

Full Duplex Wireless Communications

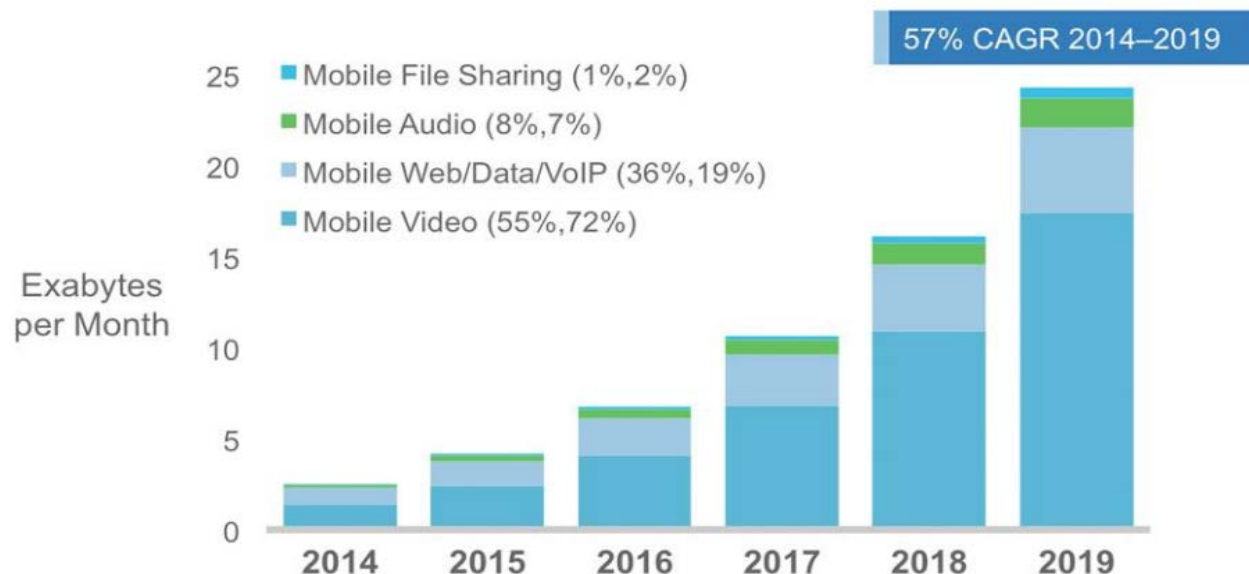
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Mobile Growth

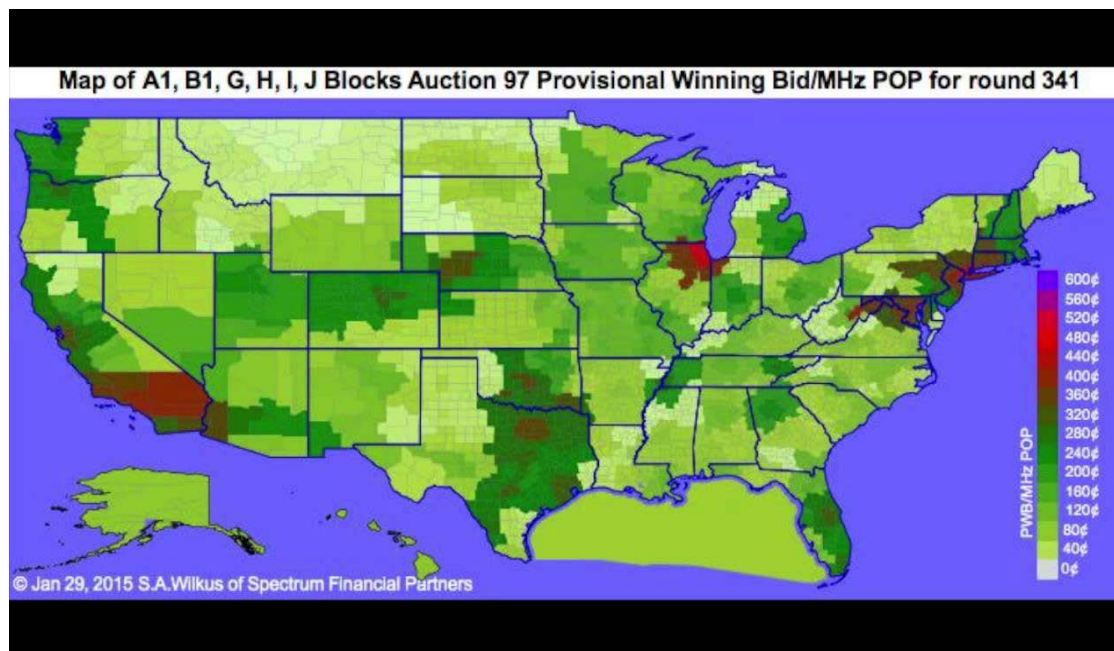
- ❑ Traffic from wireless and mobile devices will exceed traffic from wired devices by early 2016.*
- ❑ Mobile video is expected to dominate traffic with up to 72% of the total traffic by 2019.



Figures in parentheses refer to 2014, 2019 traffic share.
Source: Cisco VNI Mobile, 2015

Spectrum Crunch?

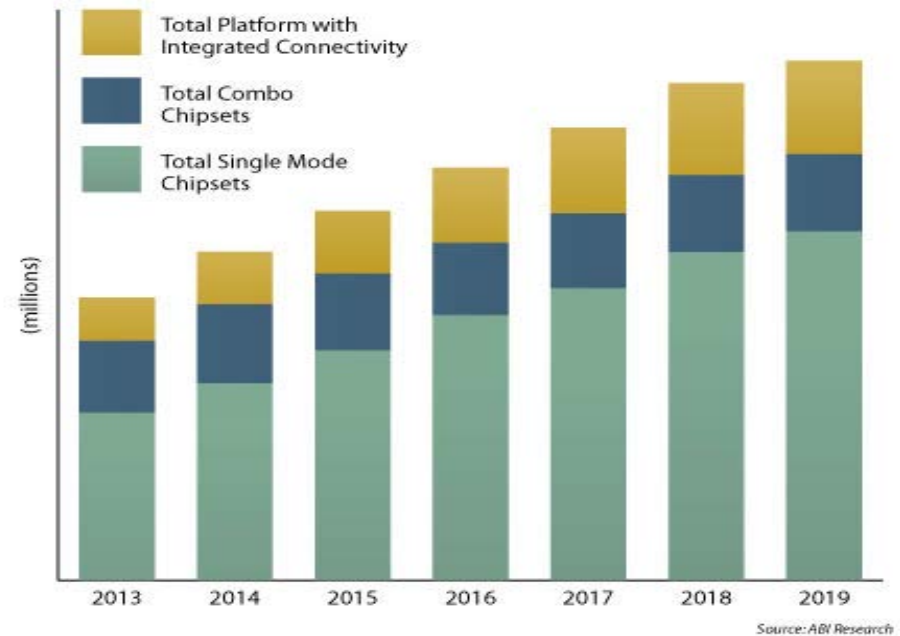
- ❑ In the recent auction (Auction 97, January 2015), the FCC received \$45B in bids for a total of 65 MHz of spectrum,
 - ❑ A record average of \$2.11/MHz-pop.
 - ❑ Considerably higher than the average of US \$1.28/MHz-pop paid in 2008 for 700MHz spectrum
 - ❑ A large multiple over the AWS spectrum prices paid in 2006 (US \$0.56/MHz-pop).
- ❑ From 1994-2014, \$53B raised in spectrum auctions. **In 2015 alone, \$45B was raised!**



Unlicensed Spectrum

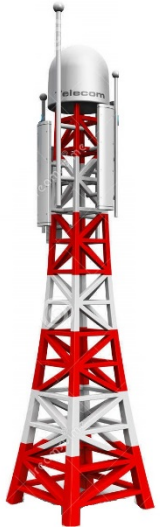
- ❑ From 2015 to 2019, cumulative shipments of connectivity chipsets (Wi-Fi, Bluetooth, NFC, etc.) will almost double to over 39 billion.
- ❑ Spanning the period from 2010 to 2019, over 60 billion wireless connectivity chipsets will have shipped.

Standalone, Combo ICs and Platform Solutions Shipments
World Market, Forecast: 2013-2019



As the number of clients accessing unlicensed spectrum increases, the ability to access the spectrum decreases exponentially, leading to lower QoS and poor user experiences.

Duplexing



TDD

Time utilization 50%
Freq. utilization 100%



Same frequency, different times



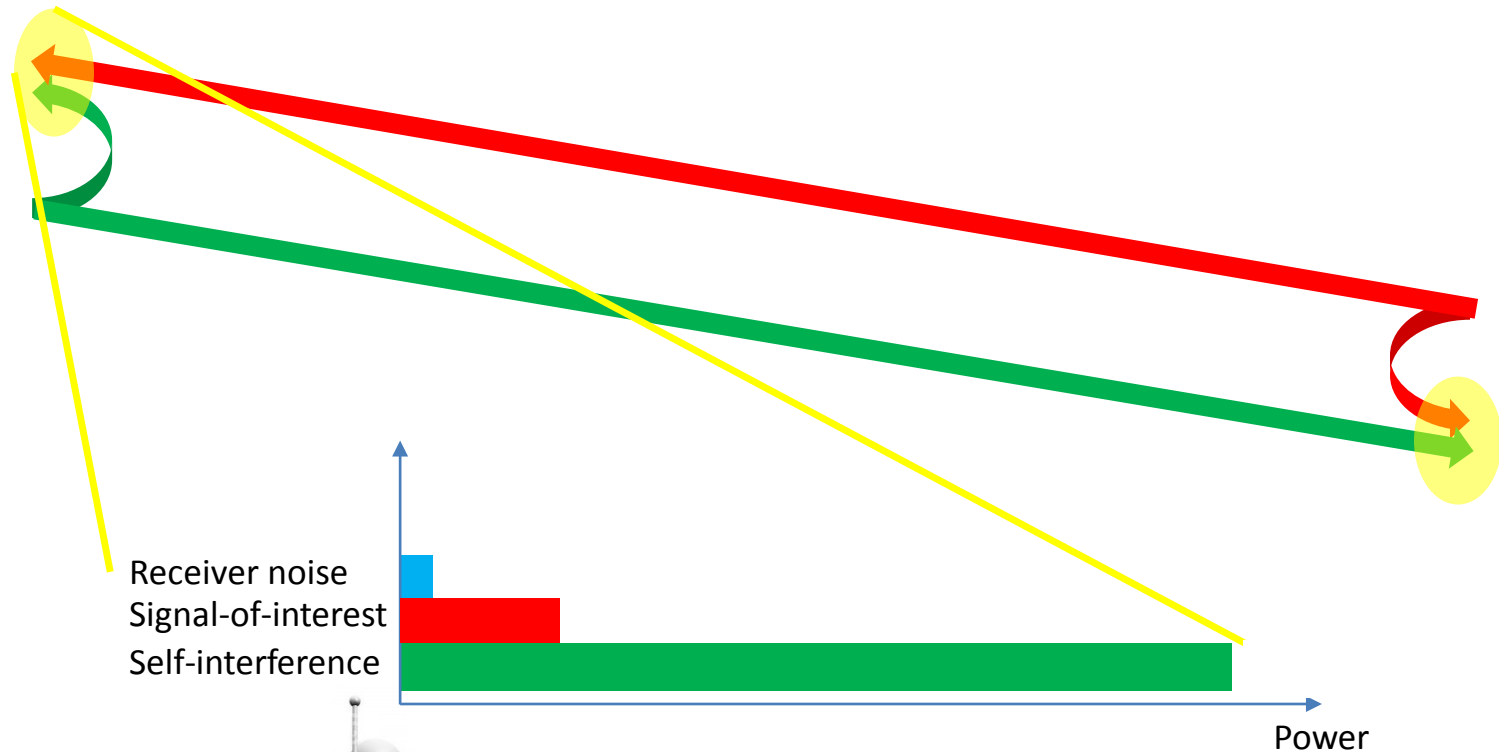
FDD

Time utilization 100%
Freq. utilization 50%



Same time, different frequencies

Challenges



Traditionally, full-duplex transmission was not feasible due to the significant self-interference power that disrupts the receiver operation.

“The screaming in ones’ own ear syndrome”

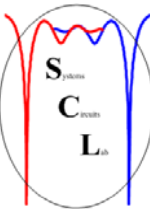
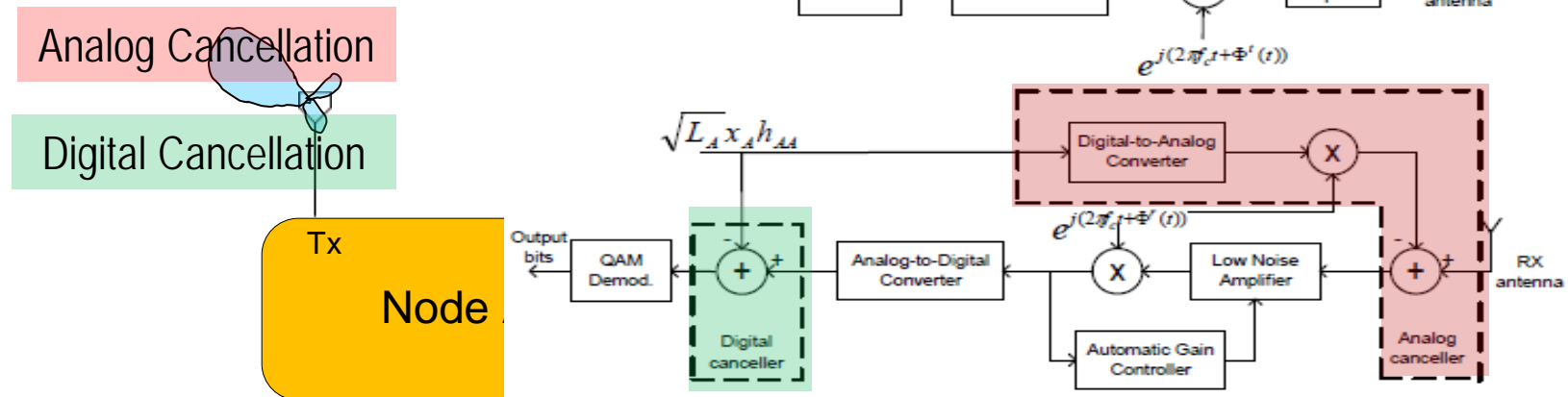
The self interference signal (SI) has to be reduced to close to the noise floor for correct operation of the system.



Self-interference Cancellation Techniques

- Self-interference cancellation techniques can be divided into two main categories.

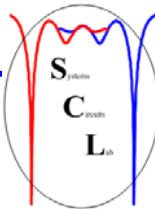
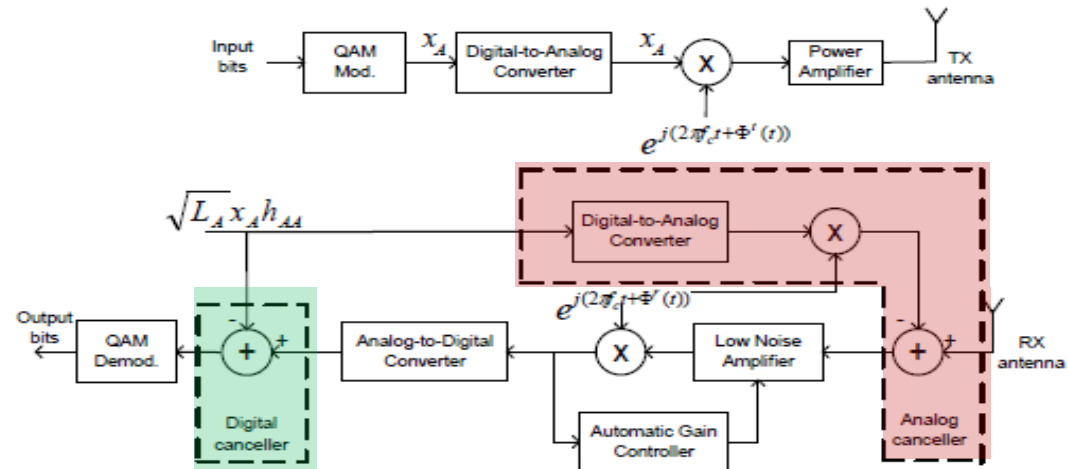
- **Passive cancellation**, where the self-interference signal is canceled by suppressing the propagation channel. **Suppress both the SI signal and the transmitter noise but with limited cancellation capability.**



Related Work

Self-interference cancellation using *analog* and *digital* cancellation techniques.

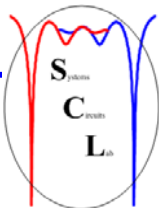
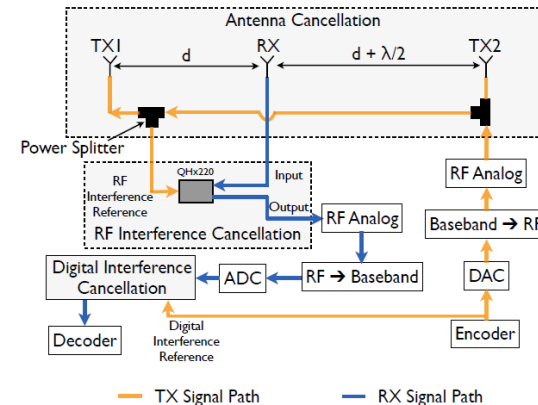
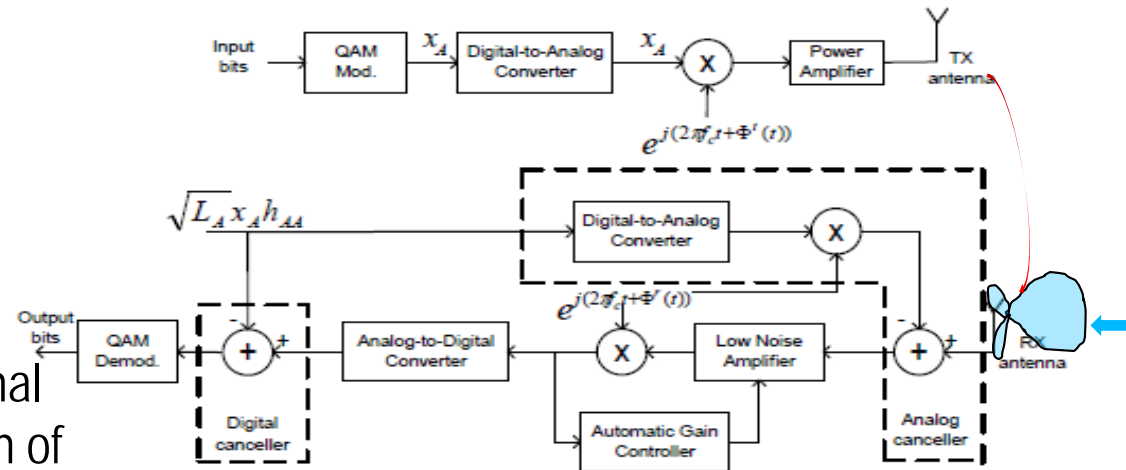
- Advantages
 - Low complexity
- Disadvantages
 - Does not suppress the noise (the gain is noise limited)
- Achievable gain
 - Phase noise dependent (35dB to 40dB based on the available chipsets).



Related Work

Self-interference cancellation using *passive* plus *analog/digital* cancellation techniques.

- Advantages
 - Suppress part of the noise.
- Disadvantages
 - Using Fixed pattern directional antenna affects the reception of the signal from far node.
 - Appropriate antenna placement is required especially for wide-band systems.
- Achievable gain
 - ~85dB for the first architecture and ~60dB for the second one..



Related Work

Self-interference cancellation using *RF* and *digital* cancellation techniques.

- Advantages
 - Suppress both the self interference and the noise associated with it.
 - Achieves high cancellation gain.
- Disadvantages
 - High complexity (RF Multi-Tap filter)
 - Large dimensions
 - Not suitable for handheld devices
- Achievable gain
 - 65dB cancellation gain alone.
 - 105 dB gain combined with digital cancellation

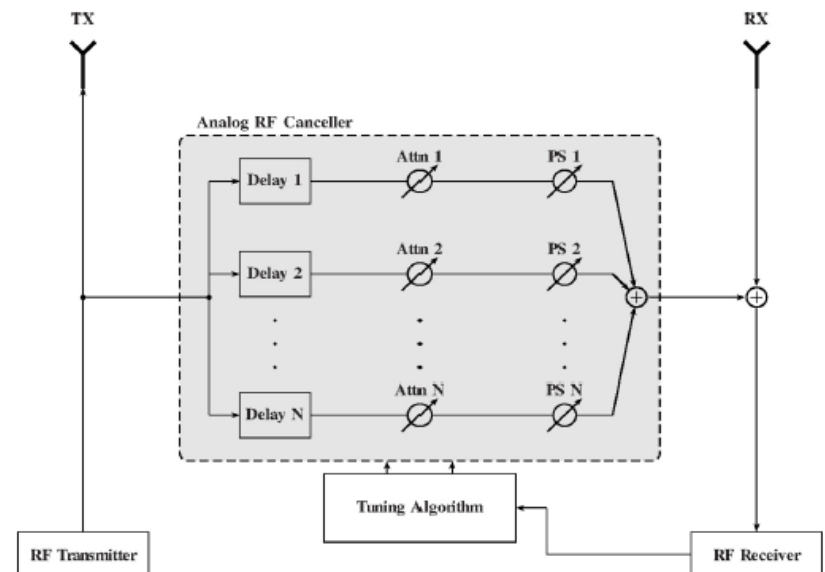
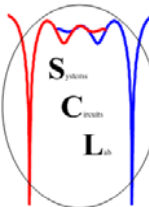
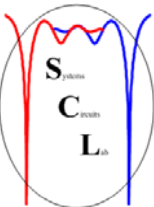


Fig. 1. Analog RF canceller consisting of N paths with fixed time delay, variable attenuators, and variable phase shifters.



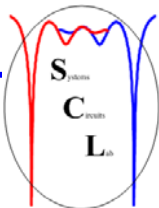
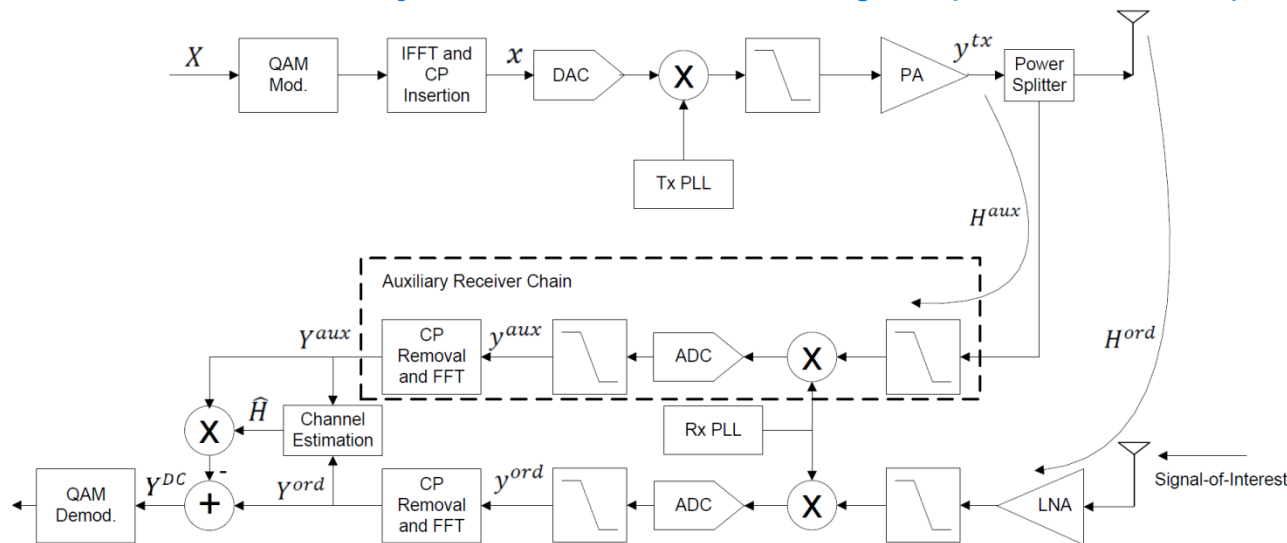
Proposed Solution

- Proposed a new digital cancellation techniques that is capable of *suppressing the major noise components in the system* (e.g. nonlinearities and phase noise).
- Proposed a new passive cancellation techniques using *reconfigurable antennas* for better system performance from both *SI cancellation and far node reception perspectives*.



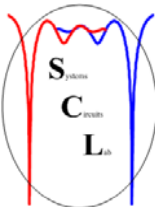
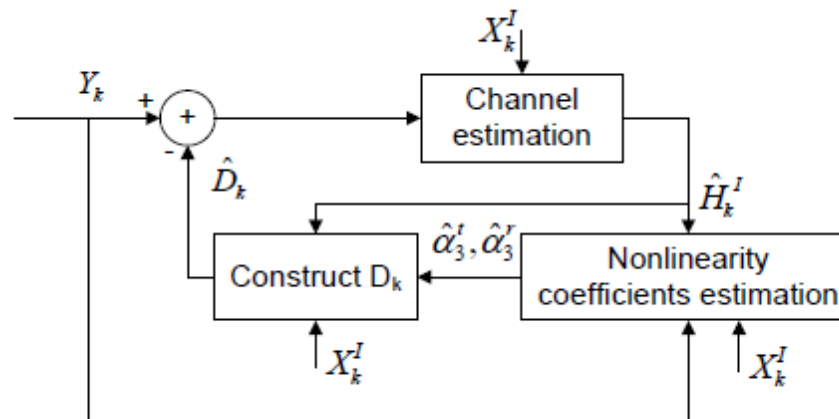
All-Digital Self-interference Cancellation

- Instead of using the transmitted base-band signal as a reference for SI cancellation, use the transmitted RF signal.
- All transmitter impairments will be mitigated and the system will be limited by the receiver impairments.
- Sharing the Rx PLL between the auxiliary and ordinary receiver chains alleviate the receiver phase noise effect.
- The receiver nonlinearity could be eliminated using the previous technique.



Nonlinearity- Suppression

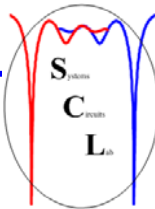
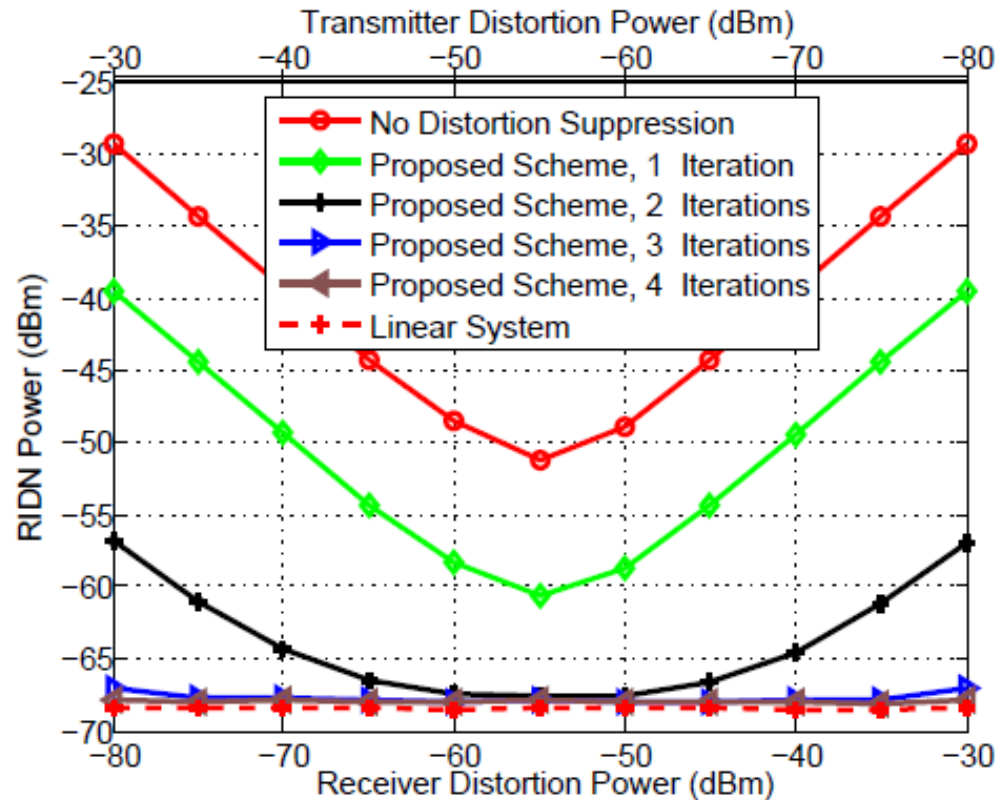
- SI cancellation with Tx and Rx nonlinearity distortion suppression.
- In this work, the full-duplex system performance is improved by suppressing the distortion caused due to system nonlinearities.
- Both transmitter and receiver nonlinearity are considered.



Performance

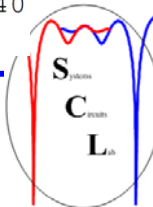
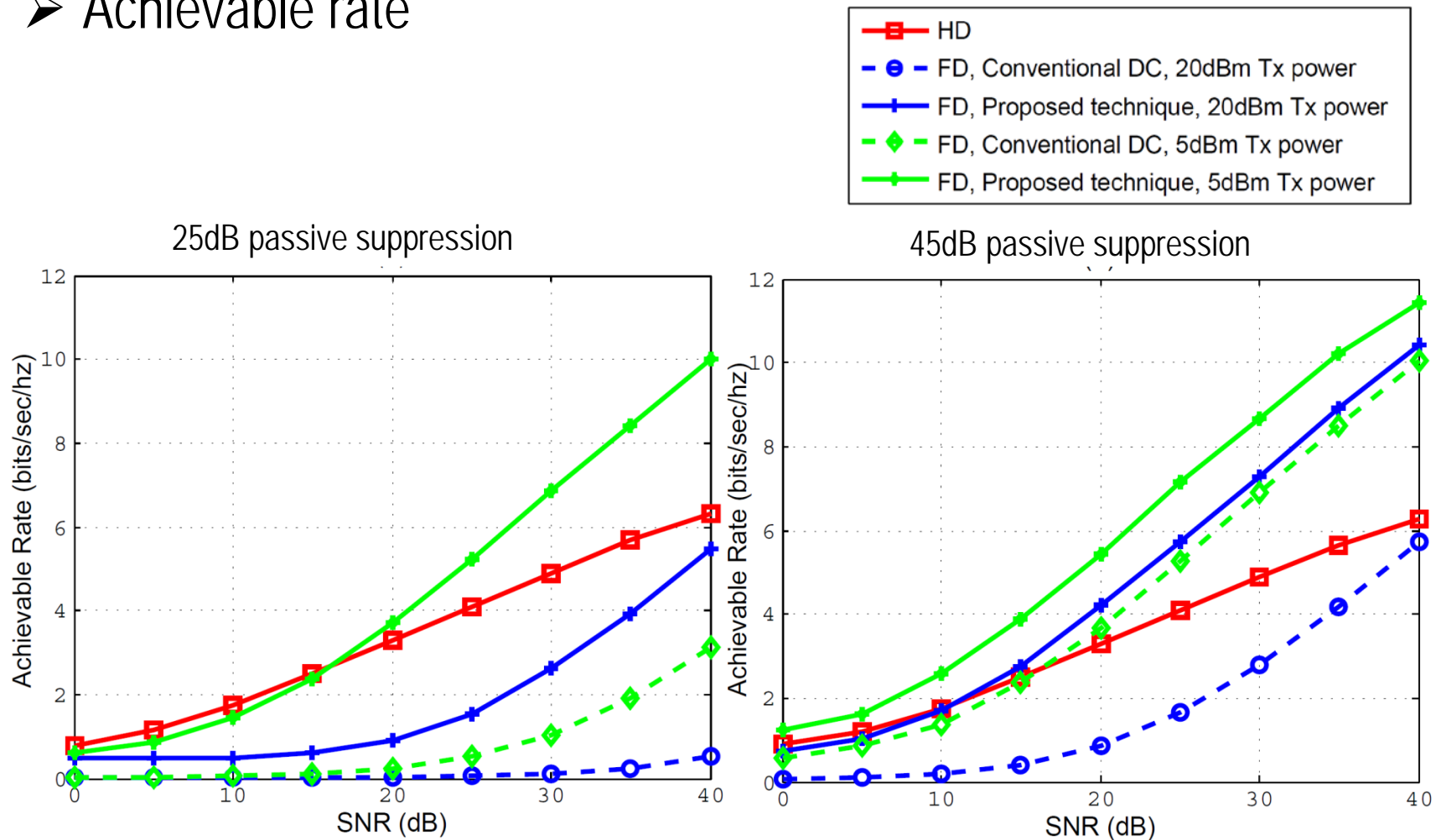
➤ SI cancellation with Tx and Rx nonlinearity distortion suppression.

- ✓ RIDN is the residual interference plus distortion plus noise
- ✓ Complete distortion suppression to the level of the next bottleneck.
- ✓ Same performance when transmitter or receiver distortion dominates.



All-Digital Self-interference Cancellation

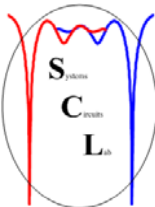
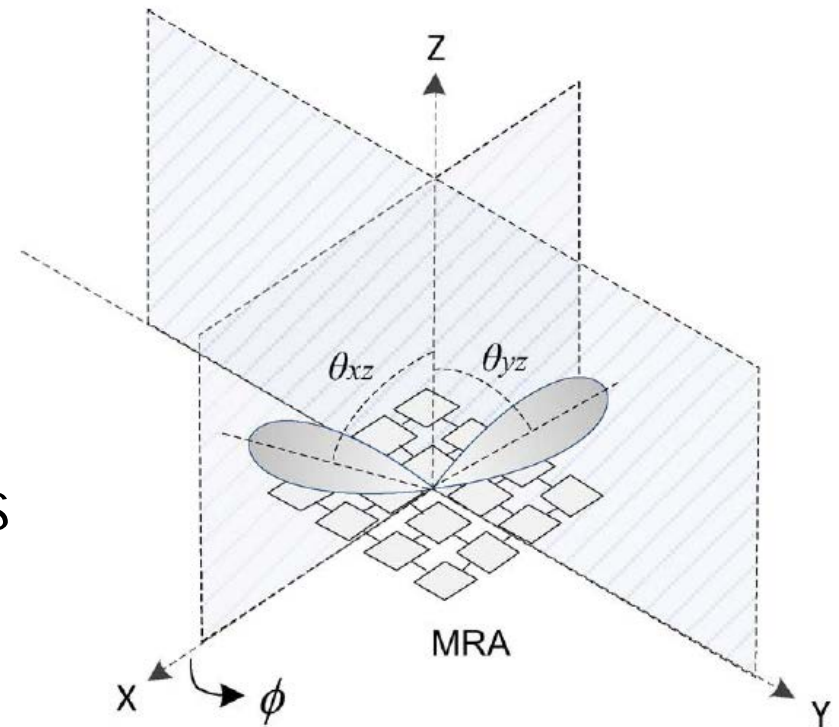
➤ Achievable rate



Passive Suppression

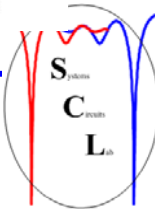
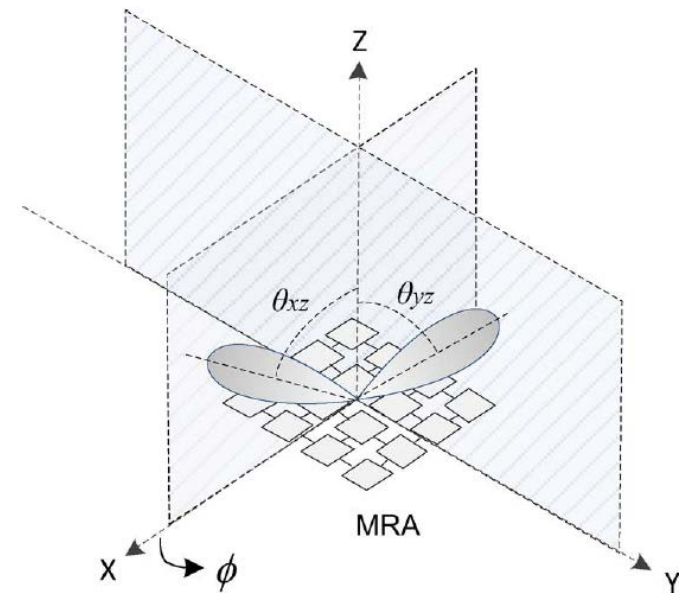
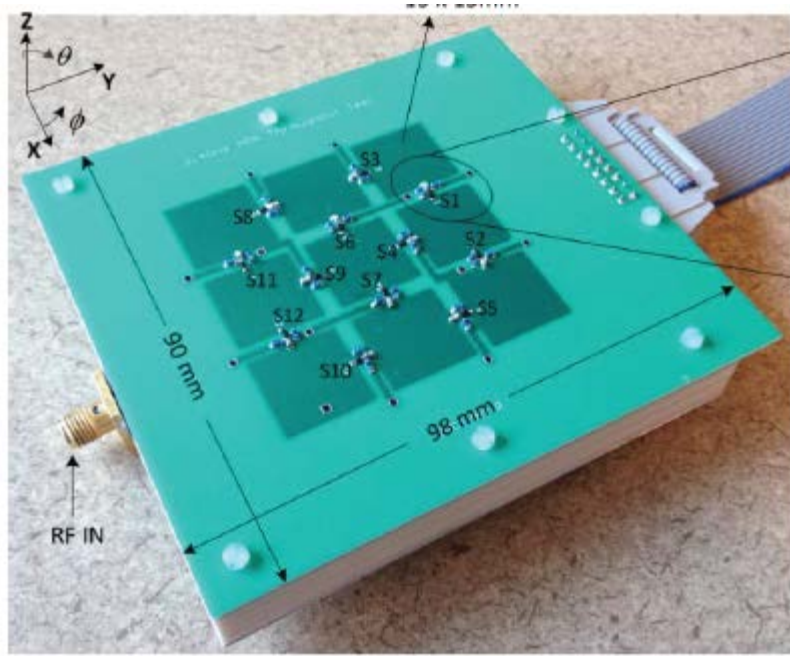
➤ Passive SI cancellation using Multi-Reconfigurable Antennas (MRA).

- Reconfigurable antenna is capable of dynamically change its pattern to point in one of "M" predefined directions.
- The number of antenna patterns (M) could be as large as 4096 patterns.



Passive SI Cancellation Using MRA.

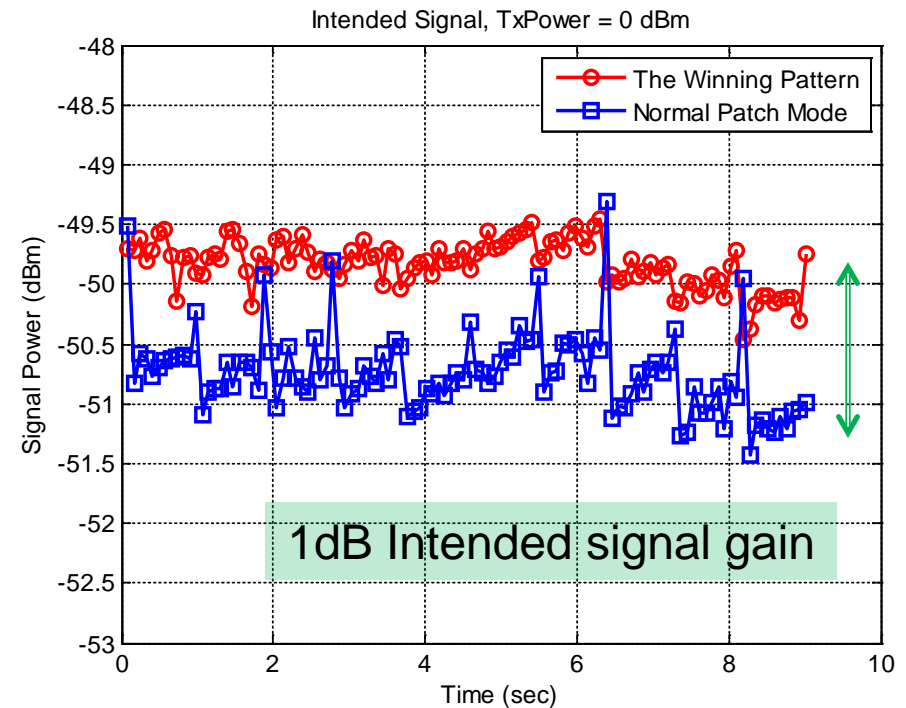
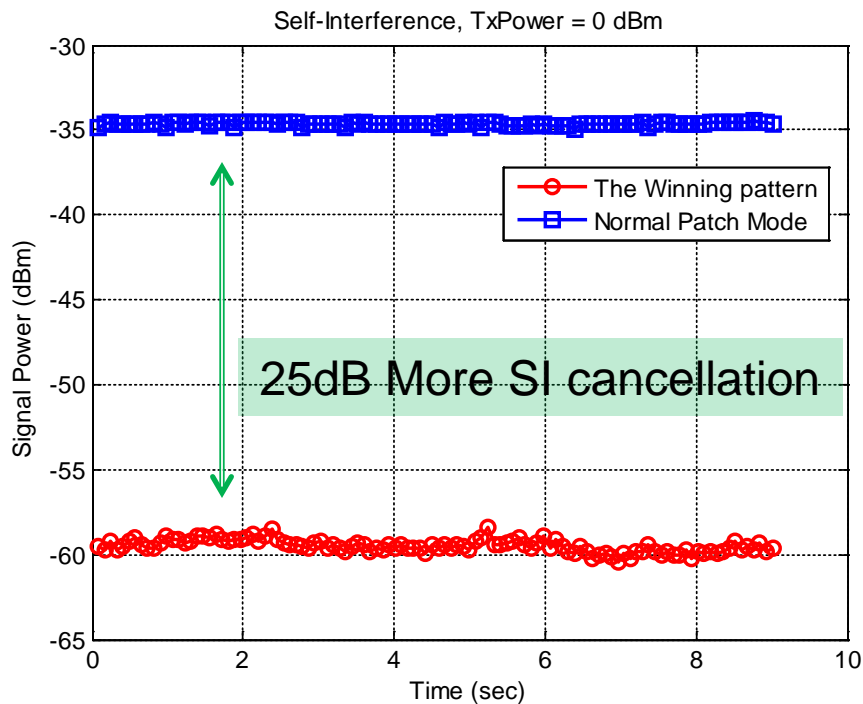
- The fabricated MRA has 4096 different patterns.
- The pattern is selected using 12-bits digital interface.



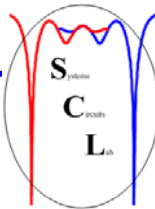
Results

➤ Passive SI cancellation using MRA.

Experimental results in typical indoor environments

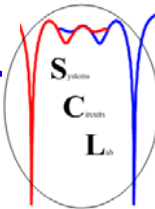
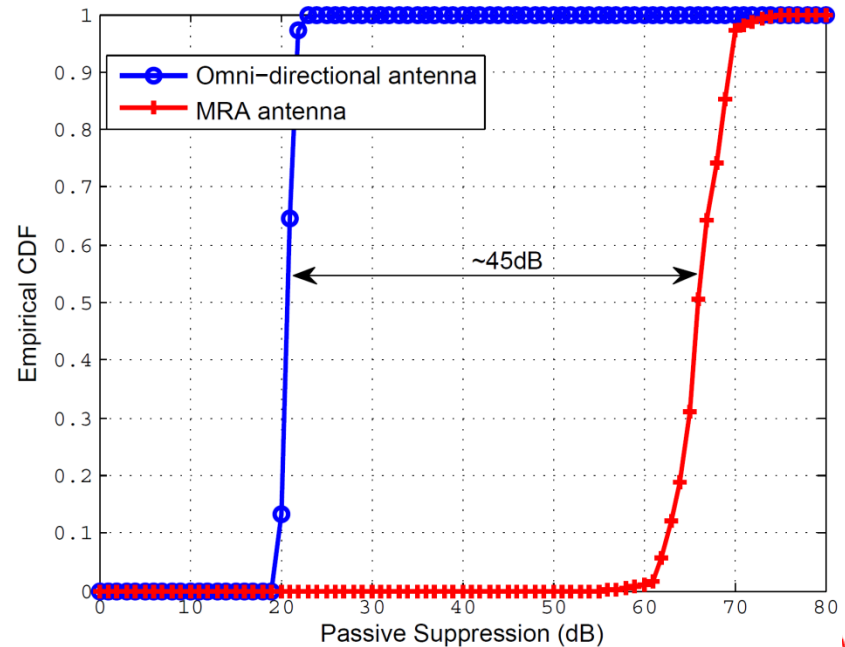
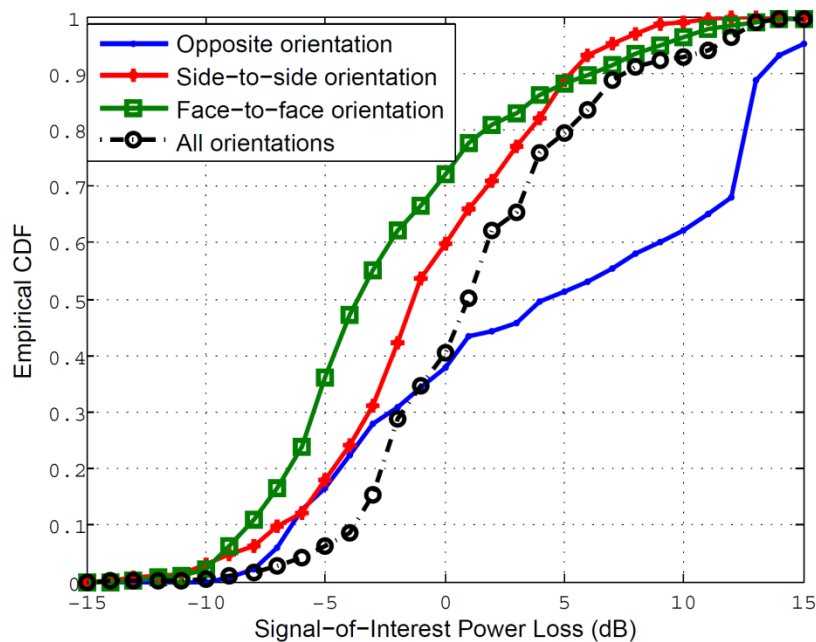


26dB SIR gain



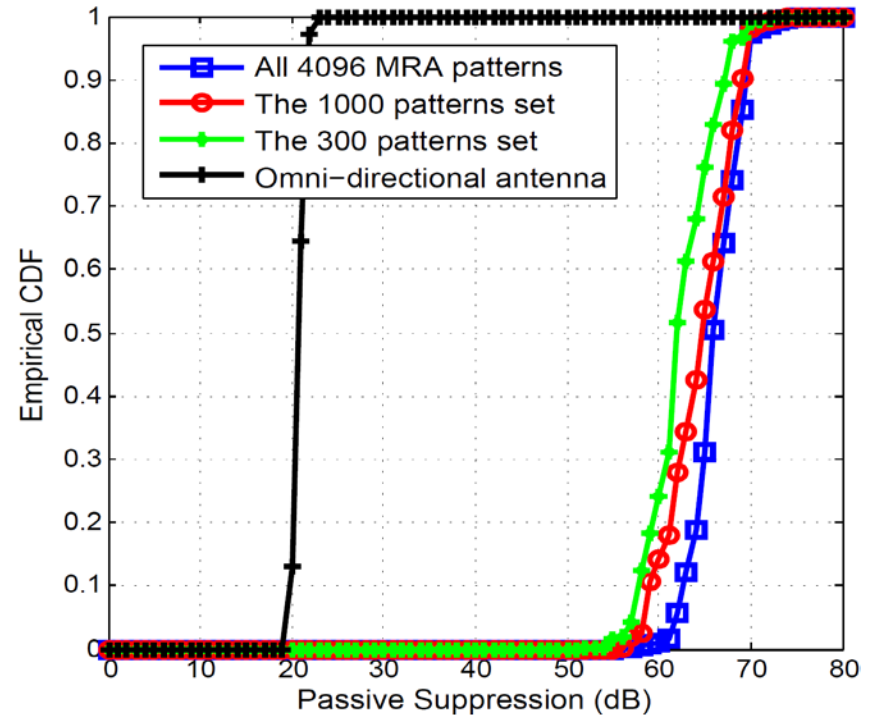
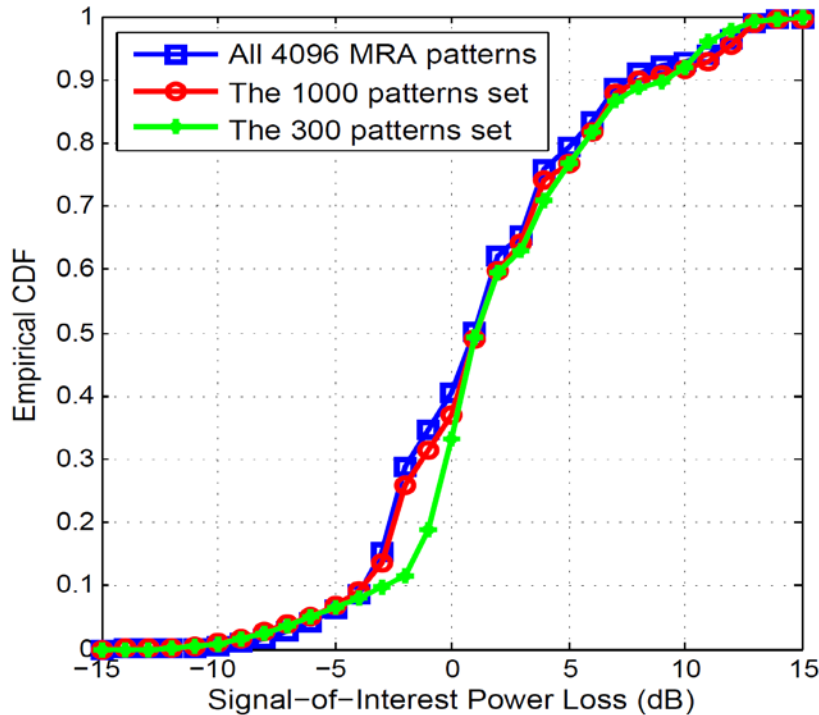
Passive SI Cancellation Using MRA.

- Training sequences are transmitted at the beginning of each data frame for pattern selection purposes.
- The pattern that maximizes the SIR is selected.
- The selected pattern affects both the received SI and SOI.

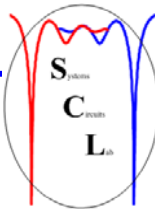


Passive SI Cancellation Using MRA.

➤ Pattern selection heuristic performance

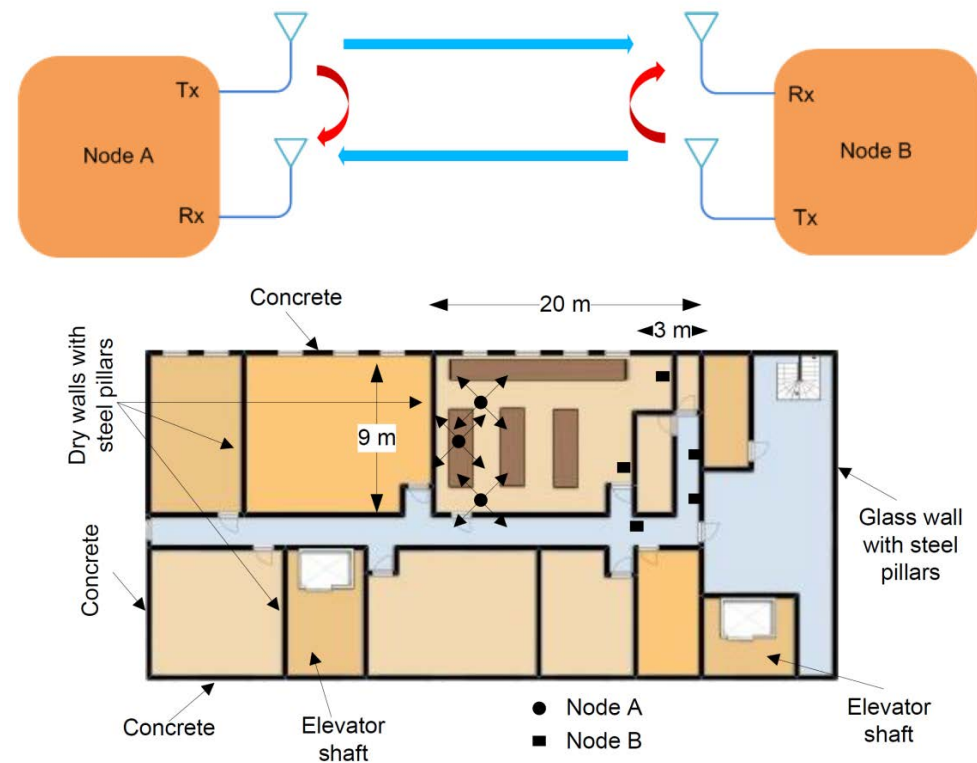
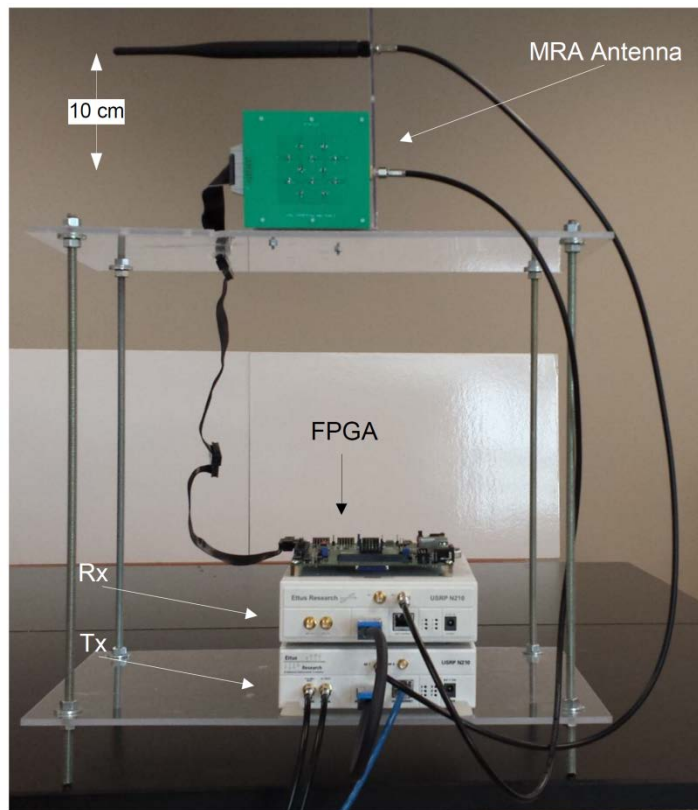


- ❑ No signal-of-interest power degradation.
- ❑ Only 3dB loss in the achieved passive suppression with 300 patterns.



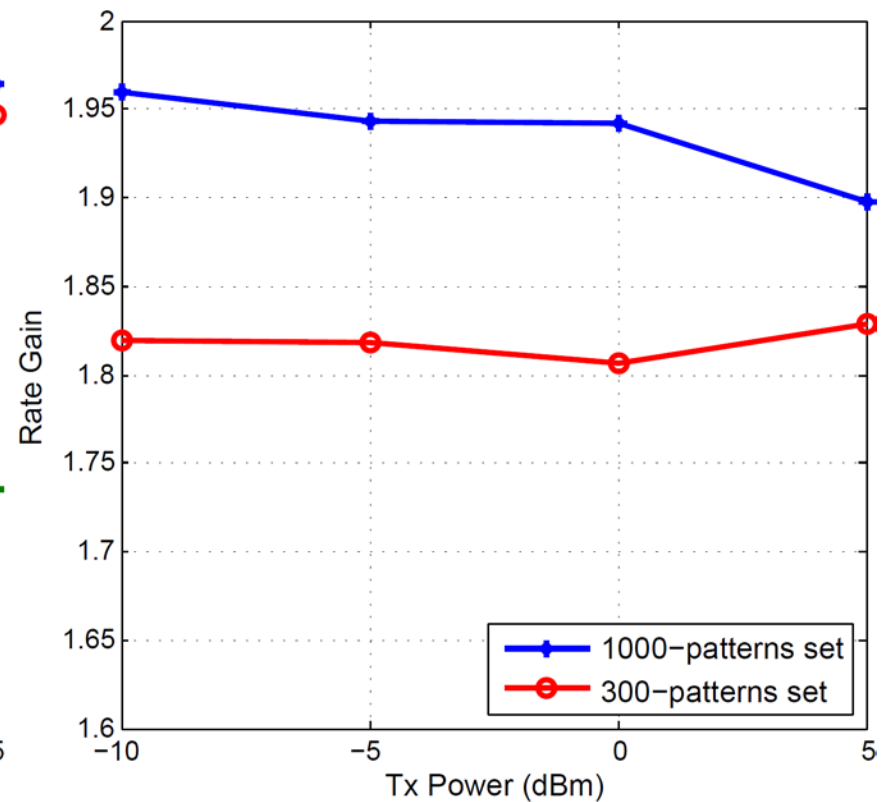
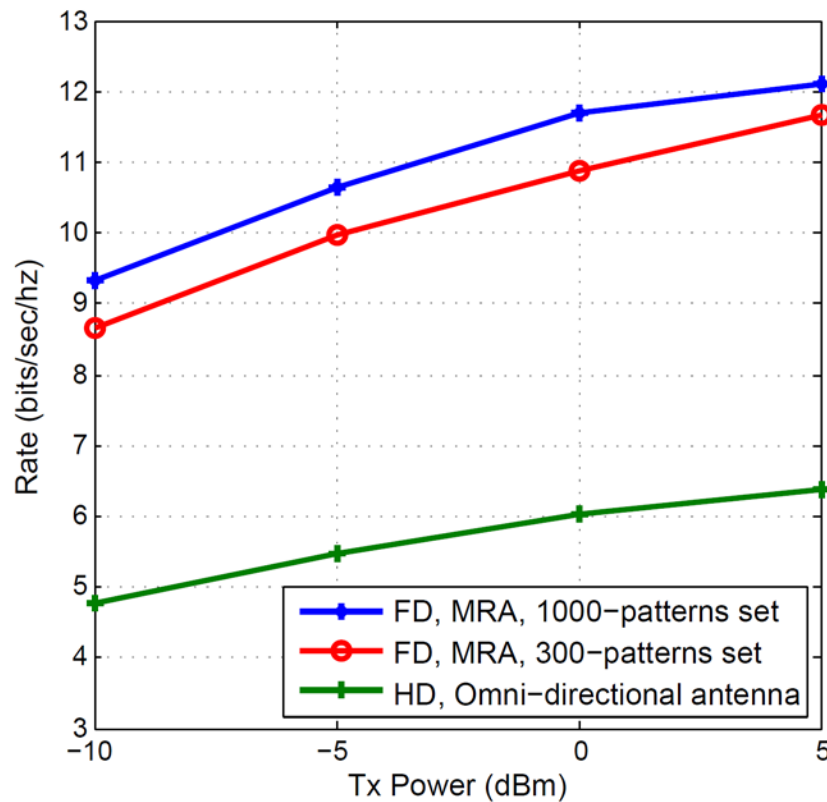
Full-Duplex Systems Using MRA

- Burst real-time Full-duplex system using USRP platforms.



Full-duplex Systems Using MRA

➤ Achievable rate



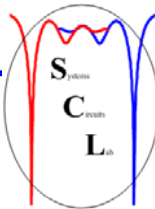
Video

Video Link: <http://youtu.be/uRMv0S-PtGk>

Acknowledgments



Note: The opinions, findings and conclusions or recommendations expressed in this publication/program/exhibition are those of the author(s) and do not necessarily reflect the views of the Department of Justice or the National Science Foundation (NSF) or any of our sponsors.



Thank You



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