Wide-Band Radio Frequency Signal Analysis and Processing using Cascaded All-Pass Networks

Under the guidance of

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Context

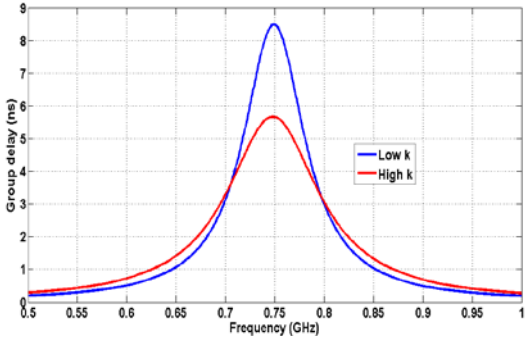
- To monitor the RF environment in real time to achieve higher spectral/temporal efficiency.
- Microwave Analog devices involve manipulating RF signals through analog means.
- Signal propagation through microwave structures can be engineered in terms of dispersion characteristics.
- Dispersive delay lines (DDL) with temporal dispersion exhibit frequency dependant group delay response.
- Challenges in the design of DDL is a compact, low loss operation over broad bandwidth with high group delay dispersion (GDD).

Contribution

- All-pass networks (APN) as DDL exhibit independent control over group delay response and magnitude of loss characteristics
- In general, APN have been designed for required phase response at a single frequency.
- Novelty of the work :
  - Designing APN circuits for required group delay responses for wide band operation at radio frequencies
  - High GDD achieved for high resolution analog signal processing applications.

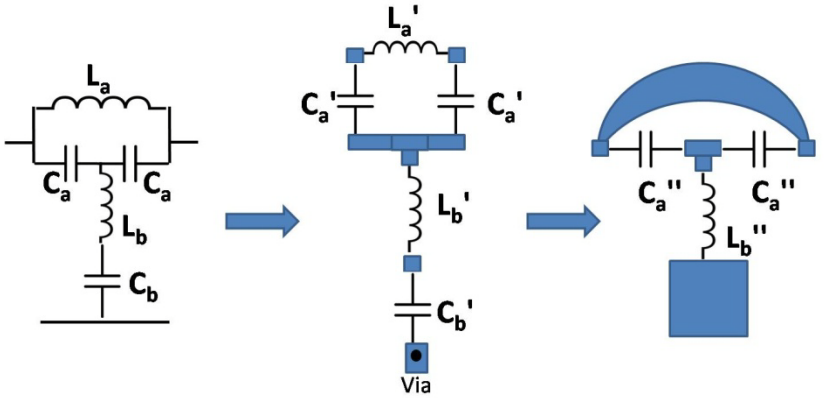
Problem & Proposed Solution

- Peak group delay of APN can be increased by a lower *k*

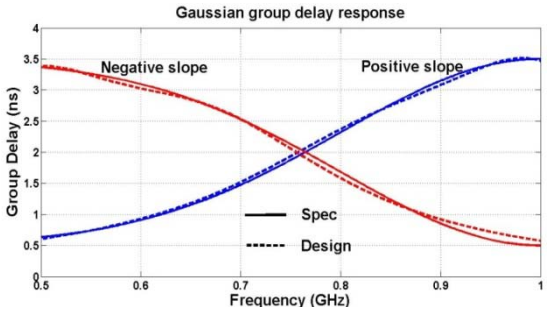


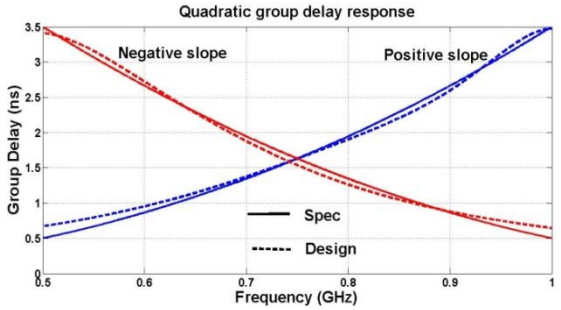
- Distributed component implementations
  - Limited by fabrication limitations on line width and gap
  - Several stages to be cascaded for high GDD
  - Large device footprint

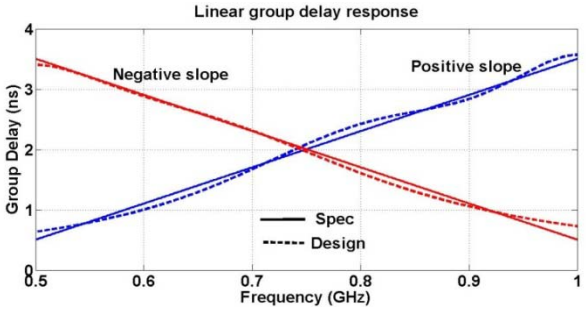
- Design of APN circuits using lumped components
- Cascade APN circuits over multiple stages with appropriate choice of resonance frequency and coefficient *k*

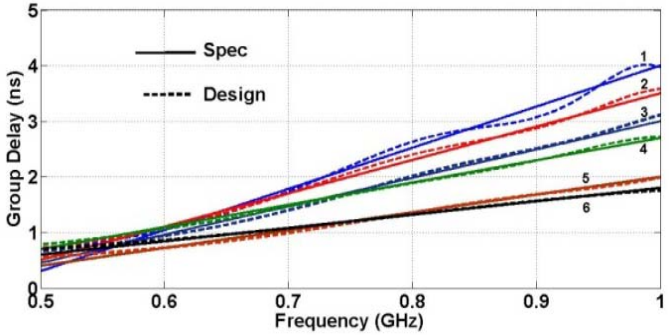


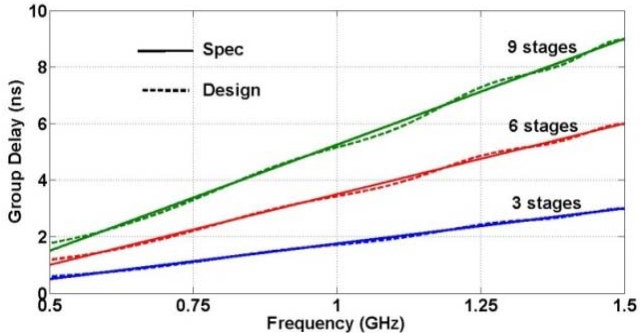
Validation/Results - Simulation

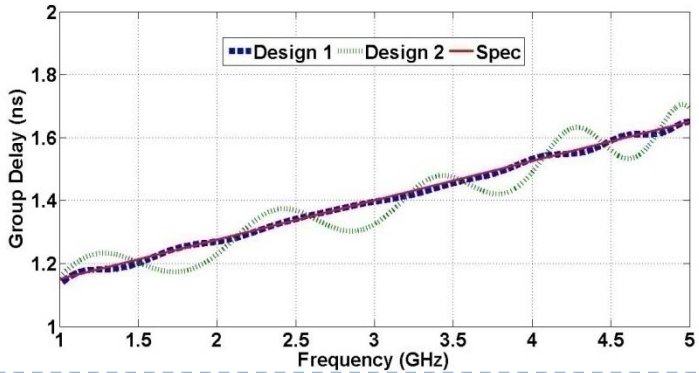






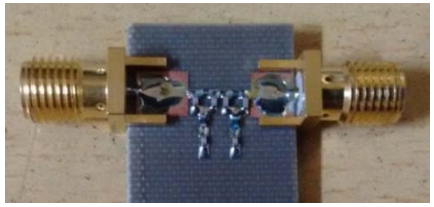


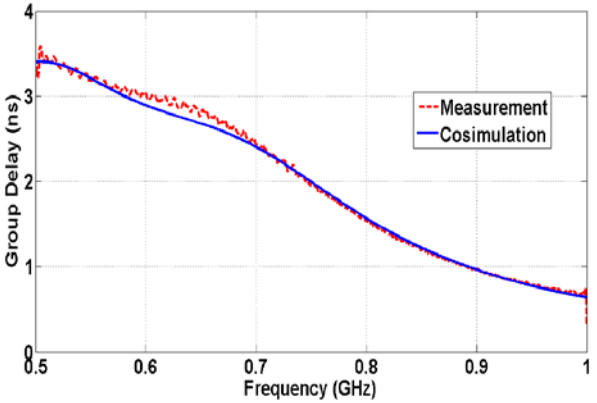


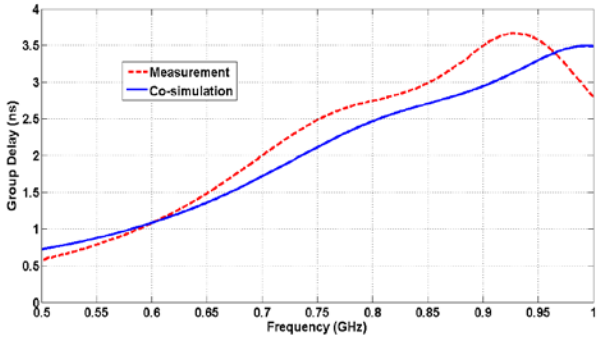


Validation/Results - Measurement

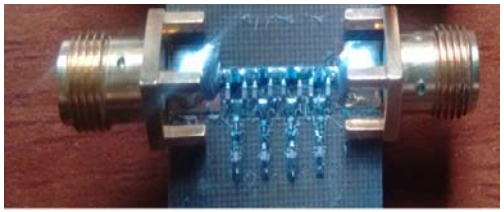
2 stage APN

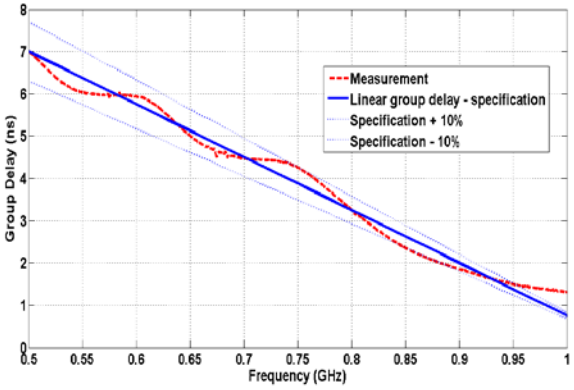




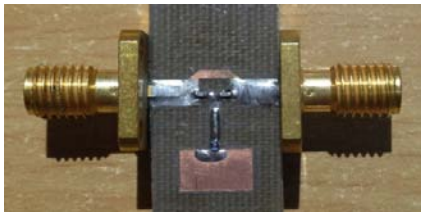


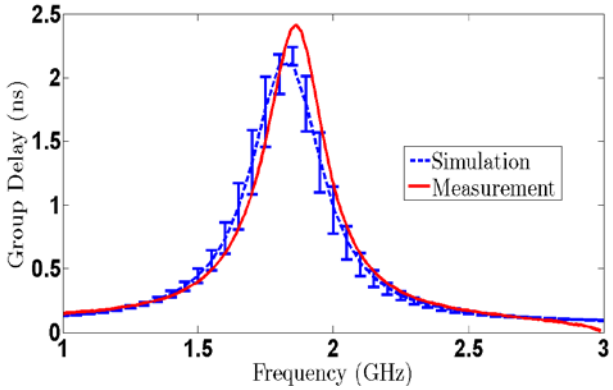
4 stage APN





APN with reduced sensitivity





Performance comparison

- Linear and non-linear group delay responses are obtained
- Positive and negative slope in the group delay response is achieved
- Device footprint is independent of frequency
- Q factor of the components affects only the loss characteristics
- High group delay dispersion
- Reduced insertion loss

Technology	Frequency (GHz)	GDD (ns/GHz)	Device footprint (mm*mm)	S21 (dB)
Stripline with Chirped EBG	[2 - 10]	-0.5	28 cm (length)	7
Distributed C section : edge coupled	[1 - 5]	+0.32	18*16.5	7
Distributed C section : broadside coupled	[6 - 10]	-0.215	12.5*14.9	6
Lumped SMD design Four stage APN	[0.5 - 1]	-12	12*6.8	3

Performance comparison

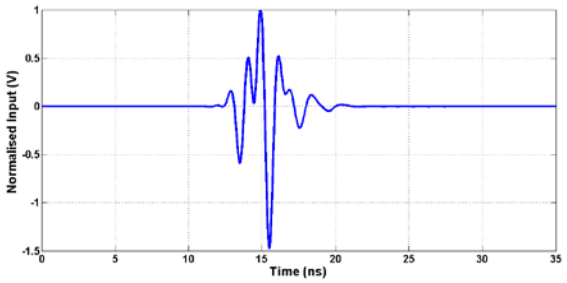
- Peak group delay is thrice that reported using single stage APN
- Reduced device footprint
- Scalability is limited by SRF of the available SMD components

Technology	Group Delay (ns)	f_r (GHz)	S21 (dB)	Device footprint (mm*mm)
Complementary slot stub	0.5	2.5	0.5	39*43
Complementary Deformed structure	0.8	2.5	0.9	18*35
APN (reduced sensitivity)	2.4	1.85	2	10*15

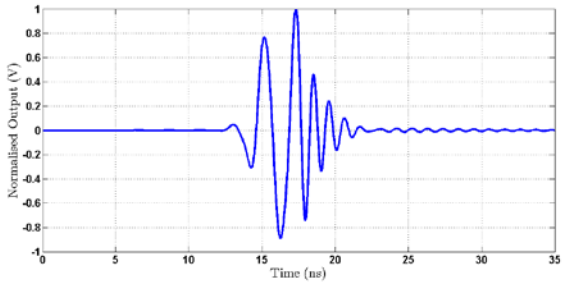
Analysis

- Signal propagation is analyzed for linear group delay response.
- Signal experiences expansion of pulse width, reduction of peak amplitude and temporal displacement of spectral components.

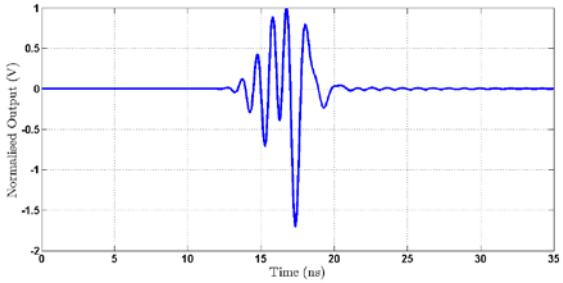
Input



Output



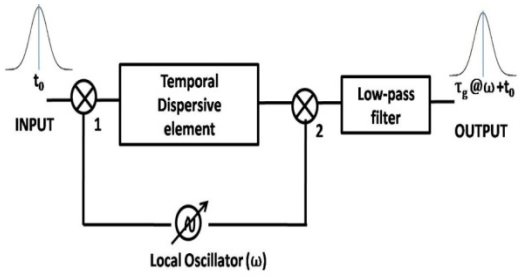
Positive slope
Group delay response

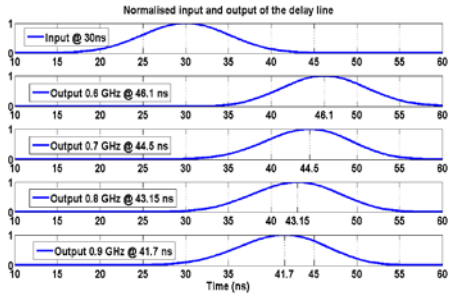


Negative slope
Group delay response

Future work

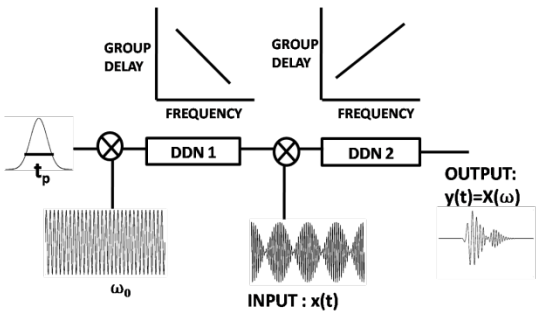
- System setup and measurement incorporating the developed APN circuits to demonstrate applications such as
  - Reconfigurable delay line

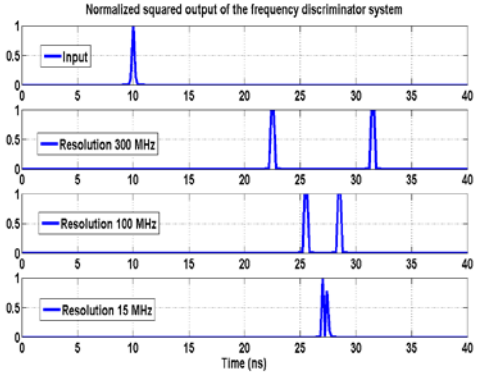




Technology	Frequency (GHz)	Delay variation (ns)	S21 (dB)
SAW	[0.085-0.105]	0.06	26
CRLH	[2-3.25]	2	3
Lumped APN	[0.5-1]	6	3

  - Frequency Discriminator





Technology	Frequency (GHz)	Resolution (MHz)	S21 (dB)
CRLH	[2 -3.25]	300	3
Distributed APN	[0.5 - 1]	449	7
Lumped APN	[0.5 - 1]	15	6

PUBLICATIONS

- P. Keerthan, K. J. Vinoy, "Design of Cascaded All-Pass Network with Monotonous Group Delay Response for Broadband Radio Frequency Applications," *IET journal on Microwaves, Antennas and propagation, in press, accepted January 2016*
- P. Keerthan, K. J. Vinoy, "Real-Time Frequency Discriminator using Two Stage All-Pass Network," *IEEE MTT-S International Microwave and RF Conference, 2014*, pp. 65-68, 15-17 Dec. 2014
- R.Kumar, P. Keerthan, K. J. Vinoy, "Design of Wideband Tunable Dispersive Delay using Cascaded All-Pass Networks," *IEEE MTT-S International Microwave and RF Conference, 2015*
- P. Keerthan, R.Kumar K. J. Vinoy, "Wideband Real Time Frequency Measurement using Compressive Receiver," accepted *SPCOM 2016*
- P. Keerthan, R.Kumar K. J. Vinoy, "All-Pass Network Implementation with Reduced Component Value Sensitivity for High Dispersion Group Delay Engineering,", under review, *Microwave and Wireless Component Letters*
- P. Keerthan, R.Kumar K. J. Vinoy, "Design and Analysis of Wideband Microwave Frequency Measurement with Improved Resolution," under preparation, *IEEE Transactions on Microwave Theory and Techniques*