

Th2A-3

High-Power Tunable FDD Front-End Employing a Balanced CMOS N-Path Receiver and Evanescent-Mode Cavity Filters

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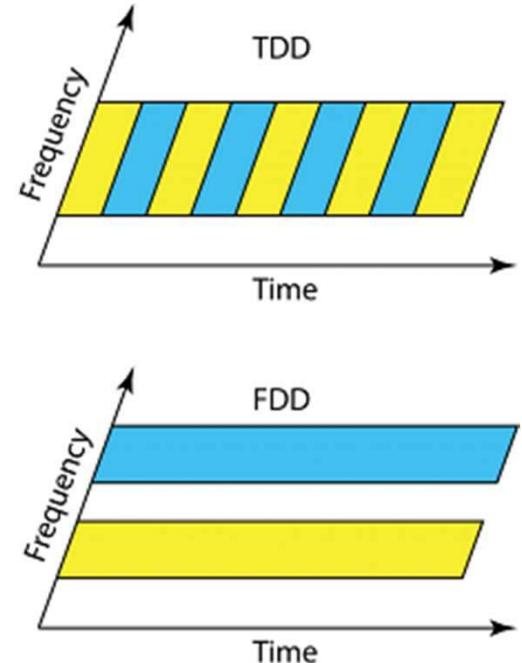
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Outline

- Introduction
- Current Single-Antenna Solutions
- Proposed FDD System
- Principle of Operation
- Measurements Results
- Summary

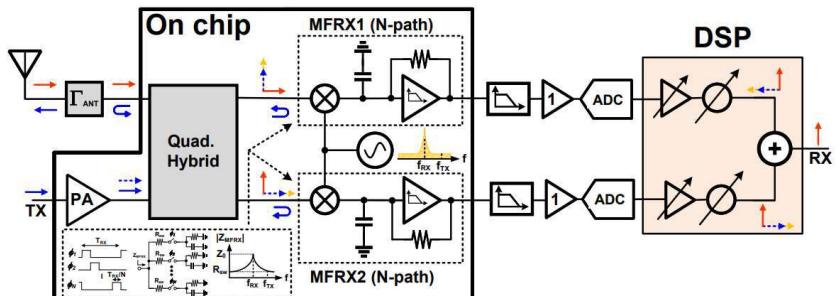
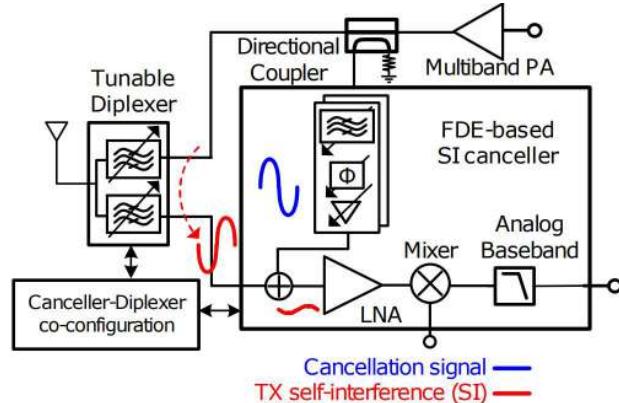
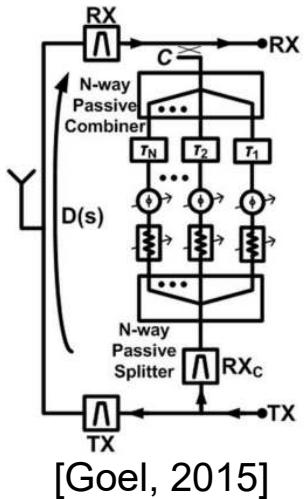
Introduction

- FDD operation in current and future wireless systems
 - Efficient spectrum utilization
 - Advantageous compared to TDD
 - » Lower latency
 - » Higher SNR
 - » Smaller guard periods
 - » No sync between neighboring base-stations
 - Particularly important in massive-MIMO applications



Single-Antenna FDD Solutions

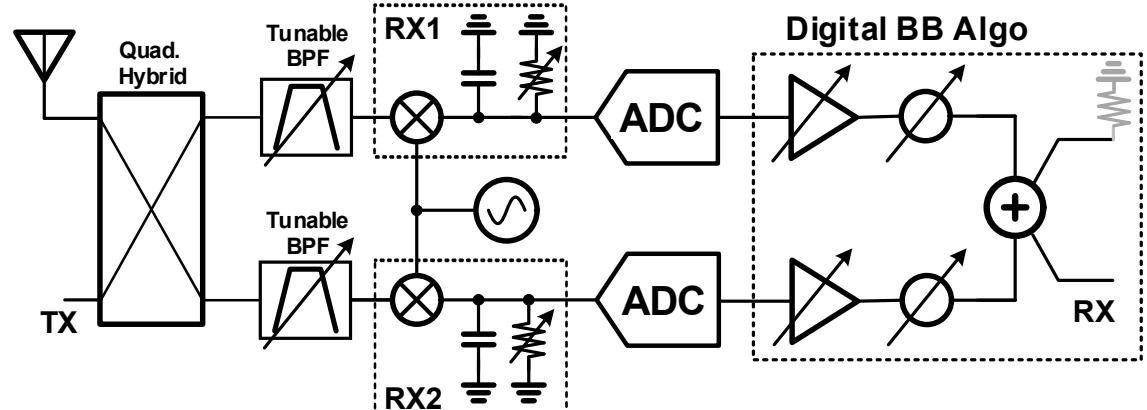
- Tunable diplexers + RF SIC
- Balanced N-path RX + Digital SIC
- Challenges
 - Cancellation BW
 - Antenna VSWR Coverage
 - NF degradation
 - Frequency range
 - Power Handling
 - Linearity



[Zolkov, 2022]

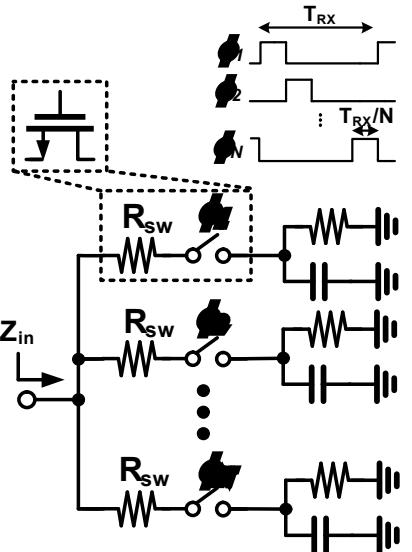
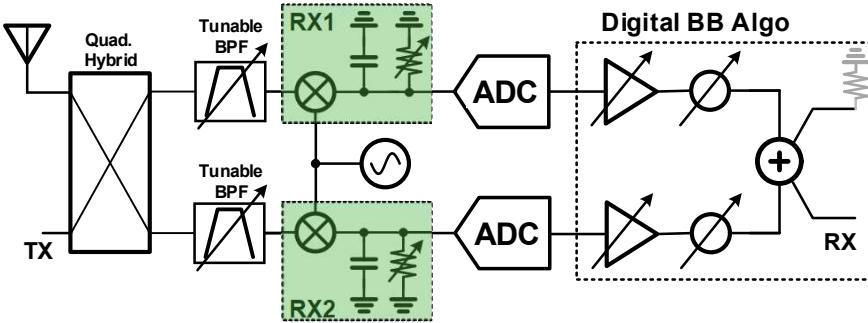
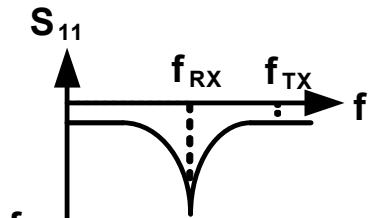
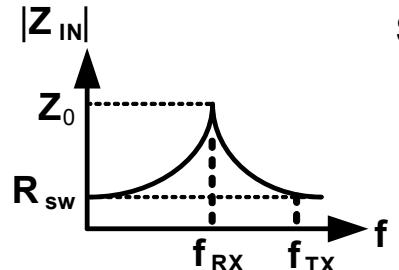
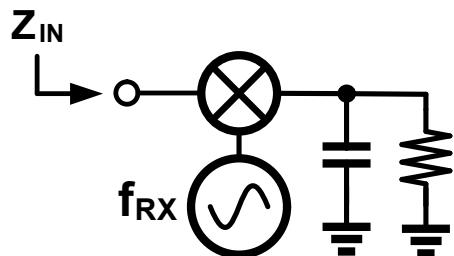
Proposed FDD Front-End

- Balanced CMOS N-path RX
- Tunable evanescent-mode cavity filters precede each N-path
- Digital baseband algorithm
 - RX signal reconstruction
 - TX noise rejection in RX band



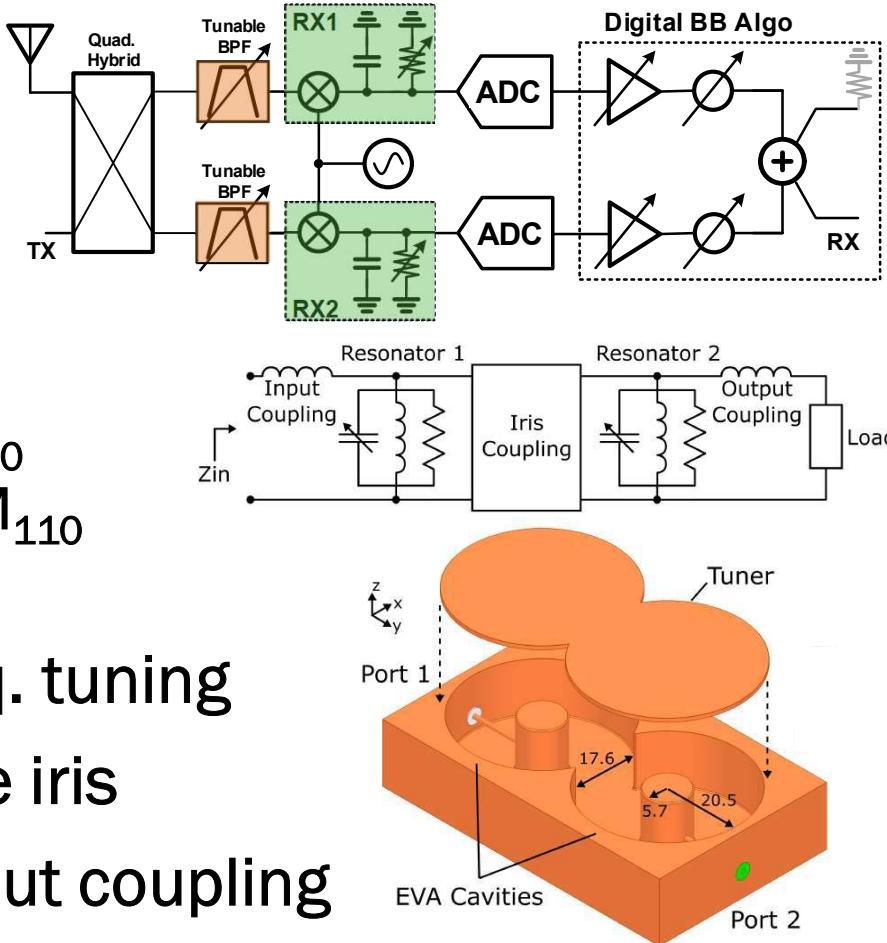
N-Path Mixer Operation

- Successive switch toggling
- Impedance matching at f_{RX}
- Low impedance at f_{TX}
- Blocker tolerance out-of-band
- Frequency of operation tuned through the LO signal

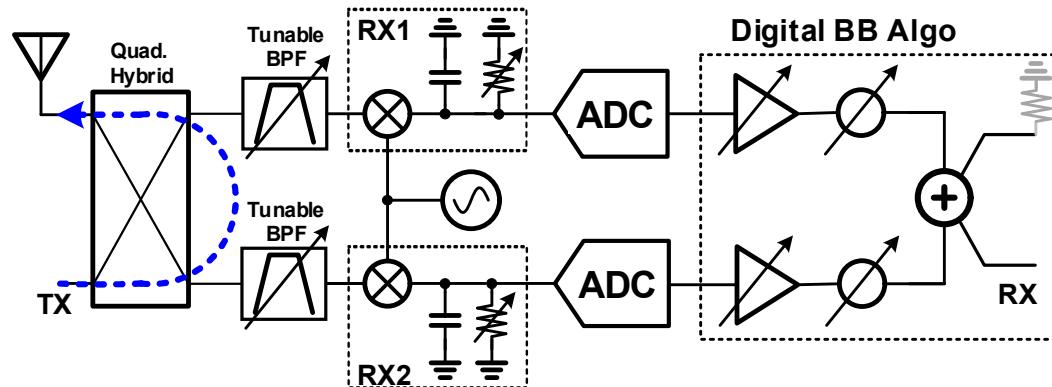


Tunable Evanescent-Mode BPF

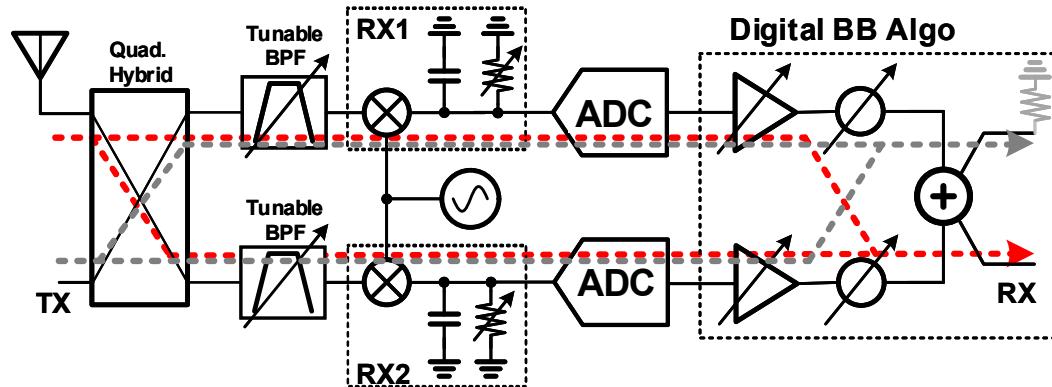
- Two-pole BPF
- Evanescent-mode resonators
- High-Q cylindrical waveguide cavity
- Capacitive post
 - Lowers resonant freq. of the fund. TM_{010}
 - Minimal impact on the second-order TM_{110}
 - Wide spurious-free bandwidth
- Flexible metalized membrane for freq. tuning
- Inter-Resonator coupling via inductive iris
- Flanged SMA pins provide input/output coupling



- The TX band can be selected anywhere on the spectrum in the stop-band of the tunable filters
- TX signal
 - Reflects at the high OOB BPFs' input impedance
 - Reconstructs in-phase at the antenna with minimal IL



- N-path mixers and cavity filters tuned to the RX frequency
- RX signal
 - Absorbed in the matched receivers
 - Reconstructed in quadrature in digital baseband
- TX noise in the RX band
 - Absorbed in the receivers and cancelled out in digital baseband
 - Insensitive to antenna VSWR.]
 - Minor VSWR impact on RX NF



Combined Filtering Response

- Evanescent-mode BPF cascaded by an N-path mixer

- Power delivered by the BPF to a load Z_L

$$P_{\text{out}} = \frac{\left(V_{\text{out}} \frac{Z_L}{Z_L + Z_{\text{filter,out}}} \right)^2}{2Z_L}$$

- 50Ω vs. load R_{SW} load

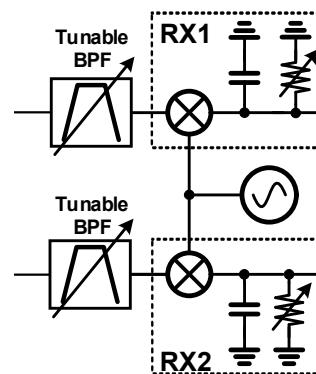
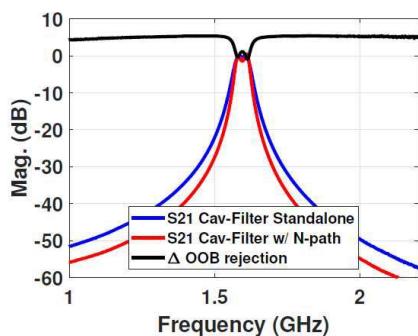
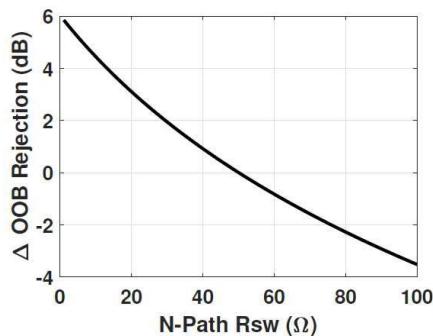
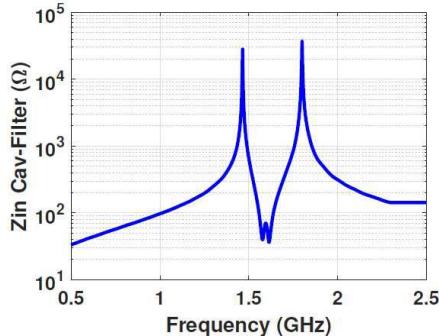
$$\Delta P_{\text{out}} = \frac{R_{SW}}{50} \left(\frac{Z_{\text{filter,out}} + 50}{Z_{\text{filter,out}} + R_{SW}} \right)$$

- N-path standalone OOB rejection

$$S_{21,\text{Npath}} = 2\sqrt{\frac{Z_0}{R_{SW}}} \frac{R_{SW}}{R_{SW} + Z_0}$$

- For $R_{SW} = 4\Omega$, $Z_L = 50\Omega$

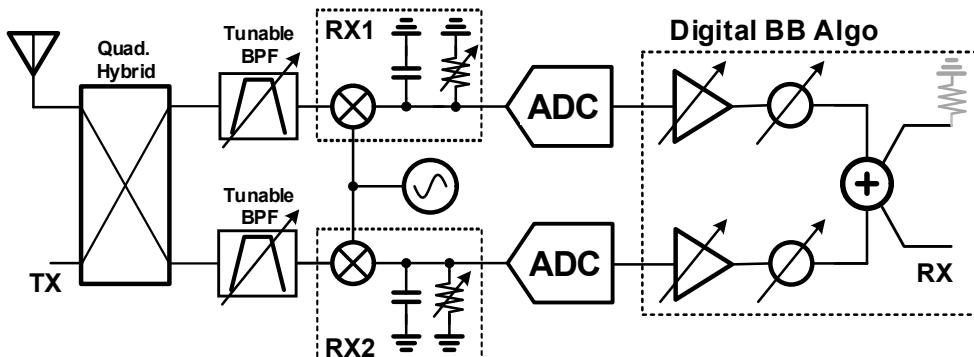
$$\Delta OOB = dB_{20}(S_{21,\text{Npath}}) - dB_{10}(\Delta P_{\text{out}}) \approx 6 \text{ dB}$$



- Measure in-phase and in-quadrature TX-to-RX transfer functions and take the inverse
- Multiply the combined signals (RX+TX noise) by the TFs and subtract
- RX signal reconstructed and TX noise cancelled out
- Equalizer based on peak correlation and channel impulse response for RX demodulation

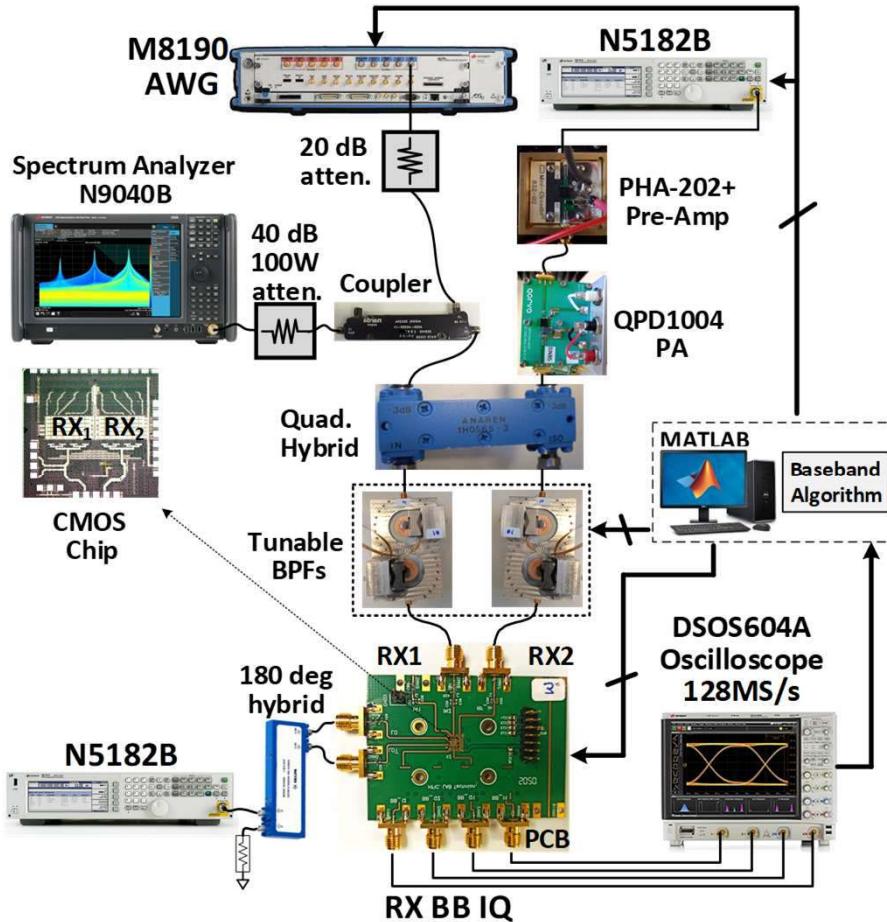
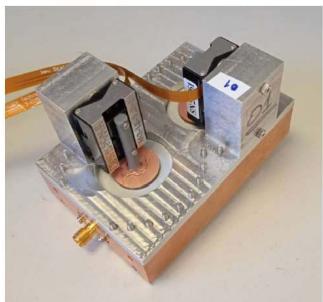
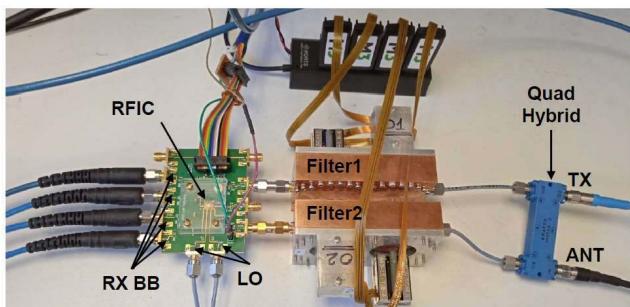
$$\left(\frac{Y_{norm}^I(f)}{X_{ref}^{TX}(f)} \right)^{-1} ; \quad \left(\frac{Y_{norm}^Q(f)}{X_{ref}^{TX}(f)} \right)^{-1}$$

$$Y_{Joint}^{I^{norm}}(t) \cdot \left(\frac{Y_{norm}^I(f)}{X_{ref}^{TX}(f)} \right)^{-1} - Y_{Joint}^{Q^{norm}}(t) \cdot \left(\frac{Y_{norm}^Q(f)}{X_{ref}^{TX}(f)} \right)^{-1}$$



Measurement Setup

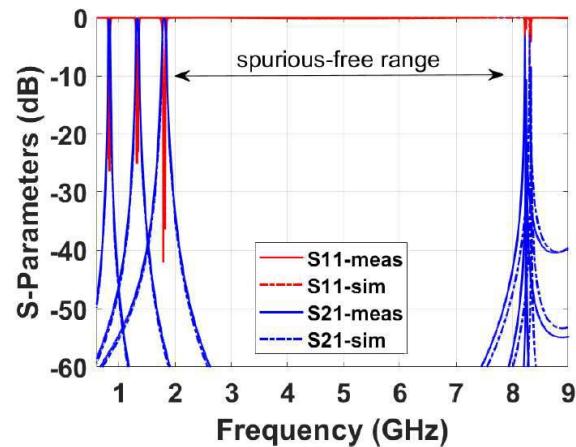
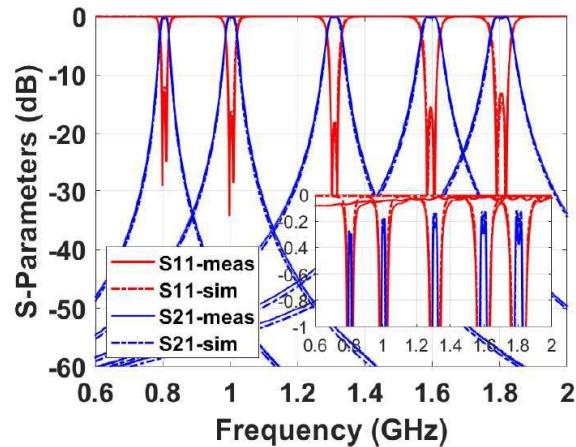
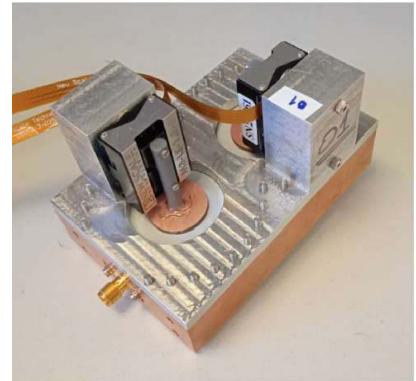
- 65nm CMOS N-path receivers
- Evanescent-mode cavity filters
- Anaren 1H0565 quadrature hybrid
- Qorvo QPD1004 GaN PA + Mini-Circuits PHA-202+ driver
- 16-QAM, 10 MHz TX and RX signals



Static Measurements

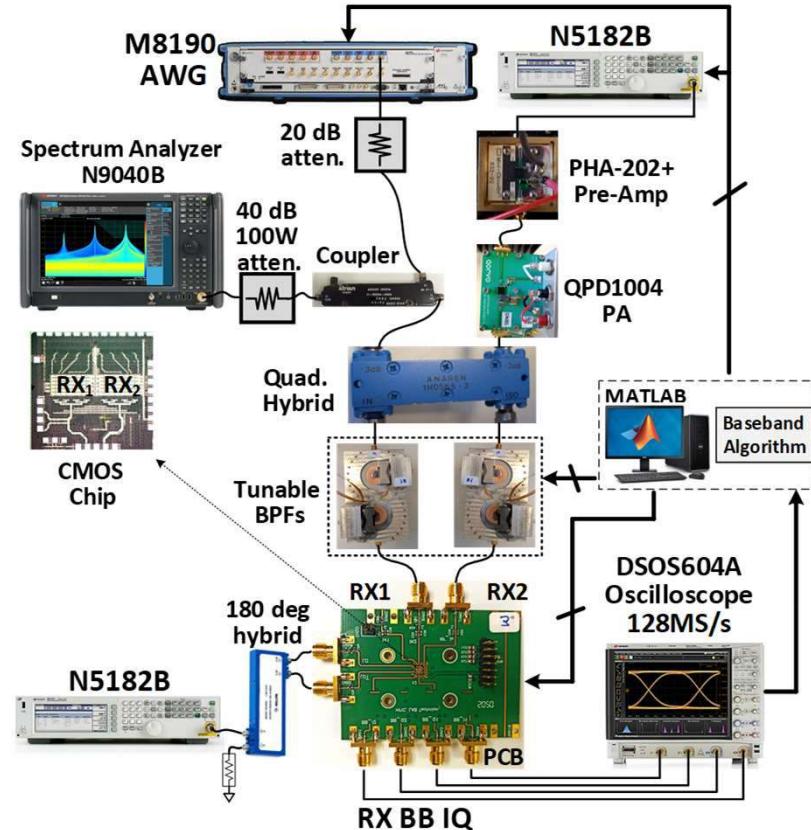
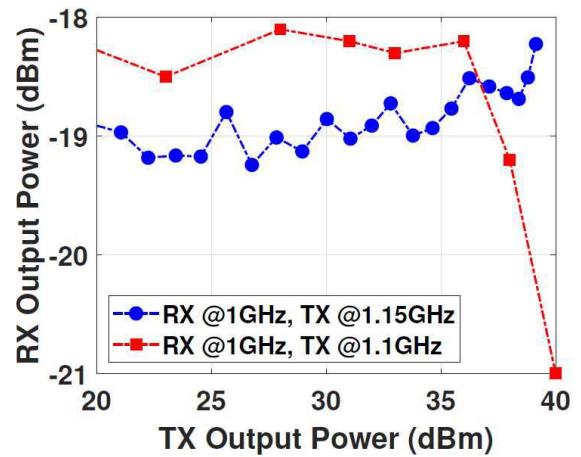
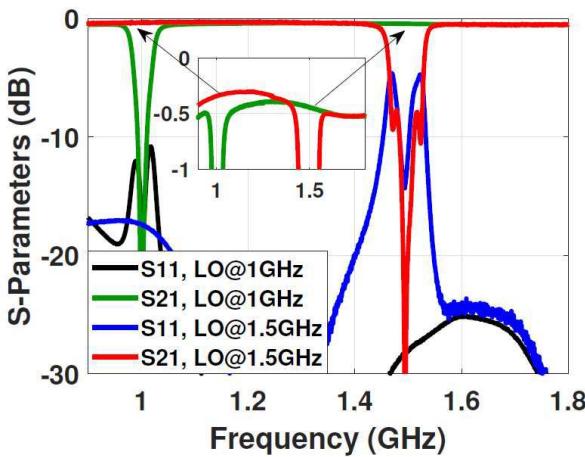
- Cavity Filter Standalone

- 0.8-1.8 GHz tuning range (gaps from 192 to 670 μm)
- IL lower than 0.4 dB
- OOB rejection > 22 dB at $\pm 100 \text{ MHz}$
- 8.2 GHz spurious free range
- Power handling > 100 W



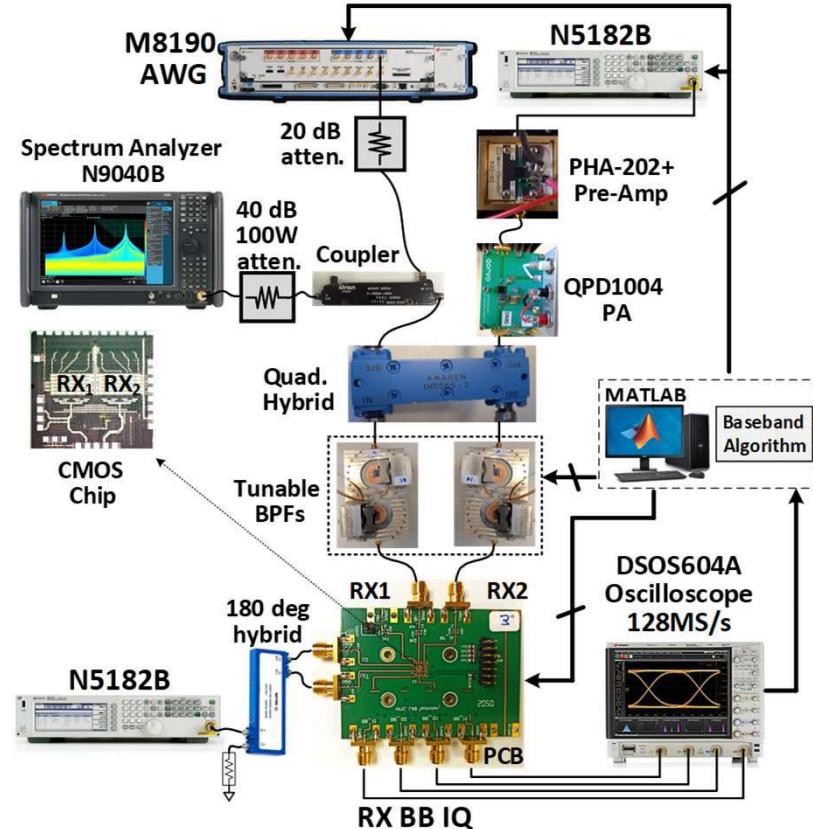
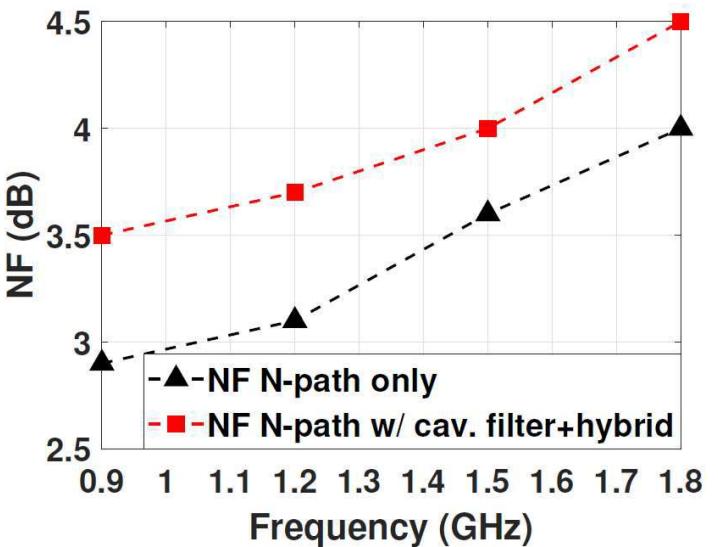
Static Measurements

- Combined Cavity Filter and N-path Response
 - TX IL < 0.4 dB
 - S11 < -12 dB
 - B1dB > 40 dBm @150 MHz offset
 - B1dB = 38 dBm @100 MHz offset



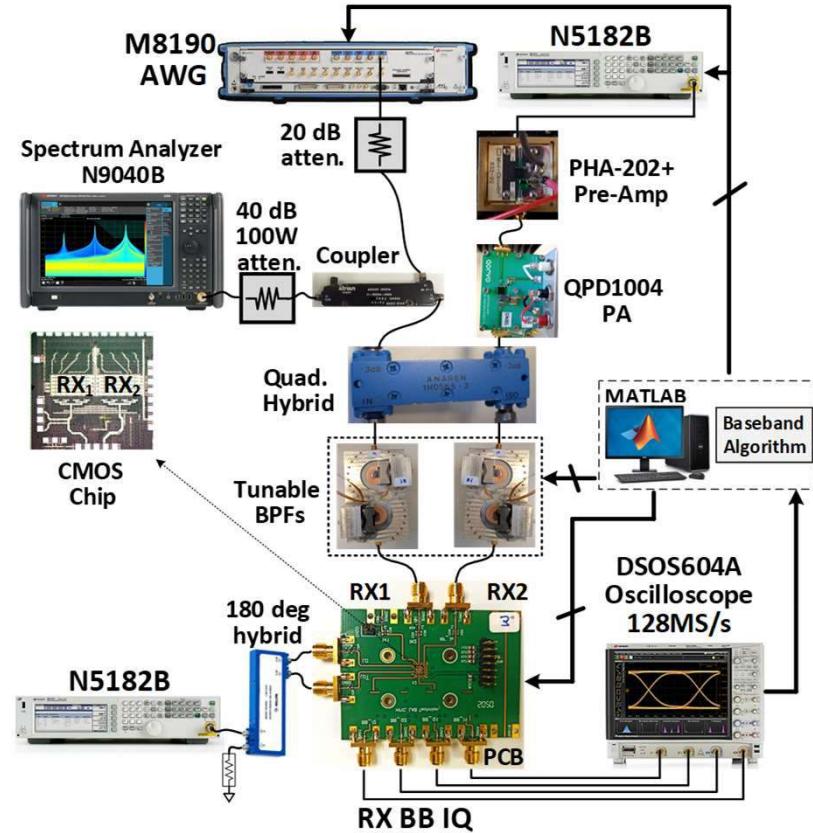
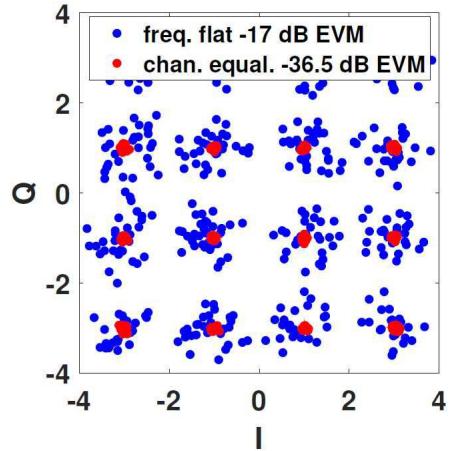
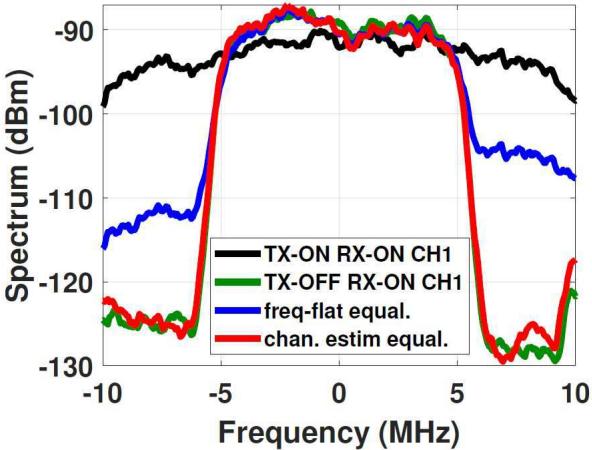
Static Measurements

- NF < 4.5 dB across tuning range
- 0.4 dB degradation compared to N-path standalone
- Cavity filter's harmonic impedance does not impact NF



Dynamic Measurements

- 25 dBm average TX power @1.1 GHz
- -40 dBm average RX power @1 GHz
- SNR = 0 before digital equalization
- EVM = -17 dB w/ freq. flat equalization
- EVM = -36.5 dB w/ channel estimation



Summary

- A 0.9-1.8 GHz tunable FDD transceiver front-end
- Evanescent-mode filters and a balanced 65 nm CMOS N-path RX
- Supports 100 MHz TX-RX spacing
- Lower than 0.4 dB degradation to both TX and RX paths
- RX B1dB > 38 dBm and >40 dBm at 100 and 150 MHz TX-RX offset
- Signal processing algorithm in digital baseband for TX noise cancellation and RX demodulation

Thank You!