



A Personal Software-Defined Radio (SDR) UHF RFID Reader With Subranging Tunable Microwave Network (TMN)-Based TX Cancellation

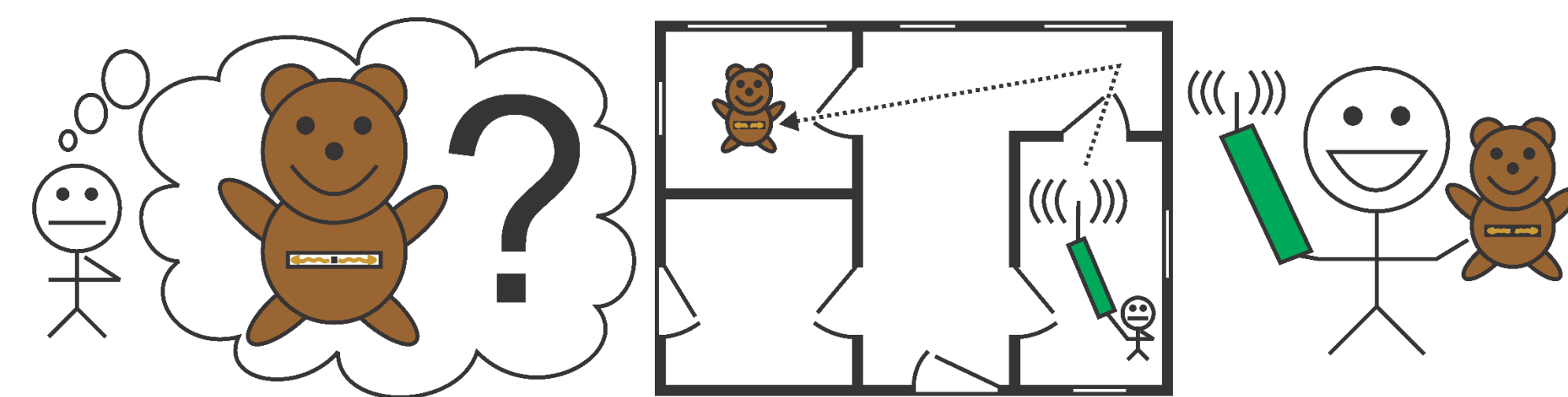
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Abstract

A low-cost software-defined UHF RFID reader designed for personal applications is introduced in an effort to bring RFID technology into mainstream household use. The reader is based around cheap and readily available components, including the SX1257 I/Q transceiver, the Altera 10M02 family of FPGAs (only 2304 logic elements each), and an ARM Cortex M0 microcontroller. TX cancellation is accomplished by a reflective power canceller (RPC) terminated in a high-resolution subranging tunable microwave network capable of attenuating transmit leakage at the receiver input by over 50dB. The reader achieves -73dBm of sensitivity at the antenna port when attached to a channel model and connectorized tag and achieves an open area tag read range of 2.6m with a 1.2dBi dipole antenna and 15.2m with a 12.5dBi patch antenna.

Motivation: Personal RFID Reader

Eventual Goal: Locate Objects Around the House

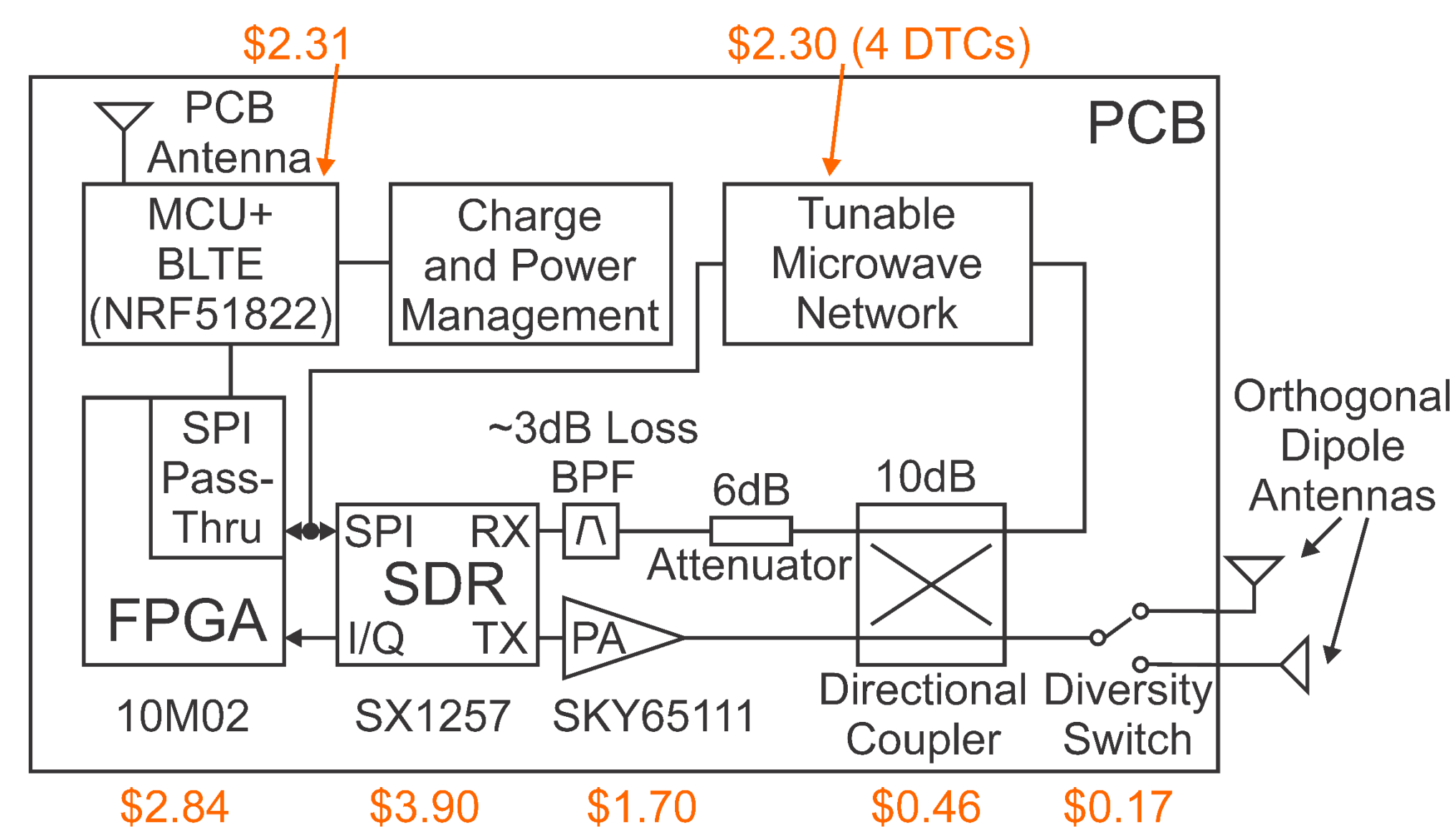


Everyday Lost Object (Teddy Bear) Contains Embedded Cheap RFID Tag

Find Object Using RFID Reader and Localization

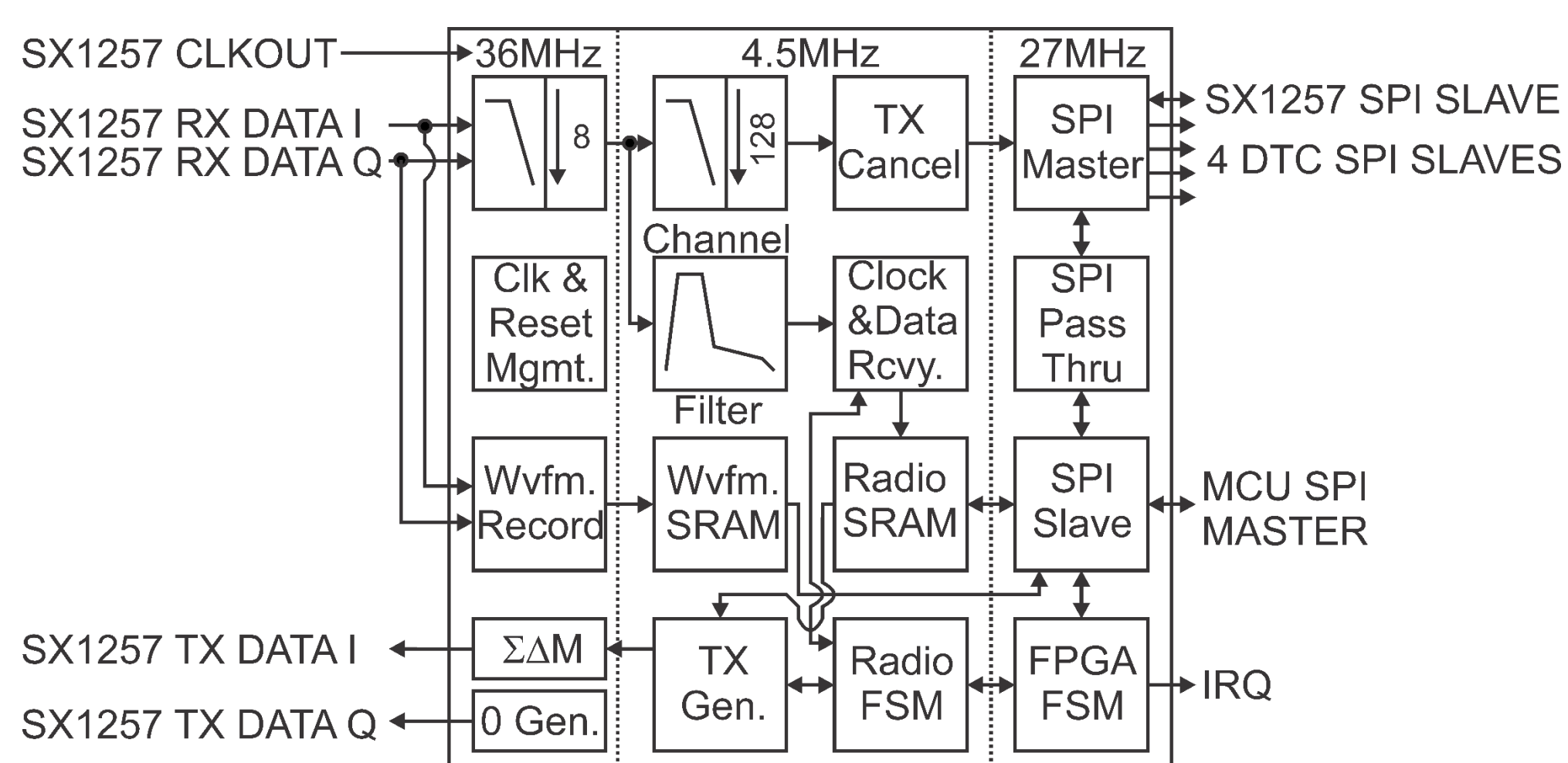
Trivial Solution: Use ~\$24 RFID Reader ASIC + MCU + PA

Improved Solution: Low-Cost SDR/FPGA-Based Reader (Lowest Publicly Available Prices on Digi-Key Shown)



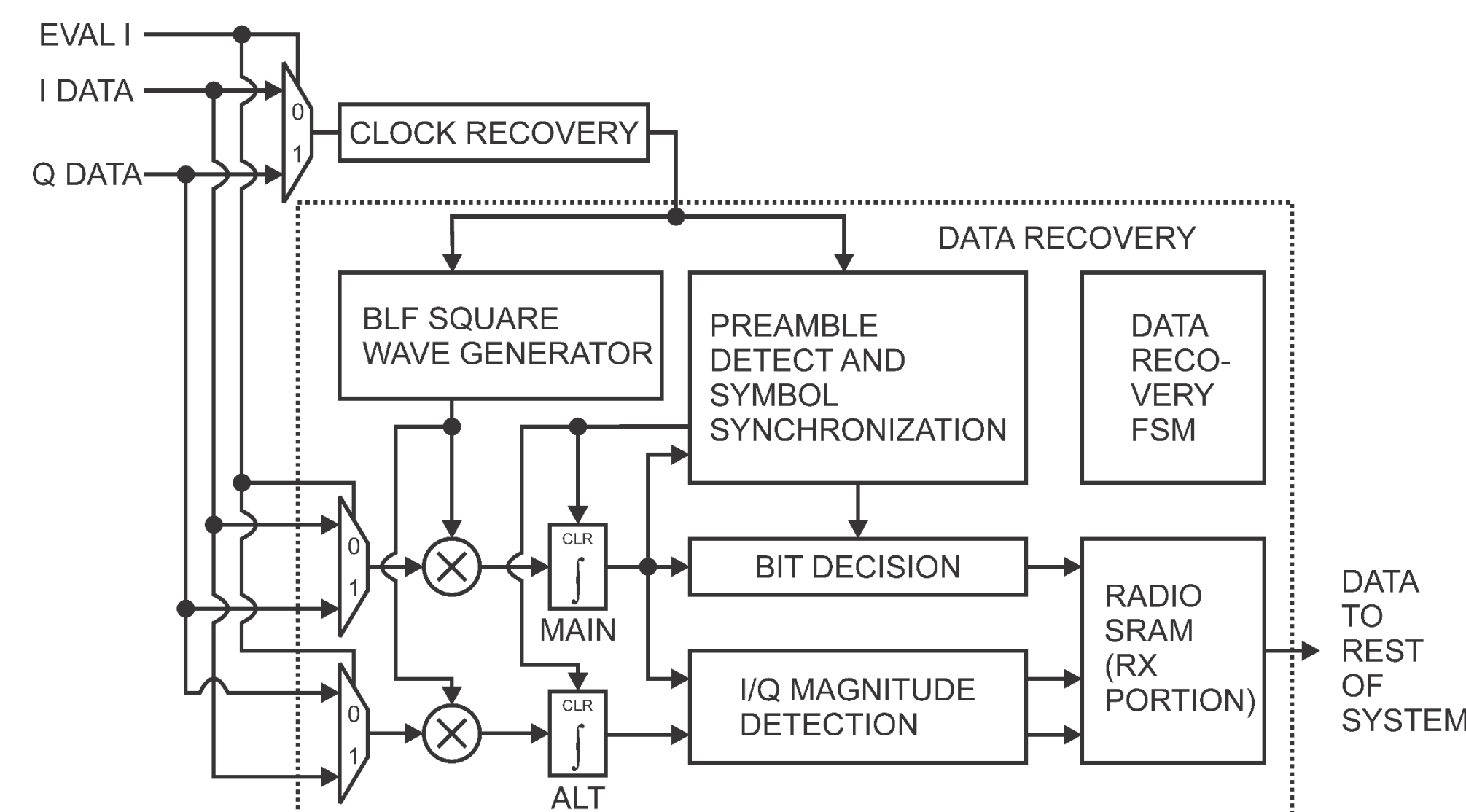
FPGA: Must Meet Strict EPC Gen Latency Requirements

Implementation: Complete Reader Digital Back End For Interface with Low-Cost, Low-Speed MCU in < 2304 LE

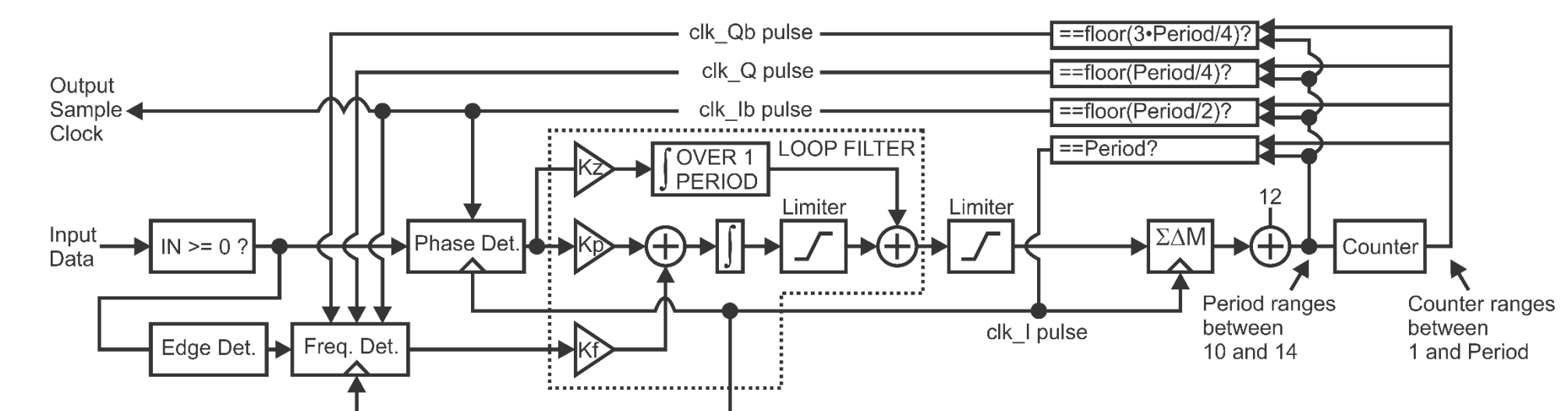


Low Resource Count FPGA Blocks

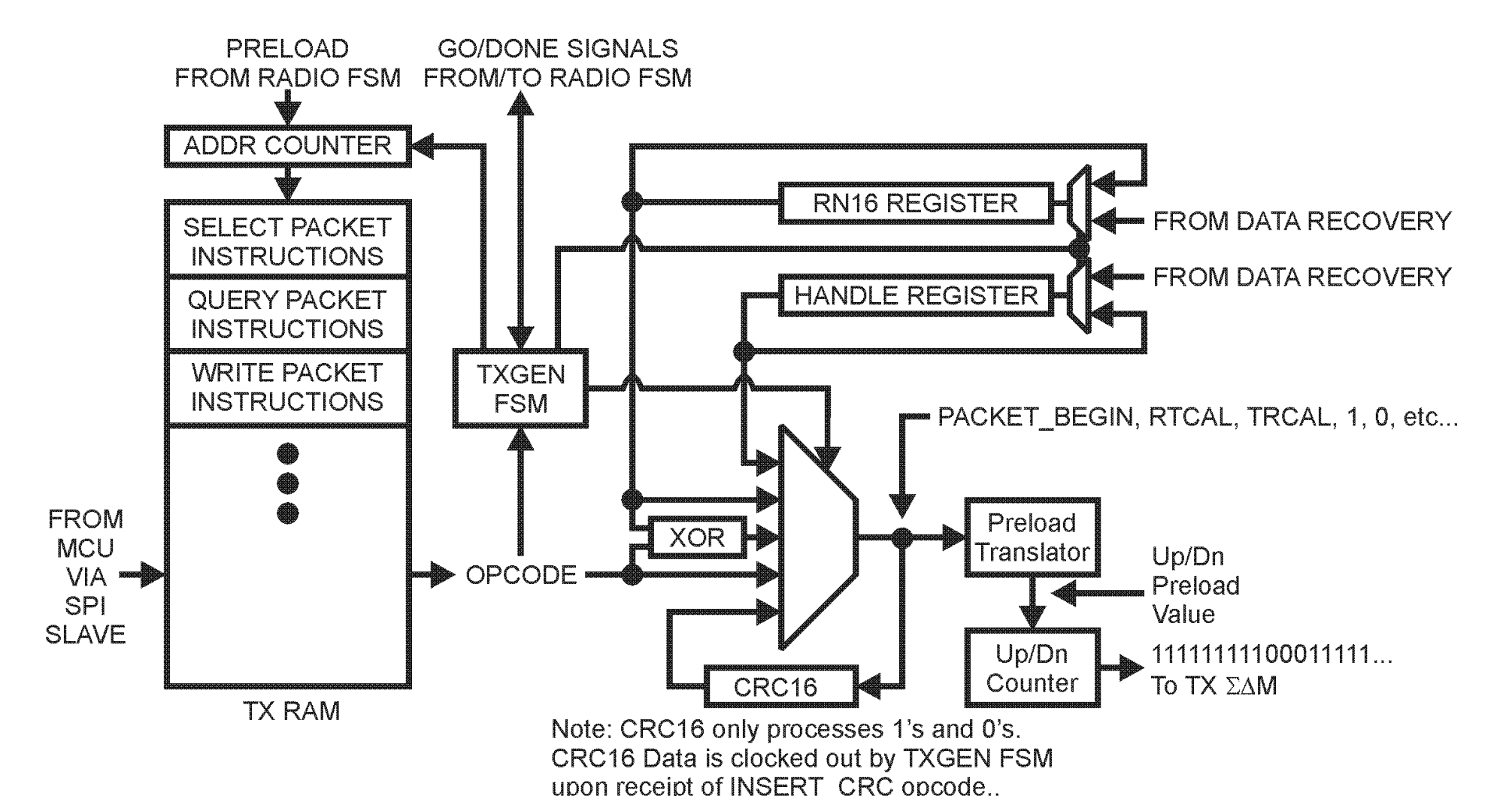
Data Recovery: Correlate Input Waveform Against Square Wave Per Half-Symbol; Integrate and Decide



Clock Recovery: Use Analog-Inspired Loop to Minimize Resource Count. Simple Phase/Frequency Detection. SDM Prior to Counter (NCO) for Noninteger Period.



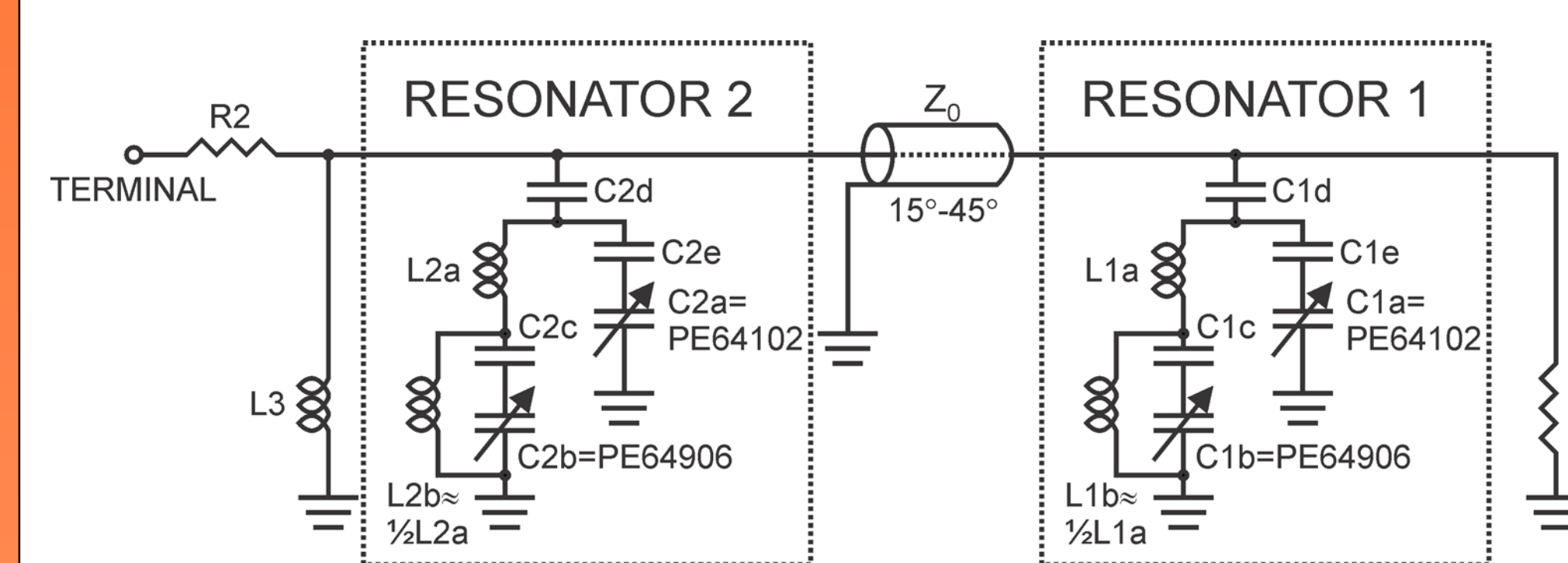
TX Waveform Generation: Use Opcode-Based Processor Approach To Drive Up/Down Counter



Opcode	Value	Explanation
TXCW	0000	TX CW Tone for 1.8ms.
BEGIN SELECT	0001	Begin a select packet.
BEGIN REGULAR	0010	Begin a regular packet.
DUMMY ZERO	0011	Insert a zero, don't count it in CRC.
SINGLE ZERO	0100	Insert a zero, count towards CRC.
SINGLE ONE	0101	Insert a one, count towards CRC.
RTCAL	0110	Insert RTCAL.
TRCAL	0111	Insert TRCAL.
NAK END	1000	Provides short TX CW time after NAK.
XOR NEXT 16b	1001	XOR next 16b with RN16.
INSERT CRC	1010	Insert CRC.
INSERT RN16	1011	Insert RN16.
INSERT HANDLE	1100	Insert Handle.
LAST WRITE	1101	Break write loop in Radio FSM.
END PACKET	1110	Return control to Radio FSM.
BEGIN IMMED	1111	Begin an immediate response packet.

TX Cancellation

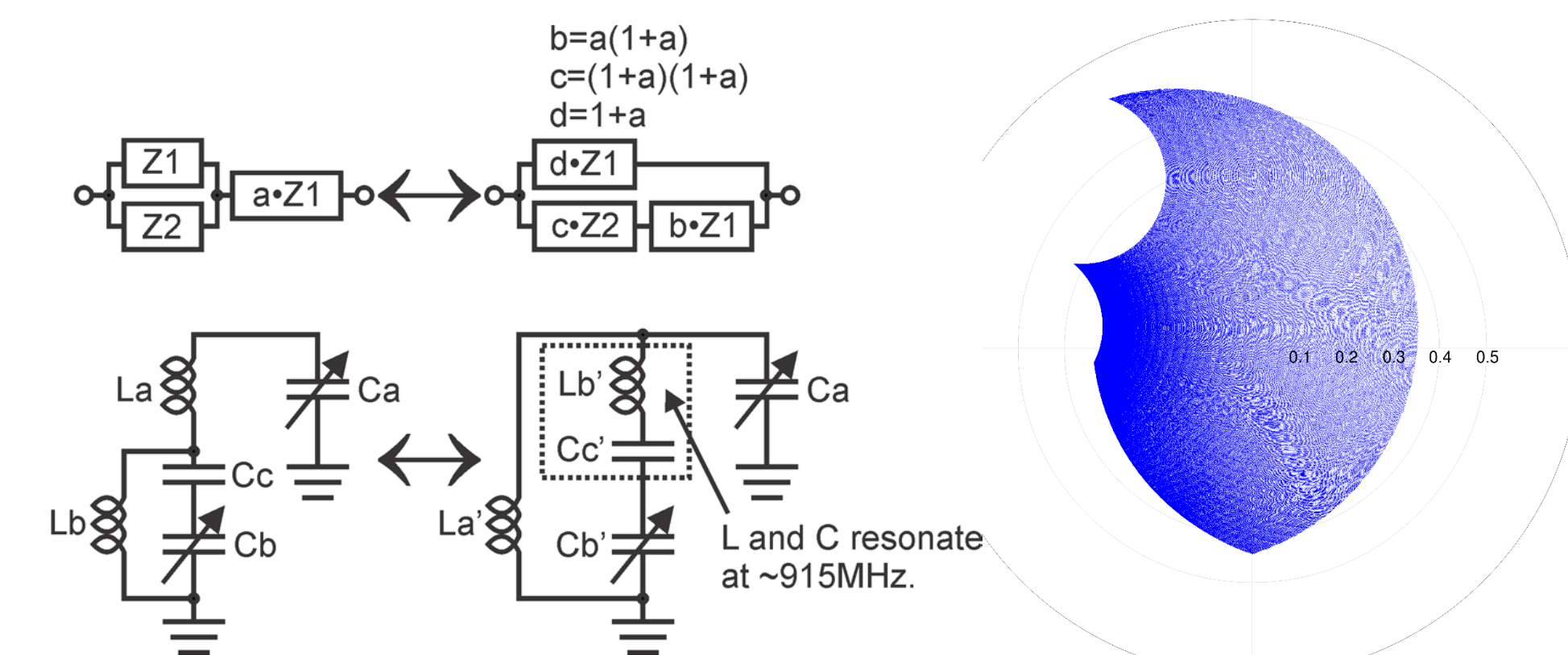
Challenge: Digitally Tunable Capacitor Resolution is Too Limited to Achieve Required TX Cancellation



Solution: Use Inductive Dividers to Create Subranging Tunable Capacitors in Each Resonator

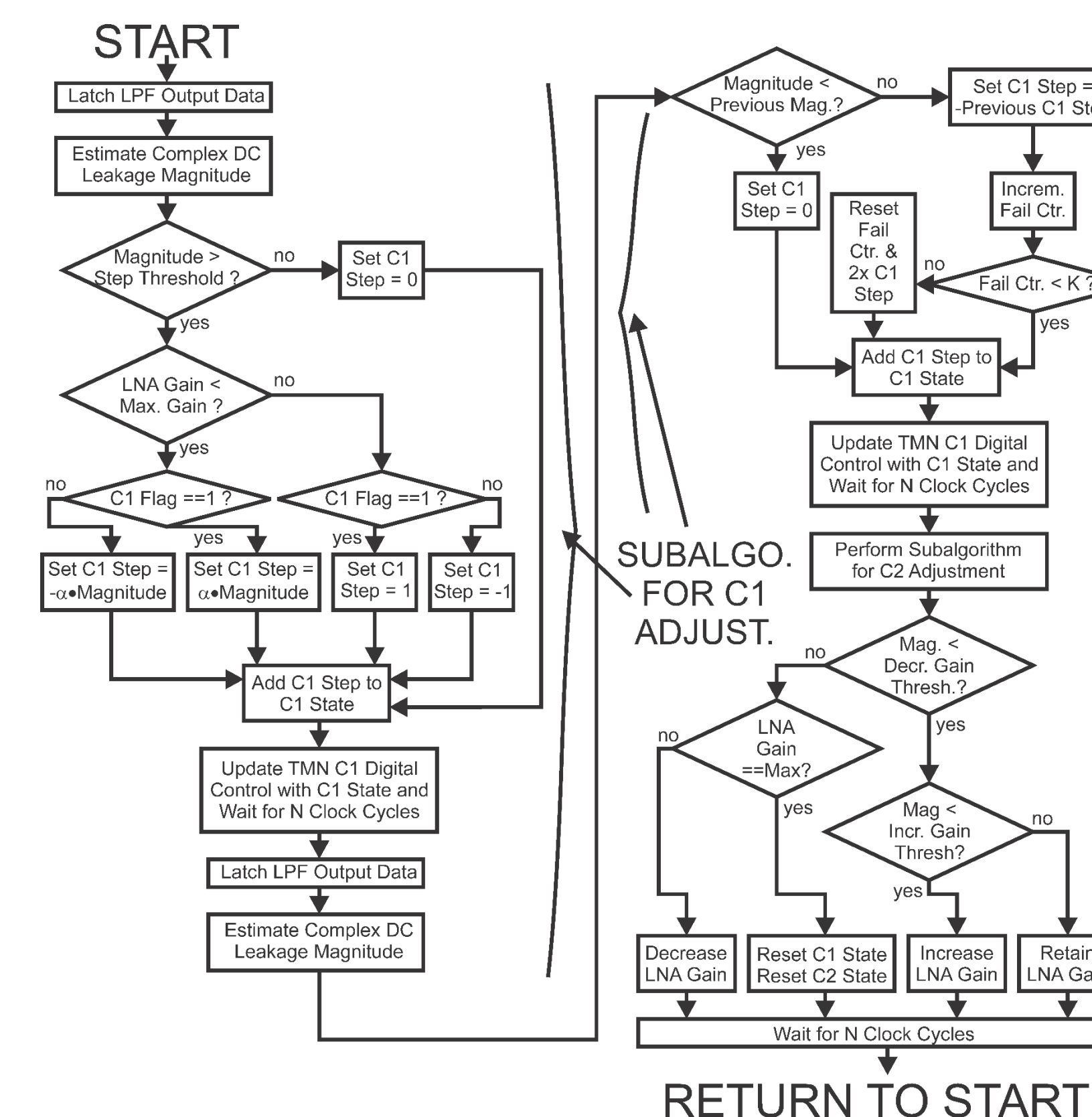
Challenge: Cover All Reflection Coefficients Γ Corresponding to Antenna S11 < -10dB (0.3)

Zobel Transform Used to Subrange Simulated Γ Coverage



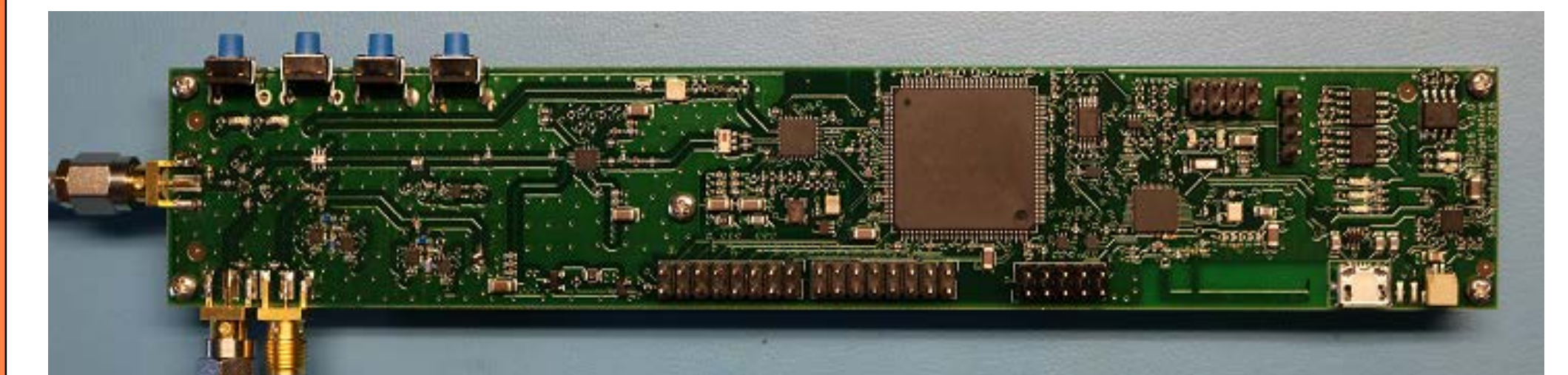
Solution: Ensure Tuning Out of Residual Inductances Use CXd (above) to Compress Realized Set of TMN Γ

Challenge: Low-Complexity TMN Tuning Algorithm That Can Fit on 2304-LE FPGA → Achieve 222 LE

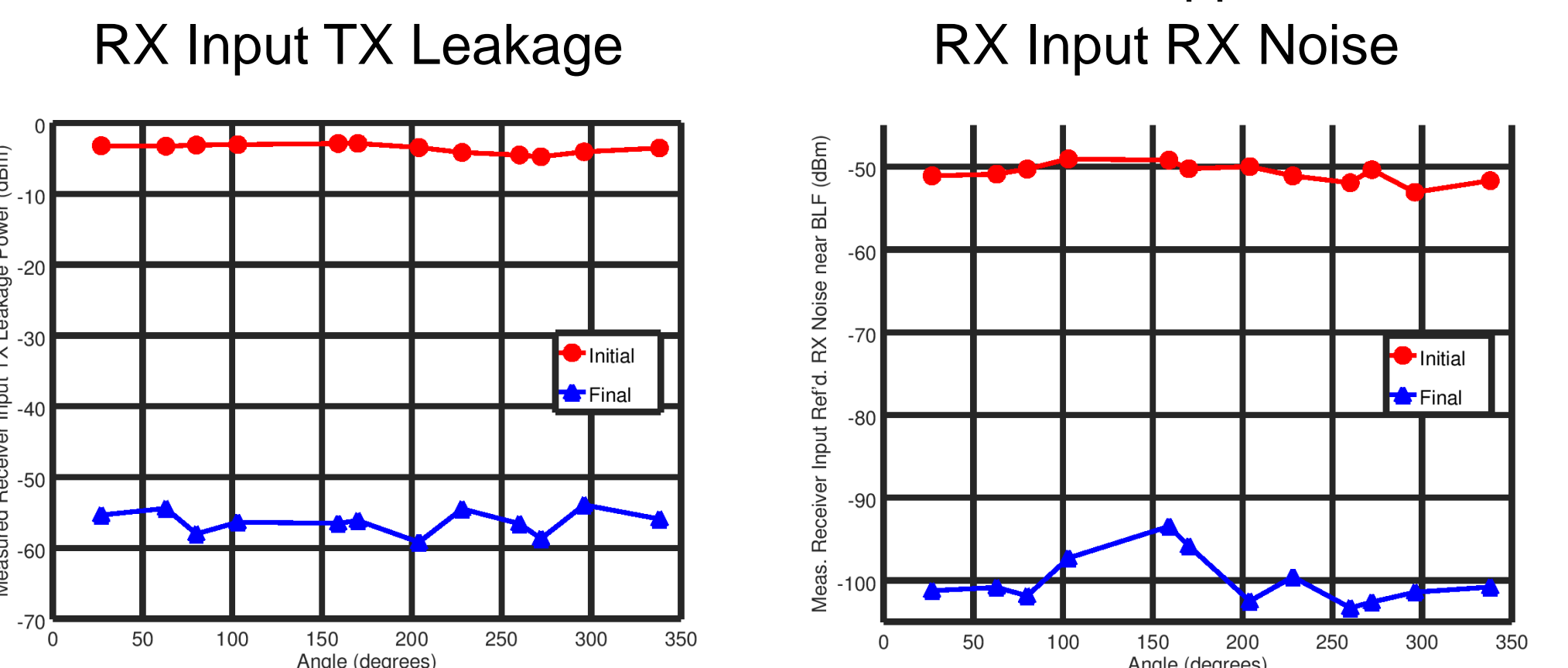


Measurement Results

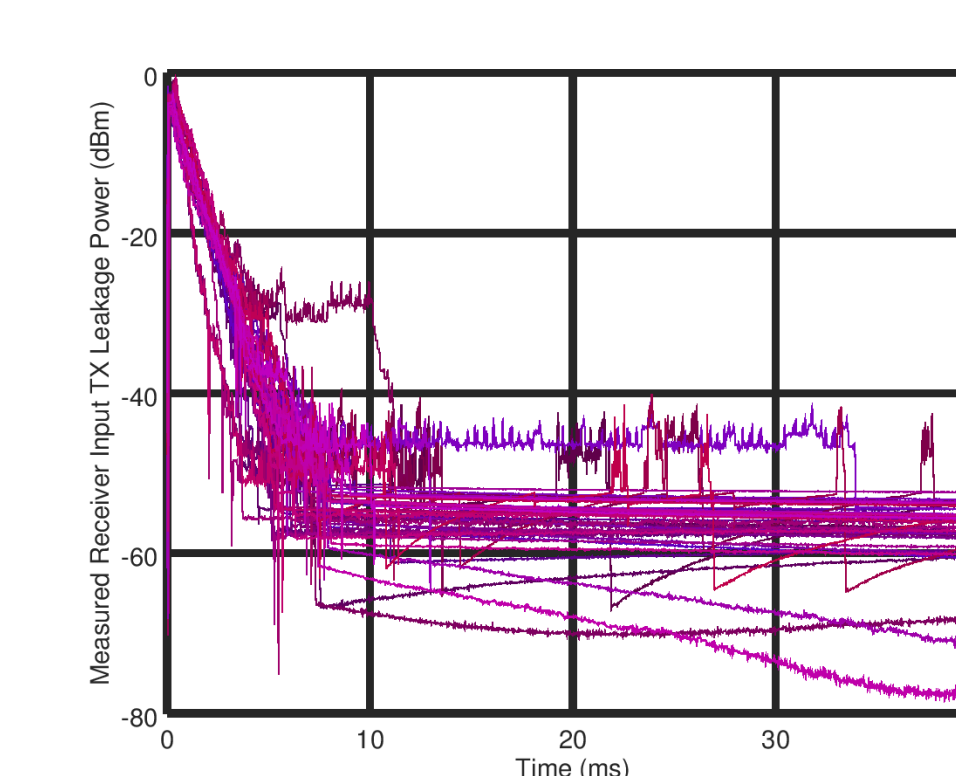
Implemented Low-Cost Software-Defined RFID Reader



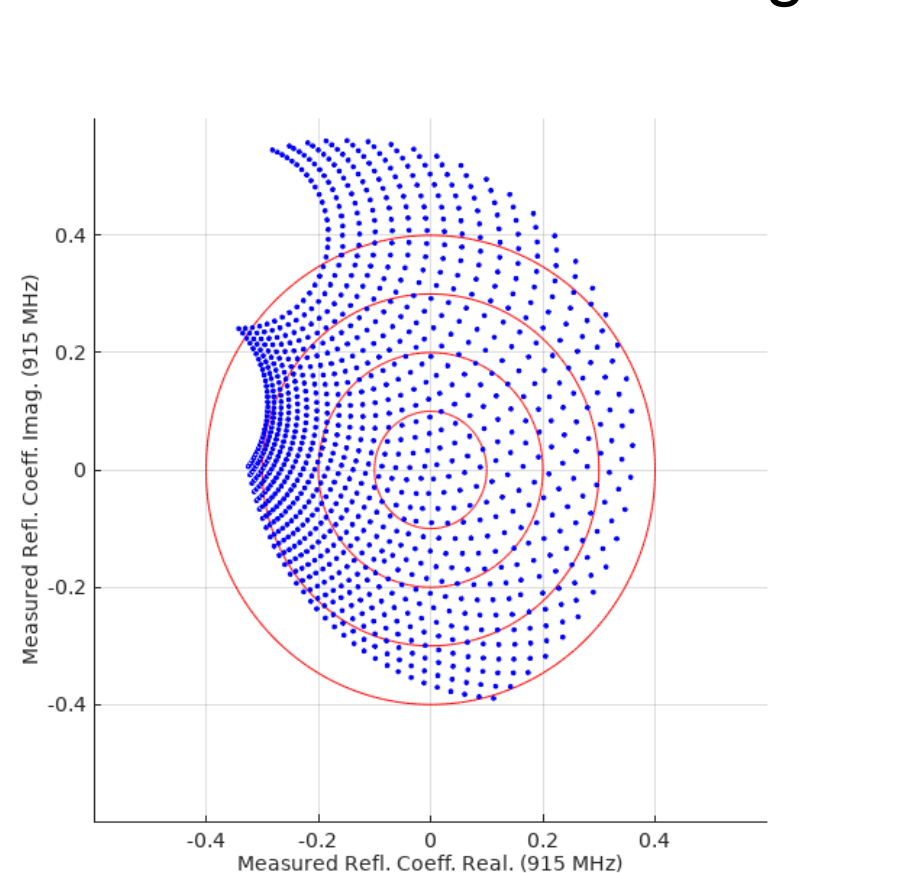
TMN: Before and After TX Cancellation Applied



TX Cancellation Convergence
48 runs - 4 each for 12 \angle
@ S11 ~ -10dB



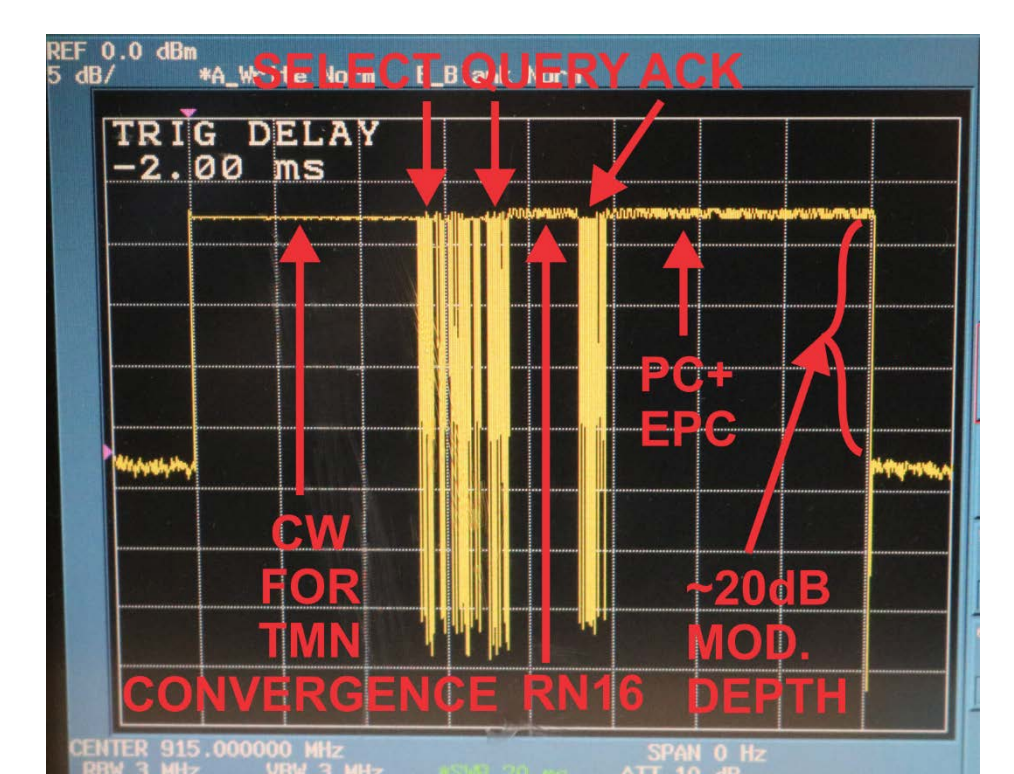
TMN Coarse Γ Coverage



Reader Performance Summary

Parameter	Result
Board Size	10in ²
Output Power	26dBm
Modulation Depth	>18dB
Sensitivity	-73dBm
Range - 1.2dBi Dipole	2.6m
Range - 12.5dBi Patch	15.2m
Inventory 50 Tags	20s

Example Reader Waveform



Range Testing Photo



FPGA Resource Consumption

Block	4-LUT	FF	LE	9x9 Mult.	RAM Bits
RX Filters	569	437	631	16	0
Clock Recovery	126	49	129	0	0
DR-PMF & Bit Decis.	50	33	50	0	0
DR-Symbol Sync	117	61	117	0	0
DR-IQ Magnitudes	160	88	160	0	0
DR-SRAM Mixing	68	8	68	0	128
DR-Local Protocol	86	81	86	0	0
Radio FSM	499	286	499	0	128
SPI	137	17	142	0	0
TX Cancel	199	146	218	0	0
TX Gen	222	118	222	16	8192
TX $\Sigma\Delta$	159	82	160	0	0
Others	35	37	69	0	8320
Total	2156	1320	2281	32	16,512
Limit	2304	2304	2304	32	110,592