ADVANCED SOLID-STATE COMPONENTS FOR MILLIMETER WAVE RADARS

by

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Abstract

Low power components for use in W-band (75-100 GHz), chirp radars have been developed. The development was based on a chirp bandwidth of 1.5 GHz. The components included resistive mixers for frequency conversion and generation of the chirp waveform at the radar output frequency and for bandwidth compression in the receiver front end, varactor multipliers, phase stabilized power sources to provide basic RF power for radar processing, and IMPATT amplifiers to boost the output power from the low power levels available from the mixers.

A. Introduction

The components described in this talk were developed to show the feasibility of operating a millimeter-wave radar with a linear FM chirp waveform used for pulse compression. In this project we were concerned only with the design of the millimeter wave components and were able to assume that all the signals with frequencies in Ku-band and lower are derived from a single, stable master oscillator. We did, however, impose limitations on the "low" frequency power demanded by the millimeter wave components so that it would have been practical for all the power to be supplied from a single solid-state source at each frequency. The chirp bandwidth was chosen to be 1.5 GHz; this sweep could reasonably be generated at lower frequencies and represented a potentially useful bandwidth.

The block diagram for a basic implementation is shown in Fig. 1. In the transmitter there is a waveform generator to create the FM chirp and an amplifier to increase the output power level. The waveform generator operates inside a feedback loop in order to improve the frequency linearity of the chirp waveform. This loop can contain the amplifier as well as the waveform generator so that the major portion of the phase distortion in the transmitter is cancelled. The receiver contains a mixer followed by a low noise amplifier and second IF conversion stage; there is also another waveform generator to generate an FM chirp for the local oscillator to the input mixer so that bandwidth compression is performed at the receiver input.

In order to maintain the frequency stability and phase coherence that was assumed for the low frequency driving signals, it was necessary to provide each of the waveform generators with millimeter wave power that was suitably stabilized in phase and frequency. This stabilization was accomplished by designing circuits that could injection lock the output of a klystron and simultaneously control the natural frequency of oscillation of the klystron to be coincident with the frequency of the injected signal.

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B. Component Design and Performance

1. Waveform Generator

The waveform generators were required to create the FM chirp signals for the transmitter and receiver. The generation of the millimeter wave chirp was done with an upconverter to translate a chirp generated at a low frequency to the output frequency. In addition, there had to be some provision for detecting the frequency linearity of the output chirp waveform so that a signal could be obtained to control the VCO providing the chirp. It was decided that this function could be performed most efficiently by sampling the output and translating back to the original frequency. The major benefit derived from this approach was that it allowed the linearity of the chirp to be measured at lower frequencies where compact nondispersive delays are available to allow the comparison of the chirp waveform with a delayed version of itself.

Because the two translation operations were so similar there was very little difference in the design of the up and downconverters. Of the two options available for use in the frequency converters, varactor converters or nonlinear resistive mixers, the latter type were universally chosen for this demonstration because of the easier task of matching to a resistive load rather than a reactive load. The millimeter wave Schottky diodes that were used in the frequency converters had a planar, honeycomb array structure, and their basic characteristics have been described previously.[1]

The typical converter circuit used is shown in Fig. 2. The converter is single ended, requiring only one diode. The diode is mounted in a modified Sharpless wafer package. This package has one port for the injection of bias and IF signals which is isolated with a low pass filter from two RF waveguide ports. The waveguide ports are used for the injection of millimeter wave pump power and in the case of an upconverter for the extraction of the converted signal. (With the downconverter the second waveguide port is used to inject the input signal, and the converted signal is extracted from the IF port). Isolation between the two waveguide ports was achieved with bandpass filters that were coupled to the diode package with two-section transformers. The transmission and reflection of the filters had a major influence on the final output characteristics of the converter circuits. Special low loss filters using rectangular TE_{101} cavities were developed with tightly controlled characteristics. The filters in conjunction with a multislug tuner at the IF port were used to achieve the flat in-band response that would be needed in this type of application. Most of the waveguide filters were based on a three-section, .1 dB Chebyshev ripple design and had an excess insertion loss of ∿.5 dB.

The most important performance measure for the upconverters is the converted output power. Fig. 3 shows a typical upconverter output where the minimum peak power is 1 mW and the output ripple is less than 1 dB peak-to-peak across the band. For the downconverters the important factor is conversion loss; the typical conversion loss achieved with the downconverters developed in this project was 10 dB.

The output power from the upconverter in the transmitter chain was raised to the 30 mW level by a two stage IMPATT amplifier. The two stage, circulator coupled amplifier is provided with a broadband isolator at the output to prevent out of band oscillation when the unit is connected to a high VSWR load. No isolation is required between stages. The overall gain of this unit for a 1 mW input is 15 dB with less than 2 dB gain variation over a 1.5 GHz bandwidth centered at 94 GHz.

2. Stabilized Millimeter Wave Power Sources

The millimeter wave power used to create the transmitter and receiver local oscillator waveforms was supplied by klystron oscillators. The output of the klystrons was stabilized in phase and frequency by injection of a low level signal into the tube through a circulator as shown in Fig. 4. This low level locking signal was derived from a stabilized Ku-band signal with a x5 varactor multiplier. The bulk of the circuitry in Fig. 4 was needed to compensate for the narrow locking bandwidth of the klystrons. This bandwidth was so narrow for the locking power available (≈16 dB below the output power) that normal temperature and power supply variations would have been sufficient to unlock the klystron. To counter this effect the reflector voltage of the klystron was used to control the free running frequency of the klystron to be equal to the frequency of the injection locking signal. The control signal for the klystron reflector voltage was derived from the phase difference between the locking signal and the klystron output. Any change in the klystron's free-running frequency changes the relative phase of the output so this parameter could be used to control the klystron reflector voltage. The use of frequency converters with an IF frequency of 1.6 GHz made it possible to use the same component design for this control circuitry as was used for the waveform generator converters. This design choice also made it possible to implement the required phase bridge with off-the-shelf, commercial microwave components.

The x5 multiplication needed to provide the injection locking power for the klystron was performed with specially designed snap-action millimeter wave varactors. These diodes were similar to the varactors reported earlier[1] but were made with a lower doped epitaxial layer. The multiplier circuit used did not contain any special provision for idler tuning and had 7 mW output with 8% efficiency at 80 GHz.

3. Receiver

The millimeter wave receiver had a mixer front end that could accept local oscillator and input signals over the 1.5 GHz chirp bandwidth. Its construction was essentially the same as that used for the frequency converters in the waveform generators. The conversion loss of the mixer with 1 mW of local oscillator power ∿9 dB at the peak of the IF response with a bandwidth of ∿0.4 GHz. The first IF amplifier was a 4 GHz paramp with a 1.6 dB NF. The noise figure measured with hot and cold loads was 11-12 dB although the experimental uncertainty was high because the hot load noise temperature was only ∿390K.

C. Summary

The feasibility of operating a linear FM chirp radar at frequencies in W-band (75-110 GHz) has been demonstrated by developing the solid-state components needed to produce the needed waveforms and process the return signal at the receiver input. This demonstration effort relied on semiconductor devices that were developed primarily for use in V-band (50-75 GHz) and was mainly directed at developing the high frequency circuitry needed for the different circuit functions. These developments included high quality waveguide bandpass filters, and improved IMPATT amplifier circuitry. The components developed for the project included a bandwidth compressing mixer with a conversion loss of 9 dB for the receiver, chirp generators for both the transmitter and the local oscillator for the mixer in the receiver, a two stage IMPATT amplifier with 15 dB gain at a 1 mW input level, and moderate power (20-30 dBm), phase stabilized millimeter wave power sources.

D. Acknowledgement

We would like to thank R. M. Madden for supplying the silicon varactors used in the x5 multiplier circuits.

Reference

1. H.L. Stover, et al., "Solid-State Components for a 60-GHz Receiver Transmitter" 1973 IEEE International Solid State Circuits Conference, Philadelphia, Pennsylvania.

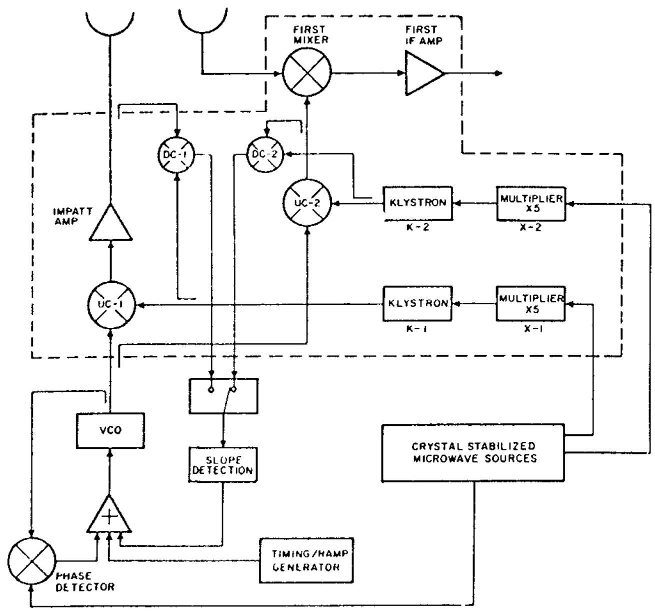

Fig. 1. Basic Block Diagram

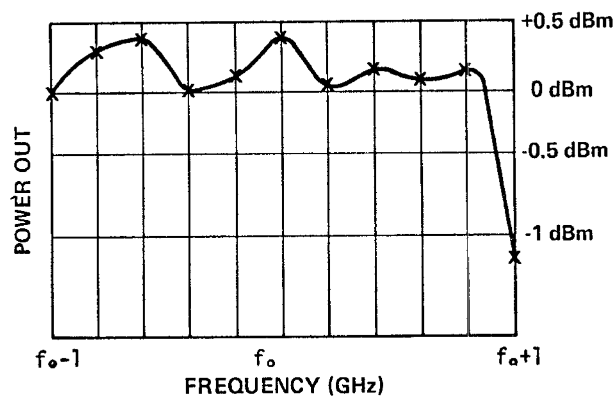

Fig. 2. Frequency Converter Circuit

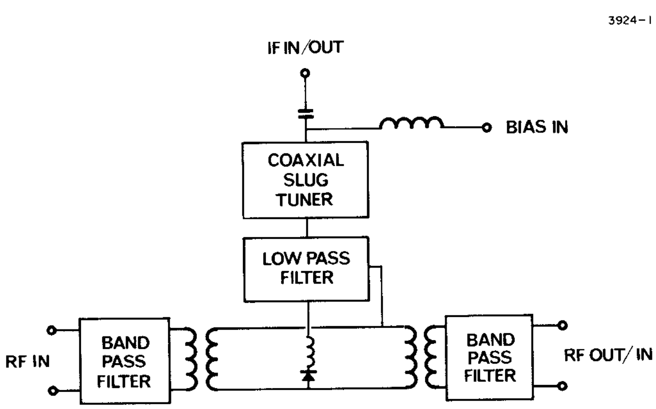

Fig. 3. Upconverter Output Characteristic

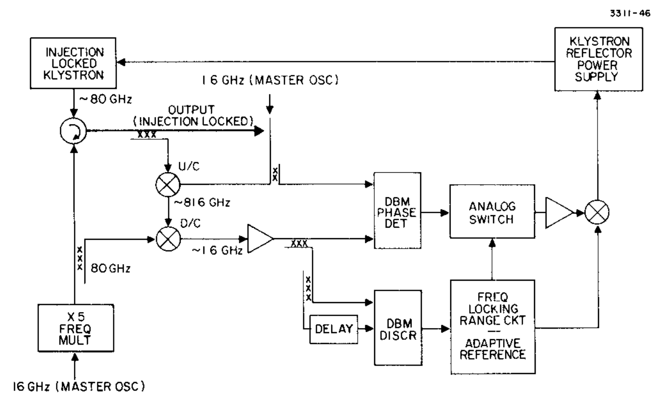

Fig. 4. Klystron Stabilization Circuit