Millimeter-wave Dual Mode Radar for Headway Control in IVHS

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Abstract

In intelligent vehicle and highway systems (IVHS), lateral and headway vehicle control is used to maintain stable driving. Headway control keeps the controlled vehicle an appropriate distance from vehicles directly ahead. Each vehicle needs to have an obstacle detection system installed to monitor distances to the preceding vehicle and its relative speed.

In the future, headway control systems for consumer use must be cheap and capable of operating in all environmental conditions. To enable such equipment to be built, a dual mode millimeter-wave radar has been proposed. It would be able to operate in both radar mode, in which it would measure the distance to the leading vehicle, and in communication mode, in which it would exchange data with a vehicle ahead of it. By operating in two modes alternately, the dual mode radar can provide the headway control system with all the data needed to control the distances to the leading vehicles, their speeds, acceleration conditions, and the leading vehicle's steering angle and brake signal. The data can then be used for stable control of the vehicles. This paper describes the concept of the dual mode radar system and the results of the experiments undertaken.

1. Introduction

In recent years numerous intelligent vehicle and highway systems (TVHS) have been proposed and developed in response to increasing demands of efficient, convenient, and safe driving on the highway. With these systems, lateral and headway vehicle control maintains driving stability. Headway control keeps the controlled vehicle an appropriate distance from vehicles directly ahead Each vehicle needs to have an obstacle detection system installed to monitor distances to other vehicles and their relative speeds.

In these headway control systems, radar sensors have typically been used. Inter-vehicle or roadside-vehicle communication systems or vision systems with image processing have also been used for more stable vehicle control. This is needed because of the problems involved in recognizing the lane separation of leading vehicles.

In future, headway control systems for consumer use in IVHS must be low cost and capable of operating in all environmental conditions. To enable such equipment to be built, a dual mode millimeter-wave radar system with a tag has been proposed. It would be able to operate in both radar mode, in which it would measure the distance to the leading vehicle and in communication mode, in which it would exchange data with a vehicle ahead if that vehicle had a millimeter-wave tag or ID card installed at the rear side. The tag system is very simple and since it has no RF source, it is also very cheap.

By operating in two modes alternately, the dual mode radar can provide the headway control system with all the data needed to control the distance and azimuth angle to the leading vehicles, their speeds, acceleration conditions, and (for more stable platoon driving control) the lending vehicle's steering angle and brake signal. In addition, this dual mode radar can send data to the leading vehicle about the status of the vehicle behind. This data is very useful for ensuring more stable headway driving control.

2. The Concept of the Dual Mode Radar System

Figure 1 shows the basic block diagram of a conventional millimeter-wave radar sensor used in the conventional way. It consists of a VCO, a transmitting antenna, a receiving antenna, a homodyne mixer and a video amplifier.

Figure 2 shows a basic block diagram of the communication system used in the proposed dual mode radar. It consists of a base station and a tag. The base station comprises a VCO with ASK modulator, a transmitting antenna, a receiving antenna, a homodyne mixer, and a video amplifier. This construction is similar to conventional radar sensor equipment. The radar sensor therefore can be used as the base station of the proposed communication system by adding an ASK modulator. The tag consists of a receiving antenna, a detector, a video amplifier, a reflection type PSK modulator, and a receiving/transmitting antenna. It has no RF power source, and so can be manufactured at a lower price. Figure 3 shows the basic block diagram of the proposed dual mode radar. By automatically choosing the mode-select signal, it operates alternately in communication and radar mode. The specification of the test equipment of the proposed dual mode radar is shown in Table 1.

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3. S/N Consideration

3.1 Communication mode

The power that the tag can receive (Prt) from the dual mode radar (base station) is expressed in following equation:

$$Prt = Gt \cdot Gr \cdot Pt\,(\lambda/(4\pi d))^2$$

where λ is a wave length of the RF signal, d is the distance between the dual mode radar and the tag, and Gt, Gr are the antenna gain of the radar and the tag respectively.

In the tag, the received power Prt is modulated with the reflection type PSK modulation. It is then retransmitted from the same antenna to the radar.

The RF power received by the radar (Prb) from the tag is expressed in the following equation:

$$Prb = Gt \cdot Gr \cdot Prt \cdot Ld\,(\lambda/(4\pi d))^2 = (Gt \cdot Gr)^2\,(\lambda/(4\pi d))4 \cdot Ld \cdot Pt$$

where Ld is the loss of the PSK modulator and transmission line of the tag RF circuit.

A calculated Prb via distance d is shown in Figure 4. The Prb at 100m is estimated at –106dBm. The noise power of 20kHz bandwidth is plotted in Figure 4. The estimated C/N at 100m of 6dB is based on this plotting.

3.2 Radar mode

The received power (Prr) of the radar reflected by two obstacles — a metal plate of 0.5m square and the rear of a car — was measured. The results are shown in Figure 4. We can see that Prr is very large compared to Ptr. The SN limitation is therefore decided by communication mode.

4. System of tests

Figure 5 shows the field test system of the dual mode radar. In radar mode, the FMCW method is used. The VCO of the dual mode radar generates FMCW and CW RF signals alternately. In radar mode, linear ramp voltage is chosen and in communication mode, constant voltage is chosen for the varactor voltage of the CVO. This mode select signal is shown in figure 6.

In communication mode, tests are performed with an 8 bit transmission signal. When downlinked, the signal is inserted into dual mode radar (base station) and the 60GHz RF signal generated by VCO is modulated to the ASK with the 8 bit signal. This modulated RF signal is transmitted through the transmitting antenna to the tag. At the tag the modulated ASK RF signal is received and detected. The 8 bit signal that is detected is amplified and regenerated to a clear pulse. When uplinked, the regenerated signal is delayed 16 bits and then inserted into the PSK modulator with a 450kHz subcarrier. The CW RF signal radiated from the radar and received by the receiving and transmitting antenna of the tag is modulated by the 8 bit signal with a 450kHz subcarrier and retransmitted through the same antenna to the base station. At the base station the received phase modulated RF signal is detected by the homodyne mixer and passed through a 450kHz narrow band pass filter, then regenerated to a clear pulse signal.

In radar mode, an FMCW RF signal is transmitted through the transmitting antenna. The obstacle with a tag installed) reflected the FMCW RF signal, then is received by dual mode radar through the receiving antenna and detected by the same homodyne mixer.

5. Test Results

Figure 7 (a) shows the detected signal with the 450kHz subcarrier of the homodyne mixer and Figure 7 (b) shows the envelope wave form in communication mode. Figure 8 shows the detected signal of the same homodyne mixer in radar mode. Figure 9 shows the measurements of the uplink and downlink SN ratios in communication mode. The dual mode operation has been successfully tested.

The results indicate that it is possible to use the proposed dual mode radar for communication and range measurement between the leading vehicle and following vehicle.

6. Conclusions

A dual mode radar for headway driving control systems is proposed. This radar would be able to communicate and measure the distance between the leading and following vehicles in all environmental conditions. This capability is very useful for stable headway driving control in IVHS, and because the proposed communication system can use the radar sensor as communication equipment, lower costs will result.

A dual mode radar system with higher bit rates is now being investigated and the authors are looking forward to reporting the results at the earliest opportunity.

Table 1: Specification for test equipment

Base station of dual mode radar	Frequency		59.5GHz
	RF power		5mW
	Tx & Rx antenna gain		29dBi
	Modulation	Radar mode	FMCW
		Comm mode	ASK (downlink) CW (uplink)
	Transmission rate		2kbps
Tag	Tx & Rx antenna gain		24dBi
	Modulation (uplink)	Reflection type PSK with 450kHz subcarrier	

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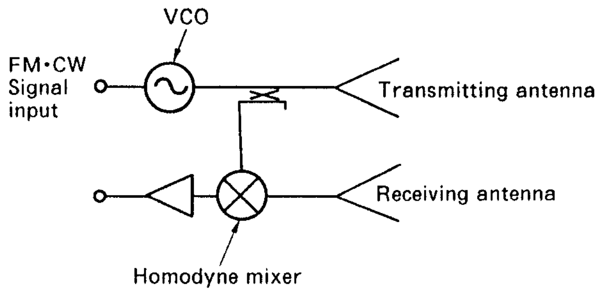
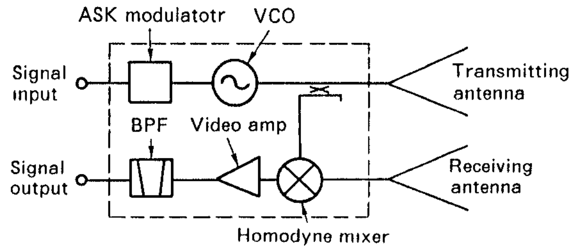
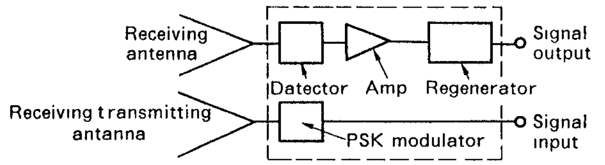


Figure 1: A conventional millimeter-wave radar.



(a) Block diagram of base station



(b) Block diagram of tag

Figure 2: The communication system used in the proposed dual mode radar.

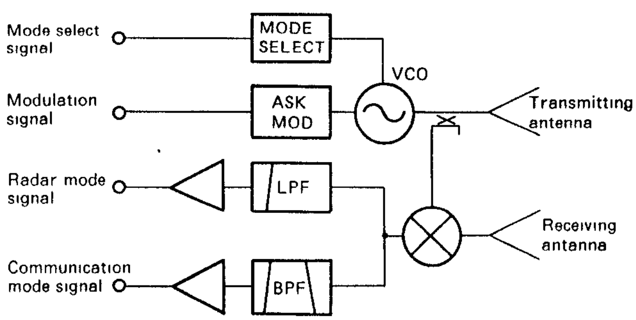


Figure 3: The basic diagram of the proposed dual mode radar.

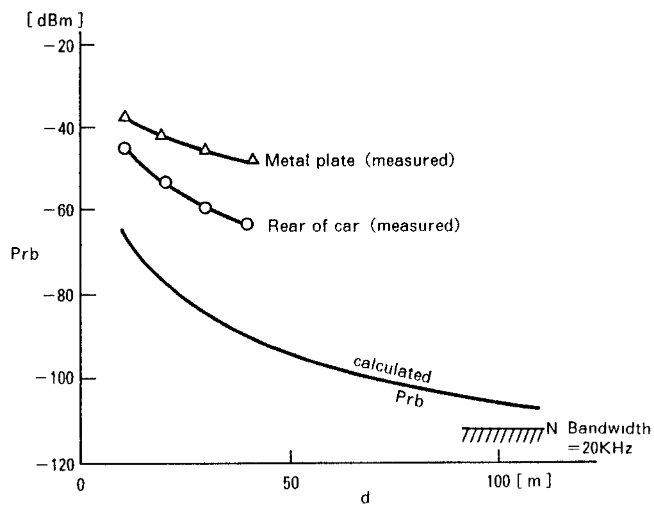


Figure 4: Calculated measured prb via distance d.

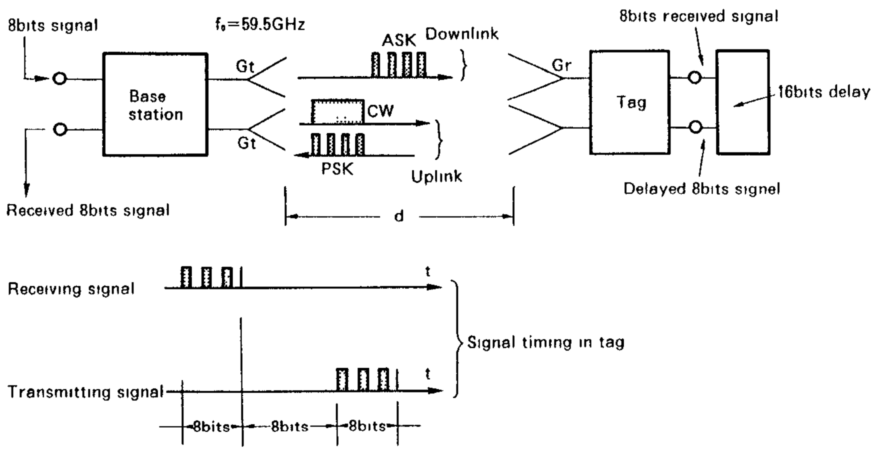


Figure 5: The field test system of the dual mode radar

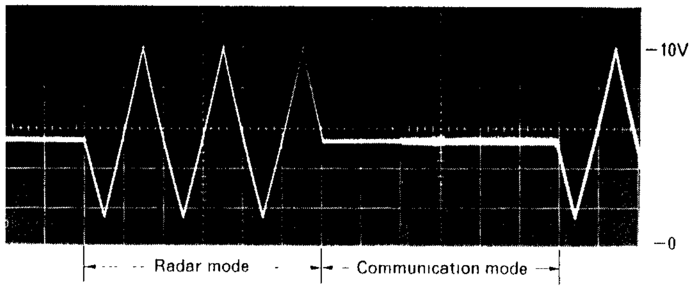


Figure 6: Mode select signal.

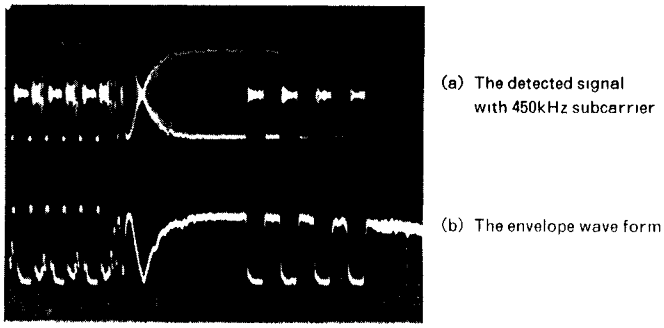


Figure 7: The detected signal in communication mode.

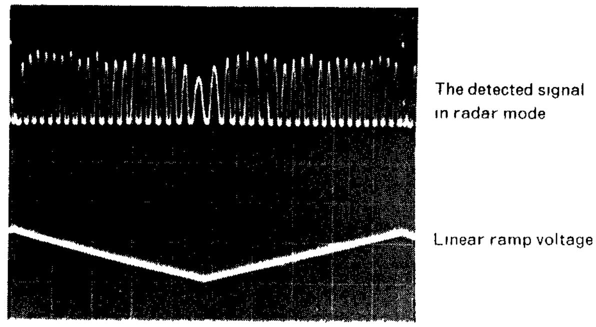


Figure 8: The detected signal in radar mode.

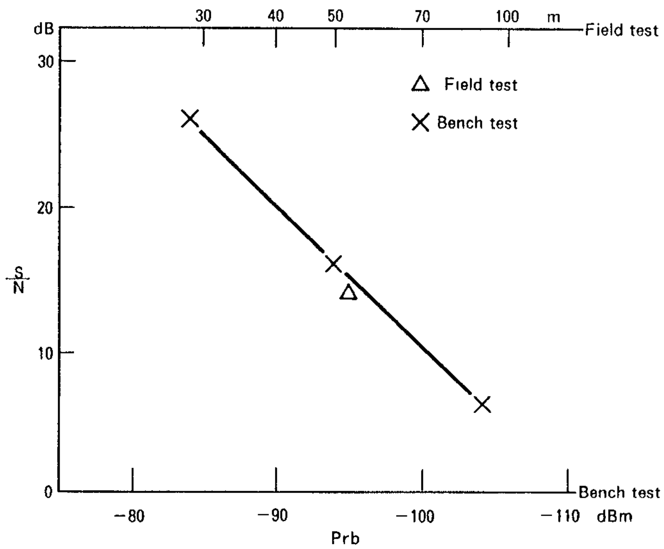


Figure 9: The uplink SN ratios.

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