THE SIGNAL DIGITAL PROCESSING IN THE MILLIMETER BAND FMCW RADAR

A.V. Varavin, G.P. Ermak, A.S. Vasilev, I.V.Popov

Usikov Institute for Radiophysics and Electronics NAS of Ukraine
12, Akad. Proskura str., 61085 Kharkov, Ukraine
Tel.(057)720 3548, E-mail: ermak@ire.kharkov.ua

The frequency-modulated continuous wave-radars - (FMCW-radars) are widely applied in the car road safety systems, the aircraft altimeters, the fusion plasma microwave diagnostics and in other ranging systems of different usage. The most optimal choice in terms of the "cost-quality" criterion for the radars that function at tens of meters distances is a transceiving set homodyne circuitry preference. The Gunn oscillators and Schottky diode barrier mixers usage in such radar sets let one create solid-state midget microwave detectors of different purposes. However, designing the transceiving set-based measuring system, one is confronted with a number of difficulties, depended on the high requirements over the transmitted waveshape and the generator and reception path gain frequency responses linearity.

Such problems solution in a tradition way, applying linearizers and analog processing circuits, considerably complicates and raises a price of the detectors manufacturing, especially for the mass production. One of the ways of these problems solution is the signal digital processing and shaping methods by means of the microprocessor units application.

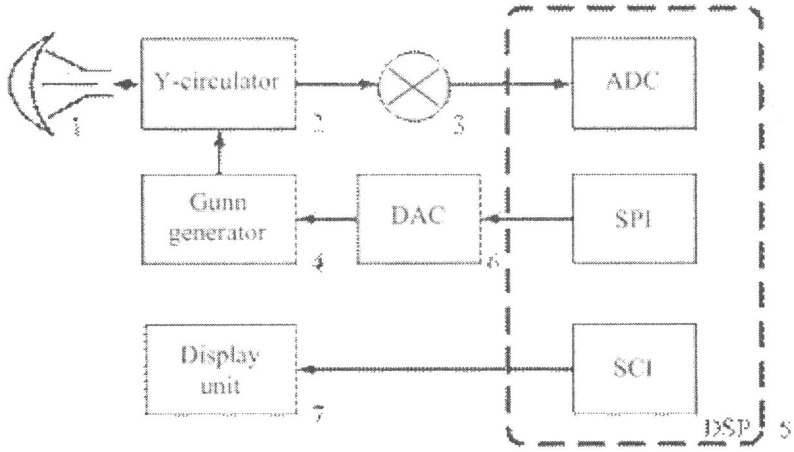

Fig. 1. The radar system block diagram

The possibility of digital signal processor (DSP) application, for the signal shaping and processing in a short-range homodyne FMCW-radar, investigation findings are considered in the research. The radar system (RS) block diagram is shown in fig. 1. The radar system is made up with an antenna system 1, realized as a horn-lens, a Y-circulator 2, a mixer 3, a Gunn oscillator 4 with the varactor frequency tuning, a signal processor 5, a digital-to-analog converter (DAC) 6 and a display unit 7.

The transmitter-receiver path is realized over the homodyne Y-circulator-based circuitry 2. The Gunn oscillator has a 1GHz electronic tuning band and output power < 30 mW. The difference frequency of the transmitted and sensed signals is shaped into the mixer 3 output. It is assembled with a point-contact diode or a Schottky-barrier diode.

The DSP 5 controls a radar system, shapes the transmitted signal and processes the sensed one. The signal processor consists of:

- an analog-to-digital converter (ADC), meant for the intermediate-frequency (IF) signal quantization;
- an SPI bus transceiver, controlled the DAC operating;
- an SCI bus transceiver that realizes the data exchange with display and control units;
- a high-speed calculating core (HS CC) that implements all digital signal processing functions: a spectral analysis, a digital signal filtering and data generation for indication.

1-4244-1237-4/07/$25.00 ©2007 IEEE

The HS CC also can analyze the signal processing results and controls several execution units (EU).

The DAC 6 is to tune the Gunn oscillator frequency by the sawtooth voltage, supplied the varactor. Shaped in such a way FMCW is transmitted by the radar antenna system.

The display unit 7 is to display the object radar data in a spectral form, where a frequency of a spectral line is directly proportional to the reflector distance, and an amplitude – to the reflector absolute cross-section.

The homodyne FMCW-radar operating principle is that: a microwave frequency signal, generated by the Gunn diode, is linearly modulated in frequency in compliance with a varactor input voltage and transmitted into free space through the circulator and antenna system. Meanwhile some power leaked out the circulator with an antenna system-returned signal make up the reference (heterodyne) signal on the mixer diode. The object-returned signal gets back into the antenna system and, passing through the circulator, inputs the mixer with a delay for time τ:

$$\tau = \frac{2R}{c},$$

where c – the light speed, R – a distance.

The simultaneous supply of both powers onto the mixer – the reference voltage (a continuous triangle, fig. 2, a) and a returned one (a dashed triangle), shifted for τ, – results in the mixer output voltage onset, the difference (intermediate) frequency value F_{IF} is equal to a difference between reference and returned signals frequencies (fig. 2, b):

$$F_{IF} = \frac{\Delta F\tau}{T} = \frac{2\Delta F}{cT} R \; F_{IF} = \frac{\Delta F\tau}{T} = \frac{2\Delta F}{cT} R,$$

where ΔF – a microwave oscillator frequency deviation, T – a modulation period. The F_{IF} is proportional to the distance to the reflector.

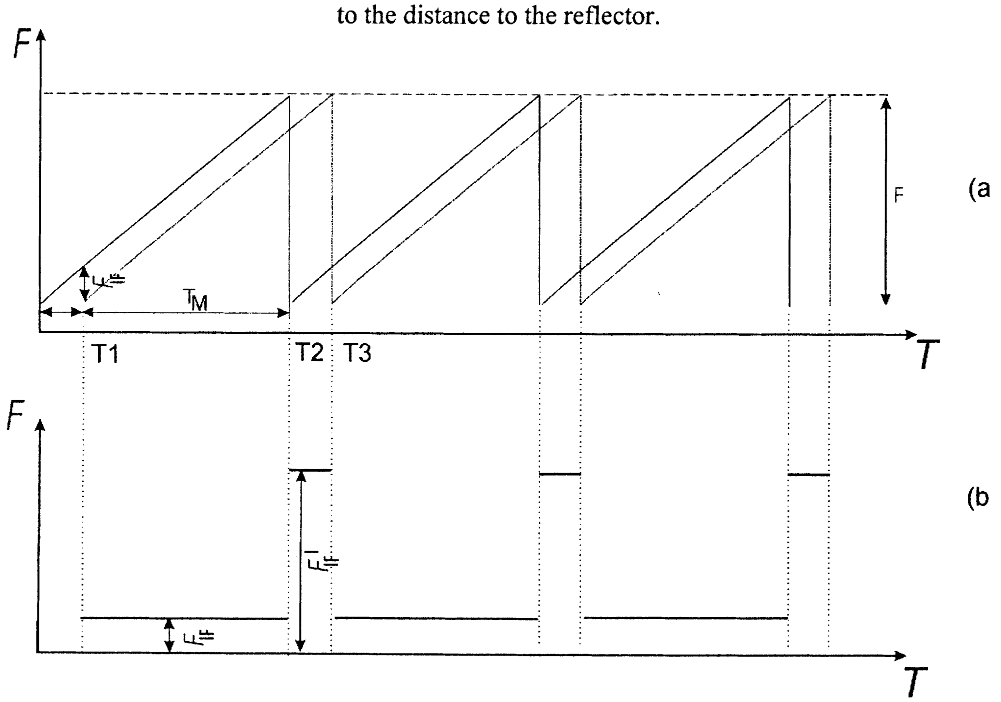

Fig. 2. Principle of FCMW radar

Also one can see there is the mixer output F^1_{IF} frequency on a part of the oscillator frequency variation period (a $T2$ –$T3$ interval) that has no a direct relation with the R distance (fig. 2, b). The different frequencies parts presence causes the output mixer voltage is a nonharmonic signal. It is a spectrum that owns a set of components [1,2].

At the same time the components are in the signal difference frequency spectrum because of the oscillator and transmitter-receiver path amplitude-frequency characteristics irregularity.

To exclude the output signal spectrum components ensued from such radar effects the following signal digital shaping and processing approaches are offered and implemented:

– a shaping of the optimal frequency modulation signal form of the oscillator;

- a synchronous operating of the returned signals transmission and reception;
- a digital filtering and fast Fourier transform of the receipted signals

An operating algorithm of the control signal shaping unit consists in follows. The varactor diode control electrode is injected with sawtooth voltage (in the range from +5V up to +12V), the DSP synthesize by means of a transmission a digital code, equal the next amplitude value of the sawtooth control waveform, and transmit into the DAC control register through the SPI interface. The DAC, receipted the next digital code, sets the voltage, corresponding to such a code, onto its analog output. Further, the DAC output voltage comes through an amplifier and a low-pass filter into the varactor, tuning the oscillator frequency.

To exclude the culprit frequency F^{1}_{IF} from the signal spectrum, its onset reasons are considered hereinbefore, one needs: to set a time delay between sawtooth pulses that, actually, excludes the difference frequency F^{1}_{IF} appearance in the T2-T3 interval (fig. 2). The time delay is also used for the digital filtering and fast Fourier transform algorithms operating.

There is a sampling of one intermediate-frequency signal value from the ADC, synchronously to the oscillator frequency tuning. Iterating such a procedure for required number of times (2^N times, where N, in this case, can take on such values as 7,8,9 and 10), one obtains the synthesized linear-frequency modulated (LFM) signal and synchronously generated array of the sensed values.

As the sensed signal spectrum contains the parasitics because of the oscillator and transceiving path amplitude-frequency response ripples one needs to get the prefiltering before the Fourier transform. The filtration is realized in the following way: the pickup signal is operated with the "moving average" that is as an envelope filter. The enhanced envelope includes the parasitics. As enhanced the alias frequency is excluded from the pickup signal, hereby, there is the high-frequency component, handed over information about reflections within the given range, only in the filter output. Hereupon fast Fourier transform (FFT) is implemented for the filtered signal by the Henning window function-based "Radix 2" algorithm. The transform is realized on a basis of the Standard Template Library, optimized for the operated core. Have applied the FFT, there are only the components relative to the reflections from the objects onto the directivity diagram in the received spectrum.

If there is some reflecting object onto the radar antenna directivity diagram, one can detect a value, which amplitude specifies the considered object reflection power and filter number defines the radar-object distance, in one of the Fourier spectrum filters. Similarly for the case of more the one objects observing: each reflector is corresponded with own spectral component. Basing the post processing information one can organize a decision-making system and actuators control.

The remote display unit, which LCD indicates the sensed signal spectrum, is provided for the system. The communication between the radar and display unit is implemented with the serial line.

It's essential to note that a digital transmission signal processor appliance provides one with following advantage: simple implementation of the radar connection to a personal computer (PC) over the standard PC interface such as RS-232. Using the Ethernet network interface to connect a PC to a radar one can attach practically unrestricted number of radars and their communications.

Conclusion

Hereby, the digital signal processor appliance to shape and process signals in the FMCW-radar lets us:

- improve the spectral responses by the optimal form shaping of the oscillator frequency modulation signal;
- compensate the oscillator and transceiving path amplitude-frequency characteristic ripples;
- realize the digital filtering and fast Fourier transform for the sensed signals;
- implement the in-sync mode of the returned signals receiving;
- increase the resolvability over the distance owing to output signal spectrum processing.

References

1. I.M. Kogan, Short-range radiolocation, pub. "Sovetskoe Radio", Moscow, 1973.
2. S. Plata, FMCW radar transmitter based on DDS synthesis, 16th International Conference on Microwaves, Radar and Wireless Communications (MIKON 2006), Conf. Proc., Krakow, Poland, vol. #3, p.1179-1183, 2006.