Fourier-Based Transmission Line Ultra-wideband Wilkinson Power Divider for EARS Applications

By

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NSF EARS Award 1247946

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Outline

- Motivation and Challenges
- Research on Power Dividers
- Wilkinson Power Divider Design
  - Conventional *Vs* Proposed Ultra-wideband Schematics
- Simulation and Experimental Results
- Summary
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Motivation and Challenges

- Most of the frequency spectrum is allocated to different wireless services
- Typically, some of these assigned bands remain idle some of the time
- Cognitive Radios (CRs) are gaining attention as an attractive solution to maximizing bandwidth utilization and channel capacity

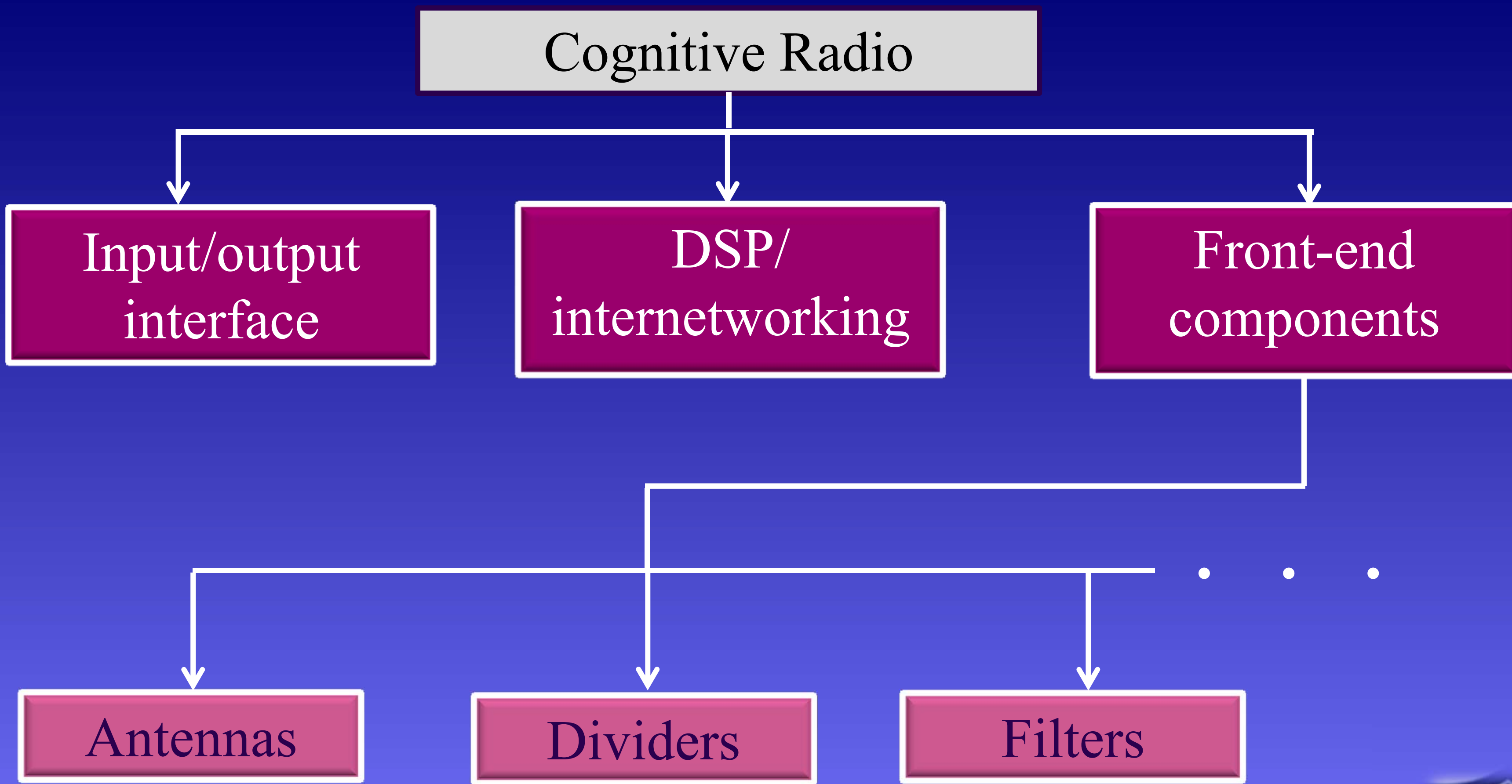
Motivation and Challenges

- In CR, the temporarily unallocated frequencies are loaned to secondary users as long as the "legitimate/primary" users are not receiving/transmitting data
- The concept of CR *enhances access to the radio spectrum*

However

- To bring this concept to reality, we require front-end microwave components that support CR operation over wide frequency range (e.g. spectrum sensing)

CR Framework



Examples of Front-end Components

Antenna array

Power divider

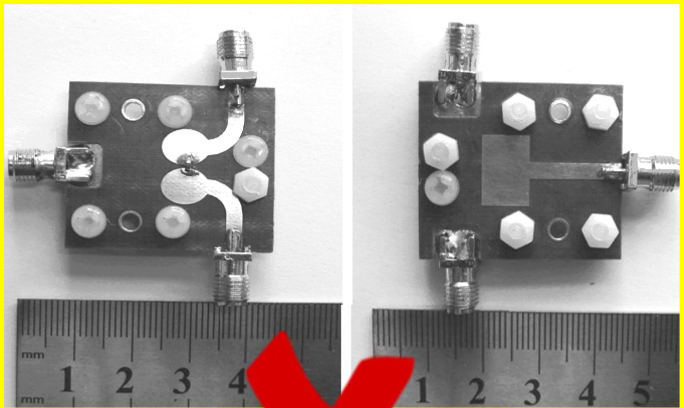
Ultra-wideband Spectrum

- The frequency spectrum ranges between 3.1 GHz and 10.6 GHz
- Approved for commercial applications (FCC, 2002)
- Most widely used in medical treatments, tactical and strategic communication, through-the-wall imaging, high data rate transmission, etc.

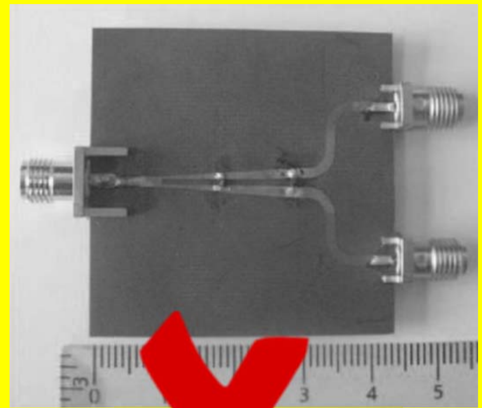
Research on Power Dividers

Different approaches have been recently reported:

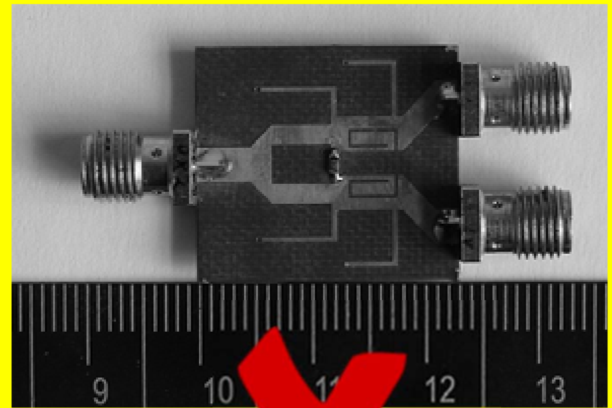
Multilayer substrate



Tapered lines



Stubs based



Increased fabrication cost

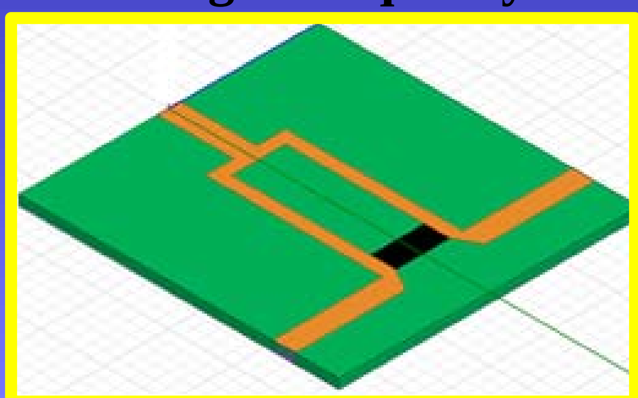
Larger circuit area

Larger circuit area, difficulty in cascading

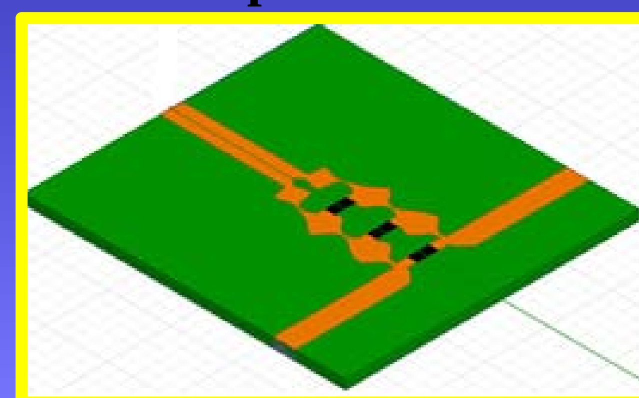
Proposed UWB Wilkinson Power Divider

Each uniform impedance branch in the power divider is replaced by a single non-uniform transmission line (NTL) transformer

Single Frequency



Proposed UWB



Design Objectives

- Objective 1: NTL that matches a source impedance Z_s to a load impedance Z_l

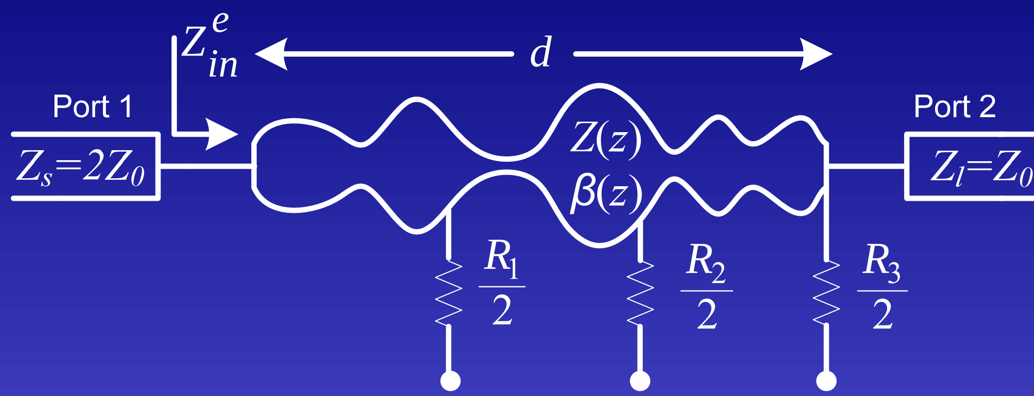
  ✓ Even Mode Analysis

- Objective 2: Achieve optimum output ports isolation and matching conditions

  ✓ Odd Mode Analysis

Even Mode Analysis

- Accomplished by enforcing the magnitude of the reflection coefficient $|\Gamma|$ to be zero (or close to zero) over UWB frequency range
- $|\Gamma|$ at the input port can be expressed in terms of Z^e_{in}



Even Mode Analysis

- Z^e_{in} is calculated from *ABCD* parameters of NTL

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdots \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \cdots \begin{bmatrix} A_K & B_K \\ C_K & D_K \end{bmatrix}, \quad i = 1, 2, \ldots K$$

- *B* and *C* values are calculated in terms of a truncated Fourier series

$$\ln\left(\frac{Z(z)}{Z_c}\right) = c_0 + \sum_{n=1}^{N}\left[a_n \cos\left(\frac{2\pi nz}{d}\right) + b_n \sin\left(\frac{2\pi nz}{d}\right)\right]$$

- Optimum values of the Fourier coefficients are obtained by minimizing an error function in MATLAB

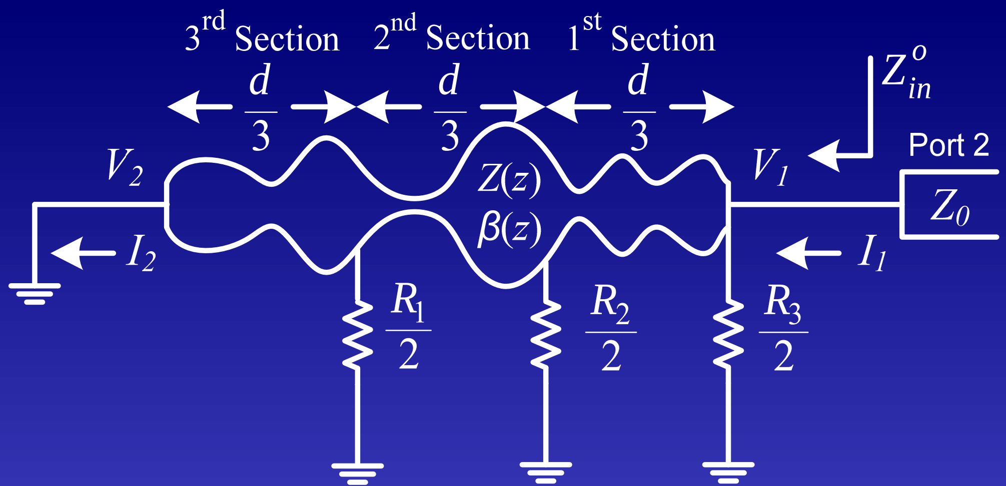
$$\text{Error}_{\text{in}} = \max(E^{\text{in}}_{f_1}, \ldots E^{\text{in}}_{f_j} \ldots E^{\text{in}}_{f_m})$$

where

$$E^{\text{in}}_{f_j} = \left|\Gamma_{in}(f_j)\right|^2 \qquad \Gamma_{in}(f_j) = \frac{Z^e_{in}(f_j) - Z_s}{Z^e_{in}(f_j) + Z_s} \qquad Z^e_{in}(f_j) = \frac{A(f_j) Z_l + B(f_j)}{C(f_j) Z_l + D(f_j)}$$

Odd Mode Analysis

- Carried out to obtain the resistor values R_1, R_2 and R_3 for achieving the optimum output ports isolation and matching conditions



- *ABCD* matrix of the network is calculated as follows:

$$[ABCD]_{\text{Total}} = [ABCD]_{\frac{R_3}{2}} \cdot [ABCD]_{\text{1st Section}} \cdot [ABCD]_{\frac{R_2}{2}} \cdot$$

$$[ABCD]_{\text{2nd Section}} \cdot [ABCD]_{\frac{R_1}{2}} \cdot [ABCD]_{\text{3rd Section}}$$

Odd Mode Analysis

- Finally, we have:

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{\text{Total}} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

- Setting V_2 to zero, and solving for $\frac{V_1}{I_1}$, we obtain:

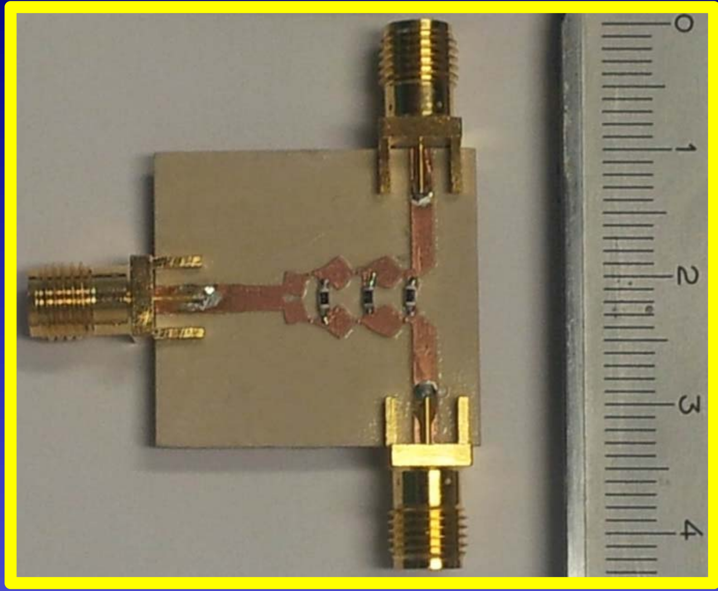
$$\frac{V_1}{I_1} = \frac{B}{D} = Z_{in}^{o}$$

- For perfect output ports matching over the UWB range, the below error needs to be minimized over the R_1, R_2, R_3 design space

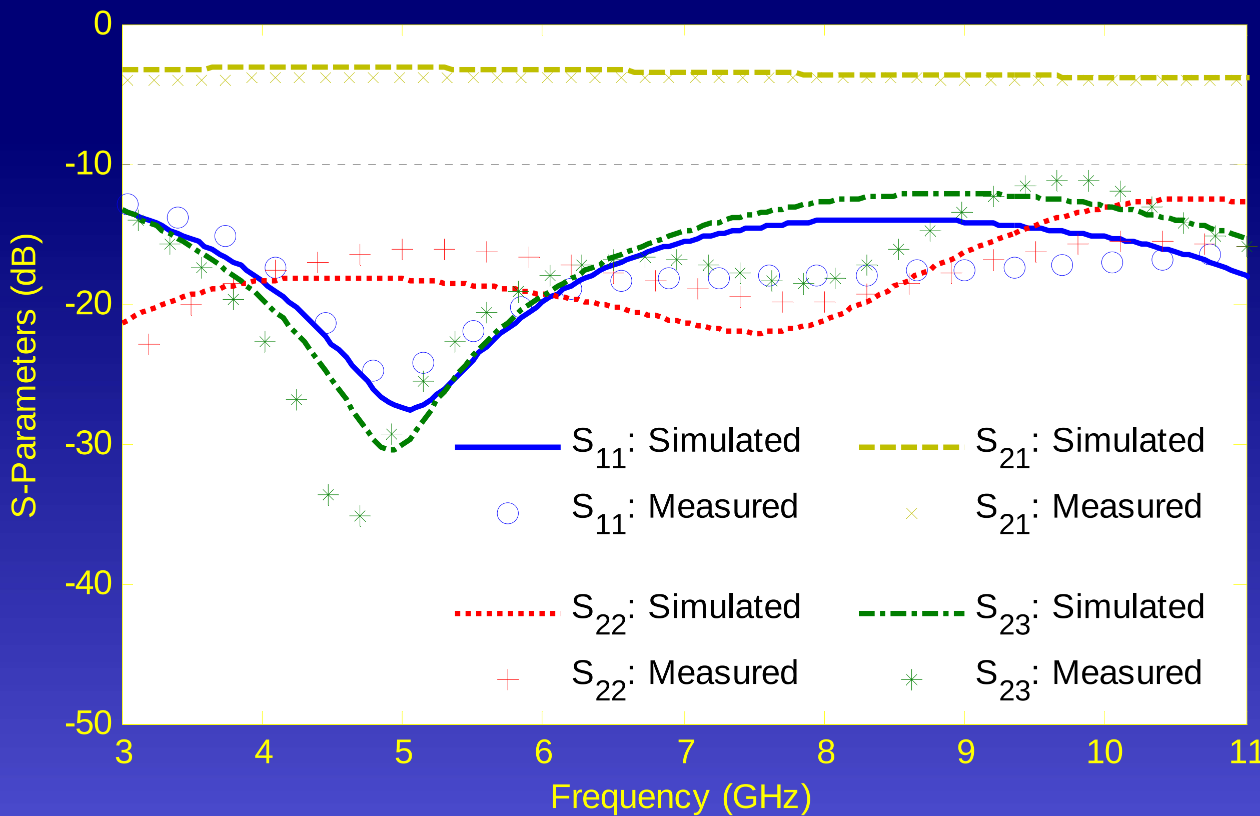
$$\text{Error}_{\text{out}} = \max(E_{f_1}^{\text{out}}, \ldots E_{f_j}^{\text{out}} \ldots E_{f_m}^{\text{out}}), \qquad E_{f_j}^{\text{out}} = \left|\Gamma_{out}\left(f_j\right)\right|^2$$

Simulation and Experimental Results

- Characteristic impedance of 50Ω
- Rogers RO4003C substrate with relative permittivity of 3.55, thickness of 0.813 mm, and loss tangent of 0.0027 is employed
- Length of each NTL arm of the proposed WPD is set to 10 mm

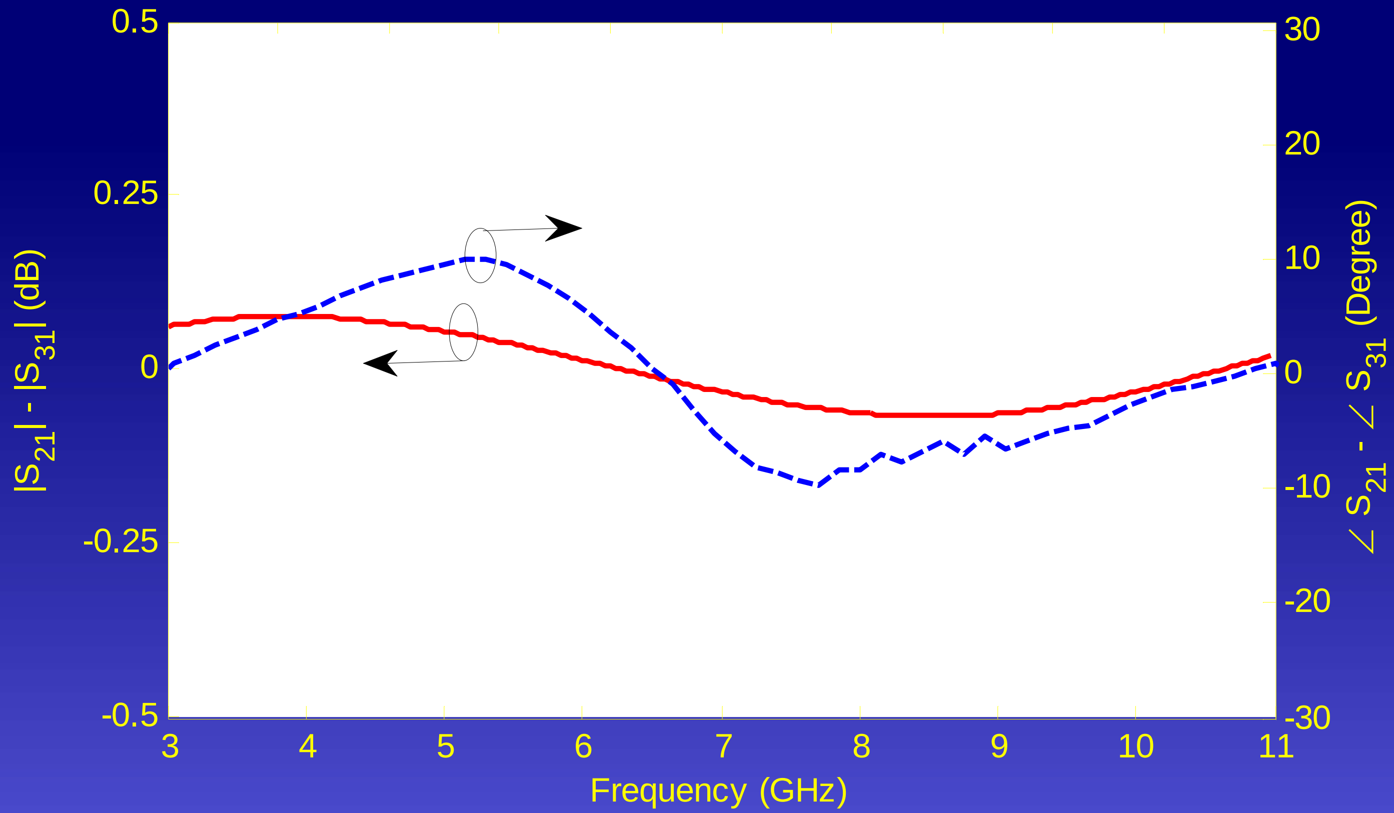


S-Parameters



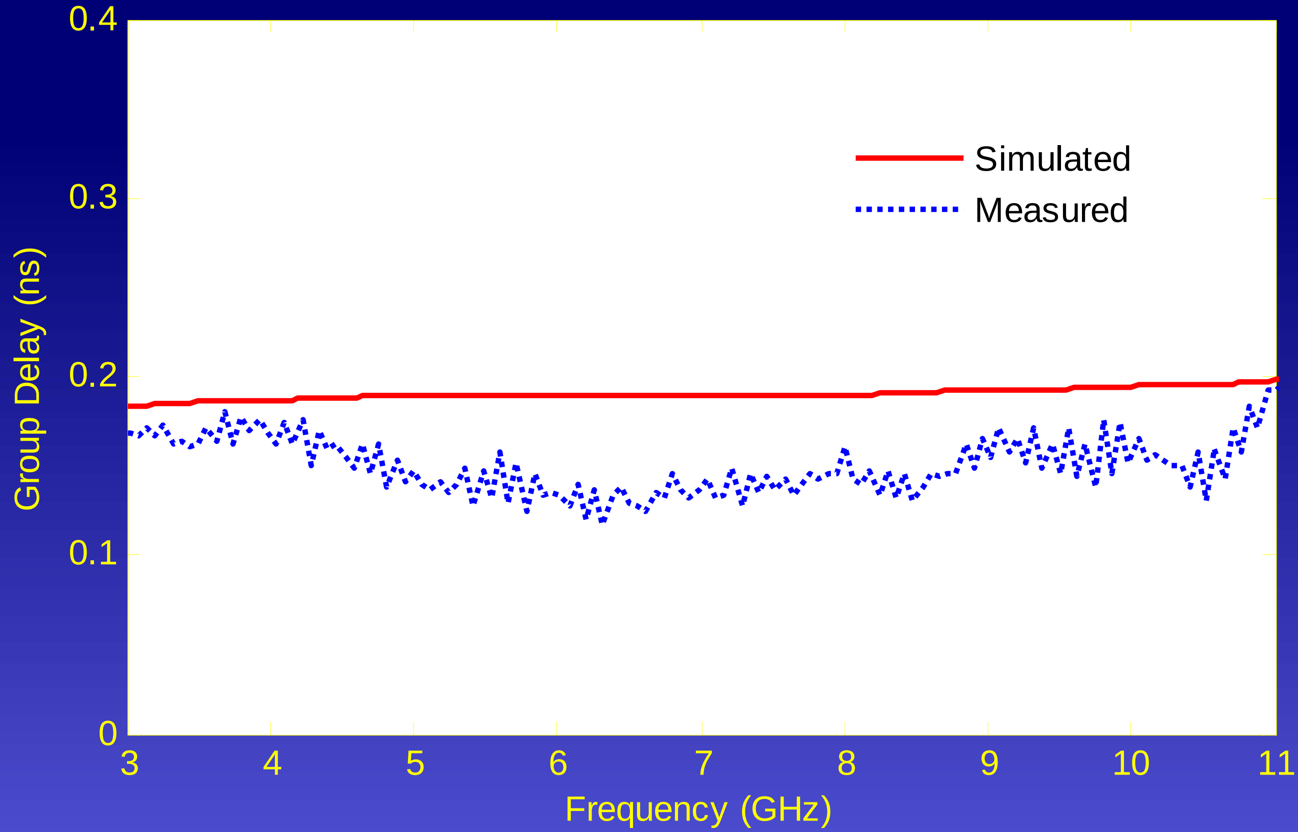
- Input and output ports matching parameters S_{11} and S_{22}, respectively, and the isolation parameter S_{23} are below -10 dB over the UWB range.
- S_{21} is in the range -3.2 dB to -4.2 dB over the UWB frequency range.

Imbalance



- The measured phase imbalance is less than ± 10° over the entire design frequency range
- The obtained amplitude imbalance is around ± 0.1 dB over the entire UWB range

Group Delay

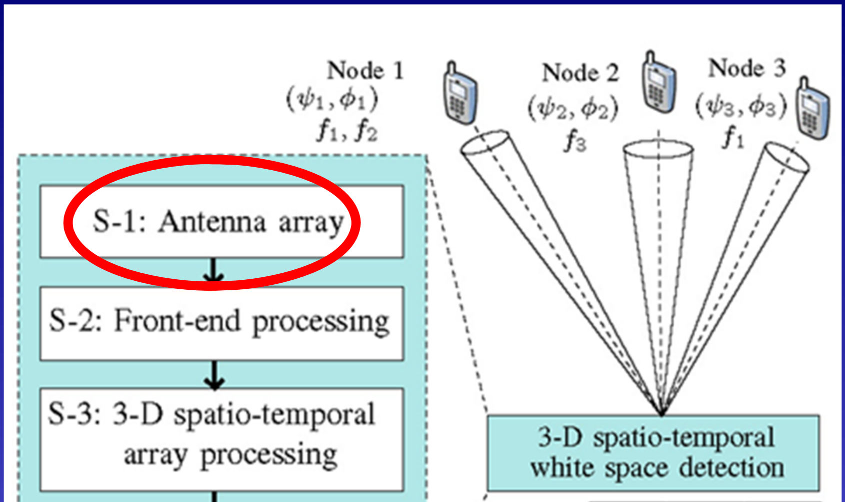


Simulated and measured group delay are:

- Almost flat over the UWB range
- Less than 0.2 ns

3-D IIR Digital Beam Filters for Space-Time White Space Detection in Cognitive Radio

- Four sub-systems are proposed for space-time white space detection (Univ. of Akron Contribution)
- A power divider is essential in feeding the antenna array in S-1! (Univ. of Toledo Contribution)



$\Upsilon_{f_k}^{(\psi_i,\phi_i)}$	$i=1$	$i=2$	$i=3$
$k=1$	1	0	1
$k=2$	1	0	0
$k=3$	0	1	0

$$\Upsilon_{f_k}^{(\psi_i,\phi_i)} = \begin{cases} 1 & \text{if carrier } f_k \text{ is occupied along } (\psi_i,\phi_i) \\ 0 & \text{if carrier } f_k \text{ is vacant along } (\psi_i,\phi_i) \end{cases}$$

- After S-4, an algorithm to solve the link scheduling and routing problem efficiently utilizing 3D sensing information is required (Univ. of Norfolk Contribution)

Summary

- For the first time, a CAD method for the design of an UWB WPD based on Fourier impedance profiles has been presented.
- The design optimizes both cost and real estate!
- The proposed WPD has been fabricated. There is a close match between simulations and measurements.
- The proposed WPD can serve as a front-end module in realizing EARS hardware.

Acknowledgment

- This research is supported in part by NSF EARS Award 1247946 (Collaborators – Norfolk State, Ohio Northern, University of Akron)

- The authors gratefully acknowledge the motivation and support from NSF EARS Program Director Dr. George Haddad

Thank You