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The diagram illustrates three types of duplexing:

- TDD Operation:** Shows a base station and a mobile phone. In the "Even time slot", the phone transmits to the base station. In the "Odd time slot", the base station transmits to the phone. A legend indicates blue for "Transmit signal" and purple for "Receive signal".
- FDD Operation:** Shows a base station and a mobile phone. In the "Every time slot", both transmit and receive simultaneously. A legend indicates blue for "Transmit signal" and purple for "Receive signal". A power spectrum graph shows a purple bar for f_{RX} and a blue bar for f_{TX} at different frequencies.
- Full-Duplex Operation:** Shows a base station and two mobile phones. The base station transmits to one phone and receives from another simultaneously. A legend indicates blue for "Transmit signal" and purple for "Receive signal". A power spectrum graph shows a single bar for $f_{RX} = f_{TX}$ at the same frequency.

The figure is divided into four main sections:

- Block Diagram (Top Left):** Shows a full-duplex radio system. A TX (Transmitter) and RX (Receiver) are connected to a circulator. The TX signal is sent to the RX via the circulator. The RX signal is sent to the TX via the circulator. The TX and RX are connected to a circulator. The TX signal is sent to the RX via the circulator. The RX signal is sent to the TX via the circulator.
- PCB Layout (Bottom Left):** A photograph of the PCB layout showing the TX and RX paths. The dimensions are 2.1mm by 2.3mm.
- Isolation Graph (Middle Left):** A graph of TX/RX isolation (dB) vs. Frequency (GHz). The graph shows two curves: "without cancellation" (blue) and "Gen1 (ISCC2014)" (red). The "without cancellation" curve shows a deep null at 1.34 GHz, while the "Gen1" curve shows a shallower null. The "Gen2 (ISCC2015)" curve (green) shows a deeper null than Gen1.
- Chip Layout (Bottom Right):** A photograph of the chip layout showing the TX and RX paths. The dimensions are 1.8mm by 0.8mm. The layout includes components like LNTA, Mixer, RX Baseband TIAs, Integrated Circulator, Circulator LO Path, Analog BB Canceller, TX BB Output Buffer, TX BB Input Buffer, Reconnection Circuit, and SPI.

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2. W. Li, J. Lilleberg, and K. Rikkinen, "On rate region analysis of half-and full-duplex OFDM communication links," *IEEE J. Sel. Areas Commun.*, vol. 32, no. 9, pp.1688 – 1698, Sept. 2014.
3. A. Sabharwal, P. Schniter, Dongning Guo, D. W. Bliss, S. Rangarajan, R. Wichman, "In-Band Full-Duplex Wireless: Challenges and Opportunities," *IEEE J. Sel. Areas Commun.*, vol.32, no.9, pp.1637-1652, Sept. 2014 (and reference therein)
4. Y. Yang and N. B. Shroff, "Scheduling in Wireless Networks with Full-Duplex Cut-through Transmission," In Proc. *IEEE INFOCOM* N.15, 2015.

Poster based on:

1. J. Marašević and G. Zussman, "On the Capacity Regions of Single-Channel and Multi-Channel Full-Duplex Links," *accepted to ACM MobiHoc*'16, 2016.
2. Jelena Marašević, Jin Zhou, Harish Krishnaswamy, Yuan Zhong, and Gil Zussman, "Resource allocation and rate gains in practical full-duplex systems," in Proc. *ACM SIGMETRICS*'15, June 2015.
3. Jin Zhou, Tsung-Hao Chuang, Tolga Dinc and Harish Krishnaswamy, "Reconfigurable receiver with >20MHz bandwidth self-interference cancellation suitable for FDD, co-existence and full-duplex applications," in Proc. *IEEE ISCCC*'15, Feb. 2015.
4. Jin Zhou, Peter R. Kinget and Harish Krishnaswamy, "A Blocker-Resilient Wideband Receiver with Low-Noise Active Two-Point Cancellation of >0dBm TX Leakage and TX Noise in RX Band for FDD/Co-Existence," in Proc. *IEEE ISCCC*'16, Feb. 2014.

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Testbed:

The testbed setup involves a **TX** (Transmitter) and an **RX** (Receiver). The **TX** consists of a **Signal Generator** connected to an **Antenna**, which transmits through a **Wireless Channel** to the **RX**. The **RX** consists of an **Antenna** connected to a **~20dB Circulator**, which is then connected to an **Analog SIC** block. The output of the **Analog SIC** is connected to a **NI USRP** (National Instruments Universal Software Radio Peripheral). The **NI USRP** is connected to an **Ethernet Data + Control Information** block. The **NI USRP** has **TX** and **RX** ports. The **Ethernet Data + Control Information** block is connected to a **Signal generator** and a **Send & receive data** block. The **Signal generator** is connected to the **NI USRP** via **Digital SIC ~50dB**. The **Send & receive data** block is connected to the **NI USRP** via **Digital SIC ~50dB**.

The plots show the following:

- Tx IQ Baseband signal**: Time-domain plot of the transmitted signal.
- Tx IQ Baseband Amplitude Spectrum**: Frequency-domain plot of the transmitted signal.
- Rx IQ Baseband signal**: Time-domain plot of the received signal after circulator isolation.
- Rx IQ Baseband Amplitude Spectrum**: Frequency-domain plot of the received signal after circulator isolation.
- Residual SI Waveform**: Time-domain plot of the residual self-interference waveform.
- Residual SI Spectrum**: Frequency-domain plot of the residual self-interference waveform.
- Received signal after analog SIC cancellation**: Time-domain plot of the received signal after analog SIC cancellation.
- Received signal after digital SIC cancellation**: Time-domain plot of the received signal after digital SIC cancellation.

Chip-based Receiver

RX based on our RFIC chip

Testbed PCB Design

TX with off-the-shelf quadrature modulator and PA

- Near optimal polynomial-time algorithm for general SINR regime
- Near optimal fast algorithm for high SINR approximation
- Measured and modeled cancellation profile

- The problem is non-convex and hard to solve in general
- However, we design an alt. max. algorithm that is guaranteed to converge to a stationary point (a global max in practice)
- We also design a simple heuristic with similar performance

Alternating Maximization vs Heuristic

Avg DL SNR = Avg UL SNR

- Adaptive self-interference-cancellation
- MAC layer algorithm design for full-duplex networks
- Testbed development and algorithm implementation

The block diagram illustrates the system architecture. A 'Varying Environmental Reflection' is shown as a signal reflecting off two surfaces. This signal enters a 'Non-Magnetic Oscillator' block. The output of the oscillator is split: one path goes to a 'Mixed-domain Self-Interference Canceller' block, and the other path goes to a '2nd-Order Feedback Network' block. The 'Mixed-domain Self-Interference Canceller' block also receives a signal from a 'TX' block. The output of the 'Mixed-domain Self-Interference Canceller' is sent to an 'ADC' block. The output of the '2nd-Order Feedback Network' is also sent to the 'ADC' block. The output of the 'ADC' block is sent to a 'Digital Self-Interference Cancellation' block. The output of the 'Digital Self-Interference Cancellation' block is sent to an 'Adaptive Self-Interference Cancellation' block. The output of the 'Adaptive Self-Interference Cancellation' block is sent to a 'DAC' block. The output of the 'DAC' block is sent to the 'TX' block. The 'TX' block also receives a signal from the 'Non-Magnetic Oscillator' block.

The graph, titled 'Algorithm: Preliminary Simulation Results', shows 'Cancellation (dB)' on the y-axis (ranging from 0 to -50) versus 'Frequency (GHz)' on the x-axis (ranging from 1.2 to 1.5). Three curves are plotted: '2 filters' (green), '3 filters' (purple), and '5 filters' (blue). All curves show a sharp drop in cancellation (increasing dB value) around 1.35 GHz, reaching a minimum around 1.4 GHz. The '5 filters' curve reaches the lowest minimum (approximately -48 dB), followed by the '3 filters' curve (approximately -45 dB) and the '2 filters' curve (approximately -42 dB). The curves then rise sharply towards 0 dB as frequency increases beyond 1.45 GHz.

- Design scheduling algorithms that support both half and full-duplex users
- Design challenges:
 - Full-duplex users are prioritized: how do we guarantee fairness/QoS?
 - Correlation between UL/DL rates
 - Feasible rate region need not be convex
- Develop scheduling and resource allocation algorithms:
 - Decide which MS gets which channels
 - Decide who transmits when

Users

OFDM Channels:

UL	DL
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10