Full Duplex Radios

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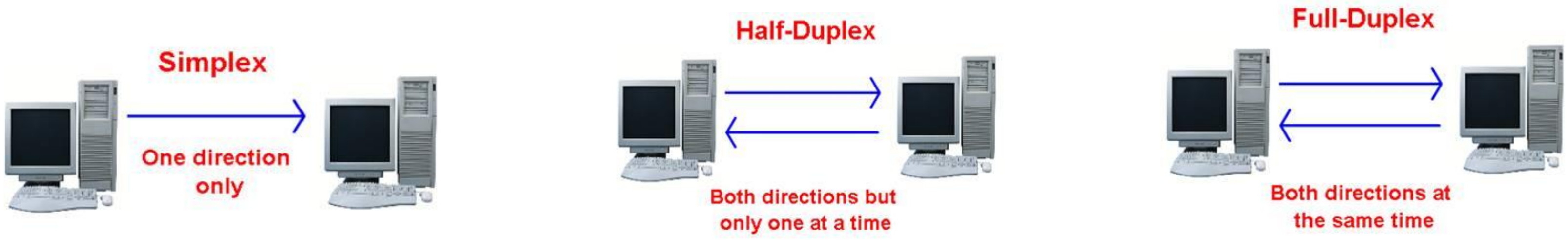
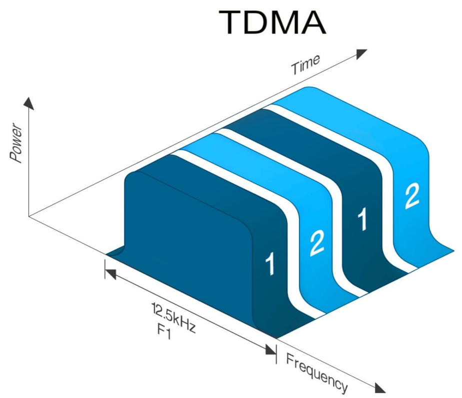
Types of Communication

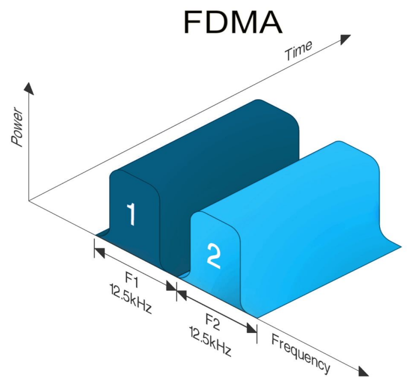
- **Simplex** – Data can be transferred only in one direction.
- **Half – Duplex** – Data can be transferred in both directions but not simultaneously.
- **Full – Duplex** – Data can be transferred in both directions simultaneously.



Current State of Radios

- Conventional half duplex wireless systems rely on transmitting and receiving in **different time slots** (TDMA) **or frequency sub carriers** (FDMA).
- Demand for telecom services is booming, but radio spectrum is limited.
- Have to do more with less, design radios with **greater spectral efficiency**.
- Solution is full duplex radio, which promises doubling the data rate in comparison to its half duplex counterpart.





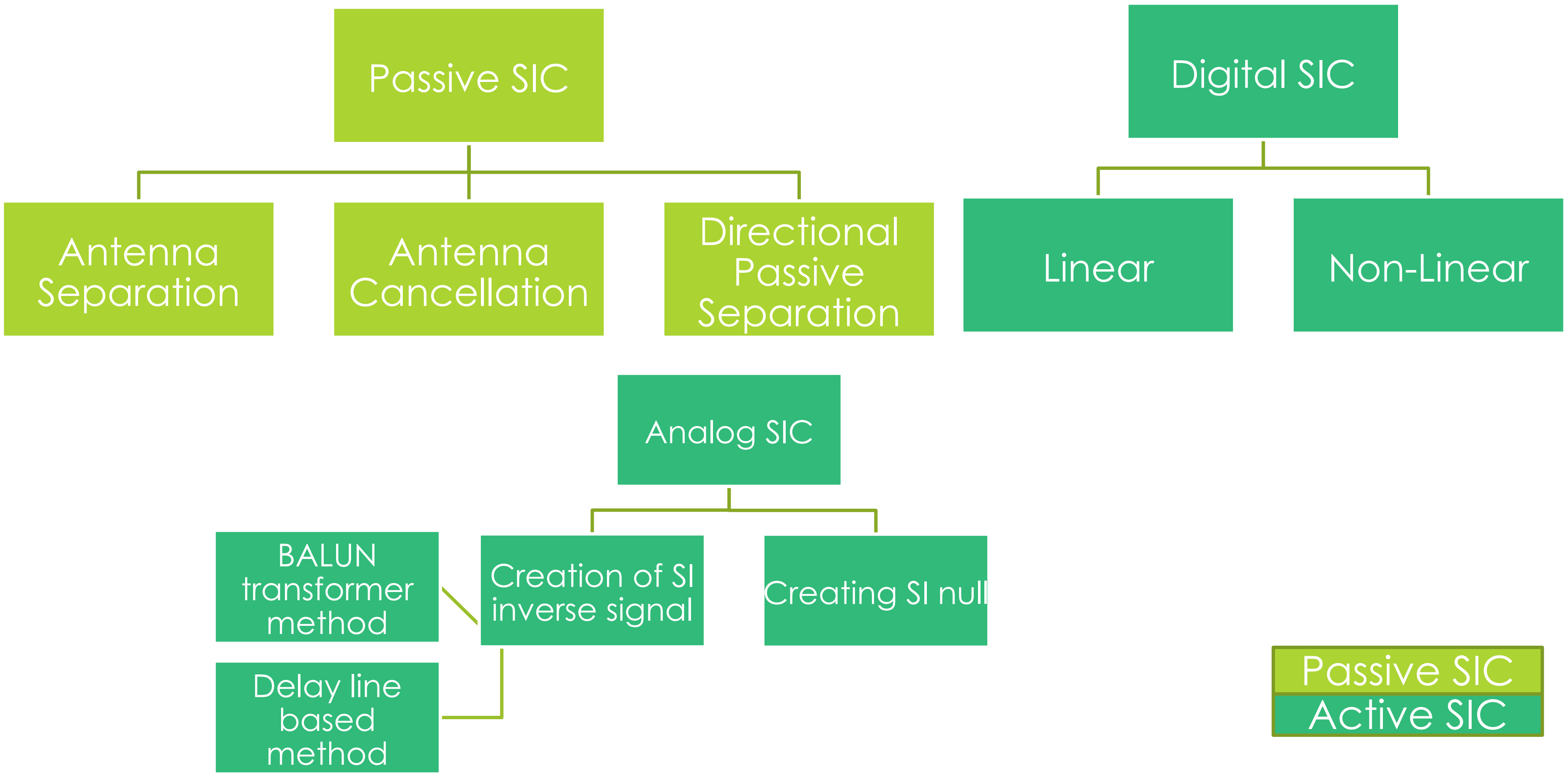
What are Full Duplex Radios (FDR)

- Radios which **simultaneously transmit and receive** at the same frequency/time slot.
- Theoretically, promises **doubling of throughput** over half-duplex radios.
- Key challenge to achieving FD performance is **Self-Interference (SI)**, which is the transmitted signal being added to the receive path of the FD node.
- Thus, the **main objective for FD design is to reduce the strength of SI as much as possible** – ideally, down to noise floor.

Advantages

- **Throughput gain**: Nearly doubles the throughput of a single-hop wireless link in the physical layer.
- **Solving hidden terminal problem**: FD avoids unnecessary packet drops due to hidden node problem.
- **Reducing congestion with the aid of FD MAC scheduling**: Aggregate network throughput is increased while simultaneously benefitting from spatial diversity gain.
- **Reduces end-to-end delay in mesh networks**: As a relay, FD radio can simultaneously transmit and receive.

Self-Interference Cancellation (SIC)-Methods



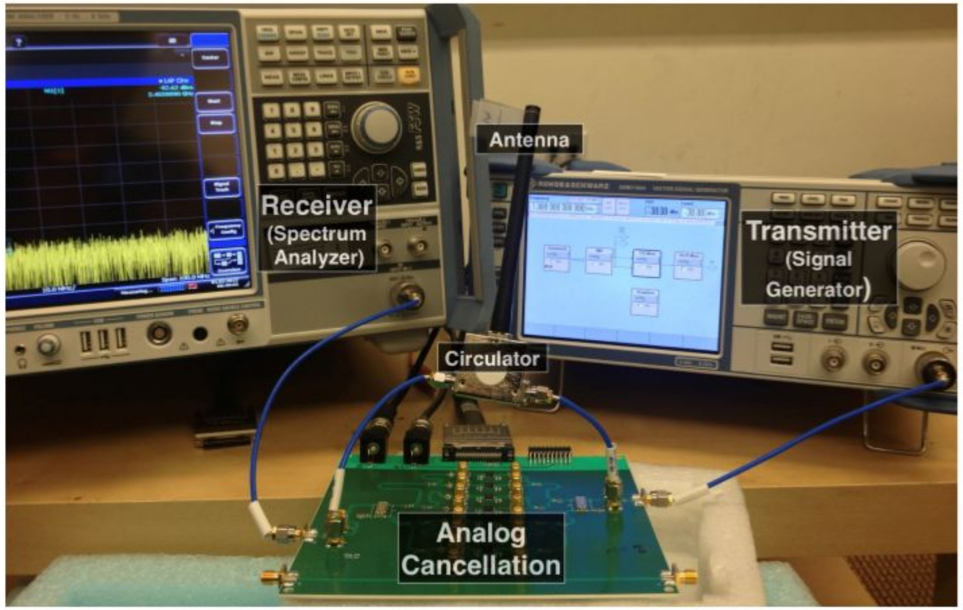
Performance Comparison of Existing SIC Techniques

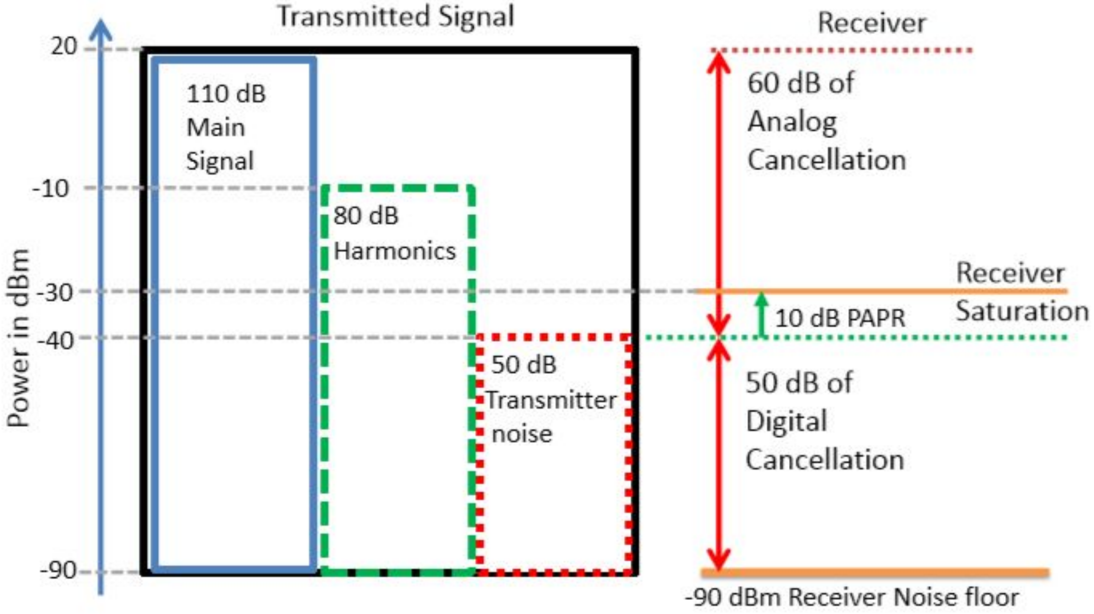
Algorithm	Transmit Power	Center Frequency	Bandwidth	Antenna Distances	Cancellation Capability	Full-Duplex Gain
Antenna Cancellation	0 dBm	2.4 GHz	5 MHz		60 dB	1.84
Antenna Separation (AS)	-5dBm ~ 15dBm	2.4 GHz	625 KHz	20 cm	39 dB	>1 (2.0% BER)
				40 cm	45 dB	>1 (2.2% BER)
AS + Analog Cancellation	-5dBm ~ 15dBm	2.4 GHz	625 KHz	20 cm	70 dB	>1 (3.0% BER)
				40 cm	76 dB	>1 (1.7% BER)
AS + Analog & Digital Cancellation	-5dBm ~ 15dBm	2.4 GHz	625 KHz	20 cm	78 dB	>1 (1.9% BER)
				40 cm	80 dB	>1 (2.6% BER)
Directional Diversity	12 dBm	2.4 GHz	20 MHz	10 m	NA	1.6 ~ 1.9
				15 m	NA	≥1.4
Balun	20 dBm	2.4 GHz	10-40 MHz	20 cm	113 dB	1.45
Circulator	20 dBm	2.4 GHz	20-80 MHz	Single Antenna	110 dB	1.87
SDR Platform		2.52 GHz	20 MHz		103 dB	1.9

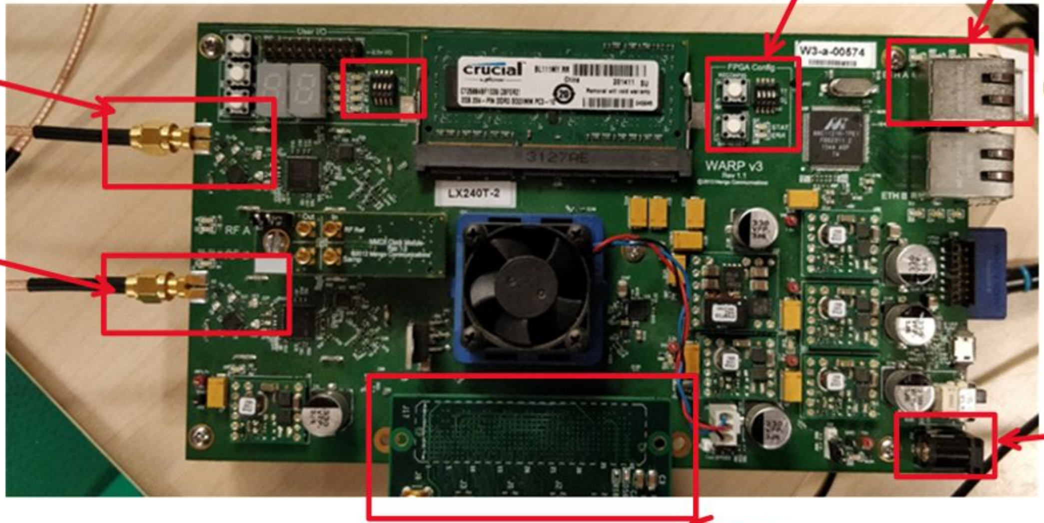
‘Full Duplex Radios’

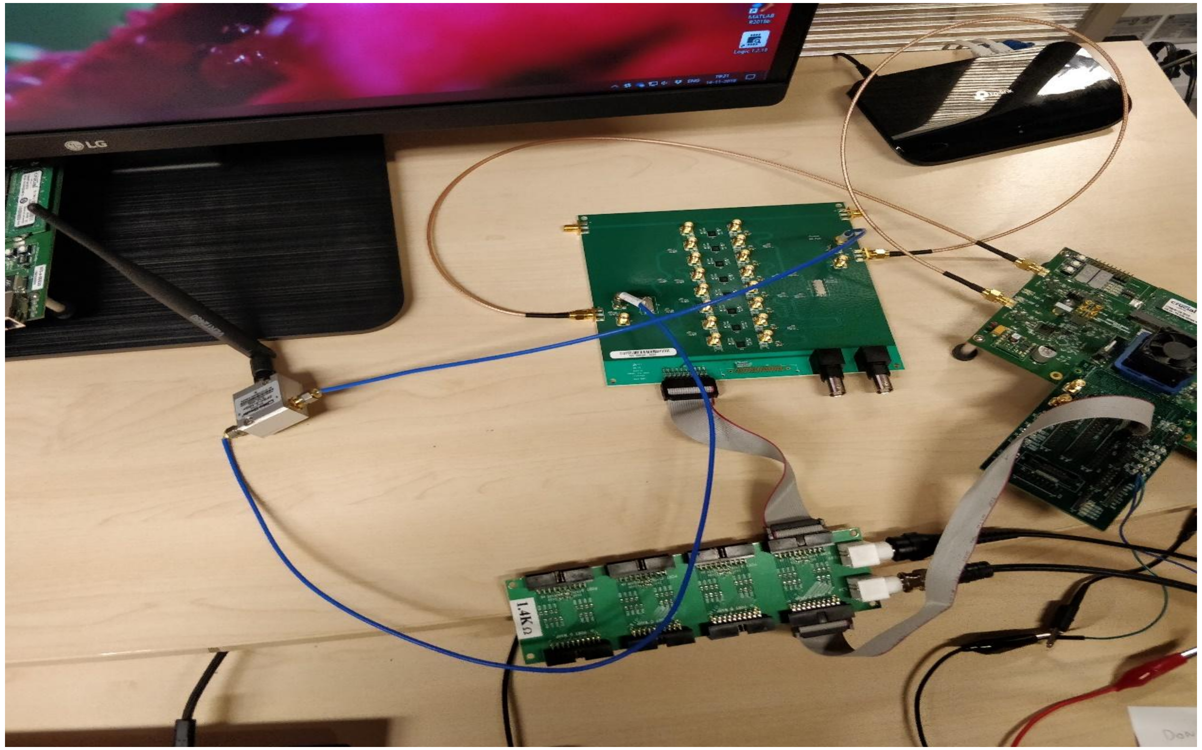
ANALOG CANCELLATION

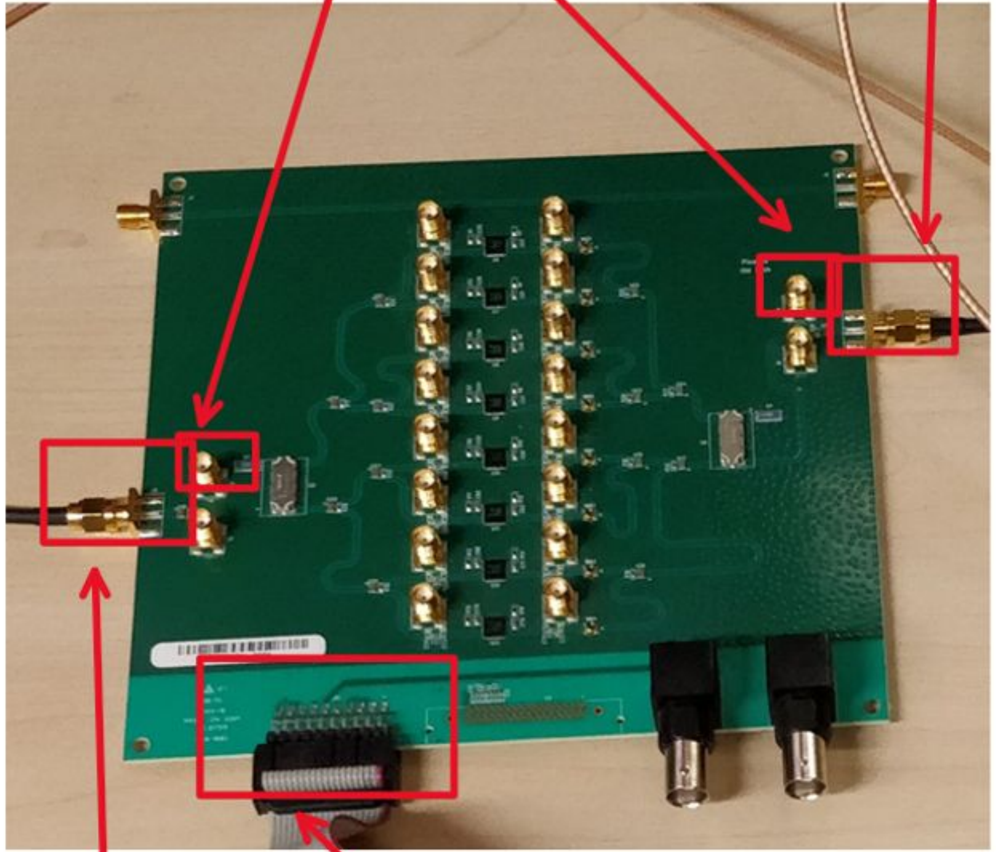
- 8 delay lines with attenuators.
- Uses WARPLab platform.
- Provides 60 dB of cancellation.






Configure for use with SD card
RFA - Transmitter
Use ETH A
RFB - Receiver
12
FMC Header
crucial
WARP v3
LX240T-2
W3-a-00574


LG


Connections to splitter
Output
Input
FRC cable
connection from
voltage converter
board

Digital Cancellation – Linear cancellation (48 dB)

- Received sample y[n] at any instant can be modeled as a linear combination of up to k samples of the known transmitted signal x[n] before and after the instant n.

$$y[n] = x[n-k]h[k] + x[n-k+1]h[k-1] + \ldots + x[n+k-1]h[-k+1] + w[n]$$

- H matrix is estimated using preambles $x_{pr}[n]$.
- Above eqn can be rewritten as $y = Ah + w$. A is a Toeplitz matrix of $x_{pr}[n]$.
- And we find max likelihood estimate of h using: $min\,||y - Ah||^2$.
- With this estimate of *h* perform cancellation on the rest of the received symbols.

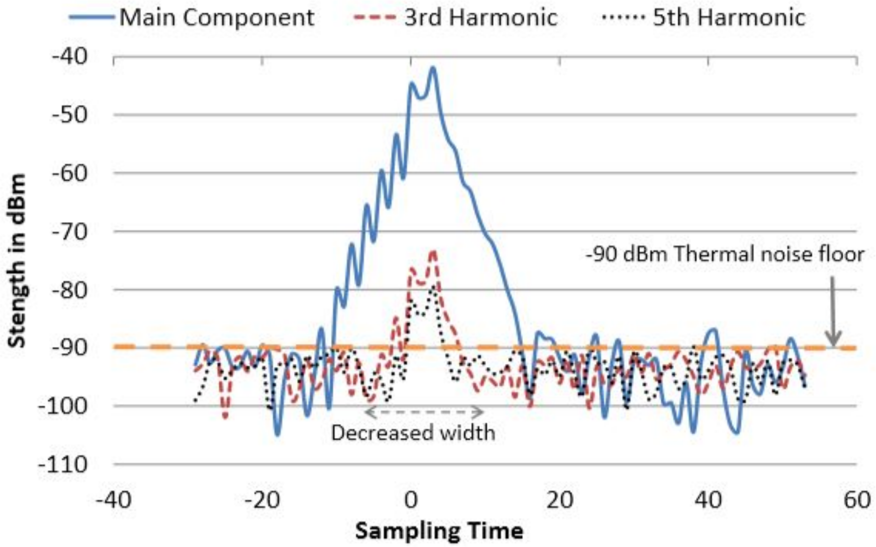
$$A = \begin{pmatrix} x_{pr}(-k) & \ldots & x_{pr}(0) & \ldots & x_{pr}(k-1) \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ x_{pr}(n-k) & \ldots & x_{pr}(n) & \ldots & x_{pr}(n+k-1) \end{pmatrix}$$

Digital Cancellation – Non-linear Cancellation (15-20 dB)

- Removing the higher order harmonics left after linear digital cancellation.
- Taylor series expansion is used for modelling these harmonics.

$$y(n) = \sum_{m \in \text{ odd terms}, n=-k,\ldots,k} x(n)(|x(n)|)^{m-1} * h_m(n)$$

- Focus only 1,3,5,7,9,11th orders as they contribute the most, reduce computation.



References

- Full Duplex Radios, SIGCOMM'13 *Dinesh Bharadia, Emily McMilin, Sachin Katti.*
- Full-Duplex Wireless Communications: Challenges, Solutions, and Future Research Directions, *Zhongshan Zhang ; Keping Long ; Athanasios V. Vasilakos ; Lajos Hanzo*