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SHORT COMMUNICATION

Design Approach of Range Gate Generator for FMCW Doppler Radar as Presence Sensor

K.P.M. Bhat and Reena P. Nibandhe

Institute of Armament Technology, Pune – 411 025

ABSTRACT

The paper presents the design philosophy and hardware details of a range gate generator as presence sensor suitable for an X-band frequency-modulated continuous wave radar. A logic circuit to indicate the target presence between 20 m to 30 m with a maximum of ± 0.5 count cycle-limited error has been designed and incorporated.

Keywords: Range gate generator, presence sensor, FMCW radar, Doppler radar, remote sensing, frequency-modulated continous wave systems, digital modulation

1. INTRODUCTION

Doppler radar has a variety of applications, such as intruder alarms, proximity fuses, airborne altimeters and target presence sensors[1]. The principle and operation of Doppler radar is extensively covered in text books[2,3]. The principal advantages of Doppler radar over other methods of measurements lie firstly, in the lack of any need for physical contact with the system under examination, and secondly, in the ability of microwaves to be directed into areas which would normally be inaccessible. In many radar applications, such as altimeters and presence sensors, it is necessary to make distance measurement to the target or object. In most of the presence-sensing applications, range gating constitute one of the objectives probably to initiate certain intended control actions.

Both pulse and continuous wave (CW) radar systems are, in principle, capable of approximately the same range performance for the same average power. Secondly, the number of independent elements of range information obtained by a radar system is directly proportional to the transmitted spectrum width, so that short-pulse systems and wide-band frequency-modulated continuous wave (FMCW) systems have a correspondingly large number of range elements, while an unmodulated CW system yields no range information. A detailed analysis of an FMCW ranging system is also well-documented in literature[4].

In this paper, an approach for the generation of range gate information extracted from the Doppler signal of an FMCW radar has been presented. A brief theory of a half-rectified triangular-type FMCW system suitable for ranging application is provided. The non-radio frequency system configuration and hardware details are described.

2. THEORY OF FMCW RADAR RANGING

Traditionally, a full triangular or sawtooth waveform FMCW system is used. By using such linear modulating waveforms at the transmitter,

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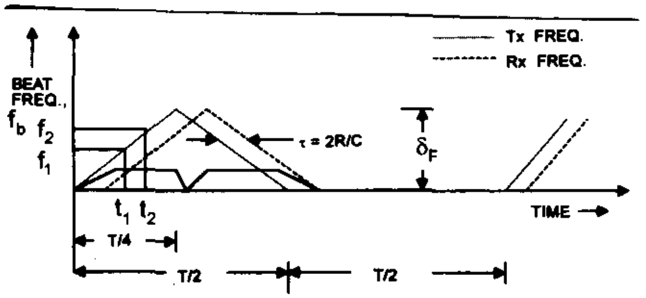

Figure 1(a). Frequency-time relationship for stationary target.

the range R can be expressed as

$$R=\frac{C\Delta f}{4\delta_F f_m} \tag{1}$$

where

- C Velocity of light
- Δf Frequency shift in Hz of the transmitter at the time the signal is transmitted and received
- δ_F Radio frequency modulation bandwidth in Hz
- f_m Transmitter modulation rate in Hz.

For the half-rectified triangular modulating waveform, the frequency-time relationship is shown in Figs 1(a) and 1(b) for stationary and moving targets, respectively. In the system proposed, the transmitter produces a CW signal of constant amplitude, whose frequency is swept through the modulation bandwidth (δ_F) in a time period $T/2$, where T is the period of full triangular-modulating waveform. The receiver picks up some of target reflected signal after delay of time

$$t_2 - t_1 = \tau = 2R/C$$

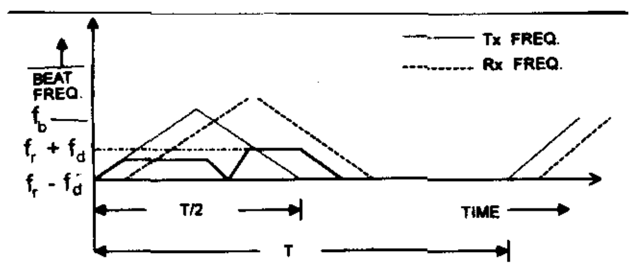

Figure 1(b). Frequency-time relationship for moving target

due to its travel to and from the target. During this time, the transmitter signal frequency changes from f_1 to f_2. If the echo signal is heterodyned with a portion of the transmitter signal using a nonlinear device (mixer), a beat note will be produced. The beat note contains two distinct tones. One of these components is a frequency proportional to the product of the range of the reflecting element and the slope of the modulating waveform. The other component is the Doppler frequency.

If there is no relative motion between the target and the source (stationary target case), there is no Doppler shift, and hence the beat frequency (f_b) is a measure of the target's range. For a half-rectified triangular modulation and a stationary target case of Fig. 1(a), f_b is constant except at the turnaround region. If the modulating frequency is f_m, one can write as

$$f_b = f_r = 4\,R f_m\,\delta_F/C \tag{2}$$

where f_r is the beat frequency only due to target's range. Thus, measurement of the beat frequency determines the range.

For a moving target case, the relative motion between the target and the transmitter source causes Doppler shift, manifesting the frequency- time plot of Fig. 1(b) to shift up and down. When the source approaches the target, the beat frequency produced during the increasing and decreasing portion of frequency-modulated cycle can be written as

$$f_b\ (\text{up}) = f_r - f_d$$

and

$$f_b\,(\text{down}) = f_r + f_d \tag{3}$$

respectively where f_d is the resultant Doppler frequency. If the source is receding from the target, the definitions of f_b (up) and f_b (down) in Eqn (3) will be reversed. However, in both cases, the range frequency f_r, can be expressed as

$$f_r = \tfrac{1}{2}\,[f_b(\text{up}) + f_b(\text{down})] \tag{4}$$

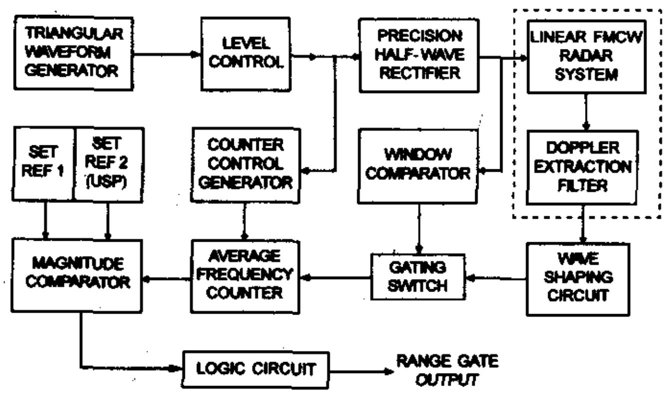

Figure 2. Schematic of the proposed range gate generator

3. DESIGN APPROACH

The schematic of the proposed range gate generator is shown in Fig. 2. The typical X-band FMCW radar operating at 10 GHz with δ_F = 120 MHz is assumed to be used as radio-frequency section. The range gating requirements are: (i) minimum range 20 m, (ii) typical range 25 m, and (iii) maximum range 30 m.

The modulating frequency (f_m) is chosen to be 2.5 KHz in Eqn (2). For the stationary target case, the beat frequencies corresponding to the specified ranges will therefore, lie between 160 KHz and 240 KHz.

The triangular waveform with high linearity and specified time period $T = 1/f_m$ = 0.4 ms can be generated using function generator. The level control in conjunction with a precision half-wave rectifier generates the desired modulating signal for the radar.

An average frequency counter along with a magnitude comparator and a logic circuit is proposed for range gating signal generation. Whereas the counter control generator provides the necessary stop reference for the frequency counter, the window comparator avoids the counting error by inhibiting the counter during the turnaround period and also constitutes the counter gating signal. The averaging is performed over two consecutive gate intervals.

The magnitude comparator is used to compare the output of the average frequency counter against two set references. Ref Set 1 is binary equivalent of 20 m called lower set point (LSP), whereas, Ref Set 2 defines upper set point (USP) corresponding to the binary equivalent of 30 m. The logic circuit gives the desired range signal when LSP ≤ O/P ≤ USP, where O/P represents the frequency counter output value.

3.1 Hardware Description

The circuit diagram of the proposed range gate generator is shown in Fig. 3. Intersil monolithic integrated circuit precision waveform generator ICL 8038 (U1) is used for producing the desired triangular wave output with high linearity (0.1%). The period and symmetry of output waveform can be adjusted with timing resistors *R*1 and *R*2 along with capacitor *C*1. An inverting amplifier with adjustable gain (*U*2) followed by unity gain inverting amplifier (*U*3) and a precision rectifier (*U*4) generates the half-rectified triangular waveform compatible with the input of the modulator. Output of *U*4 simultaneously drives a window comparator having adjustable threshold levels. In the present setup, 10 per cent and 90 per cent of peak output amplitude of *U*4 is set as the low and high threshold levels, respectively.

Since the frequency counter operation needs to be synchronised, the necessary control signals are derived from the periodicity of modulating signal. Window comparator output constitutes the gating signal for a transistor-transistor logic (TTL)-compatible range-bearing signal and thereby forms counter-enable control. The counter-reset signal is generated with a combination of Schmitt trigger, differentiator, invertor and a precision rectifier (*U*7 to *U*9).

For the range of interest and for a stationary target case, it can be shown that count value extends from a minimum 12 to a maximum 19. To meet this requirement, two stages of 4-bit binary up/down counter (74LS191) are cascaded. Two parallel 4-bit magnitude comparators (7485) are having their one of the input derived from the frequency counter. The second input are permanently fed with two reference binary values, LSP and USP. A combinatorial circuit

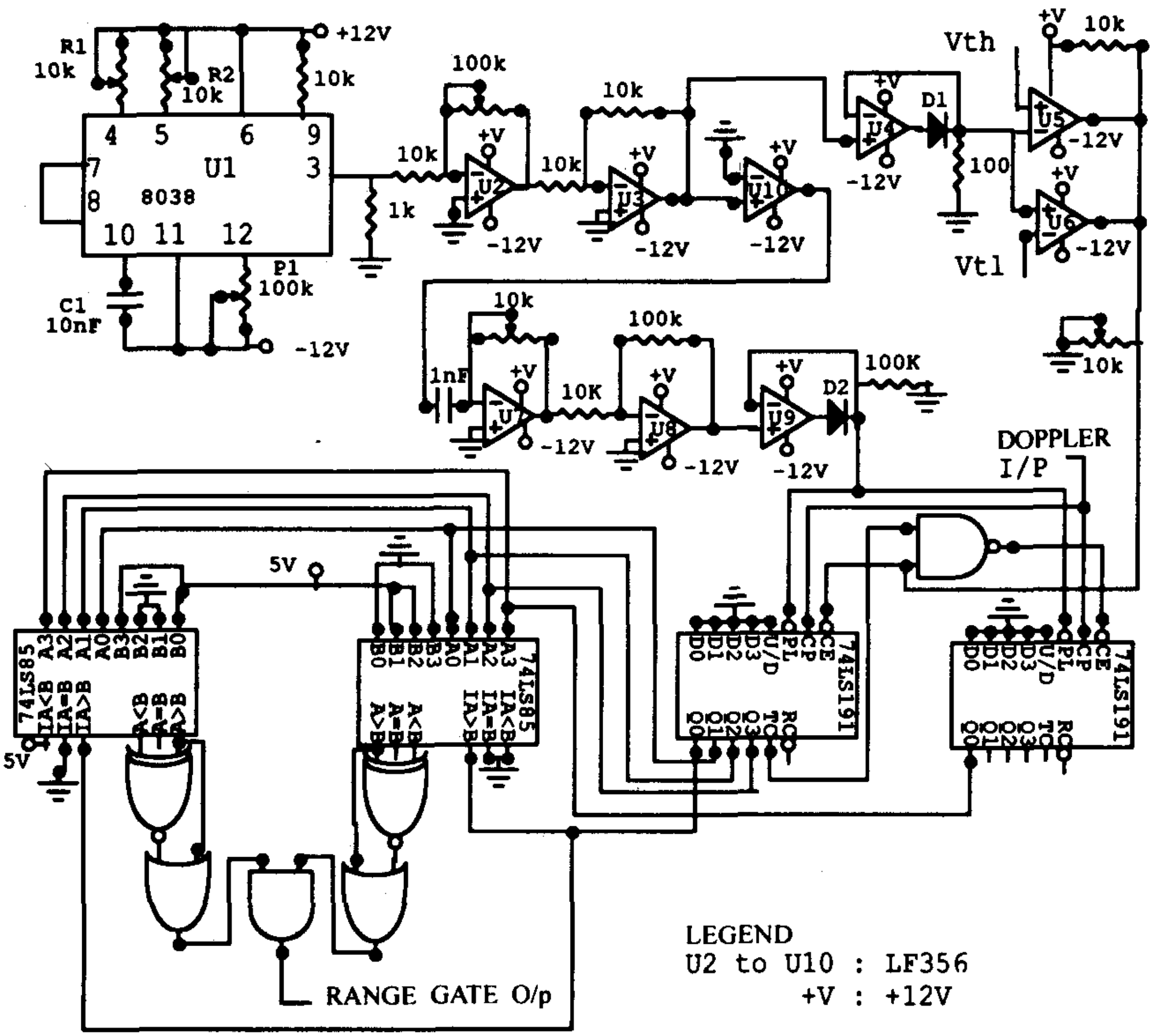

Figure 3. Hardware of the proposed range gate generator

comprising two pairs of Ex-NOR and OR gates and a two input AND gate completes the required logic circuit configuration ensuring the generation of desired range gate output.

3.2 Hardware Testing

The hardware was tested with a simulated range signal (≤ 15 mV) input from the standard function generator. The wave-shaping circuit comprising a zero-crossing detector converts the range signal into its TTL version as a compatible input for the binary counter. The actual counter readings are compared with the theoretical values for a modulating signal frequency 2.5 KHz with and without window comparator configurations. The results are presented in Table 1. A maximum of ± 0.5 counter cycle error observed in measurement, distributed over the range frequencies, is attributed to the inherent limitation of counter resolution. However, performance evaluation related to other characteristics of an FMCW radar, such as transmitter power and beam width, reflector properties, etc., is beyond the scope of this paper.

Table 1. Performance of hardware

Range frequency, f_r (KHz)	Equivalent distance (m)	Number of counter cycles: With window comparator, Theoretical	Number of counter cycles: With window comparator, Observed	Number of counter cycles: Without window comparator, Theoretical	Number of counter cycles: Without window comparator, Observed
160	20	12.80	13.00	16.00	16.00
176	22	14.08	14.00	17.60	18.00
192	24	15.36	15.00	19.20	19.00
200	25	16.00	16.00	20.00	20.00
208	26	16.64	17.00	20.80	21.00
224	28	17.92	18.00	22.40	22.00
240	30	19.20	19.00	24.00	24.00

4. CONCLUSION

Design approach for a range gate generator suitable for use with an X-band FMCW radar is provided. Necessary hardware for range gating from 20 m to 30 m is developed. A maximum of ± 0.5 counter cycle error observed over the entire range of interest is attributed to counter resolution. It is felt that this error can be tolerated in most of the intended applications. However, performance evaluation for radar-dependent characteristics is not considered.

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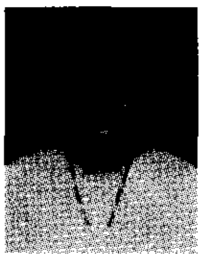
REFERENCES

1. Whitton, C.P. Industrial and scientific application of Doppler radar. *Microwave Journal,* 1975, **18**(11), 39-42.
2. Skolnik, M.I. CW and frequency modulated radar: *In* Introduction to radar systems, Ed.2. McGraw-Hill, New York, 1981. pp. 68-95.
3. Mensa, D.L. High resolution radar imaging. Artech House Inc., 1984.
4. Barton, D.K. CW and Doppler radar, *In* Radars, Vol.7; Section II. Artech House Inc., 1980. pp. 89-96.

Contributors

Mr KPM Bhat received his BSc Engineering (Electronics & Communication) from University of Kerala in 1977 and MTech (Microwave & Optical Communication Engineering) from Indian Institute of Technology (IIT), Kharagpur, in 1985. He had served at the Vikram Satellite Earth Station, Arvi, from 1979-81. He joined DRDO at the Institute of Armament Technology, Pune, in 1981 as Scientist and presently, he is Scientist E. His current areas of research include: Digital modulation techniques, fibre-optic communication and digital signal processing. He has published a few technical papers in national journals and conferences. He is a life member of the Society of Electronics Engineers (India) and the Society of Electromagnetic Compatibility Engineers (India).



Ms Reena P Nibandhe received her BE (Electronics & Telecommunications) from University of Pune in 1995. Since 1998, she has been working at the IAT, Pune, as Senior Technical Assistant A. Her areas of interest include: Digital modulation, microprocessor-based system development.