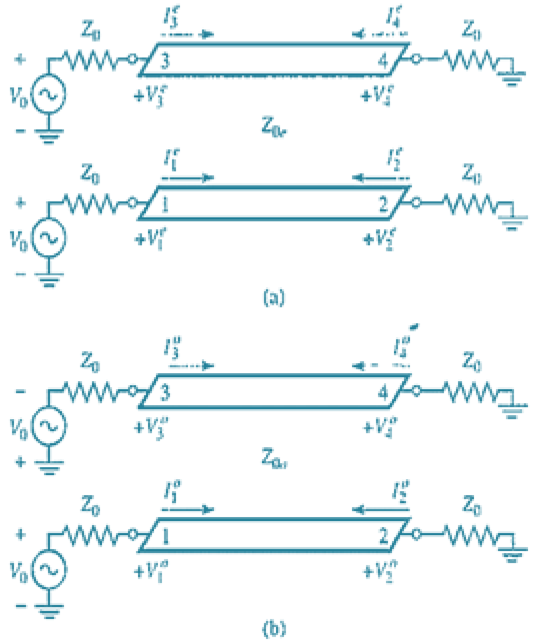
Poor Directivity

Odd Mode



Design of the Coupled Line Coupler





(a) Geometry and port designations.
(b) The schematic circuit.

(a) Even mode. (b) Odd mode.

Even Mode Impedance $Z_{0e} = Z_0\sqrt{\frac{1+C}{1-C}}$ ***Odd Mode Impedance*** $Z_{0o} = Z_0\sqrt{\frac{1-C}{1+C}}$

Performance of a Single Section Coupler

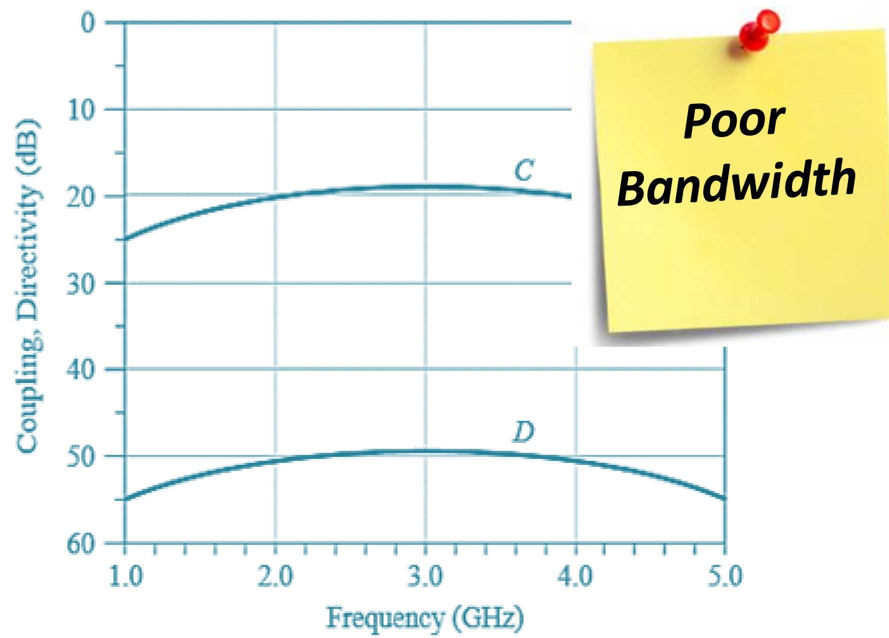
- Design:
  - 20 dB single section coupler
  - Centre Frequency: 3 GHz

$$Z_{0e} = Z_0\sqrt{\frac{1+C}{1-C}} = 55.28\ \Omega,$$

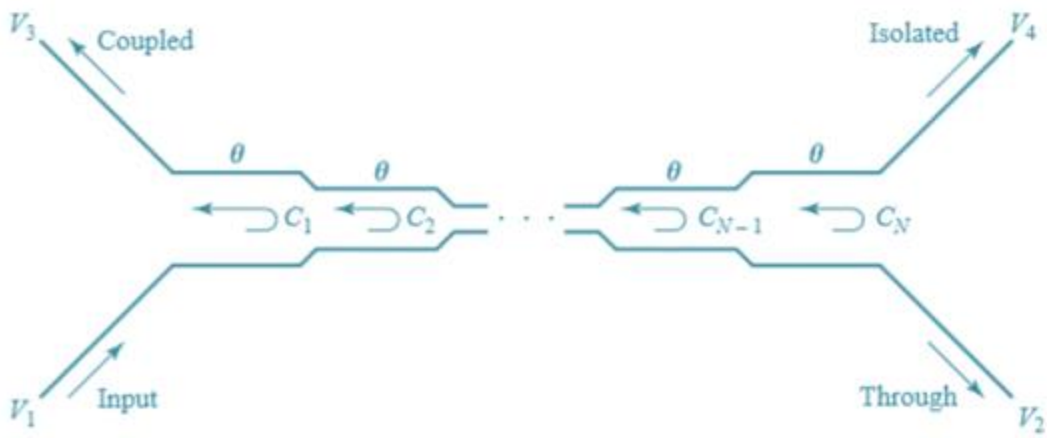
$$Z_{0o} = Z_0\sqrt{\frac{1-C}{1+C}} = 45.23\ \Omega.$$

- Synthesis
  - Width (W) = 0.259 cm
  - Spacing (S) = 0.098 cm

Coupling vs Frequency



Criteria 02: Wide Bandwidth
The Multi-Section Coupled Line Coupler



An N-section coupled line coupler

Coupled Voltage $V_3 = jV_1 sin\theta e^{-j\theta}\left[C_1\left(1 + e^{-2j(N-1)\theta}\right) + C_2\left(e^{-2j\theta} + e^{-2j(N-2)\theta}\right) + \cdots + C_M\left(e^{-j(N-1)\theta}\right)\right]$

$$= 2jV_1 sin\theta e^{-jN\theta}\left[C_1 \, cos(N-1)\,\theta + C_2 \, cos(N-3)\,\theta + \cdots + \frac{1}{2} C_M\right]$$

$$Z_{0e} = Z_0\sqrt{\frac{1+C}{1-C}} \qquad Z_{0o} = Z_0\sqrt{\frac{1-C}{1+C}} \qquad C_0 = \left|\frac{V_3}{V_1}\right|_{\theta=\pi/2}$$

Performance of a Three Stage Coupler

Coupling Coefficients

$$C_1 = C_3 = 0.0125,$$

$$C_2 = 0.125$$

Impedances

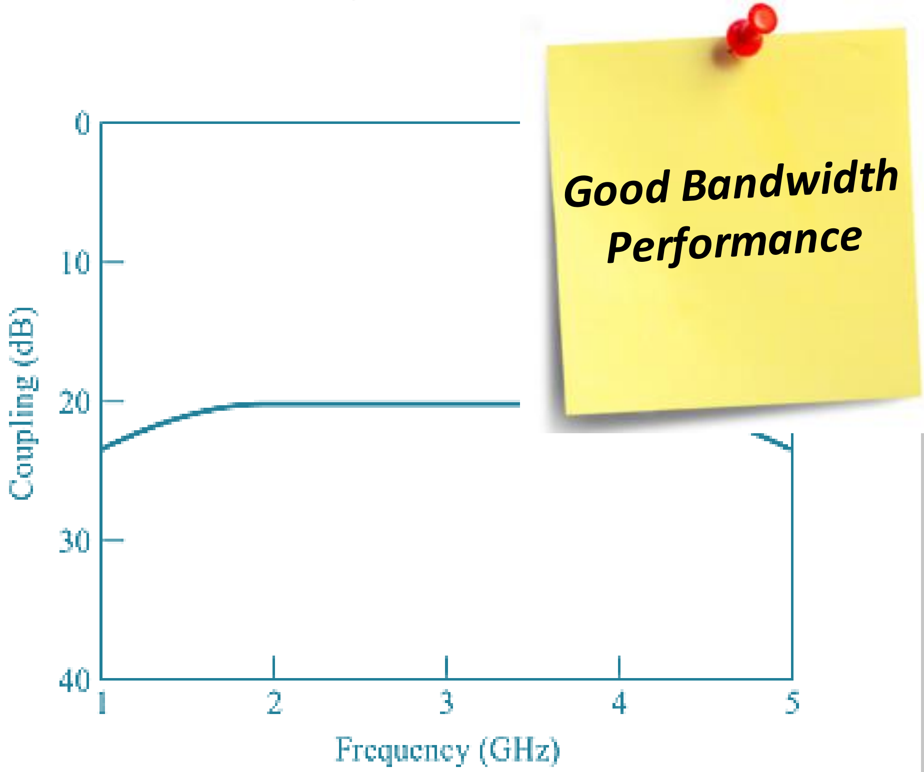
$$Z^1{}_{0e} = Z^3{}_{0e} = 50\sqrt{\frac{1.0125}{0.9875}} = 50.63\ \Omega$$

$$Z^1{}_{0o} = Z^3{}_{0o} = 50\sqrt{\frac{0.9875}{1.0125}} = 49.38\ \Omega$$

$$Z^2{}_{0e} = 50\sqrt{\frac{1.125}{0.875}} = 56.69\ \Omega$$

$$Z^2{}_{0o} = 50\sqrt{\frac{0.875}{1.125}} = 44.10\ \Omega$$

Coupling vs Frequency



Criteria 03: Improvement of Directivity

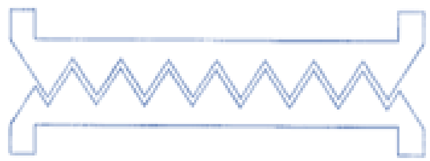
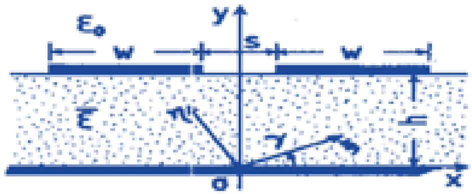
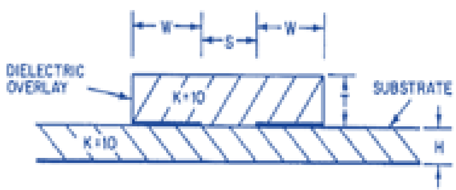
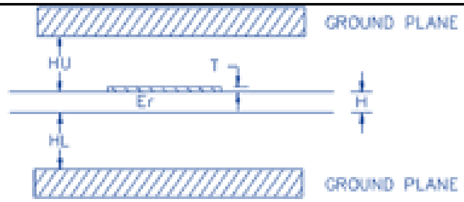
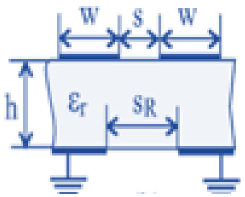
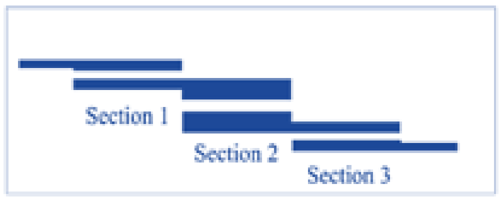
- Directivity can be improved by Compensating for the Phase Velocity Mismatch

- Two Methods;

  1. Directly equalizing the different phase velocities along the coupled lines

  2. Connection of reactive elements along the coupled lines

1. Direct equalization of phase velocities

Wiggly Line Coupler [1]	Anisotropic Substrate [5]
	
Dielectric Overlay [3]	**Suspended Substrate [6]**
	
Apertures in the Ground Plane [7]	**Stepped Impedance Method [8]**
	

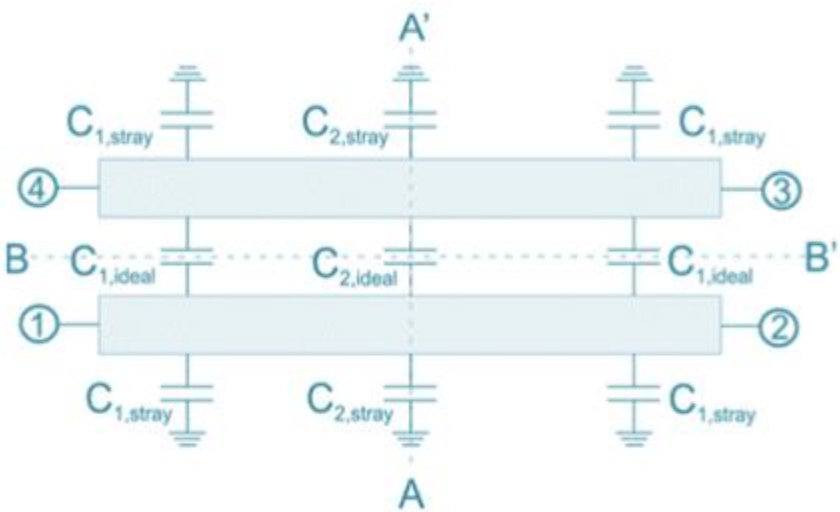
2. Connection of Reactive Components

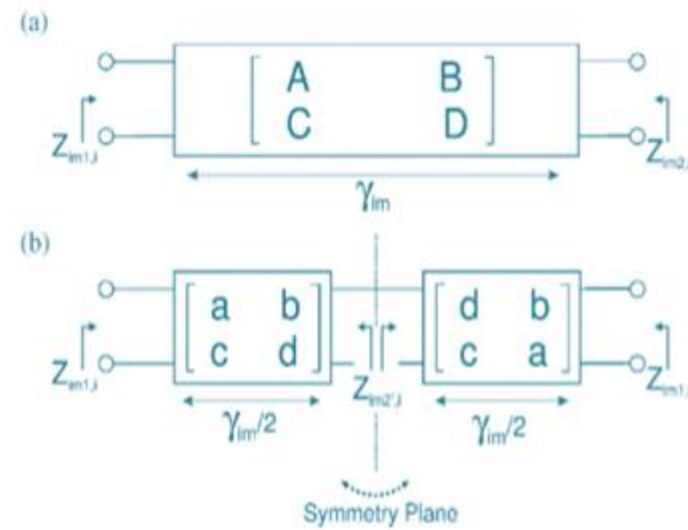
A. Inductive Compensation
   - Series
   - Shunt

B. Capacitive Compensation
   - End Capacitors
   - Centre Capacitors
   - Optimally Positioned Capacitors

Mechanism of Compensation

Image Parameter Approach





The even/odd mode inhomogeneity is characterized through $\rho = \sqrt{\frac{\varepsilon_e}{\varepsilon_o}}$ $\theta_e = \rho \cdot \theta_o.$

The Pointer – Robust Optimization

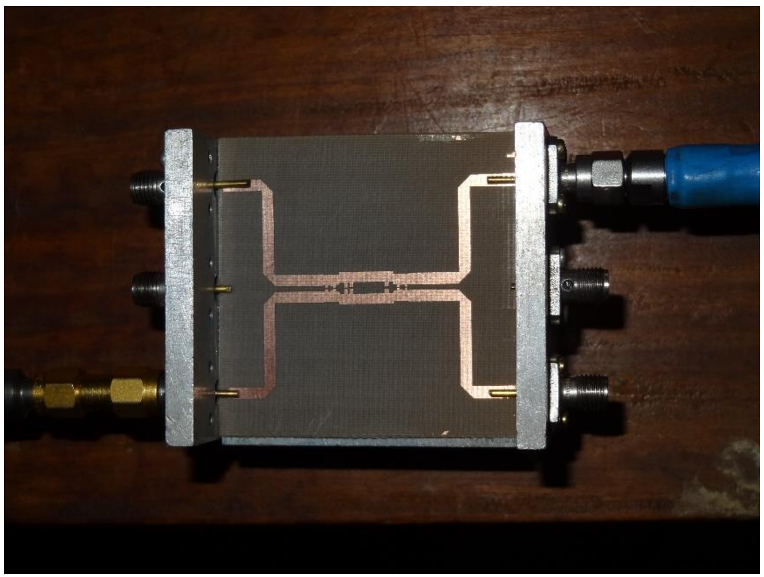
- Combines 4 search Methods,
  - Linear simplex
  - Downhill simplex
  - Sequential quadratic programming and
  - Genetic algorithm

$$\boldsymbol{Cost\ Function = Weight\ \times |Measurement - Goal|^{L}}$$

- Optimization Goals,
  - Coupling = -20 dB, weight = 1,
  - Isolation < -50 dB, weight = 2
  - Insertion Loss < -30 dB, weight = 1
  - Exponent L = 2

Fabrication & Analysis

The Microstrip Coupler Fabricated

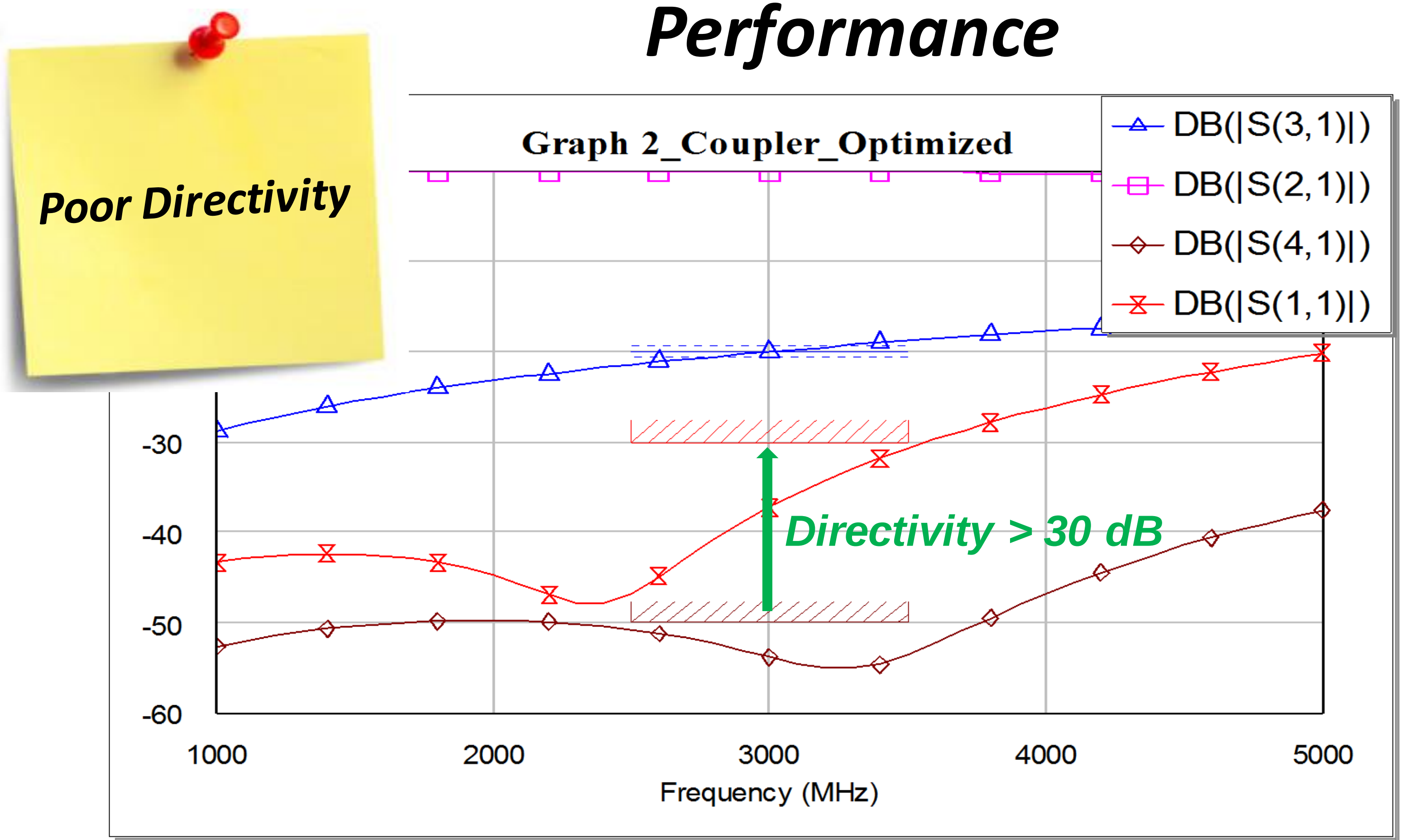


Measurement using the Anritsu Vector Network Analyzer

Design & Measurements

The Conventional Coupler

Performance



Coupling

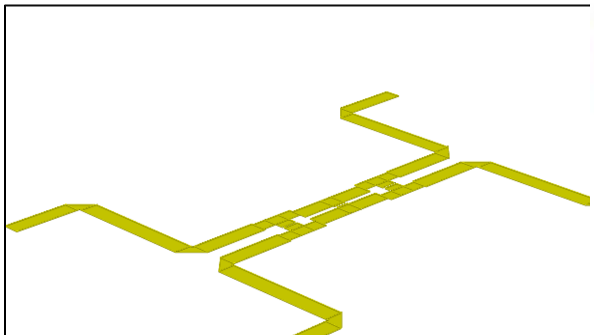
Thru put

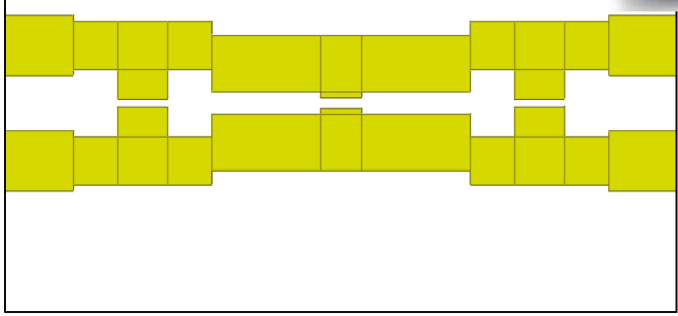
Isolation

Reflection

Coupler with a Single Centre Capacitor

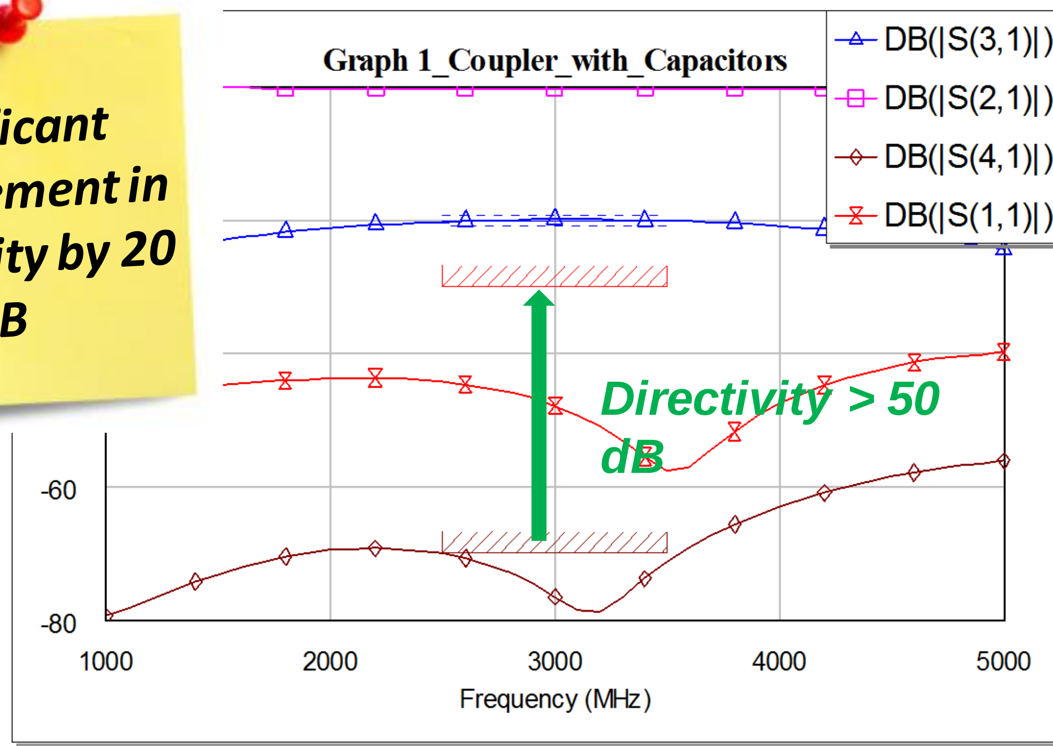
Layout





Performance

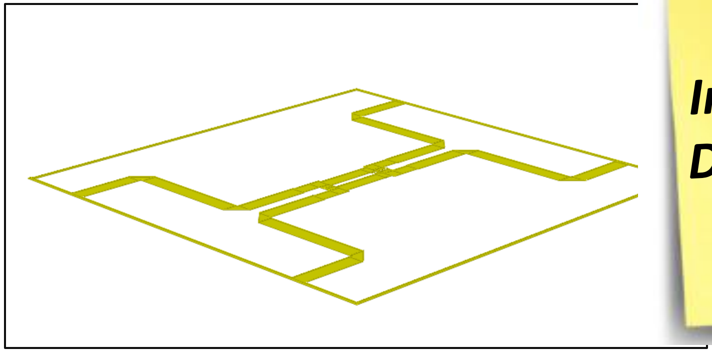
Significant Improvement in Directivity by 20 dB

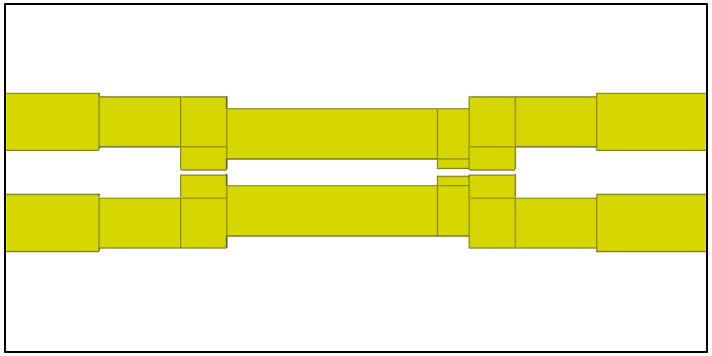


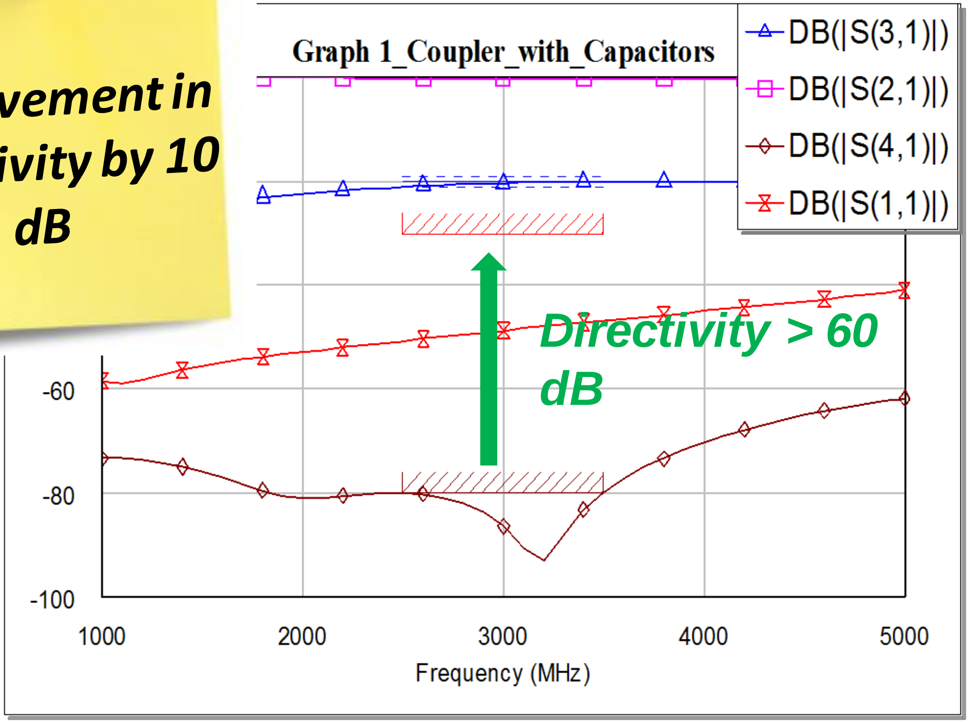
Coupler with a single optimally positioned Capacitor

Layout

Performance



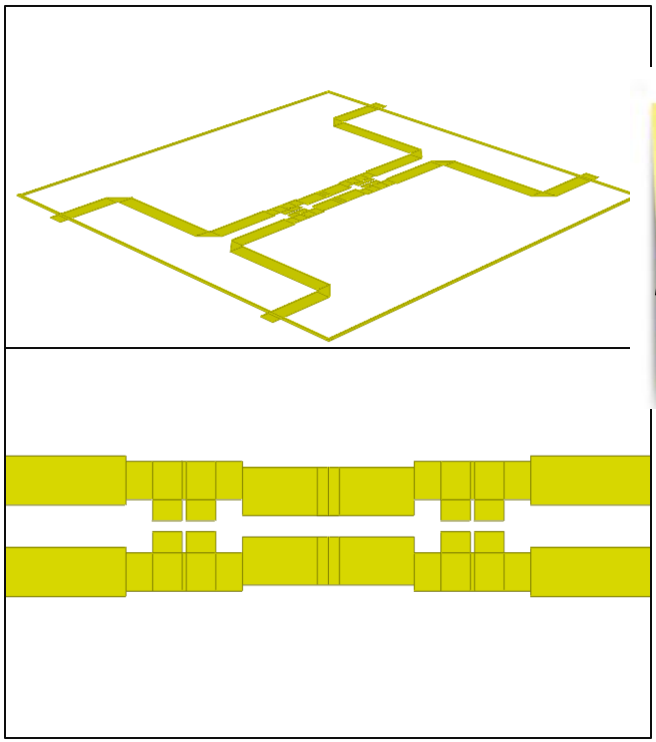




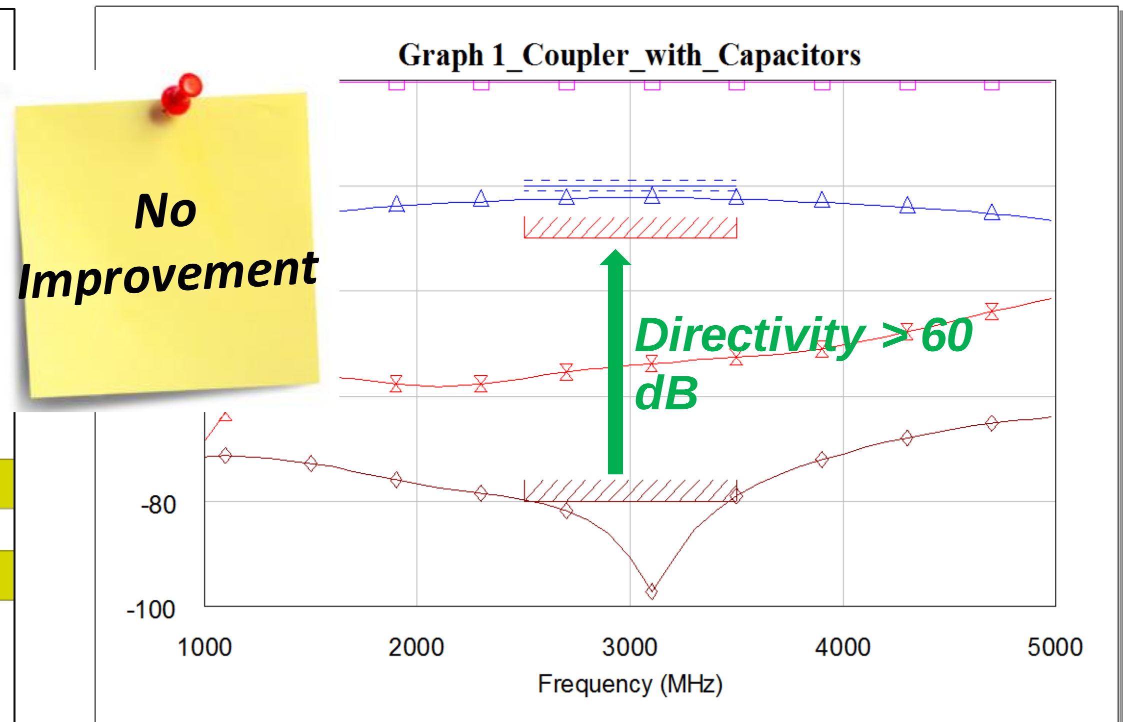
Improvement in Directivity by 10 dB

Multiple optimally positioned capacitors: Two optimally positioned Capacitors

Layout

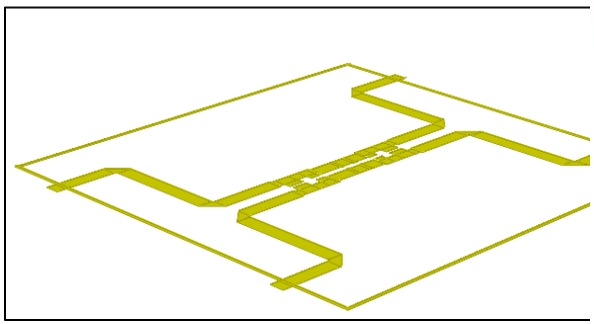


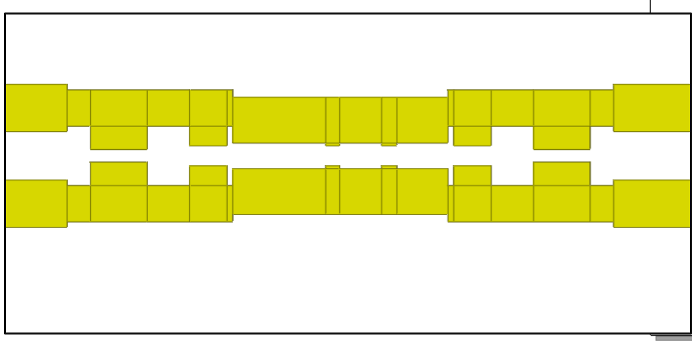
Performance



Asymmetric Coupler with optimally positioned Capacitors

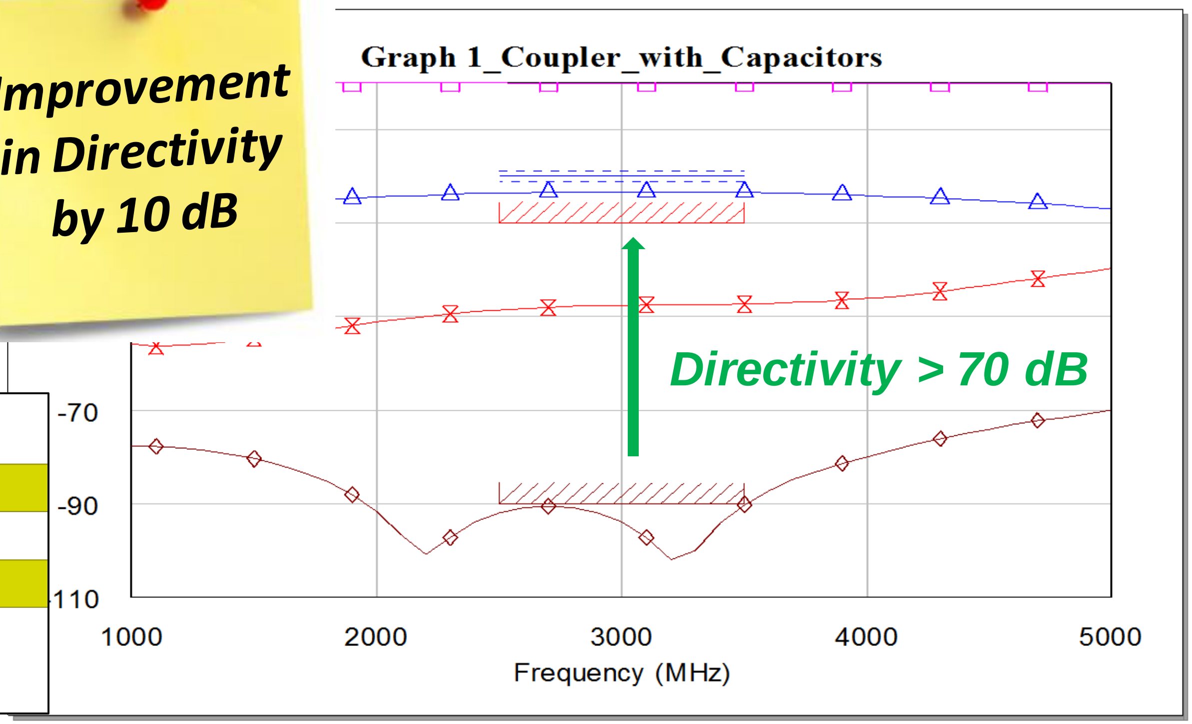
Layout





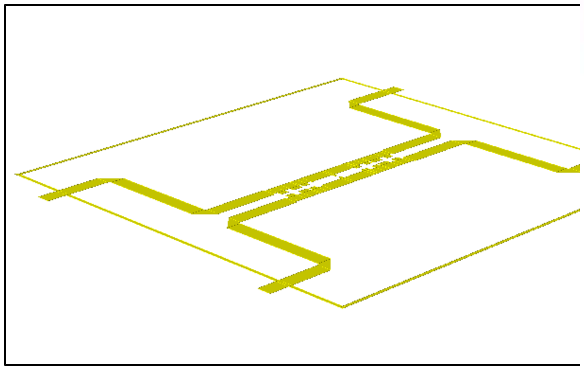
Performance

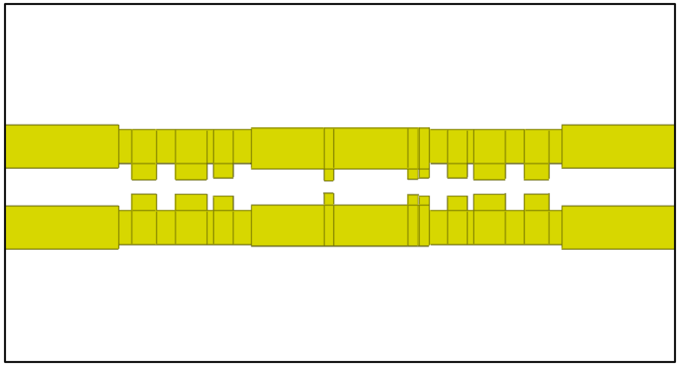
Improvement in Directivity by 10 dB



Three optimally positioned Capacitors

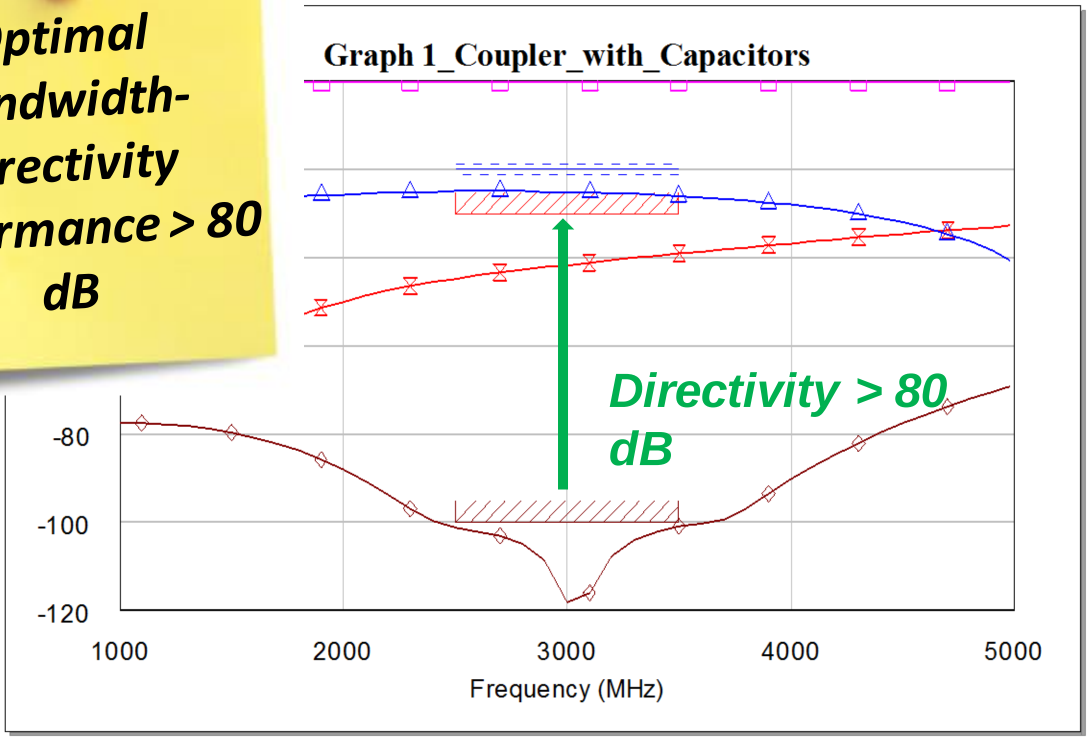
Layout





Optimal Bandwidth-Directivity Performance > 80 dB

Performance



Results

TABLE I
ISOLATION & DIRECTIVITY FOR THE DESIGNS

Design	Isolation (dB)	Directivity (dB)
1. Conventional Coupler	-50	30
2. Coupler with Center positioned capacitor	-70	50
3. Coupler with optimally positioned capacitor	-80	60
4. Coupler with 2 optimally positioned capacitors	-80	60
5. Coupler with 2 optimally positioned capacitors	-90	70
6. Coupler with 3 optimally positioned capacitors	-100	80

Conclusion

- Enhanced bandwidth performance was achieved by the implementation of multiple stages
- Directivity was improved by the use of a multiple number of optimally positioned capacitors along the coupler
- Optimization process relied on minimizing the cost function by employing the Pointer-Robust optimization approach which yielded a significant improvement
- The asymmetric optimal positioning of capacitors exhibited a significant improvement in the bandwidth-directivity performance

References

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