APPLICATION NOTE

Automotive Frequency Modulated Continuous Wave analysis

with U3851A RF Microwave Courseware

Introduction

Car accidents have always been a major problem, resulting in over a million deaths and countless injuries globally in a recent year. One of the significant factors of these tragedies is due to a limited field of view (FoV) that a driver has in a vehicle. Due to this fact, scientists and engineers are developing radar technology to assist drivers on the road. The radar applications such as lane change assist (LCA), blind spot detection (BSD), stop-and-go, adaptive cruise control (ACC) and rear crash warning (RCW), are widely used in most of the vehicles nowadays.

The most commonly used technology for automotive radar application is frequency modulated continuous wave (FMCW). This signal is also widely used for radar altimeters, navigation systems, and sensors. This signal can provide more accurate distance measurement compare to pulse radar even with objects that are closely apart. The FMCW radar system detects and provides the measurement of range and velocity of the surrounding objects simultaneously. While the real-time calculations required for the signal processing is complicated, faster processors available today is sufficient to make FMCW possible. Besides, the lower cost of these processors allows the FMCW signal is used mainly in the automotive industry. With this technology and cost feasibility, the design for a self-driving car is made possible with this radar system.

While this FMCW technology has a lot of advantages for the automotive industry, the testing of this signal in real life is difficult and expensive to setup for student learning. Therefore, we will analyze the FMCW signal with Keysight U3851A RF Microwave Courseware. In this document, we will discuss about FMCW design and simulation using PathWave System Design 2020, building up the receiver system with U3851A prototyping kit and making real-world measurement out of it and finally analyze the signal with VSA for both simulation and the real-world signal.

U3851A RF Microwave Courseware

-Ready to teach courseware

-Include software simulation and hardware validation

-Expandable to short term project learning

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Automotive Frequency Modulated Continuous Wave

FMCW radar system works with a similar mechanism as a Continuous Wave (CW) radar, in which a known stable frequency radio energy is continuously transmitted and then received from any reflecting objects. However, this CW radar signal only detects the reflecting object without providing any information about the object's distance due to lack of timing mark necessary to determine its location. In contrast to the CW radar, the FMCW system uses a transmission signal that has been modulated in frequency which allows the operating frequency of the signals to be varied during the measurement. Thus, the distance measurement is possible with this type of signals. The FMCW system makes the 360-degree view for the vehicle possible as shown in Figure 1.

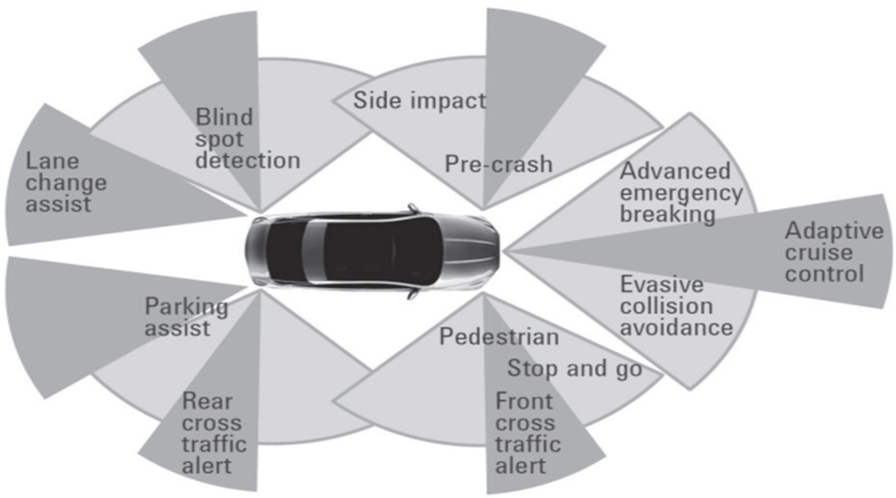

Figure 1: The sensor detection system with the FMCW signal.

FMCW radar measures the frequency difference from the transmitted and received signal to calculate the distance. The FMCW radar can provide an excellent range resolution (up to 3.5 cm) with much cheaper electronic components and can detect objects that are closely apart. This radar also can listen while transmitting a new signal and thus, allows this radar to detect multiple objects at the same time. FMCW has a drawback of creating unreal targets ("ghost targets"), these ghost targets are easily eliminated by measuring the slope of the modulation patterns. This signal also has the additional effect of Doppler frequency where the received signal will be shifted up or down and thus, produces an error in distance measurement. This problem can be eliminated by using different modulation schemes such as modulation with increasing frequency or decreasing frequency.

Frequency Band and Bandwidth

The most common frequency band used in the automotive industry is 24 GHz and 77 GHz. For 24 GHz band, the application is divided into two which are narrowband (NB) and ultrawideband (UWB). The narrowband has a bandwidth of 200 MHz, ranging from 24.05 GHz to 24.25 GHz and it includes an industrial, scientific, and medical (ISM) band. The ultrawideband spans more bandwidth (up to 5 GHz), from 21.65 GHz to 26.65 GHz. However, due to regulations and standards made by European Telecommunications Standards Institute (ETSI) and Federal Communications Commission (FCC), the UWB will be phased out in the year 2022 in Europe and the United States and only the narrowband ISM band will be allowed for longer term application. Since the bandwidth of the ISM band is very limited, coupled with demands for high-performance radar technology, the design for automotive radar in 24 GHz band becomes unattractive nowadays. The regulating authorities have opened the frequencies for automotive radar in 77 GHz range to replace the 24 GHz band. The 77 GHz band spans 4 GHz bandwidth in the range from 77 GHz to 81 GHz for automotive radar application. Thus, by having wide bandwidth, radar at 77 GHz can provide more advantages such as increasing in range resolution and velocity resolution and hence, allow the vehicles to distinguish multiple objects that are closely spaced such as clutters and motorcycles.

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FMCW Analysis

The analysis for FMCW signal at a high frequency such as 77 GHz is very costly due to the complexity of the hardware design. Hence the hardware measurement and analysis will be done with U3851A RF Microwave Courseware prototyping kit. Although the carrier frequency and the bandwidth being scaled down, however the system design and also hardware measurement is good enough to demonstrate the FMCW concept. Below are the parameters used for the analysis.

Carrier frequency: 1.8425GHz
Modulation waveform: Triangular waveform
Modulated signal frequency:200kHz
Modulated signal bandwidth: 10MHz
Sampling rate: 100MHz
Signal Power: -10dBm

Design and Simulation

FMCW system design and simulation is done by using PathWave System Design 2020. The design is made possible with PathWave System Design radar library which provides simulation and test for an automotive radar system. Below is the block diagram of generating the FMCW signal.

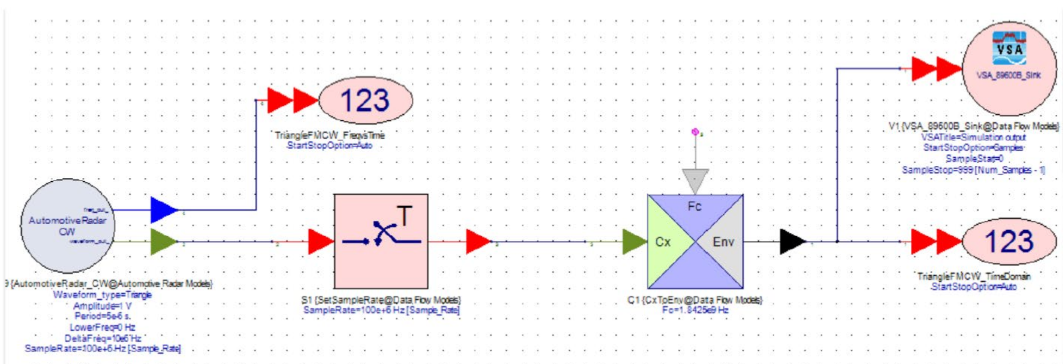

Figure 2: Block diagram of FMCW generation.

Having connected all module blocks and input all signal parameters stated above, the FMCW is now generated. A quick way to verify is to make use of the output display blocks and below are the results.

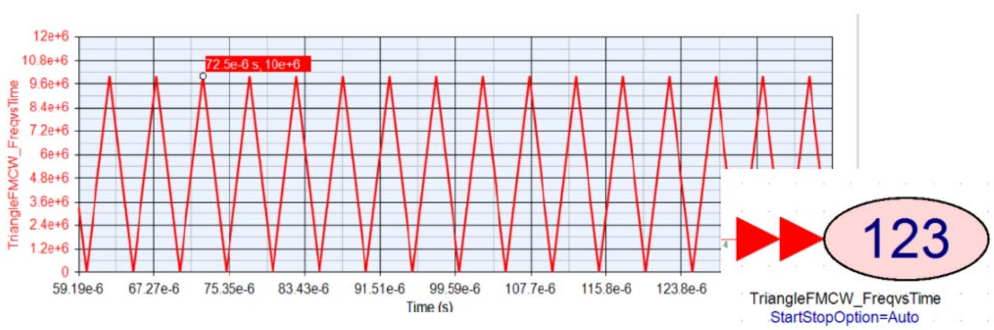

Figure 3: Triangular wave with 10MHz bandwidth.

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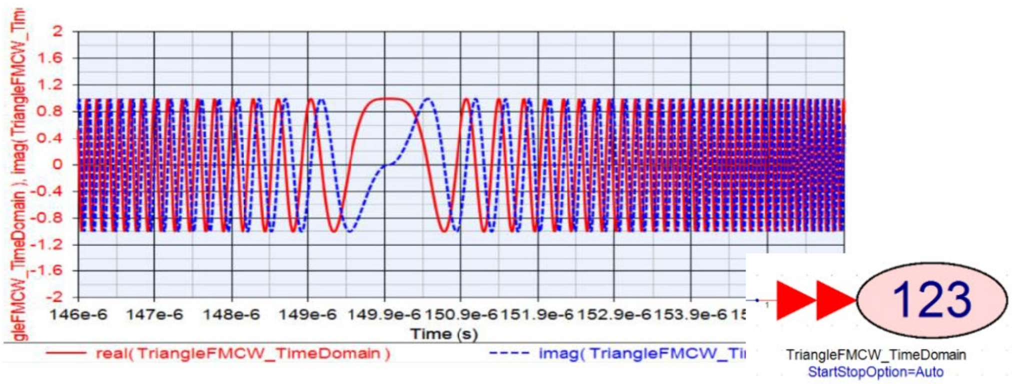

Figure 4: Modulated FMCW signal.

Simulated FMCW Analysis

To further analyze the signal, the FMCW output file from VSA is fed into Keysight VSA software. Keysight VSA contains FMCW Radar Analysis library which can demodulate the modulated FMCW signal. The signal is divided into frames for simplification of analysis. Some essential parameters are discussed below.

Figure 5: Demodulated FMCW signal and power linearity

Figure 6: Demodulated signal vs reference signal.

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Figure 5 shown the output power is linear across the time, which is desirable for the system. Figure 6 shows the comparison between demodulated waveform and a reference signal from VSA reference. Demodulated signal shows a triangular waveform pattern, indicating the signal demodulated successfully (like what we have set earlier).

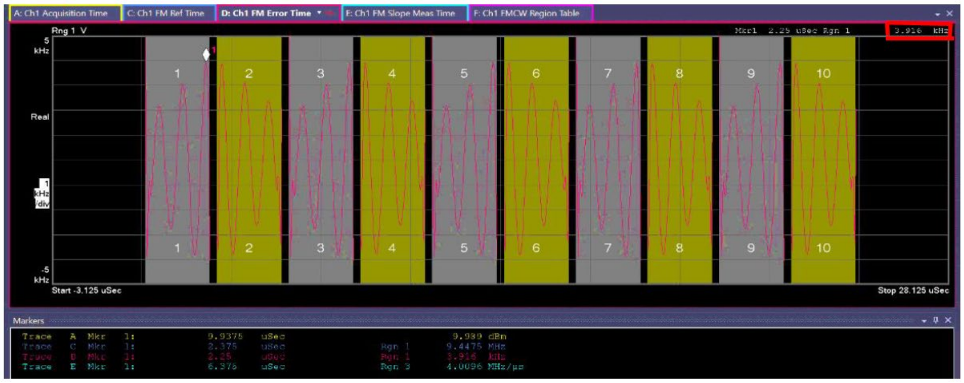

Figure 7: FM error time of demodulated FMCW signal.

While both signals have a similar pattern, there were some differences in frequency at a specific time, and this error is shown as in Figure 7. The error can be calculated with formula below.

FM Error Time (Hz) = FM Reference Time – FM Demodulated Waveform Time

This error, if it is large enough, it will have a significant impact to the range resolution and may affect the accuracy in distance measurement for short range application. The maximum error produced from this demodulation process is 8 kHz peak to peak. By converting this error into a percentage,

$$\text{Error (\%)} = \frac{\text{Peak to peak error (Hz)}}{\text{Bandwidth of the modulated signal (Hz)}} \times 100\%$$

$$= \frac{8\ \text{kHz}}{10\ \text{MHz}} = 0.08\%$$

Figure 8: FM slope time measurement.

The FM slope time analysis in figure 8 measures the steepness of the modulation. Ideally, the slope is a perfect square wave. The slope is ~4MHz/us. It can be calculated with below formula.

$$Best\ Fit\ FM\ Slope\frac{Hz}{us} = \frac{Best\ Fit\ FM\ (pk-to-peak)(Hz)}{Time\ length(us)}$$

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Prototyping and measurement

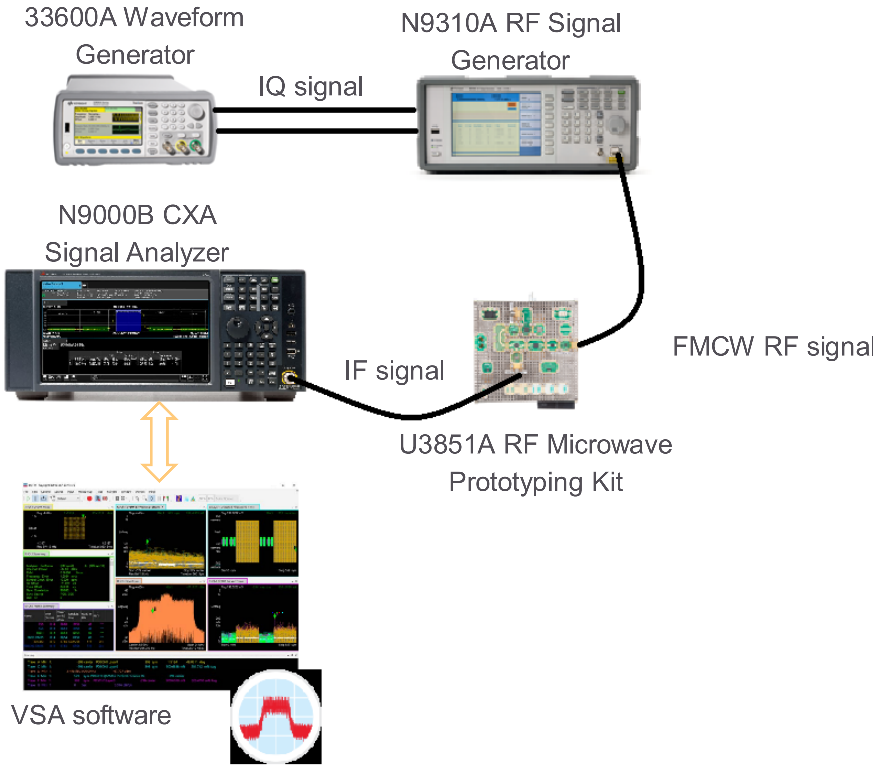

Figure 9: Hardware setup for FMCW measurement.

Figure 9 shows the connection setup to determine the properties of FMCW in hardware instruments. The downloaded CSV file from SystemVue will be fed into a waveform generator via USB. In most cases, the signal from CSV data can be easily generated by using N9310A RF Signal Generator. However, for the FMCW signal which has arbitrary real (in-phase) and imaginary (quadrature) waveform, this signal cannot be loaded directly to the Signal Generator. The Keysight 33600A Waveform Generator offers the arbitrary waveform options for wideband analysis and signal generation. By using this waveform generator, the generation of FMCW signal is made possible in the hardware instrument. VSA software in N9000B CXA is used for signal analysis.

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FMCW hardware measurement analysis

Once the connection setup is completed, a -10dBm FMCW signal is fed into the prototyping kit and below are the results. The IF output signal (168.5MHz) is fed to N9000B signal analyzer and VSA will be used to analyze the system performance. Below are the measured results.

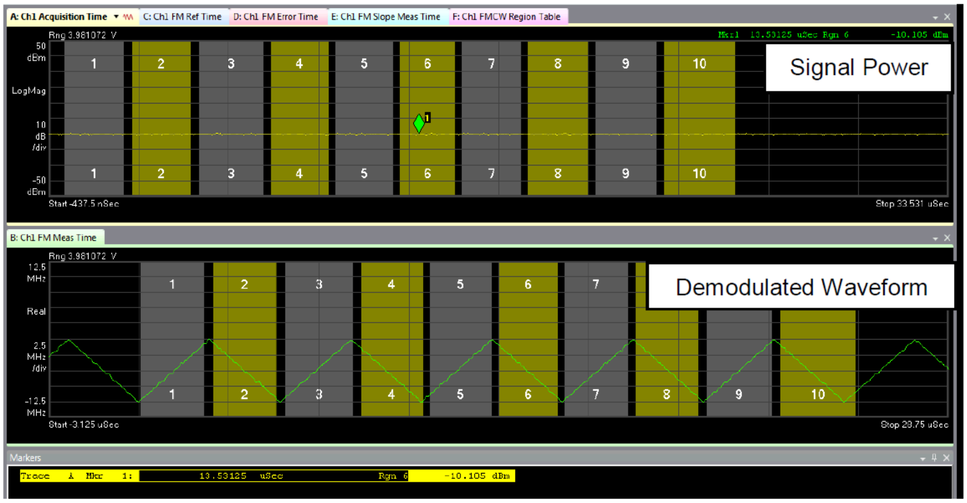

Figure 10: Demodulated down-converted FMCW signal and power linearity

Figure 11: Demodulated signal vs reference signal.

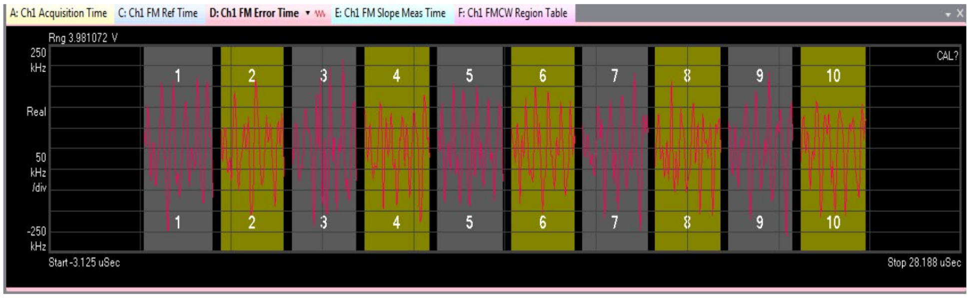

Figure 12: FM error time of demodulated FMCW signal.

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Figure 13: FM slope time measurement.

The output signal has ~-10dBm linear output power which is essential for FMCW and managed to obtain triangular demodulated waveform. Nonetheless, the FM Error in Figure 12 is huge compare to simulated result. The error has a peak to peak value of ~800kHz (8% error) which is significant for distance measurement. One way to eliminate this error is to find the average value of beat frequency to determine the range resolution. The FM slope time measurement in Figure 13 shown a similar error pattern to FM error in Figure 12.

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Conclusion

As world is improving with emerging technologies, wireless communication has become one of the key components of their success. It is essential for future engineers to be well equipped with strong RF microwave knowledge. U3851A RF Microwave Courseware focuses on the complete RF circuit design flow which can be applied other technologies analysis such as FMCW study.

This FMCW study is considered successful as the FMCW signal can down-convert and demodulate back to its original signal with some FM error. The U3851A courseware is a good tool for learning and it is inexpensive compared to a real automotive FMCW setup which utilizes 77GHz in W band. SystemVue is comprehensive simulation software that helps to build up the system easily.

The courseware brings you a whole new level of learning experience from design specifications and simulation to prototyping building and validation. This will help to deepen students' knowledge base and prepare students to be industrial ready with real-world RF design and testing exposure. The courseware can also enable analysis of technologies beyond FMCW such as microwave sensing and imaging (MSI), Vehicle-to-everything (V2X) and other IoT wireless communication (BLE, LoRa).

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