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Study of Digitally Modulated Radars

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Abstract. State-of-the-art automotive radars use multi-chip Frequency Modulated Continuous Wave (FMCW) radars to sense the environment around the car. FMCW radars are prone to interference as they operate over a narrow baseband bandwidth and use similar radio frequency (RF) chirps among them. Phase Modulated Continuous Wave radars (PMCW) are robust and insensitive to interference as they transmit signals over a wider bandwidth using the spread spectrum technique. As more cars are equipped with FMCW radars that illuminate the same environment, interference would soon become a serious issue. PMCW radars can be an effective solution to interference in the noisy FMCW radar environment. PMCW radars can be implemented in silicon as a System-on-a-chip (SoC), suitable for Multiple-Input-Multiple-Output (MIMO) implementation, and are highly programmable. PMCW radars do not require highly linear high-frequency chirping oscillators, thus reducing the size of the final solution. This article outlines the theoretical underpinnings and experimental implementation of DMR systems using Universal Software Radio Peripheral (USRP) devices, including waveform generation, signal processing, and performance evaluation. Practical insights into automotive, industrial, and aerospace applications are also explored, showcasing DMR's pivotal role in next-generation sensing technologies.

Keywords: Digitally Modulated Radar (DMR), Frequency Modulated Continuous Wave (FMCW), Universal Software Radio Peripheral (USRP), Automotive Radar, Advanced Driver Assistance Systems (ADAS), Radar Sensing.

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1. Introduction

Radar technology has been a key part of sensing systems for a long time, playing an important role in everything from military defense to tracking the weather and keeping cars safe. Traditional radar systems like Frequency Modulated Continuous Wave (FMCW) have proven to be reliable and easy to scale, but they run into real limits when used in today's world. Signal congestion and interference are getting worse, and crowded, changing environments need more precise solutions.

Digitally modulated radars (DMRs) have come up as a game-changer in this field. Unlike traditional setups, DMRs use digital modulation methods like pseudo-random binary sequences (PRBS) and orthogonal frequency-division multiplexing (OFDM) to send and handle radar signals. These methods bring several benefits, like better range resolution, stronger resistance to interference, and improved dynamic range. DMRs work well in tough situations like city traffic, factories, and aerospace because they handle problems like multi-path fading and cross-interference.

Traditional FMCW systems use a linear frequency ramp, meaning the transmitted signal s(t) is defined by its instantaneous frequency. You can describe the relationship for an FMCW signal like this:

$$s(t) = Acos(2pi\, f_c t + \pi\, K\, t^2) \quad (1)$$

Here, f_c stands for the carrier frequency, and K represents the chirp slope. This system works well, but its straight-line setup makes it easy to get messed up by other sensors nearby. On the other hand, Digitally Modulated Radar (DMR) puts a pseudo-random code into the carrier by using Phase Modulation (PM). The PMCW signal model is given by:

$$x(t) = Asum(n) c_n p(t - nT_c) \cos(2\pi\, f_c t) \quad (2)$$

Here, c_n represents the sequence of code chips, and p(t) stands for the pulse shape. Using these unique digital sequences, the radar gets a strong processing gain since the receiver reacts only to the code it sent out, filtering out interference from other vehicles that aren't synchronized.

DMRs not only perform well but are also very adaptable. Using modern CMOS technology helps these systems run efficiently, cutting down on power use and cost while still being easy to scale. DMRs are quickly being used in autonomous driving, industrial automation, and advanced military sensing technologies.

This article looks at the basic ideas behind DMRs and gives a hands-on guide on how to set them up using Universal Software Radio Peripheral (USRP) devices. Using modern hardware alongside flexible software like LabVIEW and GNU Radio, we explain how to create digitally modulated waveforms, send signals, and check their performance. In real-world tests, we show how DMRs can change what radar systems can do, closing the gap between old techniques and what future applications need.

2. Processes

The DMR system was built using a Software Defined Radio setup, with NI USRP hardware connected to the LabVIEW programming environment. The main part of this process is changing from high-frequency analog chirping to digital code modulation.

The system uses In-phase (I) and Quadrature (Q) signaling to represent the complex baseband signal. By showing the signal as;

$$z(t) = I(t) + jQ(t) \quad (3)$$

The system can change the phase of the carrier using digital control. This lets you easily set up different Phase Shift Keying (PSK) methods, where the information is carried in the changes of the carrier's phase instead of its frequency. To get the signal ready for sending, they create a Pseudo-random Noise (PN) sequence of order 13. The system can be reconfigured to support BPSK, QPSK, π /4-DQPSK, OQPSK, 8-PSK, and 16-PSK.

This sequence gives the "orthogonality" needed to tell the radar's own signal apart from any environmental interference. A Root Raised Cosine (RRC) filter is applied before the signal goes to the USRP for RF up-conversion. This pulse-shaping stage is important because it keeps the bandwidth in check and helps cut down on Inter-Symbol Interference (ISI), making sure the digital chips stay clear and properly timed. On the receiver (RX) side, the USRP picks up the reflected signal and down-converts it, bringing the signal back to its I/Q components.

The LabVIEW backend then runs a digital cross-correlation between the received signal and the original reference code. This process cuts down on noise and random interference because only signals that match the specific PN sequence create a strong correlation peak. This digital-first approach helps the radar stay sensitive and reliable even when the RF environment is crowded.

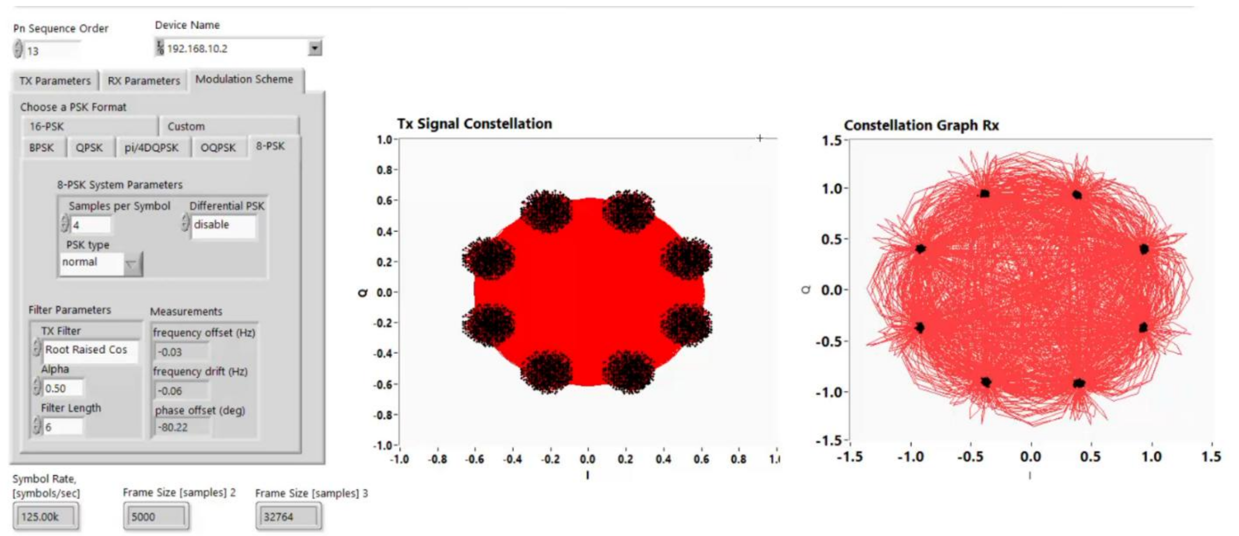

Fig. 1. Comparative Analysis of 8-PSK Digital Radar Signal Recovery.

To provide a clear technical overview of the two primary radar paradigms, the following table summarizes the fundamental differences between traditional analog systems and the proposed digital approach:

Feature	**FMCW (Standard)**	**PMCW / DMR (Proposed)**
Modulation	Linear Frequency Sweep	Phase/Digital Coding (PSK/QPSK)
Interference	High (Cross-chirp interference)	Low (Code-domain isolation)
Hardware	Requires high-linearity VCOs	Digitally intensive (CMOS friendly)
Resolution	Limited by Sweep Bandwidth	Limited by Chip Rate
MIMO Scaling	Complex (TDM/FDM)	Simplified (CDM/Coding)

Table 1: Technical Comparison of Radar Architecture

Conclusions

Switching from analog FMCW to Digitally Modulated Radar (DMR) changes the way vehicles sense their surroundings, moving away from frequency-based methods to relying on code-domain techniques. This study showed how a Phase Modulated Continuous Wave (PMCW) system can be practically built using a USRP-based software-defined radio (SDR) setup. Our experimental results, recorded using LabVIEW, confirm several important points about digital radar sensing.

The practical test of a Digitally Modulated Radar system on the USRP platform shows that moving from analog-focused sensing to a code-domain setup can really work. Using LabVIEW-based digital signal processing, this study showed that a phase-modulated carrier can be generated, sent, and recovered accurately within a software-defined setup.

The results show that combining In-phase and Quadrature (I/Q) modulation with pseudo-random sequences offers a solid foundation for future sensing technology. The system was able to keep the signal clear by using coherent down-conversion and digital synchronization, even when there were carrier frequency offsets and phase noise. The successful recovery of high-order PSK constellations shows that DMR can bridge the gap between fast data communication and precise radar sensing.

In the end, this shows that moving complexity to the digital side lets radar systems handle interference better and scale up their hardware, which is key for busy automotive and industrial setups.

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