



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

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August 2023



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1. Abstract

Frequency-Modulated Continuous-Wave (FMCW) are a type of radar which continuously emit and receive RF signals while modulating their frequency. Because of this continuous transmission there tends to be a lot of leakage between the receive and transmit channel which leads to these systems normally relying on using two antennas, one for transmit and one for receive. The question arose however as to whether we would be capable of using a single antenna for an FMCW system by cancelling the leakage signal by sending a second input waveform with the same amplitude and shape as this leakage but in anti-phase. This cancellation wave was created by UCL's ARESTOR system and its ability to generate waveforms digitally and convert them to analogue RF signals. For this project a Printed Circuit Board (PCB) was assembled and tested, and an algorithm was developed that managed to cancel leakage very successfully for single-frequency tones but struggled at finding an optimal solution for Linearly Frequency Modulated (LFM) waves otherwise known as chirps.

2. Introduction

ARESTOR is a research initiative spearheaded by the Radar Group at UCL's Electronic and Electrical Engineering Department. This project's overarching ambition is to craft a versatile reconfigurable RF platform to cater to a diverse array of academic endeavours. At the heart of ARESTOR is the state-of-the-art Xilinx Radio Frequency System on Chip (RFSoc). This groundbreaking chip amalgamates advanced digital signal processing capabilities with a sophisticated digital-analogue and analogue-digital conversion system, optimized for high-frequency RF signals.

Originally, the vision for ARESTOR was to primarily serve passive and active radar operations, as well as electronic surveillance receivers. However, as research progressed, the platform showcased its adaptability and has since expanded its domain, making inroads into realms like Integrated Sensing And Communications (ISAC) and the ever-evolving Internet of Things (IoT).

A particular radar type that merits attention within this research is the Frequency-Modulated Continuous-Wave (FMCW) radar. Although they share similarities with continuous-wave radars in their continuous signal emission, FMCW radars have a unique capability: modulating the frequency of these emitted signals. This distinct characteristic enhances their adaptability, making them the go-to choice for cost-effective, short-range sensing tasks. Notably, many in cases like automotive radars and geological monitoring.

However, a persistent challenge that besets FMCW radars is their requirement for concurrent transmit and receive operations. The go-to method of using a singular antenna for both functions often culminates in detrimental signal interference. While the prevalent remedy is to allocate distinct antennas to each channel, this workaround can inadvertently complicate design schematics and escalate manufacturing expenses. As this research delves deeper, the onus is on finding innovative solutions to these challenges, ensuring the continued evolution and adaptability of ARESTOR's applications.

3. Literature Review

The operational mechanics of Frequency-Modulated Continuous-Wave (FMCW) radars have been thoroughly documented in the annals of radar technology. According to a basic explanation provided by (Radartutorial.eu,2019), FMCW radars dispatch continuous electromagnetic waves with varying frequency over time. The rebounded echo of these waves is then captured by an antenna. A crucial principle in its working is the comparison of the frequency of transmitted waves with the received echoes. The difference in frequencies aids in calculating the distance to the target. It's important to note that the waveform's transmission duration should significantly exceed its receiving time for accurate distance calculations. Moreover, diverse frequency modulation patterns exist for these radars, highlighting the need for adaptable software designs.

As the technology matured, a 1990 paper (Beasley et al., 2002) shed light on challenges FMCW radars faced, especially in target distance reporting, in contrast with pulse radars. These radars necessitate concurrent transmitting and receiving of signals. This simultaneous operation can lead to interference between channels when a single antenna is utilized. Two primary complications emerge from this - noise sidebands masking valid targets and power leakage desensitizing the receiver. An intriguing solution highlighted by the source is the utilization of a "reflected power canceller." This apparatus, bearing resemblance to certain PCB designs, employs a vector modulator, which uses directional couplers to adjust and cancel out the reflected power. Optimally, this method shines with high bandwidths and gain.

Furthermore, the W-band operation of FMCW radars has been dissected by (Kalantari et al., 2020). Emphasis is laid on achieving at least 40dB of isolation between transmitting and receiving channels. While the exact frequencies differed from our system, the isolation levels discussed offer a ballpark figure for our own requirements.

(Venkatamuni et al., 2009) provides a deeper dive into the signal isolation challenge. The researchers pinpointed a technique of discerning the in-phase (I) and out-of-phase (Q) components of the received waveform via an I/Q demodulator. They devised a formula for determining the ideal active cancellation signal to diminish channel leakage. By adopting this principle, with tailored values, one can iterate and refine active cancellation signals for linearly frequency-modulated signals.

Lastly, (Kalantari et al., 2021) endorsed the need for robust Tx-Rx isolation, stipulating around 45 dB for effective radar operation, echoing findings from Source 3. The discussed radar system harnesses the same I/Q demodulation principle for assessing rebounded signals. Additionally, it introduces an analogue form of power cancellation, leveraging a 90-degree offset modulated signal via a directional coupler to counteract leakage.

This literature review offers a comprehensive overview of the foundational principles and challenges of FMCW radars. A recurring theme across sources is the isolation challenge and its solutions, from reflected power cancellers to I/Q demodulation strategies. Moving forward, a comparison between the discussed techniques and newer technologies may be essential.

Additionally, a deep dive into the potential limitations and advantages of each method, considering different scenarios, would provide a holistic understanding of FMCW radar functionalities.

4. Methodology

4.1 Printed Circuit Board (PCB)

The foundational step for our research was the assembly of a Printed Circuit Board (PCB) designed to manage the transmission and reception of RF signals. This PCB was engineered to facilitate a transmit channel, labelled J2, that directed waveforms towards an antenna, marked as J6. The critical challenge was to ensure that during this transmission process, there was minimal "leakage" of the RF signal to the receiving channel, J4. Additionally, the PCB should efficiently channel the "antenna" signals at J6 towards J4 for accurate measurement.

To achieve this desired configuration, a circulator was integrated into the system. This circulator acted as a selective channel gatekeeper: allowing the RF signal to flow seamlessly from J2 to J6 but significantly restricting the flow from J2 to J4. Furthermore, it was designed to permit J6 to transmit signals to J4 while simultaneously blocking the J2 pathway.

However, in real-world applications, a perfect blockade is seldom achieved. Some residual signals, despite our best efforts, managed to traverse down unintended channels. To counter this, we introduced cancellation signals emanating from J3, directed through a strategically placed directional coupler.

Our anticipatory calculations projected a circulator attenuation of the undesired signal by approximately -20dB. However, real-time measurements deviated slightly, achieving an attenuation closer to -16 dB. From these measurements, it was inferred that about -2dB of this value could be attributed to power losses within the connecting wires, a deduction drawn from the power measurements between J1 to J5.

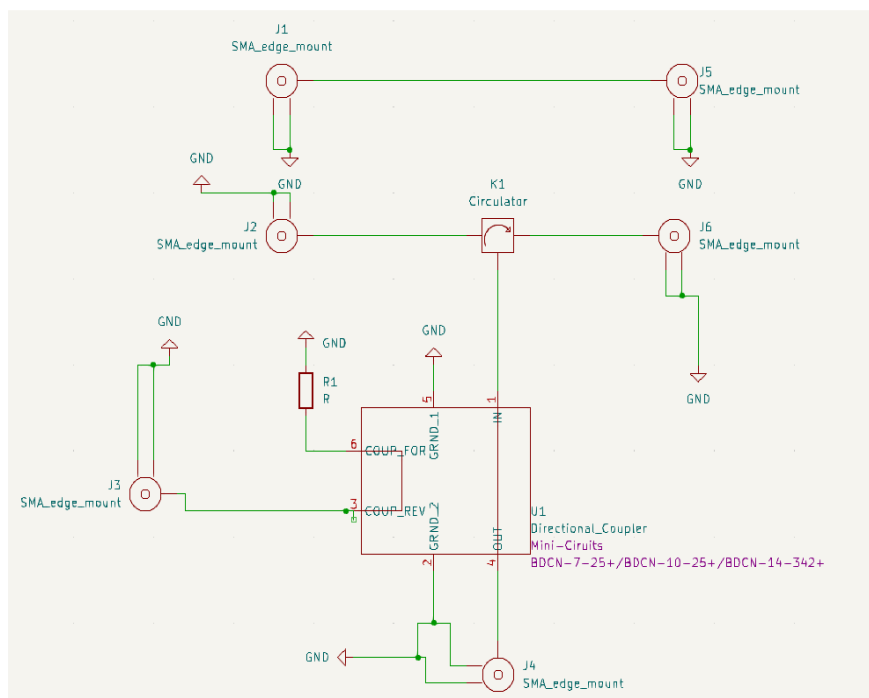


Figure 1: PCB components schematic.

4.2 Cancellation Algorithm for Single-Frequency Tones

To evaluate the effectiveness of our cancellation efforts, a single-frequency tone, consistent in amplitude, was introduced into the transmit signal. The subsequent ADC power reading at J4 was meticulously documented. With these readings in hand, our team devised a Python script intended to methodically sweep through a spectrum of 200 cancellation waveforms, each manifesting a unique phase-shift.

Preliminary results, derived from this algorithm, indicated that the most efficacious phase-shift oscillated between 0 and 0.5 radians. Subsequent algorithm iterations were more nuanced. They engaged in repeated phase-shift sweeps, successively narrowing down their range, to zero in on the most optimal phase-shift value. The conclusive result highlighted that the ideal phase-shift rested at 0.24 radians. When coupled with the precise amplitude settings, a significant -30dB of cancellation was observed.

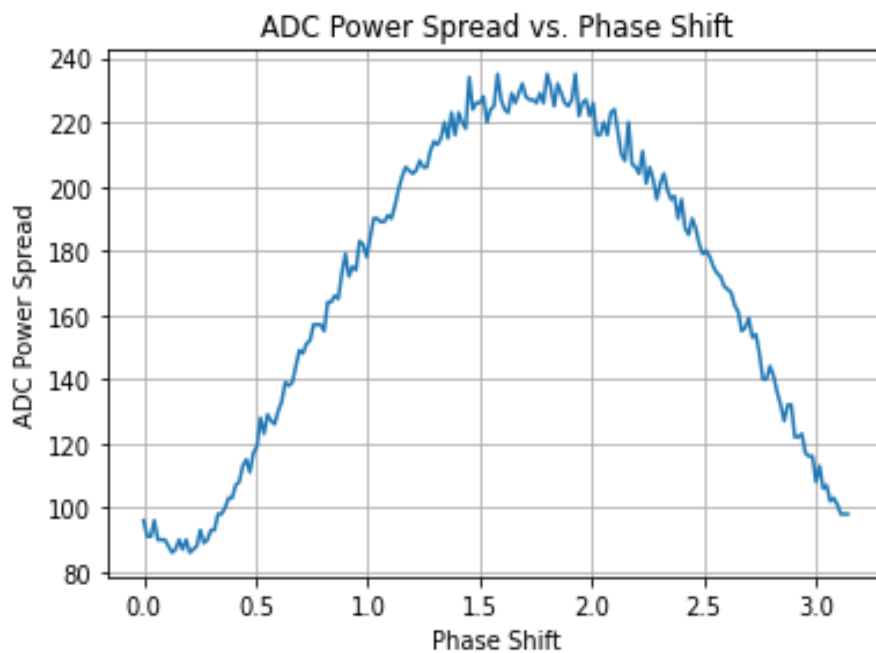


Figure 2: Maximum ADC reading for different cancellation wave phase-shifts.

3. Cancellation Algorithm for Chirps

Our initial approach for chirps relied on the maximum ADC power values, but this proved to render the algorithm highly susceptible to outliers. To remedy this, we adopted a more robust evaluation metric. We employed the average of the sum of the squares of the In-Phase and Quadrature components of each transmission's power.

However, chirps, given their variable frequency, introduced another layer of complexity to the cancellation algorithm. Since their frequency isn't constant, a mere phase-shift proved inadequate. Our adapted approach integrated a time offset, strategically delaying the chirp's commencement, enabling it to align in anti-phase with the leakage. Despite this innovative solution, the inherent unpredictability of chirps meant it was challenging to definitively pinpoint the precise optimal cancellation signal. This signals potential avenues for further research and methodological refinement in future iterations of this project.

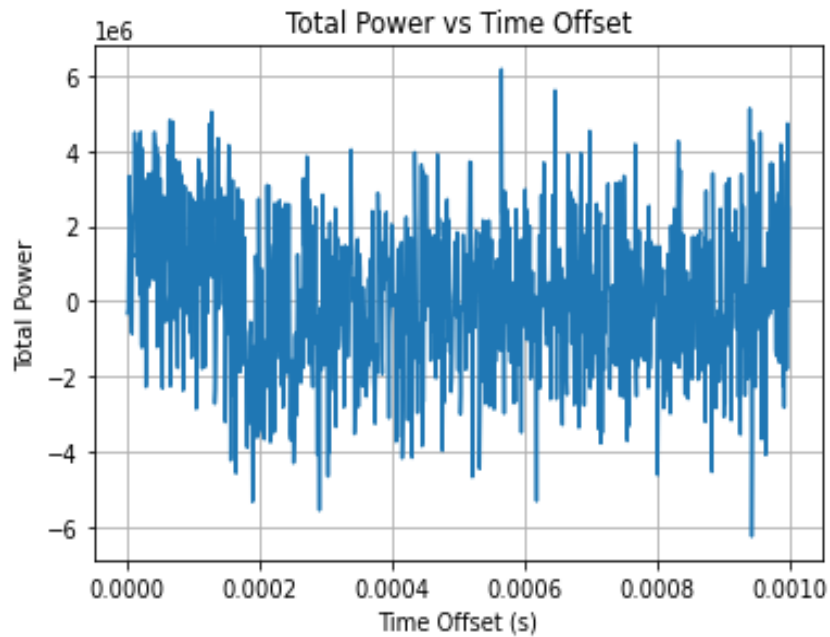


Figure 3: Maximum ADC reading for different cancellation wave phase-shifts.

In conclusion, through an amalgamation of hardware adjustments and iterative algorithm refinements, we were able to significantly attenuate undesired signal transmissions, paving the way for more accurate and efficient FMCW radar applications.

5. Future Work and Recommendations

5.1 Chirp Cancellation Troubleshooting

As evidenced by the inconclusive results when it comes to the possibility of adequately cancelling leakage produced by chirps more work continues to be required in this area. This is especially true because of the general importance of chirps for FMCW radar usage. The first step which should be considered is to troubleshoot and debug the current algorithm to ensure that it is not just a simple bug that is making it hard for the algorithm to find an optimal time-delay for cancelling chirps. To this end, perhaps using a publicly available simulator like the Quite Universal Circuit Simulator (QUCS) could help us run the code in a more accurate manner that would allow us to get more trials done without wasting processor clock cycles.

5.2 Exploration of Advanced Optimisation Methods

In case that the debugging of the current chirp cancellation algorithm is successful, but we are still unable to derive an optimal time delay from it, new, more versatile algorithms need to be explored. This is because perhaps it is the nature of a chirp that makes it hard for the current type of search algorithm to detect the optimal cancellations signals as the ADC power output

levels may not directly lower as the optimal time-offset is approached. This is yet another factor that could be more accurately explored through the use of a pre-built simulator. Even if it turns out that the current algorithm works for finding optimal chirp cancellation signals, it may still be worthwhile to search the literature for more versatile and computationally efficient algorithms to employ.

5.3 Cancellation of reflected signal

For the testing that has been conducted during the project thus far a resistor has been placed on the SMA connector where the antenna would be. This resistor absorbed most of the signal sent to it. This may not be an entirely accurate assumption to make when making our cancellation model however as when using a real antenna, we would expect to see some of the input signal reflected off the antenna and passed down the circulator and into the receive channel. This has not been accounted for in the current algorithms that have been employed, but in order for the system to be more versatile it should be able to simultaneously cancel both the input signals "leakage" through the circulator and this reflected signal.

6. Conclusion

We have managed to demonstrate that the principle behind how ARESTOR would support single-antenna FMCW radars has been demonstrated to work. That being said, there is a long way to go before this technology to be proven to be effective and even longer way before we know whether this method yields practical results.

7. Acknowledgements

I would like to thank the Laidlaw foundation for sponsoring this project, the UCL radar team for their constant friendliness, and Dr Colin Horne and Dr Nial Peters for the patience they have had with me and their indispensable support without whom I would have never been able to enjoy this experience.

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