Millimeter-wave Technology in Automobile Safety Systems

Increased use of millimeter-wave radar technology in automobile safety systems creates the need for improved test systems.

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Microwave and millimeter-wave radar technology is being used on automobiles for various functions, including Collision Warning/Avoidance (CW/A) and Adaptive Cruise Control (ACC). The increased use of radar technology is due to its advantages over other sensor types, most notably its ability to work equally well in day or night and in most weather conditions. It can also be used for target identification and for detecting road conditions by using scattering signature information. Due to the increased and critical impact of radar on vehicle safety, conducting accurate verification and calibration of the radar module and system at various development, production, and installation stages is of greater importance. Before the radar systems can be accurately analyzed and tested, it is important to understand what needs to be measured. ACC radar sensors provide range and closing-rate information to an automobile's cruise control system for the control of the brakes, throttle, and automatic transmission of the vehicle. The ACC system maintains a constant distance between vehicles by adjusting the speed of the vehicle according to the speed of the automobile ahead, based on parameters inputted by the driver. The radar system can also be used to locate and track multiple targets on the road ahead.

In order to track multiple targets correctly, the ACC radar system must be able to detect targets up to 200 meters ahead and have an angular coverage of at least &#177 8&#176 (Figure 1). A typical automotive radar will transmit three to five beams each with a width of approximately 3&#176 or use beam scanning to illuminate the center lane and those immediately to the left and right. Some radar will transmit a single wide beam approximately 12&#176 in width and use monopulse receive techniques to locate vehicles off of the boresight on the left and right of the automobile. To achieve such narrow beam widths, electrically large antennas with high gain of 26 - 34 dBi must be used. For these high-gain antennas to be small enough to fit on an automobile, millimeter-wave frequencies must be used. Early systems were developed for the 94 GHz band and the 60 GHz oxygen absorption band, however, all new systems being developed use the newly allocated 76 - 77 GHz band.

Figure 3. New radar test systems can conduct both target simulation and signal analysis

Several different modulation schemes are currently being used for the 76 - 77 GHz radar modules. The majority of radar sensors use Frequency Modulated Continuous Wave (FM-CW) modulation. Other modulations used are a discrete form of FM-CW, referred to as Frequency Shift Keying (FSK), and the traditional pulse Doppler modulation.

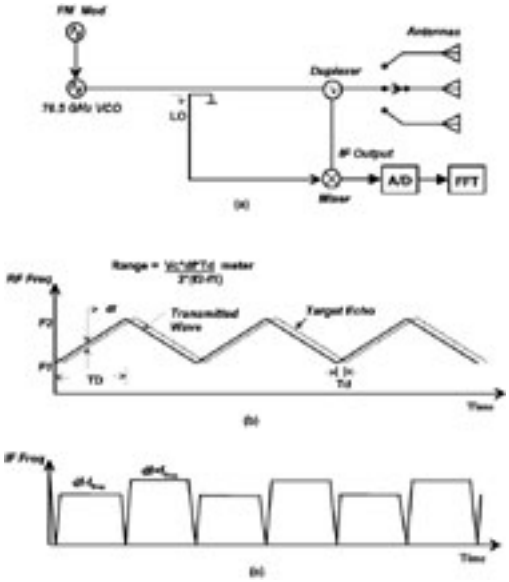

Figure 2. Typical Frequency Modulated Continuous Wave (FM-CW) radar.

The FM-CW radar (Figure 2a) transmits a CW signal whose frequency is modulated as a function of time with a periodic waveform such as a triangular waveform. Typically, the frequency deviation is on the order of 150 MHz to 300 MHz with a period of approximately 1 millisecond. The signal reflected by the target will be delayed by a time Td and demodulated, along with the transmitted signal in the radar receiver. If the target is moving relative to the radar transmitter, the demodulated IF frequency is as shown in Figure 2b. A Fourier transform is applied to the sampled IF output. The average frequency (df) determines the range to the target and the Doppler frequency contains the relative velocity information. Ensuring the linearity of the frequency sweep of the 76.5 GHz source is a critical step in FM-CW radar. A Gunn Oscillator is usually used with a frequency locked loop, although newer designs make use of MMIC-based Voltage Controlled Oscillator (VCO) technology. The post processing of the FM-CW signals is usually done using standard Fourier Transform DSP techniques providing simple and fast data analysis. The FSK radar is a variant of the FM-CW radar. The radar transmits a CW signal whose frequency is changed by typically 150 kHz to 500 kHz every microsecond. The IF output is processed in a similar manner to the FM-CW radar. The phase

difference between the received signals at the different frequency points contains the range data while the Doppler information is contained in the IF frequency. Due to the type of processing performed, FSK radar usually only responds to Doppler-shifted return signals. FSK radar requires good phase stability but is otherwise simple from a hardware standpoint. The radar, however, requires extensive post processing to ensure accurate range information.

New radar test systems feature advanced technology to meet increased testing requirements.

Traditional pulse Doppler radar is another type used in ACC applications. The typical pulse radar transmits two frequencies separated by 200 MHz and t = td. The transmit frequency remains at the second frequency for a time period greater than twice the propagation time to the furthest potential target. The delayed echo from the target is demodulated in the mixer, with the time delay between the transmitted pulse and the pulse echo determining the range to the target. Velocity can be determined from the rate of change of the target position or by using coherent pulse-Doppler techniques.

First generation ACC systems are designed for highway driving only. Next generation systems will make use of multiple radar sensors to extend the ACC system to city driving or stop-and-go traffic. The same radar sensors used for ACC can also be used in CW/A systems. When used in a CW/A application, the radar sensors allow for warning signals to be given and for air bags to be activated. CW/A systems can also be designed to take control of a vehicle when a collision is anticipated.

For stop-and-go ACC and CW/A systems, multiple radar sensors must be used in conjunction with the long-range forward-looking ACC radar. These sensors are typically short-range and are used to monitor the traffic in front, on the sides, and in back of the vehicle. The unlicensed ISM band of 24.125 GHz is presently being used for the short-range radar. The lower frequency is used because these radar sensors do not need to detect objects further than 30 meters away. Also, the angular coverage of the sensor can be broader for these applications. Therefore, lower gain antennas with wider beam widths can be used, resulting in radar sensors that are small enough for automobiles.

Signal Testing

The ability of the radar to detect moving targets with known radar cross-section (RCS) at ranges up to 200 meters must be tested during the development and production of the radar units. In most R&D and production facilities, it is not feasible to test a real moving target at such a distance, forcing the need to conduct actual

road tests. This is less than ideal, as road tests usually do not provide the consistency required and are expensive.

Testing of the radar units must also be done during installation into the automobile, as well as for EMC verification and for servicing radar modules after installation. In such applications, a radar test system (RTS) may need to provide functional testing as well as aid in the positional and angular alignment of the radar.

Recent advancements in testing technology have led to the development of an alternative to the traditional millimeter-wave radar test methods that use rack and stack instruments and special system configurations. The alternative solution is considerably less expensive, more accurate, and can conduct both target simulation and signal analysis in a single instrument. An example of the new solution can be seen in Figure 3. Despite their compact size, the new test systems can quickly and completely characterize all three major elements of the ACC system &#151 the transmitter, receiver, and antenna &#151 with high accuracy and repeatability. These systems are also equally adept during R&D, manufacturing, and installation. The new RTS can act as a simulator, providing a signal return from targets with a known RCS, at a nominal distance of either 5 meters or 120 meters moving at a certain velocity between 0 to &#177 250 km/h. At a target distance, the RCS level can be varied over a 50 dB dynamic range to simulate different target sizes ranging from a person walking to a tractor trailer. It can also simulate target scintillation. The RTS can be located as close as 1.5 meters from the radar, allowing for the full radar testing to be conducted in a confined area. New systems also have internal power and frequency measurement capability to characterize the radar transmit signal. In addition, the new systems provide compatibility with external low frequency power meters and spectrum analyzers. This flexibility permits the monitoring of transmitted radar modulated signals as well as conducting antenna pattern measurements.

Another important aspect of test systems is their ease of use. Because automotive design engineers do not typically have a great deal of experience with high frequency signal analysis, test systems must be intuitive and simple to operate. Single instrument solutions such as those now being introduced virtually eliminate the need for external cabling, multiple set-ups, and complex operation associated with a rack of instrumentation. The newer RTS even include a built-in laser that facilitates the mechanical alignment between the antennas of the radar and RTS, which is a very important step for accurate testing of ACC radar.

Conclusion

The integration of ACC and CW/A systems into automobiles will continue at a fast rate. Originally designed exclusively for luxury models and trucks, the popularity and safety benefits of these systems will lead to their design into more moderately priced automobiles. To accommodate this expansion, test systems that provide highly accurate analysis capability at the R&D, production, and installation levels are necessary. These test systems must also be economical to control the cost of car manufacturing. Fortunately, new radar test systems feature all the critical testing capability in a single instrument, which is providing the necessary cost efficiencies, performance, and ease of use necessary for the successful extension of automotive radar systems.

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