RADAR SENSOR FOR AUTOMOTIVE COLLISION PREVENTION

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ABSTRACT

A pulse-Doppler radar of 20 ns pulsewidth was developed and tested as an automotive collision prevention sensor. A simple but effective super-heterodyne structure was realized by the use of one FM Gunn oscillator as both the transmitter and the local oscillator. It is a unique feature of the system that the IF signal is coherent in every pulse repetition, which contributes to the realization of a pulse-Doppler system in a very simple configuration. A micro-computer is utilized in the signal processor unit which calculates danger evaluation and false alarm prevention.

Introduction

The general trend of road traffic growth all over the would has imposed a heavy toll in traffic accidents everywhere, in terms of both the personal and property damages.

Recent advances in solid state microwave power source and LSI circuit technology have brought into reality the development of automotive radars for collision prevention with reasonable cost. One such radar that has a unique combination of features is presented here.

Design Considerations

Radar Systems

The present radar is a pulse-Doppler type of a unique principle. Pulsed system had been found to offer better performance than CW systems in discrimination of multiple targets or in rainy weather[1]. Systems with much versatility like this are being called for as automotive radar sensor[2].

Construction

This radar uses one FM Gunn oscillator as both the transmitter and the local oscillator.
This gives rise to two notable advantages:
a simple but effective super-heterodyne receiver is realized, and the obtained IF signal is coherent in every pulse repetition.

Target Discrimination

The super-heterodyne configuration enables a low noise figure, which in turn allows a wide bandwidth and therefore a short pulsewidth of 20 ns, which contributes to a high range resolution.

Signal Processing

The use of a micro-computer permits the inclusion in the calculation of, besides the radar informations, such data pertaining to the carrier vehicle as velocity and steering angle. The improvement and choice of optimum danger evaluation logic for each of different vehicle types can be performed simply by computer program improvement.

False Alarm Prevention

If the alarm is generated too often, it will annoy the driver. It is important to avoid the alarm which is generated by the non-dangerous targets. A maximum limit is imposed on detection range to avoid these false alarms.

Configuration and Functions

Figures 1 and 2 show system block diagram and the general radar configuration. The sensor consists of 5 units: antenna and microwave unit, receiver unit, signal processor unit, display unit and power supply unit.

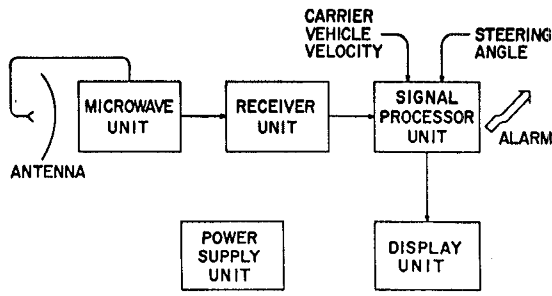

FIGURE 1 SYSTEM BLOCK DIAGRAM

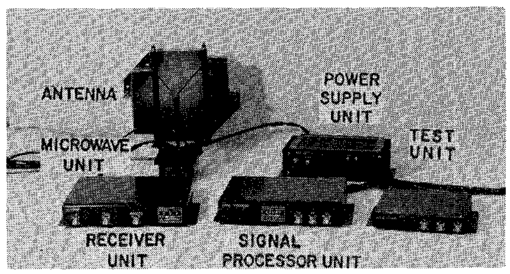

FIGURE 2 RADAR CONFIGURATION

Antenna

Antenna and microwave unit assembly is mounted in an opening cut in the center of the front grill as shown in figure 3. The parabolic reflector consists of formed parallel plates spaced closer than half wavelength, which contribute to reduce the air flow blockage to the radiator.

Microwave Unit

The block diagram of microwave unit is shown in figure 4 and the view of the microwave circuit within it is shown in figure 5.

Transmitting Operation The balanced type switching circuit is controlled to short the circuit. Oscillator output of FM-Gunn oscillator is divided in two at hybrid circuit and fed to the switching circuit,

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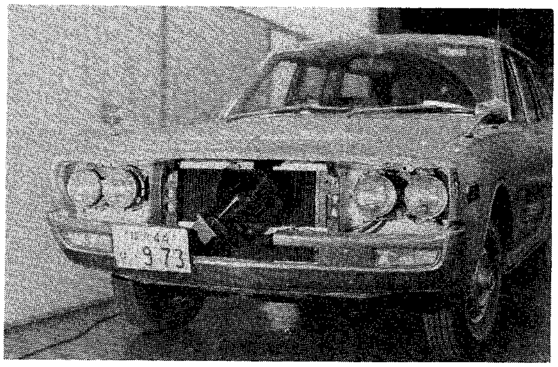


FIGURE 3 MICROWAVE UNIT AND ANTENNA MOUNTED ON AN EXPERIMENTAL VECHICLE

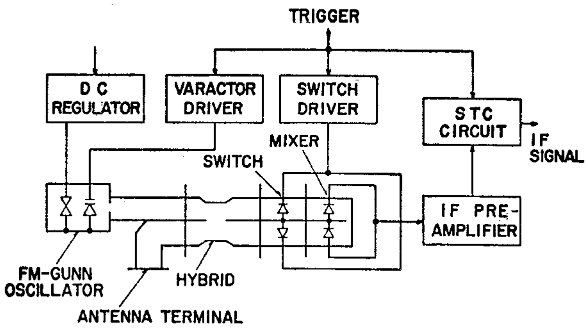


FIGURE 4 BLOCK DIAGRAM OF MICROWAVE UNIT

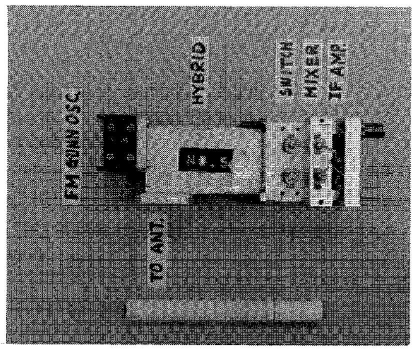


FIGURE 5 MICROWAVE CIRCUIT COMPARED WITH A CIGARETTE

then each of the outputs is reflected and fed to the hybrid circuit again and combined there, and fed to the antenna terminal.

Receiving Operation The switching circuit is controlled to open the circuit. Local signal generated at FM-Gunn oscillator is divided in two and fed to the balanced mixer through the switching circuit. Received echo at antenna is fed to the hybrid circuit through the antenna terminal, and is divided in two to be fed to the balanced mixer through the switching circuit. Received echo is converted to the IF signal by mixing with the local signal. IF signal is amplified at the IF preamplifier and fed to the STC circuit to remove the main bang.

Waveforms of each Circuit in the Microwave Unit Varactor driving signal and switch driving signal are 20 ns pulses synchronized to each other as shown in figure 6. The FM-Gunn oscillator output is a continuous wave whose frequency is controlled to provide

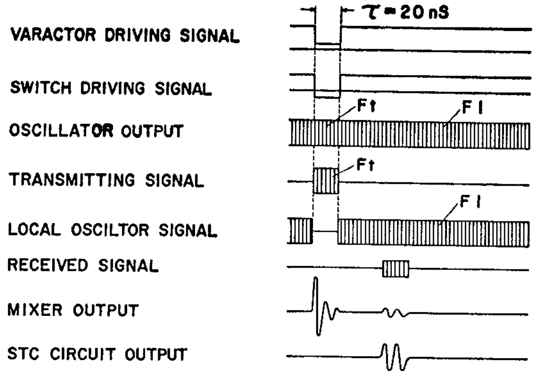


FIGURE 6 WAVEFORMS OF EACH CIRCUIT IN MICROWAVE UNIT

both transmitting and local signals: the frequency is Ft when transmitting and Fℓ when receiving. Received microwave signal is delayed by a round trip time to the target. Mixer output contains undesired main bang, so it is fed to the STC circuit to remove the main bang.

Experimental Data Figure 7 shows the mixer output waveform and detected waveform of transmitting signal observed by oscilloscope, using test signal. Main bang and test signal are observed. Figure 8 is an STC circuit output waveform, after the main bang is removed.

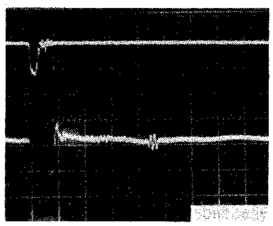


FIGURE 7
Detected waveform of transmitted signal (top), Mixer output (bottom)

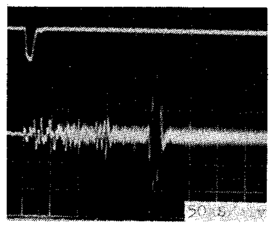
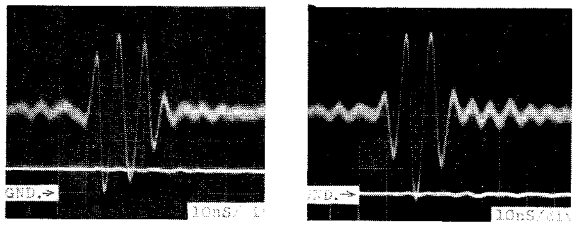


FIGURE 8
Detected waveform of transmitted signal (top), STC circuit output (bottom)

Receiver Unit

The IF signal is further amplified by the post IF amplifier and fed to the Doppler detector, which detects the Doppler frequency by sensing the polarity change of the first wave front of the IF signal.

Doppler Detection Figure 9 shows the operation of Doppler detecting circuit.



(a) IF signal (start at a positive polarity) (top) and Doppler detector output(H) (bottom)

(b) IF signal (start at a negative polarity) (top) and Doppler detector output(L) (bottom)

FIGURE 9 DOPPLER DETECTOR PERFORMANCE

The top waveform is the IF signal. First wave of IF signal is positive in polarity (a), so that the output level of polarity detector is high. In case of negative polarity (b), output is at the low level. Polarity detection operates with first signal after the time of transmitting, and the output level of polarity detection is held to the next output. Resulting from these operation, Doppler signal is obtained from the IF signal.

Detection Sensitivity The polarity detection circuit has double threshold levels to avoid the detection of signal scintillation as a Doppler signal. As a result of this operation, minimum detection sensitivity for the Doppler detection is decreased by a few dB.

Signal Processor Unit

Danger Zone The calculation of the danger zone is expressed by $R = Va^2/2\alpha$, where

Va: carrier vehicle velocity
α: deceleration (adjustable between 0.01G and 0.99G).

When the measured range becomes shorter than the calculated range "R", "ALARM 1" signal is generated and lamp and buzzer sound are actuated.

Danger Speed The calculation of the danger speed is expressed by $V_r = \sqrt{2\alpha R}$, where

R: distance between carrier and target vehicles.

When the measured closing speed exceeds the calculated speed "V_r", "ALARM 2" signal is generated and lamp and buzzer sound are actuated.

False Alarm Prevention It is noted that these "ALARM 1" and "ALARM 2" would be generated too often if only the direct information from the radar sensor is used in the calculation. Many of these alarms are caused by the non-dangerous targets and they are called false alarms. Danger zone and speed vary depending on the driving conditions, especially on the carrier vehicle velocity and steering angle. In order to prevent these false alarms, range information from the radar sensor are selected before the calculation by comparing the above data with the data given by the table which is previously prepared as a function of carrier vehicle velocity and steering angle.

Indicator

Figure 10 shows the indicator. The left hand side meter indicates the measured range by the pointer and the calculated danger zone by the LED array. The lamp is "ALARM 1". The right hand side meter indicates the closing speed by the pointer and calculated danger speed by the LED array. The lamp is "ALARM 2".

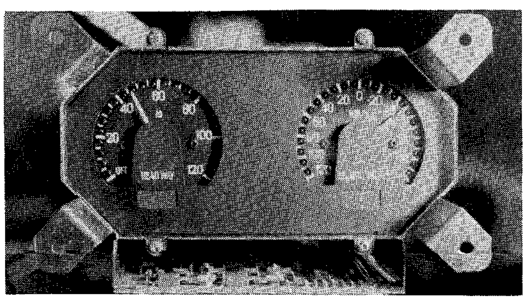


FIGURE 10 INDICATOR

Characteristics of Radar Sensor

Azimuth antenna beamwidth is selected to be 3.5°, because the experiment with 4° antenna showed that a little narrower beamwidth was desirable. Elevation antenna beamwidth is 4.1°. Varactor tuned Gunn oscillator is used as the microwave source operating at 24 GHz band, and output power is about 20 mW. The pulsewidth of transmitting signal is 20 ns, so that the range resolution of 1.5 m is obtained by detecting the leading edge of received signal. Intermediate frequency of receiver is selected by the consideration of receiver bandwidth and tuning characteristics of Gunn oscillator. Minimum detection sensitivity expressed by the ratio of received signal level to transmitting signal level is -76 dB for the range information, and -71 dB for the speed information.

Experimental Results

Target Detection

Figure 11 is an actual data obtained from radar sensor mounted on the test vehicle.

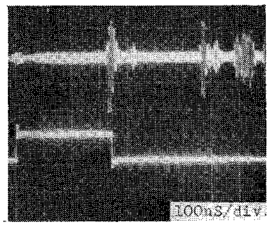


FIGURE 11
IF SIGNAL
RANGE GATE SIGNAL

Metallic pole of 150 mm diameter and 1 m length is used as a test target. Top waveform is the IF signal and shows the test target placed 50 m ahead of the test vehicle. It also shows another target behind the test target. Bottom waveform is a range gate obtained from the top signal. It shows the characteristics of detecting the nearest target. Maximum detection range is calculated from the measured parameters and radar equation. Resultant maximum detection ranges are about 53--94 m for the 1--10 m^2 radar cross section without the consideration of multipath effect.

False Alarm Prevention

A distance of approximately 100 km on a typical highway including curves was covered in the road test, and the frequency of the false alarm was 134 without false alarm prevention. These false alarms are classified according to range (R), carrier speed (Va) and steering angle (θ). The result indicates:

(1) Many of the false alarms were generated when the steering angle is within its playing angle (about ±2.5 deg.) and the range is between 50 m and 100 m.
(2) All false alarms generated at the curved road whose radius of curveture is greater than 1000 m are completely removed by the limitting of range to 50 m.
(3) At the curved road whose radius of curveture is smaller than 1000 m, the false alarms were reduced to only 3 times when deceleration constant α is set at 0.4 and to only 1 when α is 0.6.

This frequency is considered not annoying to the driver.

References

(1) L.W.Wood, R.A.Chandler, and B.D.Warner "Analysis of Radar Sensors to Automotive Collision Prevention" DOT Report No. DOT-HS314-3-601, December 1973.
(2) R.A.Chandler, L.E.Wood, and L.A.Jacobson "Analysis of Radar Sensors to Automotive Collision Prevention" DOT Report No. DOT-HS-4-00813, March 1975.