AN FM-CW RADAR MODULE WITH FRONT-END SWITCHING HETERODYNE RECEIVER

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Abstract

We have developed a 60-GHz FM-CW radar module that generates sidebands by switching a HEMT front-end. Our module also uses heterodyne detection for FM-AM conversion noise reduction. The module's signal to noise ratio was 20 dB better than a previously designed homodyne FM-CW radar module.

Introduction

Low-cost automotive radar has been the subject of much study since the introduction of a simple transmitter/receiver module for FM-CW radar (1). Although homodyne FM-CW radar is well known for its simplicity -- the same oscillator serves as both the transmitting and local oscillator (Fig.1) -- it has a relatively low S/N ratio. Unwanted envelope components resulting from transmission line effects, mixing, and frequency response limitations of the FM modulator produce noise when rectified by the mixer diodes. This noise affects the detected beat signal at the baseband frequency and limits receiver sensitivity. Raising the S/N ratio requires more power than that determined theoretically from calculating propagation losses, target cross section, receiver noise figure, and antenna gain. Increased power, however, is difficult to achieve because there are no practical high-power three-terminal devices for millimeter-wave frequency operation, and prohibitive cost and production difficulties rule out IMPATT or Gunn diodes for a low-cost and mass-producible automotive radar module.

Besides high cost and low productivity, high-power automotive radar has a few other problems, among them interference with other electronic equipment and concern about health hazards.

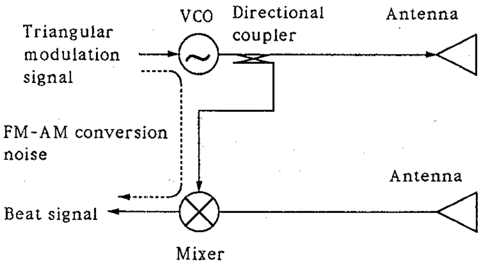

Fig.1 Homodyne FM-CW radar

Recent progress in compound semiconductor devices, especially for the HEMT has yielded economical and manufactureable alternatives. The HEMT is capable of amplification and oscillation at millimeter-wave frequencies (2). The problem is still how to get an acceptable S/N ratio at the few milliwatts of output power that can be handled by HEMT devices; that is, how to achieve a highly sensitive receiver.

Principle of heterodyne FM-CW radar

FM-AM conversion noise is the largest noise component in a homodyne FM-CW radar receiver. The second largest contributor is the low-frequency noise generated during mixing. The smallest is thermal noise. Our experience has shown that FM-AM conversion noise is 30 dB higher than thermal noise, and that low-frequency noise is 10 dB higher. It is quite clear that the FM-AM conversion noise must be reduced.

The frequency range of the detected beat signal depends on the time delay between the radar module and target, and Doppler shift caused by the relative velocity is under a few ten kHz. On the other hand, the frequency spectrum of FM-AM conversion noise contains harmonics of the modulation frequency that are

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almost the same as the beat frequency. Since the detected beat frequency and the FM-AM conversion noise have almost the same frequency range, the S/N ratio is degraded. It is possible to avoid S/N deterioration by separating the frequency range of the beat signal from that of the FM-AM conversion noise.

The principle of simple heterodyne FM-CW radar using front-end switching is explained below with the aid of Fig. 2.

Front-end switching modulates the amplitude of the received signal by a square-wave signal to generate a sideband at either side of the received signal. The beat signal is converted from the baseband to the IF by mixing the transmitted and received signal using a millimeter-wave mixer. The beat frequency and FM-AM conversion noise are present in the baseband, but only the beat signal remains in the IF band. Since the beat signal is not affected by FM-AM conversion noise, the radar module has a high S/N characteristic (Fig. 3)

Using this technique, the low-frequency noise generated by a millimeter-wave mixer, which is the second largest noise contributor in FM-CW radar, is reduced at the same time. The beat signal is converted to an IF band where the low-frequency noise level is low. The low-frequency noise level of an IF band is 10 dB lower than that of the baseband frequency.

Sidebands are modulation products of any type of modulating wave-form. Table 1 shows a signal level deterioration for a 100% amplitude modulation waveform. The signal level deterioration is defined to compare a level of a sideband separated from the fundamental switching frequency and a received signal level without switching. From the table, 100% amplitude modulation with square wave achieves the highest sideband generation efficiency. In this case, the level of a sideband is 6.9 dB lower than the received signal level without switching.

There is another advantage of a heterodyne over a homodyne radar. To reduce FM-AM conversion noise as much as possible, each component of a homodyne radar must be carefully adjusted for minimum frequency response. However, it is difficult to maintain such fine adjustments over the temperature range typical of automotive applications. Since heterodyne radar is not affected by FM-AM conversion noise, it can be used over a wider temperature range.

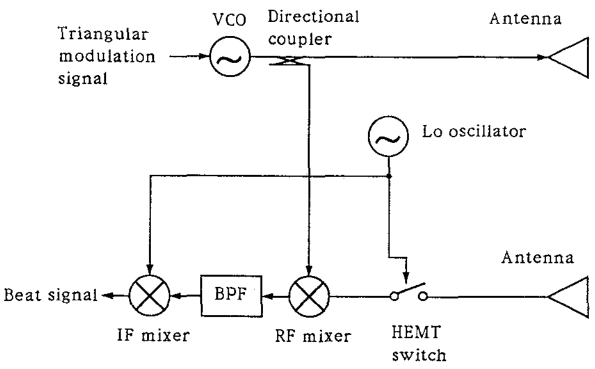


Fig.2 Heterodyne FM-CW radar

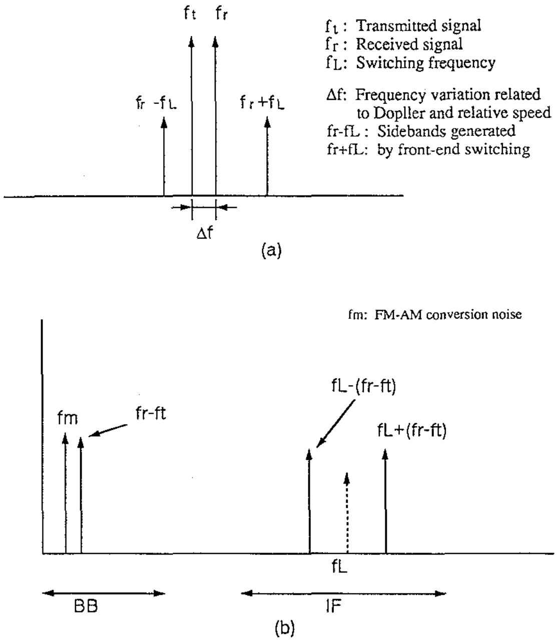


Fig.3 Spectrum of heterodyne FM-CW radar

Table 1 Signal deterioration for amplitude modulation waveform

Waveform	Signal deterioration [dB]
Sine	9.0
Triangle	10.9
Square	6.9
Full-wave rectification	10.5

Radar module structure and experimental results

A heterodyne radar module operates near 60 GHz. Because there is an absorption band caused by absorption of oxygen molecules in the atmosphere, absorption helps prevent interference between radar systems and other communication equipment (3).

Received-signal switching is easy to achieve by using a HEMT amplifier consisting of two gain stages. The HEMTs used in amplifier have a AlGaAs/GaAs structure with gates that are 0.25 μm long and 100 μm wide. The drain voltage of the first stage in the amplifier is switched by a switching signal, and the ratio of the on to off levels is 15 dB. In this case, the theoretical conversion efficiency of the amplifier is -9 dB. The gain of the amplifier without switching is 3 dB.

A structure of a heterodyne radar is shown in Fig. 4. A transmitter of a heterodyne radar module consists of a 30-GHz GaAs FET voltage-controlled oscillator, a 30-GHz GaAs FET amplifier, and a GaAs FET doubler. The output power of the module is 3 dBm. A module's receiver is constructed from the HEMT switch and a balanced mixer using GaAs Schottky-barrier diodes. The IF circuits of the heterodyne radar consists of an IF amplifier, an IF bandpass filter, a double balanced mixer, and an IF local oscillator.

Frequency responses of noise levels in homodyne and heterodyne radar are shown in Fig. 5. The noise level of a homodyne radar is 9 dB larger than that of a heterodyne radar at 59.7 GHz at the same output power. The noise level of a homodyne radar increases drastically at 59.5 GHz because the frequency response of a

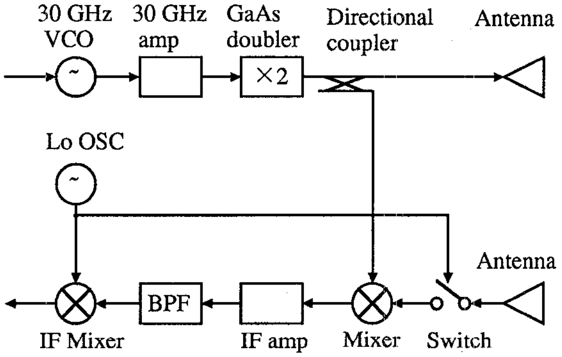


Fig. 4 Radar module structure

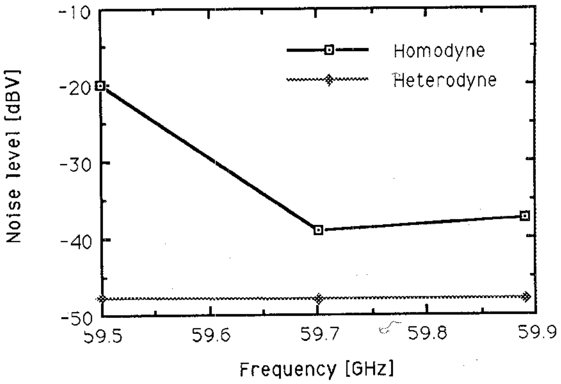
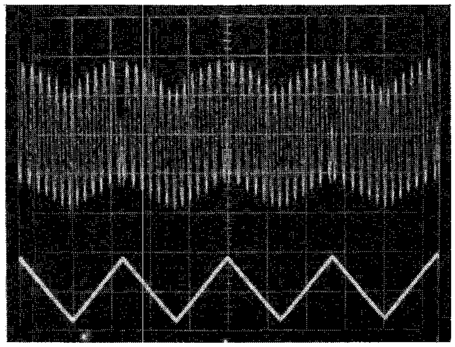
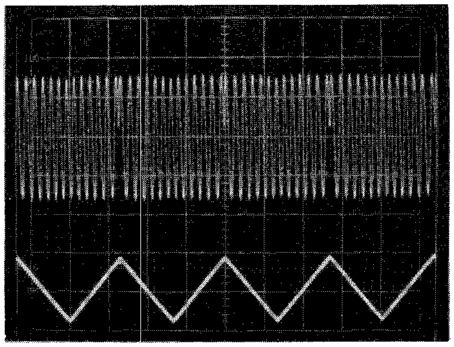


Fig. 5 Frequency response of radar noise levels



(a) Homodyne radar



(b) Heterodyne radar

Fig. 6 Baseband output signal

homodyne radar components are varies. On the other hand, a noise level of a heterodyne radar is almost constant. This proves that the noise level of a heterodyne radar is not affected by AM-FM conversion noise.

The baseband signal output of homodyne and heterodyne radars are shown in Fig. 6. The triangular waveform in the figure is a modulation signal. The figure clearly shows that the baseband signal of the homodyne radar is added to the modulation signal element on a beat signal and the modulation signal element in the baseband signal of the heterodyne radar is almost negligible.

For the experiment, transmit and receive antennas(1), each with a gain of 30 dB, were attached to the module. Evaluation consisted of measuring the S/N of the module by reflecting a radar signal from a corner-reflector that has a 12.2 dB target cross section. Figure 7 compares the FM-CW radar performance. A homodyne radar module using a Gunn oscillator with an output power of 16 dBm has a S/N of 11.5 dB when the distance between the module and target was 60 meters. The heterodyne radar module, in spite of having an output power 13 dB lower than that of the homodyne radar module, had an S/N of 19.5 dB at the same distance. Consequentially, the S/N of the radar module was improves 20 dB when using a switched front-end amplifier.

Since the S/N of the radar module improves drastically when its FM-AM conversion noise is reduced, the required module output power can be decreased to a level that can be handled by a low-noise HEMT. This means that it is possible to improve module manufacturability by using HEMT millimeter-wave monolithic integrated circuit (MWMIC) techniques. Further improvements in HEMT performance criteria, such as a gain or a noise figure, can be had by decreasing gate length, adopting a pseudomorphic structure, and by developing new materials. These improvements will further simplify the module and decrease its output power.

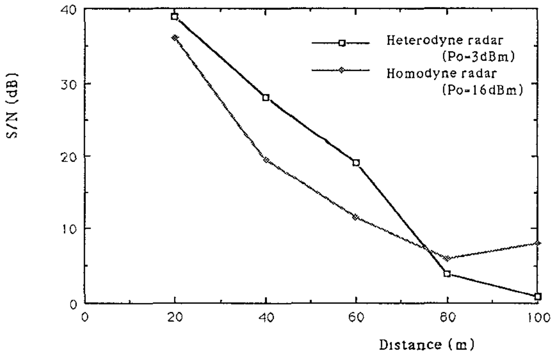


Fig.7 Comparison of FM-CW radar performance

Conclusion

We have developed a heterodyne FM-CW radar that uses front-end amplifier switching to reduce its S/N and thereby increase receiver sensitivity. We confirmed that the module's S/N was 20 dB better than that of a previously developed homodyne FM-CW radar module. This technique is suitable for all-HEMT MWMIC short-range radar applications such as automotive radars because of its low power.

Acknowledgement

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