Investigating Active Cancellation Towards a Single-Antenna Multi-Role FMCW Radar based on the ARESTOR system

Francisco Javier Bermejo Vilas | Supervisors: Dr Nial Peters, Dr Colin Horne, Dr Mathew Ritchie

UCL Department of Electronic and Electrical Engineering | Sensors Systems and Circuits
University College London, Gower Street, London, WC1E 6BT

Background

ARESTOR is a research initiative aiming to develop a reconfigurable RF sensor platform for diverse academic projects. Leveraging the advanced Xilinx RFSoC with DAC and ADC interfaces, ARESTOR has expanded beyond its initial radar detection purpose, finding applications in communications and the Internet of Things (IoT).

Frequency-Modulated Continuous-Wave (FMCW) radars stand out in the radar family. While similar to continuous-wave radars in emitting constant signals, FMCW radars possess the unique ability to vary the frequency of these signals. This trait boosts their versatility and makes them especially suited for economical, short-range sensing tasks, as seen in some automobiles.

A challenge with FMCW radars is their need for simultaneous transmit and receive functions. Using a single antenna for both often leads to signal interference. The common solution? Assigning separate antennas to each channel. However, this can introduce complications in design and increase costs.

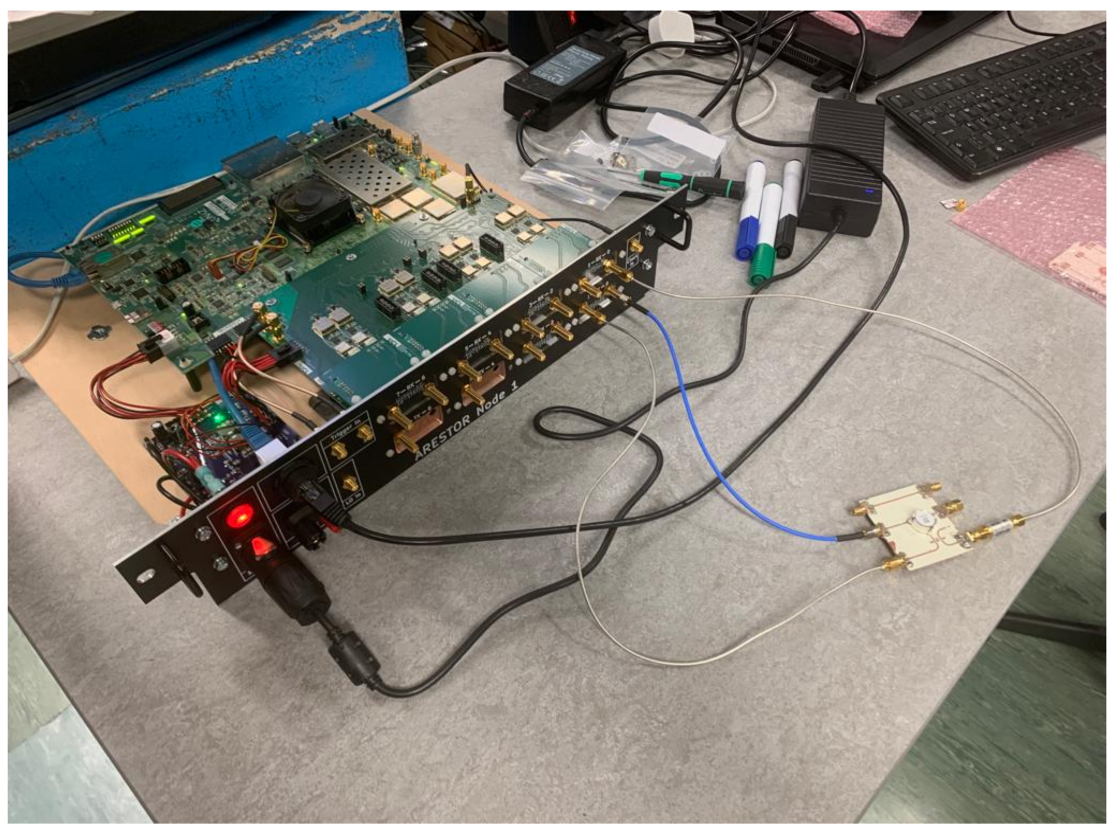


Figure 1: ARESTOR system connected to a PCB for testing.

Research Aims

An alternative workaround to reduce the interference between both channels is active cancellation. This means using a second transmit channel to input waveforms that attempt to destructively interfere with the unwanted leakage on the receive end.

Similar attempts have been carried out in the past but typically these would involve using analogue components to modify the cancellation waveforms. The ARESTOR system has ability to generate alternative waveforms digitally. This may allow us to create these cancellation signals in a simpler way which could make for a more versatile single-antenna FMCW radar.

In order to test the feasibility of the project the following would need to be achieved:

-The design and assembly of a Printed Circuit Board (PCB) based around a circulator that would redirect the RF signals towards the necessary channels.

-The development of an algorithm capable of identifying and inputting the optimal cancellation signal for a single-tone waveform for transmit

-An optimal cancellation algorithm for a single LFM wave (Chirp).

-Once these are found attempt to extend these algorithms to also cancel the signal reflection that would be seen in a real antenna.

Printed Circuit Board (PCB)

The first step of the process was to assemble a PCB which could take a transmit channel (J2) that would send the waveforms to the antenna (J6) without "leaking" RF signal to the receive channel (J4). This PCB also had to take "antenna" signals at J6 and transmit them to J4 to measure them.

This was done by using a circulator which would let RF signal pass from J2 to J6 while blocking most from going to J4 while also letting J6 send signals to J4 but blocking the J2 path.

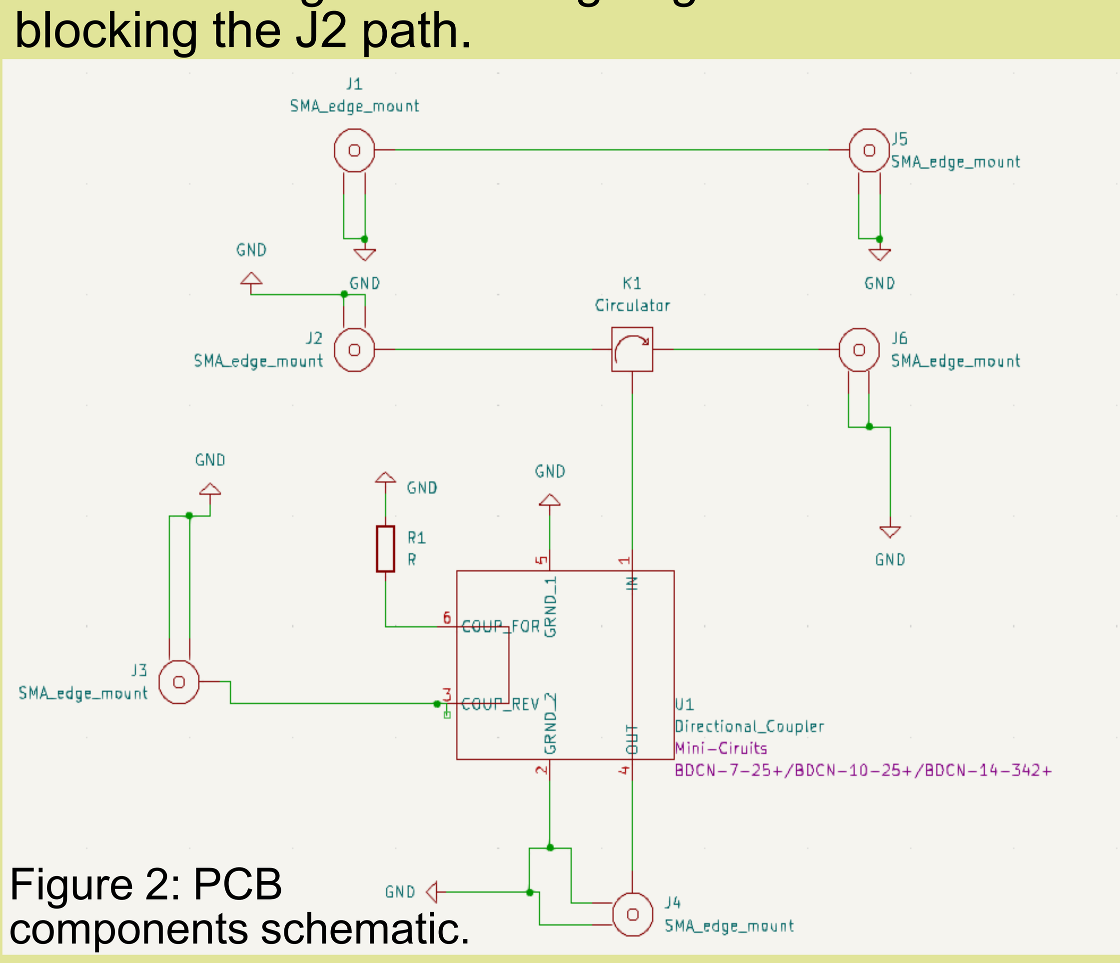


Figure 2: PCB components schematic.

Some signal still flows down the wrong channel though. Hence cancellation signals are sent from J3 through a directional coupler.

The cirulator which we employed should have attenuated the wrong channel signal by -20dB measurements suggested it only attenuated it by around -16 dB and -2dB of those were likely due to power loss in the wires which was also measured from J1 to J5.

Cancellation Algorithm for Single-Tones

-A single-frequency tone at a given amplitude was passed through the transmit signal and the maximum ADC power reading at J4 was recorded.

-A python script was then made to sweep through 200 cancellation waveforms each with a different phase-shift. (Pictured to the right)

-Results suggested optimal phase-shift value lies somehwere between 0 and 0.5 radians.

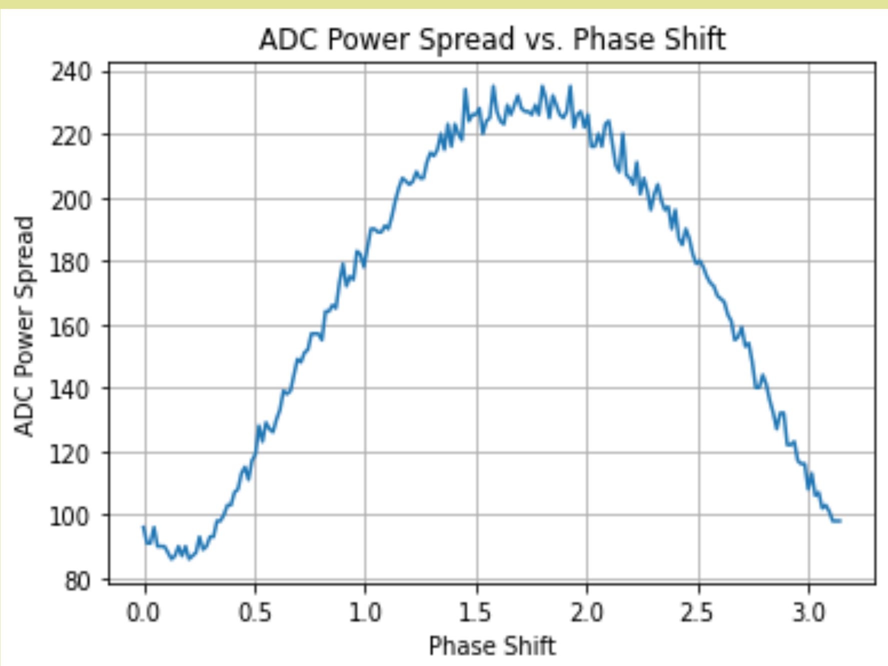


Figure 3: Maximum ADC reading for different cancellation wave phase-shifts..

-New algorithm repeatedly sweeps through phase-shifts before zeroing onto the lowest value and sweeping through a narrower phase-shift range.

-Optimal cancellation is found at a phase-shift of 0.24 radians where -30dB of cancellation are recorded at the right amplitude settings.

Cancellation Algorithm for Chirps

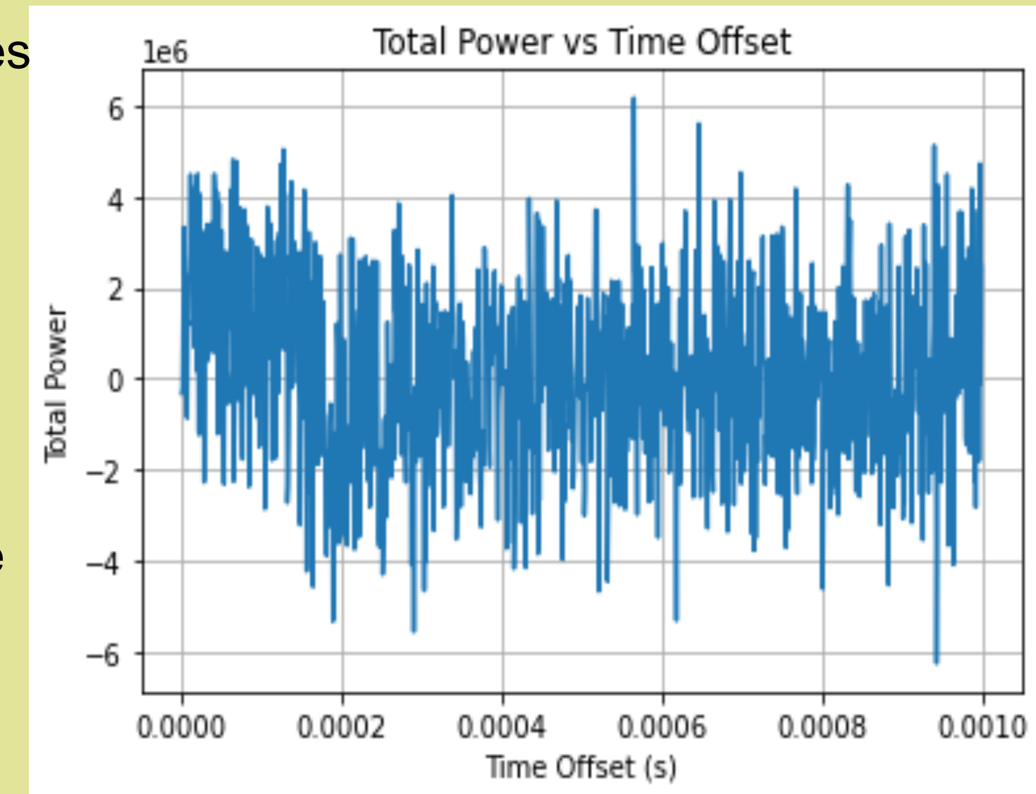
-Using maximum ADC power values for the algorithm made it too susceptible to outliers.

-Instead the average of the sum of the squares of the In-Phase and Quadrature components of the power of each transmission was used.

-Cancelling chirps could not just be phase-shifted because the frequency of the chirp is not constant.

-Instead a form of time offset was used to delay the start of the chirp such that it lines up with the leakage in anti-phase.

Figure 4: Maximum ADC reading for different cancellation wave phase-shifts.



This approach however makes it quite complicated to know when the true optimal cancellation signal is being approximated so a different approach may be more suitable to this situation.

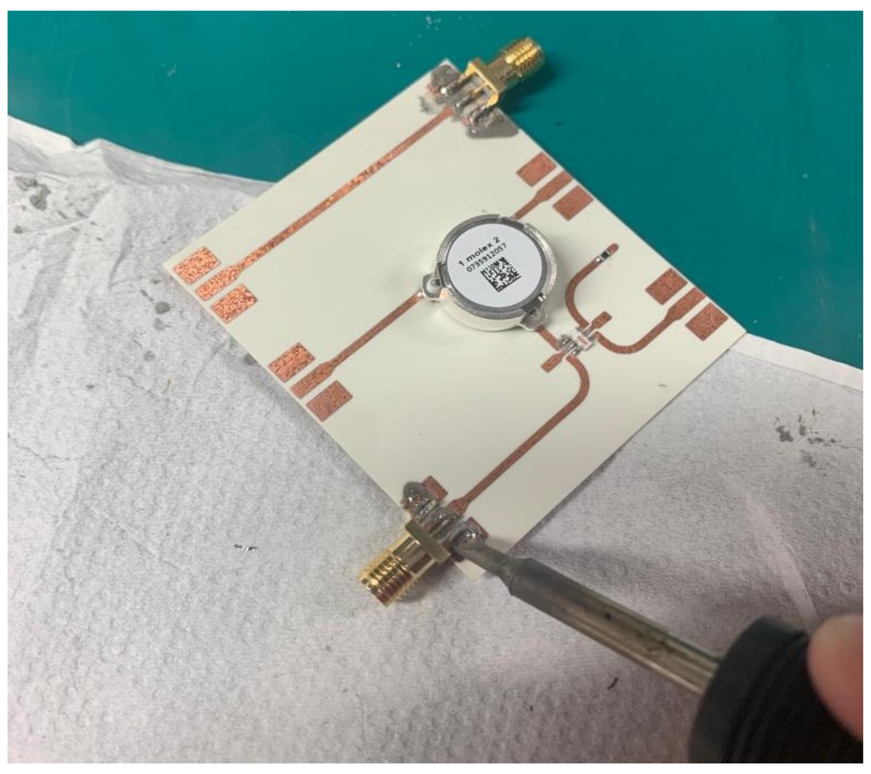


Figure 5: Soldering the SMA connectors onto the PCB.

Possible Directions of Future Research

Chirp Troubleshooting: Dive deeper into refining the current chirp optimisation process. The goal is to transition from simulations to real-world testing on the PCB.

Algorithm Enhancement for Incoming Signals: Extend the capabilities of our current algorithm to handle reflected signals passing through the receive channel.

Exploration of New Optimisation Methods: Research and identify innovative optimisation algorithms. Focus on methods that promise computational efficiency, and which would make optmisation for chirps more straightforward.

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