A SOLID-STATE 94 GHz
DOPPLER RADAR

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Abstract

The design, construction and performance of a small portable all solid-state Millimeter-Wave Doppler Radar operating at 94 GHz are described. Design trade-offs are discussed. Laboratory and field performance data are also presented.

Introduction

In recent years there have appeared a variety of solid-state Doppler sensors operating at frequencies up to V-band. Recent advances in millimeter-wave solid state sources and components have made it possible to benefit from the advantages inherent in higher frequency operation, such as:

1. Higher gain and smaller beamwidth for the same antenna size. The higher gain (increasing by a factor proportional to λ^2) results in longer range, whereas the smaller beamwidth results in improved spatial resolution, i.e. ability to discriminate between adjacent targets, as well as improved clutter rejection capability.

2. Higher Doppler frequency for the same target speeds. This in turn translates into higher sensitivity (due to the reduction of 1/f noise) and higher frequency resolution.

This paper describes the design principles and the performance of a Solid-State Doppler Radar operating in the low atmospheric attenuation window centered around 94 GHz.

Design Considerations

The radar is of a homodyne type, consisting of an RF source, a circulator, a single-ended mixer, an IF preamplifier and a parabolic antenna (see the block diagram and photograph in Figures 1 and 2 respectively). The RF source is an IMPATT oscillator (with an integral isolator) capable of delivering over 100 mW CW output power. The mixer uses a silicon Schottky barrier diode with an extremely small junction (3 μm diameter). The circulator has the dual purpose of separating the transmit and receive signals and leaking a small fraction of the signal power which serves as local oscillator (L.O.) power for the mixer.

The design goal is to achieve maximum sensitivity. The theoretical limit of tangential sensitivity is given by

$$S = -140 + 10\mathrm{Lg}_{10}\, B + NF$$

where

S = tangential sensitivity in dBm
B= IF preamplifier bandwidth in Hz
NF = Noise figure of mixer-preamp in dB

This includes thermal and 1/f noise[1] but not noise from the transmitter. It is assumed that the preamplifier has a low frequency cutoff of at least 2 KHz, corresponding to a minimum detectable target speed of about 10 mph.

Noise from the transmitter can not be neglected, however, because the isolation of the circulator is carefully controlled so that a portion of the transmitter power is used as L.O. power for the mixer. FM noise is of no importance for target distances below 2 miles. AM noise could limit the sensitivity of the radar if a large amount of power is leaked. To deter-

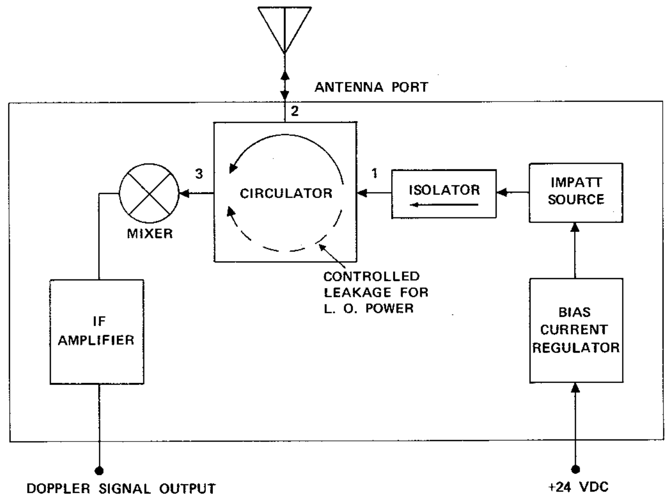

Figure 1 Block diagram of solid-state 94 GHz Doppler Radar.

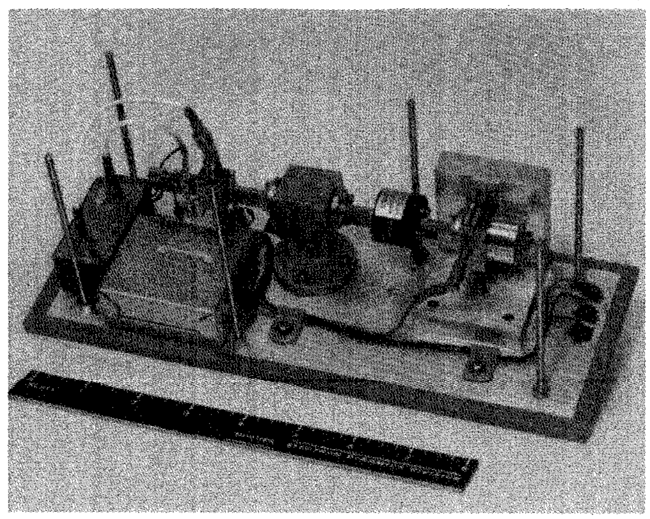

Figure 2 Photograph of Doppler Radar.

mine the optimum leakage, it is necessary to know the AM noise of a typical IMPATT diode at this frequency. Measurements of this noise have shown[2] that a typical value is 120 dB below carrier per 100 Hz bandwidth, for frequencies at least 1 KHz off the carrier frequency. Figure 3 shows the ratio $P_{received}/P_{L.O.\ noise}$ (in dB) versus L.O. power leaked to the mixer (in dBm), assuming $P_{transmitted}$ = 100 mW and a preamplifier bandwidth of 20 KHz. $P_{received}$ is the power arriving to the mixer from a target with $\sigma = 1\ m^2$, and $P_{l.o.\ noise}$ is the noise arriving at the mixer from the IMPATT source.

To minimize noise from the transmitter, leakage should be as small as possible, but as the available L.O. power is reduced, the conversion loss of the mixer deteriorates. Figure 4 shows a typical plot of conversion loss versus available L.O. power. By using forward-bias, the conversion loss can be kept reasonably low when the available L.O. power is reduced to low value (1 mW or less). This in turn reduces L.O. noise contribution to the receiver.

The maximum range of the radar depends mainly on target cross-section (σ) and transmitted power. Figure 5 shows a plot obtained from the classical radar equation, including 4 dB roundtrip atmospheric attenuation[3]. Measurements[4] of σ at X-band for cars give values of about 10 m^2. Measurements at W-band are not common; as an example,[5] a square aluminum plate of 0.66" side has a value of $\sigma = 0.1\ m^2$. Consequently, we can predict a worst case of $\sigma = 1\ m^2$ for targets such as cars, boats, etc.: typical values will be between 10 m^2 and 1000 m^2, depending on angle, etc.

With a transmitter power of +20 dBm and an antenna gain of 52 dB (24" parabola), the maximum range will vary between 1000 and 3000 meters, depending on the target.

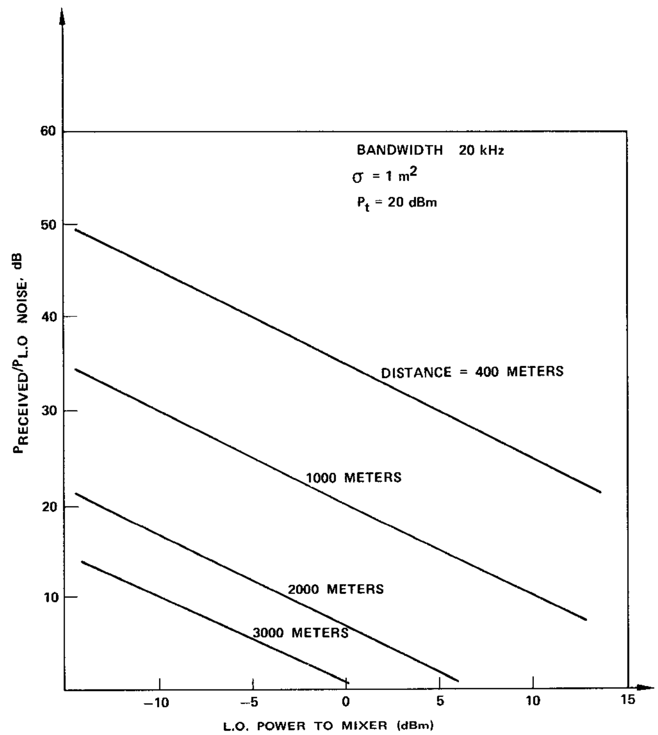

Figure 3 Shows the ratio $P_{received}/P_{L.O.}$ noise vs. L.O. power leaked to the mixer.

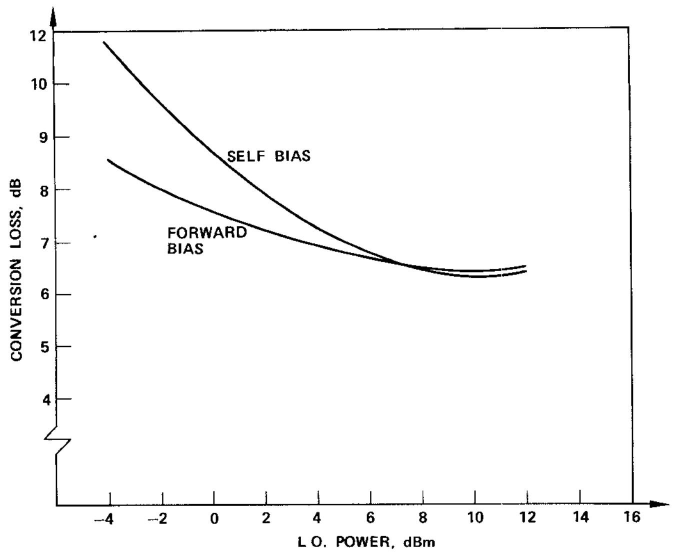

Figure 4 Shows a typical plot of conversion loss vs. available L.O. power.

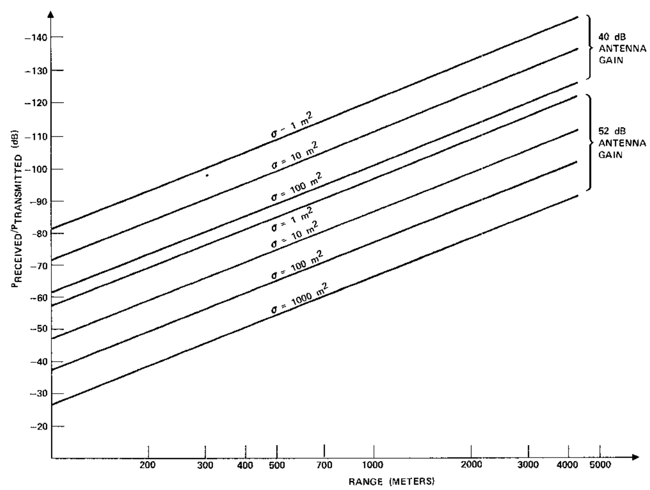

Figure 5 A plot obtained from the classical radar equation.

Construction and Performance

The unit was tested in the laboratory by using a small rotating wheel as a target. The speed of the wheel could be varied so that the Doppler frequencies fall within the intended range.

It was found that the maximum sensitivity could be obtained by carefully adjusting the isolation of the circulator (between 15 and 20 dB), the amount of forward bias and, to some extent, the input impedance of the preamplifier.

Figure 6 shows the measured output voltage of the preamplifier (in volts, peak to peak), versus the power returned to the mixer by the target. It can be seen that the tangential sensitivity is about -75 dBm.

Figure 7 shows an oscilloscope display of the Doppler signal output, with the rotating wheel as a target, when the ratio $P_{received}/P_{transmitted}$ is -70 dBm.

In field tests, targets such as cars at a distance of about 1.5 miles gave Doppler signals of about 350 mV peak; at a distance of 0.5 miles, the voltage output varies between 1 to 2 volts, and the radar could clearly discriminate between two cars in adjacent traffic lanes.

Figure 8 shows the spectrum of the Doppler return from a boat. The Doppler signal was recorded on an ordinary cassette tape recorder and then played back into an audio spectrum analyzer. The radar was "viewing" the stern of the boat as the range was increasing from 1/4 mile to 3/4 mile. Further field tests will be conducted to gather cross-section and sea-clutter data under several meteorological conditions, as well as to determine maximum usable range.

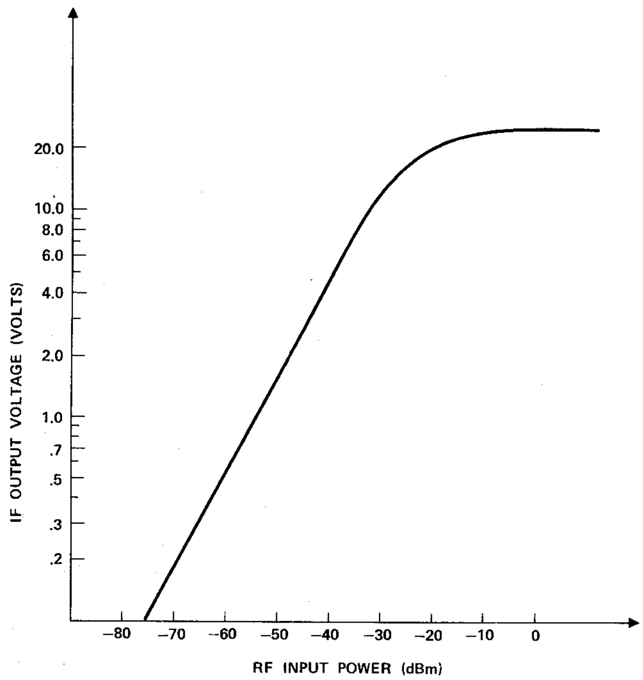

Figure 6 Measured output voltage of Doppler signal volts, peak-to-peak) as a function of power returned from target to antenna port (in dBm).

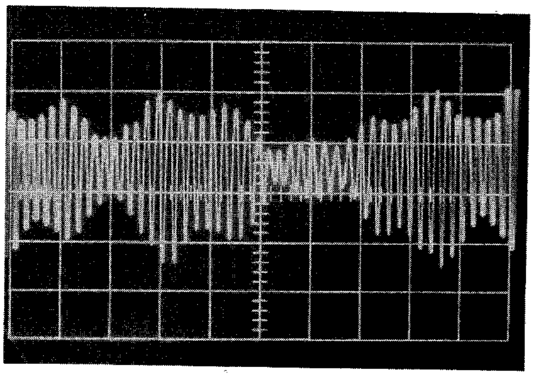

Figure 7 Doppler return from rotating wheel. $P_{received}/P_{transmitted}$ is -70 dBm. Horizontal scale: 1msec/div. Vertical scale: .5 Volts/division.

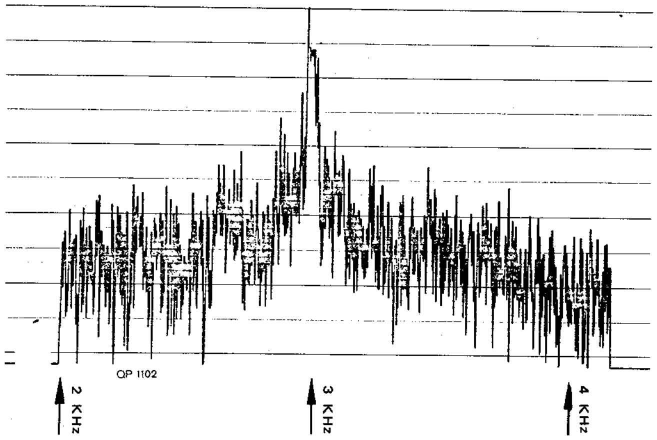

Figure 8 Spectrum of Doppler return from small boat.

Conclusions

A small solid-state 94 GHz CW Doppler Radar has been constructed. The unit demonstrates the advantages of millimeter-wave operation to reduce clutter (specially sea-clutter) and to achieve high spatial and speed resolution. Sensitivity and range can be improved by using appropriate signal processing circuitry.

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