DUAL-MODE AUTOMOBILE COLLISION AVOIDANCE RADAR

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Summary

A dual-mode (cooperative and non-cooperative) collision avoidance radar is proposed. The cooperative mode of the radar is based on tagging cooperating vehicles and other potential highway hazards with modulated fundamental frequency reflectors.

Introduction

Dr. J. Shefer of RCA and several of his co-workers have built an experimental cooperative collision avoidance radar using second harmonic reflectors that show great promise of being capable of sharply reducing highway accidents, particularly rear-end collisions.[1,2] This radar eliminates the clutter and blinding problems faced by conventional, non-cooperative automotive radars by using a receiver that is tuned to the second harmonic of the transmitted frequency. The harmonic radar therefore "sees" only vehicles or other objects equipped with second-harmonic reflectors; clutter returns from roadways, highway signs, overpasses, etc., as well as signals emitted from other collision avoidance radars are automatically rejected.

The present paper proposes a dual-mode version (cooperative and non-cooperative) of Shefer's harmonic radar. The cooperative mode of the dual-mode radar is based on tagging cooperating vehicles and other potential highway hazards with modulated fundamental frequency reflectors, rather than with harmonic reflectors as in Shefer's radar. When operating with tagged targets, the dual-mode radar retains the advantage of immunity to clutter and blinding of the harmonic radar, yet it operates at only one rather than two carrier frequencies, and requires much less transmitter power than the harmonic radar. Furthermore, modulated fundamental frequency reflectors make simpler electronic license plates than harmonic reflectors.[3] The range of the dual-mode radar when looking at tagged targets is the same as that of the harmonic radar: approximately 100 meters.

The dual-mode radar also recognizes targets that do not carry tags. However, in order to minimize the "false target" problem, the range of the non-cooperating mode of the radar is restricted to much shorter distances than the range for cooperating targets.

Description of the Dual-Mode Radar

The dual-mode radar system (see Fig. 1) can be conveniently divided into three sections: an rf section consisting of an rf transmitter, an antenna, an rf receiver, a baseband section that evaluates and processes the radar returns, and an alarm and control section.

The RF Section

The transmitter of the dual-mode radar is powered by a varactor-tuned X-band transferred electron oscillator (TEO). The frequency of this TEO is linearly modulated at a rate f_m with a frequency excursion of $2\Delta F$.

The form of the radar return from targets that are not tagged with modulated fundamental frequency reflectors can be understood with the aid of Fig. 2. This figure shows plots of frequency versus time for for the signal transmitted by the radar and the return signal from an untagged target, as well as the output that is generated when the transmitted and received frequencies are beaten in the mixer of the radar. The frequency of this output is linearly proportional to the distance from the radar to the target.

Radar returns from modulated fundamental frequency reflectors are not only shifted in frequency with respect to the transmitter frequency, but are also phase modulated. The reflectors consist of an antenna, a biphase modulator, and a tone generator of frequency f_t ($f_t >> f_b$ for R = 100 meters). The tone generator periodically drives the phase modulator between two states: when the modulator is in the first state, an rf signal incident on the antenna is reflected with a phase shift ϕ_o; when the modulator is in the second state, an rf signal incident on the antenna is reflected with a phase shift $\phi_o + 180°$. The wave shapes of the modulation and of the incident and reflected signals are shown in Fig. 3. When a phase modulated signal from a reflector is mixed in the radar with the transmitted frequency, a beat frequency is generated that is modulated at frequency f_t as shown in Fig. 4. This modulation can be removed by feeding the output of the mixer into an envelope detector.

The Baseband Section

In the baseband section of the radar, returns from tagged targets and from targets without tags are first separated by use of suitable bandpass filters. This separation is easily accomplished, because the beat frequencies f_b generated by returns from the modulated reflectors are modulated at frequency $f_t >> f_b$, while the beat frequencies generated by targets without reflectors are not modulated.

The beat frequencies generated by targets with tags are passed through an envelope detector and a lowpass filter. The cutoff frequency of this lowpass filter is set to pass beat frequencies corresponding to a maximum range of about 100 meters. The frequencies passed by the lowpass filter go to a counter and are then converted to range and closing rate (see Figs. 1 and 5). Based on range, closing rate, and true ground speed of the vehicle (the true ground speed is obtained from a separate doppler radar[2]), a decision is made whether or not the vehicle is in danger. A detailed description of suitable realizations of the "convert-to-range", "convert-to-closing-rate" and "is vehicle in danger?" are given in references 1 and 2.

The beat frequencies generated by targets without tags also pass through an envelope detector and a lowpass filter to the processor. The cutoff frequency of the lowpass filter is set to pass beat frequencies corresponding to a maximum range of only a few meters, rather than to a maximum range of 100 meters as in the case of tagged targets. On the basis of the amplitude and frequency of the beat signal, the processor decides whether or not a large target is present, and at what rate this target is approaching the vehicle. A decision "is vehicle in danger?" is then made by also taking into account the ground speed of the vehicle.

The Alarm and Control Section

The output of the two "is vehicle in danger?" functions of the processor control an alarm and the brakes and throttle of the vehicle. A description of simple versions of the alarm and brake and throttle controls can be found in references 1 and 2.

The Fundamental Frequency Electronic License Plate

A new electronic concept with broad implication in such areas as highway safety, traffic control, anti-theft protection, and vehicle inspection was recently proposed by one of the authors of the present paper.[3] This concept is based on the use of compact, inexpensive electronic license plates mounted on the rear of every motorized highway vehicle. Each license plate provides the following three functions: (1) when electronically interrogated, the license plate responds with a code representing an identifying number assigned to the vehicle to which the plate is attached; (2) the plate is the receiver and transmitter for messages to and from the vehicle; and (3) the plate serves as a transponder for use in cooperating collision-avoidance radars. A plate based on second-harmonic reflectors is described in reference 3.

We have built an experimental electronic license plate using modulated fundamental frequency reflectors of the type suitable for use in the cooperative mode of the dual-mode radar. The plate operates near 10 GHz, and uses a COS/MOS code generator to impress a 10-bit code on the biphase modulator. Coding is FSK with tones at 50 and 60 kHz. Phase diversity is used to eliminate interference effects. The bit rate is 400 bits per second, but both the bit rate and the number of bits can easily be made much larger.

Acknowledgment

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References

1. J. Shefer and R. J. Klensch, "Harmonic Radar Helps Autos Avoid Collisions", IEEE Spectrum, Vol. 10, p. 38, May 1973.

2. J. Shefer, et al., "A New Kind of Radar For Collision Avoidance", SAE Automotive Engineering Congress and Exposition, Detroit, Michigan, February 26, 1974.

3. F. Sterzer, "An Electronic License Plate for Motor Vehicles", RCA Review, Vol. 35, p. 167, June 1974.

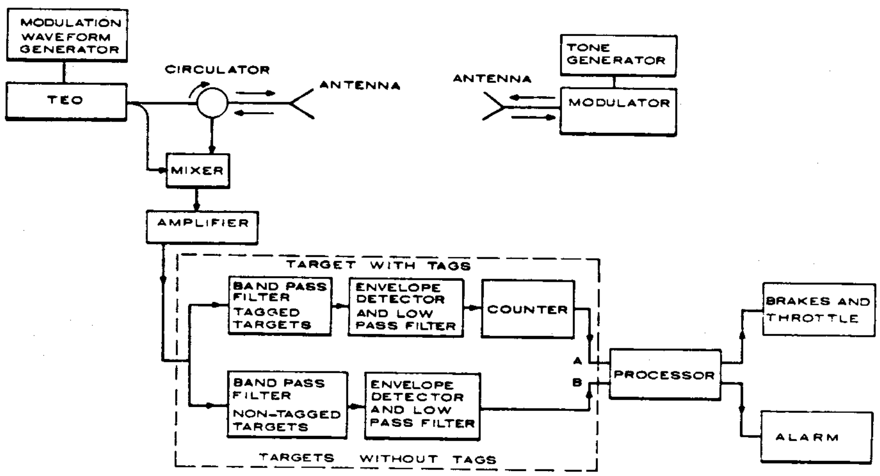

Figure 1. Block diagram of dual-mode radar and of modulated fundamental frequency reflector.

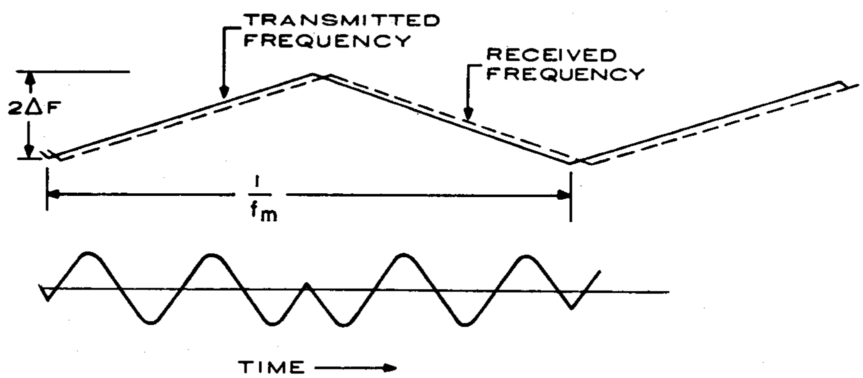

Figure 2. The top part of this figure shows plots of frequency versus time for the signal transmitted by the radar and the return signal from an untagged target received by the radar. The bottom part of the figure shows the output that is generated when the transmitted and received frequencies are beaten in the mixer of the radar.

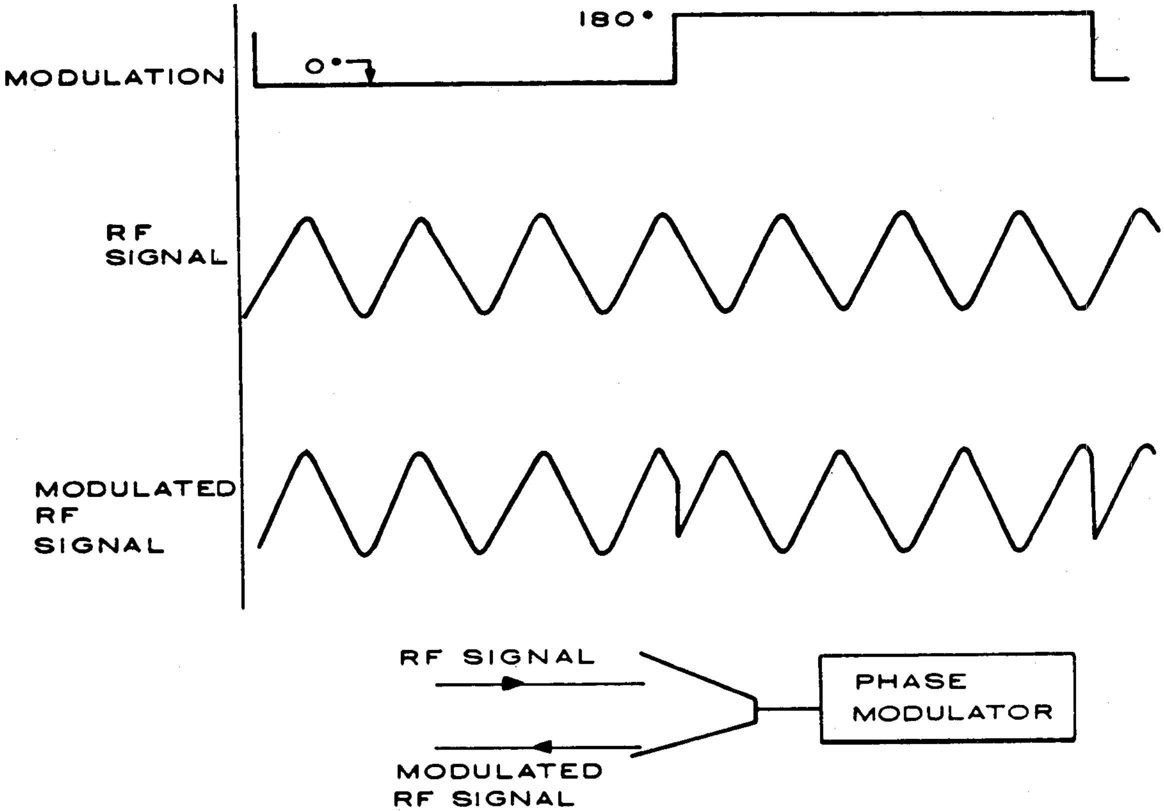

Figure 3. Wave-forms of the modulation and of the incident and reflected signals for a modulated fundamental frequency reflector.

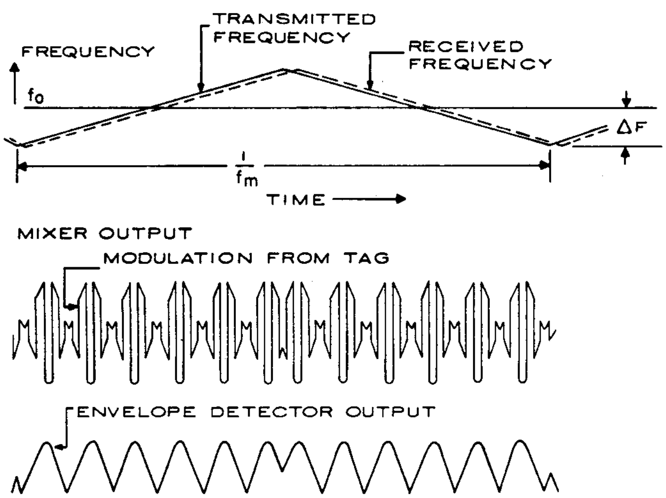

Figure 4. The top part of this figure shows plots of frequency versus time for the signal transmitted by the radar, and the returned signal from a fundamental frequency reflector. The center part of the figure shows the wave-form that is generated when the transmitted and received frequencies are beaten in the mixer of the radar. The bottom part of the figure shows the wave-form that is generated when the output of the mixer is fed into an envelope detector.

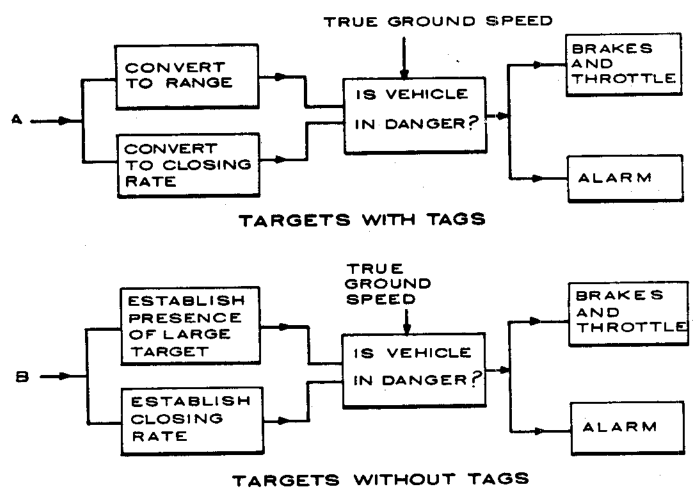

Figure 5. Block diagram showing detail of processor of dual-mode radar.