COOPERATIVE SIGNAL PROCESSING BEACON TRANSPONDER FOR AIRPORT TRAFFIC CONTROL

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Abstract

In recent years there has been an interest in physically small, low-cost, low-energy consuming electronic markers for air traffic control on the ground. In this paper a solid state 14.5 GHz low-cost beacon transponder is investigated that provides a target-like signal for a maximum range of 5 miles in various weather conditions when illuminated by an existing 14.5 GHz surface detection radar developed by Texas Instruments (TI), Dallas, Texas.[1]

Introduction

In recent years, there has been a great interest in electronic markers for tagging materials and vehicles, for air traffic control on the ground, and for surveillance or tracking of personnel over a limited area. In this paper state of the art in low-cost beacon components are investigated that provide a target-like signal for a maximum range of 5 miles in various weather conditions when they are illuminated by airport surface-detection radars. Design details of a 14.5-GHz solid-state cooperative beacon transponder are discussed. Low-cost digital logic techniques are used instead of analog techniques for isolation of receiver and transmitter, and for signal processing. A pulsed, low-Q, coaxial IMPATT diode oscillator was used in the transmitter, and a diode detector was used in the receiver. The power output measured from the IMPATT diode oscillator was 4.8 watts peak, the duty cycle was 0.7%, the pulsewidth was 450 ns, and the dc-to-RF efficiency was 7%. Output power measured from the beacon transponder was 2.4 watts and the minimum detectable signal at the receiver was -42 dBm.

Transponder Design

A block diagram of a solid-state cooperative beacon transponder is shown in Figure 1. The design of the various components in the system allows the use of microwave integrated circuits and hybrid integrated-circuit techniques. Such techniques are useful for large production at low cost. The important features of the design are: (1) One antenna system is utilized. Transmitter and receiver are combined via a circulator. A circulator was selected for ease in fabrication; however, for production models a diplexer will be used. (2) A high-power IMPATT diode oscillator is used in the transmitter. (3) For low cost and limited range (2.5 miles) in clear weather, a detector with signal-to-noise-ratio (SNR) of 13.8 dB was selected for our transponder. For 5 miles range or more and 16 mm/hr of rain with SNR ratio of 13.8 dB, a mixer pumped with a Gunn diode oscillator scheme can be used in the receiver for additional sensitivity. (4) A high-gain video amplifier with limiting capability is used to amplify the detected pulses. In the limiting mode the amplifier was designed to minimize pulse envelope distortion for any false triggering of the logic gate at close and far range from the ASD radar. (5) Low-cost digital techniques are applied for processing, gating, isolation between receiver and transmitter, and pulse shaping instead of analog techniques. Digital techniques are used where size, volume, and uniformity in circuit design are necessary. (6) Input and output pulsed RF signals from the transponder are synchronized without any change in repetition rate, pulsewidth, or duty cycle in the envelope. This is important for the airport surface-detection (ASD) radars where identification of the location is obtained from the envelope and delay-time information of the various signals received at the radar. Delay through the transponder is constant and can be taken into consideration in the radar processing and memory unit. (7) An RF switch is operated in time sequence after the IMPATT diode oscillator is operating in a steady-state condition. This control is maintained by the memory logic. This design adaptation is useful because rise and fall times of the output pulsed RF signal from the transponder are strictly dependent on the RF switch operation. To obtain fast rise times in an IMPATT diode oscillator, complicated voltage- and current-shaping networks are necessary in the pulse drivers because the matching network of the IMPATT diode oscillator depends on the pulse duration and repetition rate that cause thermal heating of the diode junction. The only disadvantage of the RF switch is in the extra insertion loss, which decreases the overall efficiency of the system. In production-type models, the switch can be eliminated and IMPATT diode oscillators with current shaping networks can be used. To conserve the dc power consumption, the IMPATT diode oscillator is also pulsed at the same repetition rate but with a much larger pulsewidth.

The key features of the breadboard beacon transponder and details of the individual components are shown in Figure 2. The disassembled IMPATT diode oscillator showing all the key mechanical details of the design is shown in Figure 3.

Test Results and Data

A semiautomatic test setup was assembled to allow simultaneous observation of all the critical test parameters of the RF components and logic circuits in the breadboard beacon transponder. Figure 4 shows a frequency spectrum of the pulsed RF output from the beacon transponder. This response was observed on the HP spectrum analyzer. The nulls shown in the figure are sharp and the envelope is very close to the (sin x/x) representation. Figure 5 shows a fixed delay, through the transponder, of 300 ns between the input and output signals from the beacon transponder. The delay is dependent strictly on the logic gate and delay mechanism built into the processor. With minor adjustments, delay can be reduced to 40 to 60 ns.

Conclusions

The characteristics of the cooperative beacon transponder are tabulated in Table 1. In this table the designed and measured results are compared. All the design goals were achieved except the power output. The power output was slightly low (2.4 watts instead of 3.3 watts) because of excessive losses in the output isolator and switch (3.2 dB instead of 2.8 dB) and lower efficiency of the IMPATT diode oscillator (7% instead of 10%). If this transponder is used with a simple dipole antenna (gain 3.2 dB) in the field tests, then the effective radiated peak power available will be measured greater than 3.3 watts. The receiver sensitivity was slightly better than the theoretical because the noise figure of the video amplifier used was lower. Based on a transmitted peak power of 2.4 watts from the beacon transponder, the maximum range to the TI ASD radar achievable should be 3.5 miles in 16 mm/hr of rainfall and greater than 5 miles in clear weather. By reduction of losses in the RF switch and isolator, more power can be achieved at the output of the transponder. Based on the beacon-transponder receiver sensitivity of -30 dBm and SNR of 13.8 dB, the maximum range from the TI ASD radar achievable should be 1.60 miles in 16 mm/hr of rainfall and 2.5 miles in clear weather.

Table 1. Characteristics of the Cooperative Beacon Transponder

Parameters	Designed	Measured	Comments
Transmitter			
frequency	14.5	14.7 GHz	Can be set to any frequency, depending on the design of cavity in the oscillator.
Pulsewidth	50 ns	50 ns	35 ns minimum. Maximum value depends on IMPATT diode circuit.
Peak power	3.3 W	2.4 W	Higher power levels can be obtained depending on IMPATT diode circuit using multiple diodes.
PRF	15 ±0.5 kHz	15 ±0.5 kHz	15 ±0.5 kHz. Variable; thus parameter is not critical.
Delay	300 ns	300 ns	40 ns minimum. Maximum value variable.
Receiver			
frequency	14.3 GHz	12-18 GHz	12-18 GHz, can be set to any frequency.
Minimum detectable power level	-42.5 dBm	-42 dBm	Intermittent output signal from the transponder.
Sensitivity with SNR = 13.8 dB, and probability of detection 0.95	-28 dBm	-30 dBm	-30 dBm. For higher selectivity, use mixer receiver.
Video bandwidth	50 MHz	50 MHz	50 MHz maximum (limited by logic circuit bandwidth). Selectable for larger bandwidths by using high-speed circuits.
Antenna			
Gain	None	None	2.2 dB for simple dipole
Power consumption,			
dc	Not specified	6 watts maximum	No attempts were made to reduce dc power consumption or design a power supply. IMPATT diode oscillator draws power only during the pulse period.

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Reference

1. A Fang, "Comparative Performance of Three Airport Surface Detection Radars," Technical Report TR71-037, Texas Instruments, Dallas, Texas (1971).

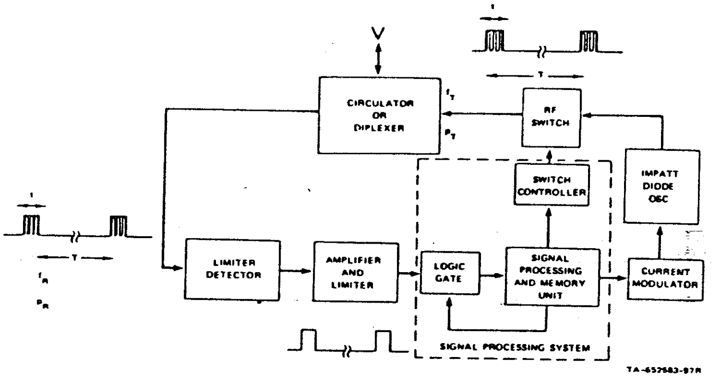

Fig. 1 Block Diagram of Cooperative Signal-Processing Beacon Transponder

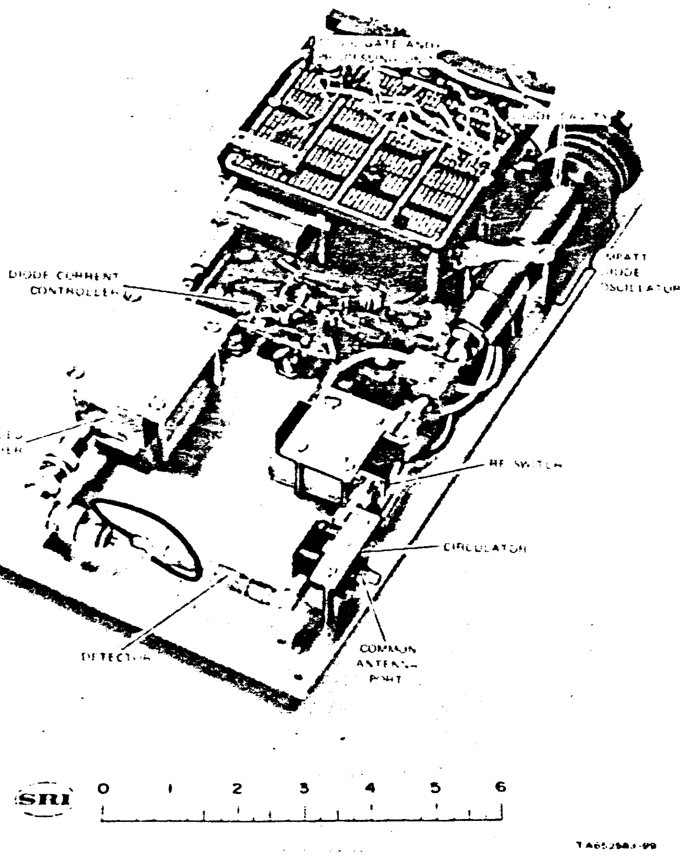

Fig. 2 14.5-GHz Solid-State Cooperative Beacon Transponder for Airport Surface Detection (ASD) Radar

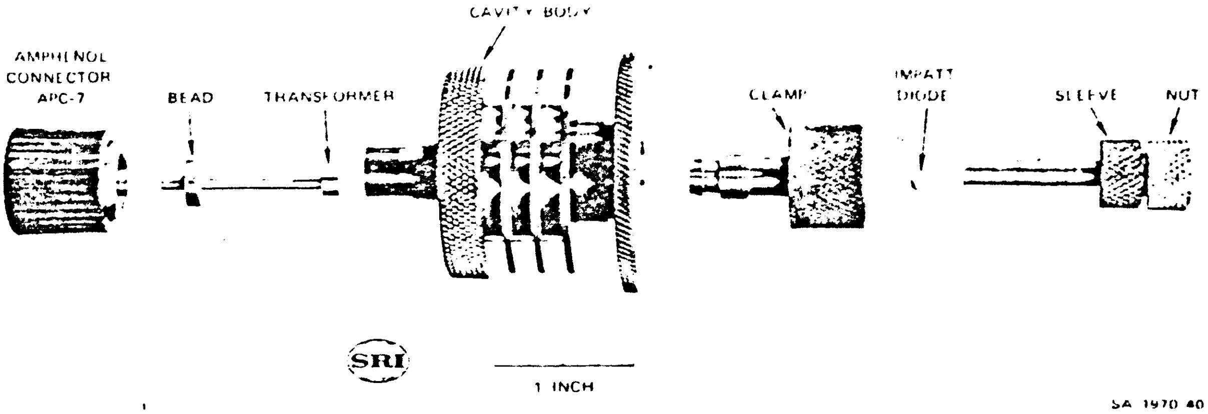

Fig. 3 Disassembled Ku-Band IMPATT Diode Oscillator

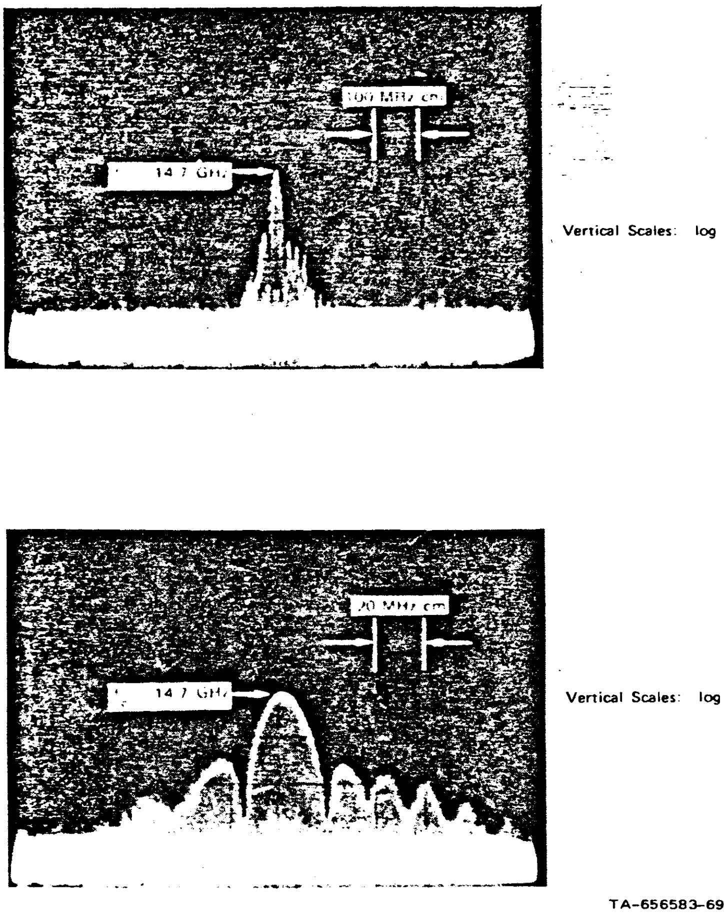

Fig. 4 Frequency Spectrum of Output Pulsed RF Signal from the Ku-Band Beacon Transponder (sin x/x)

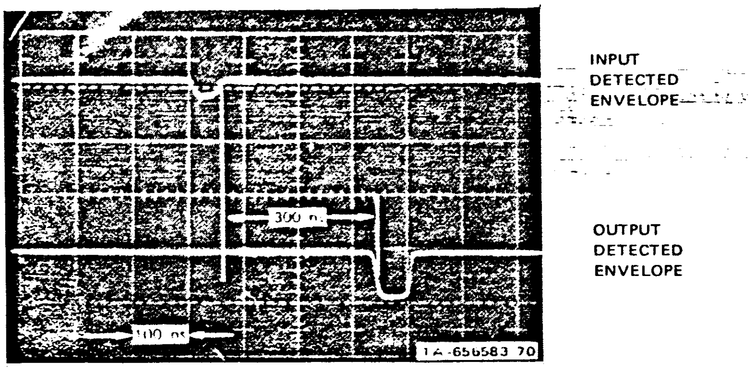

Fig. 5 Delay Between Input and Output Pulsed RF Signals to the Beacon Transponder