KA-BAND MICROSTRIP INTEGRATED CIRCUIT FMCW TRANSCEIVER*

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ABSTRACT

A high performance Ka-band millimeter-wave integrated circuit FMCW transceiver has been developed. The transceiver consists of a voltage-controlled microstrip Gunn oscillator (Gunn VCO), a 10 dB coupler, a circulator, a single-balanced mixer, a low pass filter and a single-stage IF amplifier. Both packaged and beamlead varactor diodes for the Gunn VCO were evaluated. The entire RF circuit is printed on a single ferrite substrate using thin film microstrip IC technology and integrated into a small module. The transceiver produces more than 20 dBm CW output power via a coaxial connector at 35 GHz for tuning bandwidth exceeding 1 GHz. The RF-to-IF gain is at least 23 dB using a monolithic IF preamplifier, and the SSB noise figure is better than 12 dB. The unit is hermetically shielded in a 1.2 x 1.5 x 0.375 inch (3 x 3.8 x 0.95 cm) enclosure.

INTRODUCTION

The growing interest in millimeter-wave activities has led to a strong demand for millimeter-wave integrated circuits (MMW ICs) for military and civil applications. These include missile seekers, sensors, communication instruments, and automobile anti-collision radars. Low cost, compact and reliable integrated circuit transmitters and receivers are urgently needed. Low cost millimeter-wave ICs use cost effective designs that promote simplicity in manufacturing and testing. Microstrip ICs are a viable approach since they are compatible with low cost and high volume manufacturing techniques.

In general, there are two fabrication approaches for MMW ICs. One is to connect several individually designed microstrip components by thin ribbons.[1,2] The second approach is to develop the entire RF circuit on a single substrate. The latter technique is more difficult to design, but promises to be more reliable, compact, and less costly. This paper describes the design and development of a Ka-band frequency-modulated continuous-wave (FMCW) IC transceiver (Figure 1). The entire circuit is printed on a single ferrite substrate using a thin film technique, thereby simplifying the fabrication process and improving circuit performance.

The transceiver produces more than 20 dBm CW output power via a coaxial connector at 35 GHz for a tuning bandwidth of 1 GHz. The RF-to-IF gain is at least 23 dB. A SSB transceiver noise figure is about 12 dB using a single-stage silicon bipolar monolithic IF amplifier. The entire transceiver, including the IF amplifier and biasing circuits, is hermetically shielded in a small 1.2 x 1.5 x 0.375 inch (3 x 3.8 x 0.95 cm) enclosure.

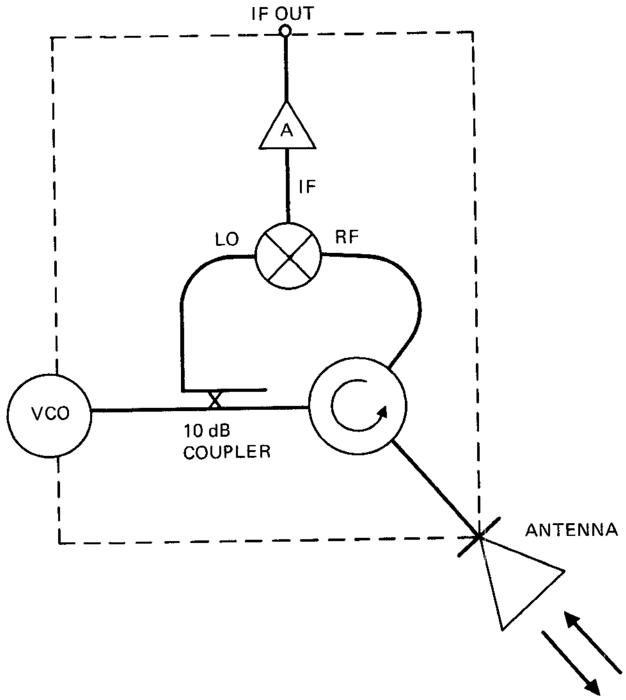

Fig. 1 Schematic diagram of an FMCW transceiver

TRANSCEIVER DEVELOPMENT

Figure 1 is a schematic of the FMCW transceiver. It consists of a microstrip VCO circuit, a circulator, a 10 dB coupler, a single-balanced mixer and a low pass filter - entirely on a ferrite substrate. The IF amplifier and the VCO bias circuits are etched on a Duroid substrate.

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VOLTAGE CONTROLLED OSCILLATORS

The Gunn VCO is the crucial component of the transceiver circuit. As shown in Figure 1, it performs the dual functions of a transmitter and a local oscillator via a 10 dB coupler. The conventional Gunn VCO design using distributed-type circuits, such as waveguide or coaxial line, are not compatible with planar microstrip ICs. Therefore, a discrete lumped element VCO design which launches directly onto a microstrip circuit via a short gold ribbon is adopted for this transceiver. The lumped element circuit is formed by controlling the package parasitics of the Gunn and the varactor diode.[3,4] Figure 2 shows the arrangement of this VCO circuit. The varactor diode is located directly on top of the Gunn diode. The varactor bias circuit, which is etched on a 10-mil (0.254 mm) thick Duroid substrate, is located on top of a pedestal raised to the same level as the varactor diode. The Gunn bias is fed through a multiple, quarter-wave section, band-reject filter fabricated on a 10-mil thick Duroid substrate. As shown in Figure 2, this VCO circuit has no bulk metal cavity or waveguide channeling. The output of this lumped element VCO is a simple three-section transformer that matches the VCO impedance to the 50-ohm line. A microstrip isolator in front of the VCO will protect the VCO from the possible pulling effect of the load impedance. Both the isolator and the VCO circuit are printed on a single ferrite substrate using a photolithography technique. Further discussion of the microstrip circulator is presented in Section B.

The circuit was built on a 0.008 inch thick ferrite material (Trans-Tech TT-2-111). A gold ribbon connects the Gunn diode and the microstrip circuit. The Gunn diode (Hughes Model 47201H) and the silicon varactor diode both are packaged in standard 35 mil (0.89 mm) diameter ceramic packages. The performance of this planar VCO is shown in Figure 3. The CW output power of the VCO is about 21 dBm (including the planar isolator

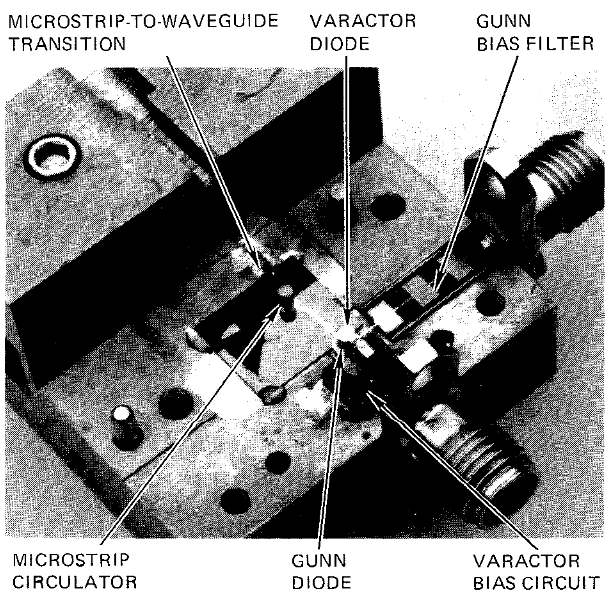

Fig. 2 Layout of a Ka-band lumped-element Gunn VCO

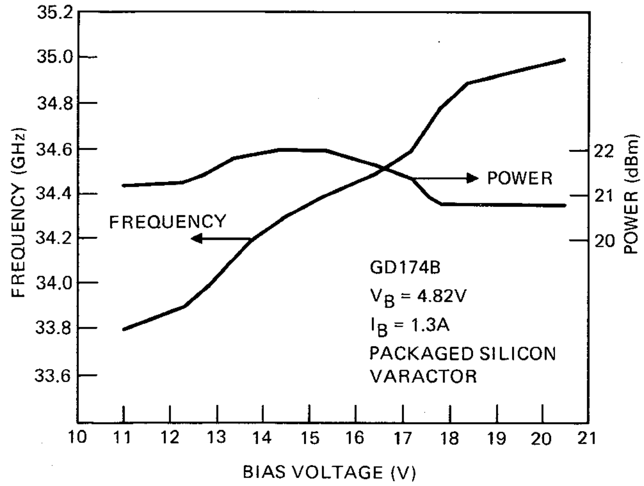

Fig. 3 Performance of a Ka-band lumped-element Gunn VCO

and transition to waveguide losses) for an electronic tuning range of 1.2 GHz. These results represent the highest CW output power to date at Ka-band from a microstrip IC Gunn VCO.

A Gunn VCO using a Hughes GaAs beam-lead varactor diode was also fabricated and tested. The beam-lead width is 0.007 inch (0.18 mm) and the length is 0.017 inch (0.43 mm). An Alpha beam-lead capacitor is used as a DC block to protect the beam-lead varactor from the high DC bias level of the Gunn diode. A simple two-section impedance transformer matches the VCO impedance to the 50-ohm line. The DC bias circuit for the varactor diode is a combination of a quarter-wave high impedance line and a quarter-wave radial line. This bias circuit presents an open shunt impedance at the 50-ohm microstrip line. Figure 4 presents the performance of this Gunn VCO using a beamlead varactor diode. The CW output power of the VCO is about 20 dBm for an electronic tuning range of 600 MHz. No microstrip

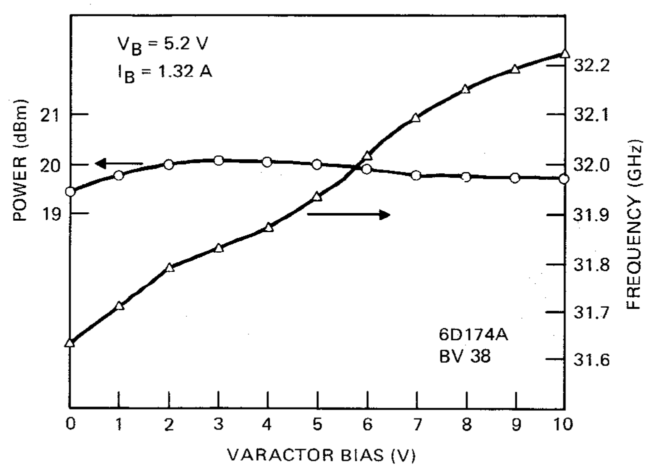

Fig. 4 Gunn VCO performance using beam-lead varactor diode

isolator was used in this circuit. The performance presented here for Gunn VCOs, using both packaged and beam-lead varactor diodes, is suitable for many high power FMCW transceiver applications.

MICROSTRIP CIRCULATOR

The circulator performs an important function in the transceiver. It is a duplexer that directs the transmitting and receiving signals to the appropriate components in the circuit. The basic theory used in the design of this microstrip circulator was introduced by Fay and Comstock.[5]

The microstrip circulator is printed on a 0.008 inch (0.2 mm) thick ferrite substrate. The ferrite material is a Ni-Zn compound with a saturation magnetization of about 5000 Gauss (Trans-Tech TT-2-111). A quarter-wave transformer was matched to each of the three junctions from a 50 ohm transmission line. A small magnet was placed directly on top of the circulator disk and is held in place by epoxy glue. The insertion loss and isolation of the circulator is shown in Figure 5. The insertion loss is about 0.6 dB while the 20 dB isolation bandwidth is about 4.0 GHz.

SINGLE BALANCED HYBRID MIXER

Mixers are required in FMCW transceiver design for receiver downconverters. Figure 6 shows a Ka-band microstrip branchline mixer fabricated entirely on a ferrite substrate. Balanced mixer operation is achieved through a pair of GaAs Schottky barrier beamlead diodes connected in series. These diodes are monolithically fabricated on a single chip so that the turn-on characteristics are extremely symmetrical. On a single chip, these beam-lead mixer devices have two Schottky diodes connected in series with four output leads. Since the diode pair are in one beam-lead chip, the mixer diodes can be easily mounted on the microstrip circuit.

The DC return for the mixer diodes is provided via a radial line stub. The combination of a quarter-wave radial line and a quarter-wave high impedance line will present an RF broadband open circuit to the mixer while it allows the DC return for the diodes. The conversion loss of this Ka-band branchline mixer on ferrite substrate is less than 6 dB across a 2 GHz bandwidth and the LO-to-RF isolation is at least 12 dB. The LO power is 9.5 dBm.

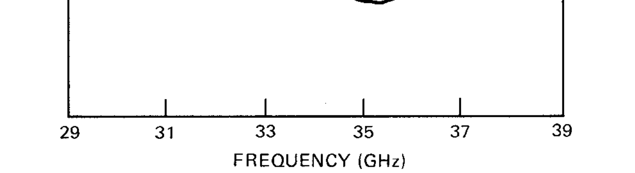

Fig. 5 Performance of a Ka-band microstrip circulator on a ferrite substrate

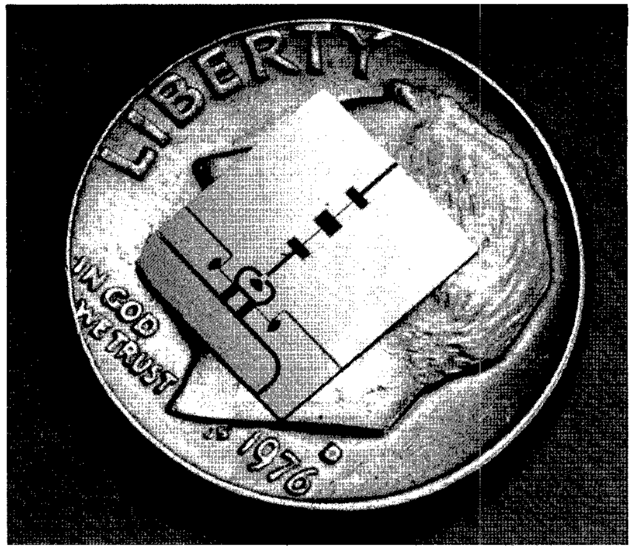

Fig. 6 Ka-band branchline mixer on a ferrite substrate

IF PREAMPLIFIER

A commercially available monolithic silicon bipolar IF amplifier (Avantek 0870) is used for the FMCW transceiver unit. The amplifier is mounted on a 10-mil thick (0.254 mm) Duroid substrate with appropriate chip capacitors and resistors. The amplifier has a typical noise figure of 3.2 dB from 0.1 to 0.5 GHz and an associated gain of 32 dB.

TRANSCEIVER INTEGRATION

The FMCW transceiver consists of a VCO, a balanced mixer, a circulator, and an IF preamplifier, all enclosed in a compact housing measuring 1.2 x 1.5 x 0.375 inches (3 x 3.8 x 0.95 mm) as shown in Figure 7. All RF components are printed on a single

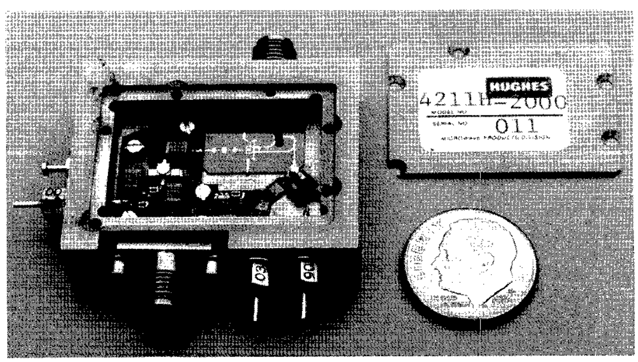

Fig. 7 Ka-band microstrip FMCW transceiver

0.35 x 0.53 inch (8.9 x 13.5 cm) ferrite substrate. The monolithic IF amplifier and all DC bias circuits are mounted on a Duroid substrate with associated chip capacitors and resistors. A 10-dB parallel microstrip coupler on the ferrite substrate will provide the mixer with at least 10 dBm of LO power from the VCO. A beam-lead capacitor located between the circulator and the mixer circuit will protect the mixer diodes from the high bias current of the Gunn VCO. The RF output of the transceiver is a coaxial (Wiltron K series) connector. All DC bias connectors are feedthrough EMI filter slugs that provide EMI filtering capabilities for the transceiver circuit.

Figure 8 shows the transmitting performance of the transceiver measured at the coaxial antenna port. The transceiver produces at least 100 mW CW output power for an electronic tuning range of about 1 GHz (using a packaged varactor diode) with a center frequency of 35 GHz. The Gunn bias level was maintained at 5.0 V and 1.18 A. The RF-to-IF gain of this transceiver using a monolithic preamplifier is shown in Figure 9. The gain is always greater than 23 dB for the IF frequency range between 50 to 500 MHz. Figure 10 shows the noise figure of the transceiver. From 50 to 500 MHz, the noise figure is mostly below the 12 dB level.

CONCLUSIONS

A Ka-band integrated circuit microstrip FMCW transceiver has been developed. All RF components are printed on a ferrite substrate, while all biasing and IF preamplifier circuits are etched on a 10-mil (0.254 mm) thick Duroid substrate. The transceiver produces more than 100 mW CW power at 35 GHz for a 1-GHz electronic tuning bandwidth. The RF-to-IF gain is more than 23 dB from 50 to 500 MHz IF bandwidth, and the noise figure is less than 12 dB. This performance and the simplicity of the design and construction make the transceiver viable for high volume and low cost applications in both civilian and weapon systems.

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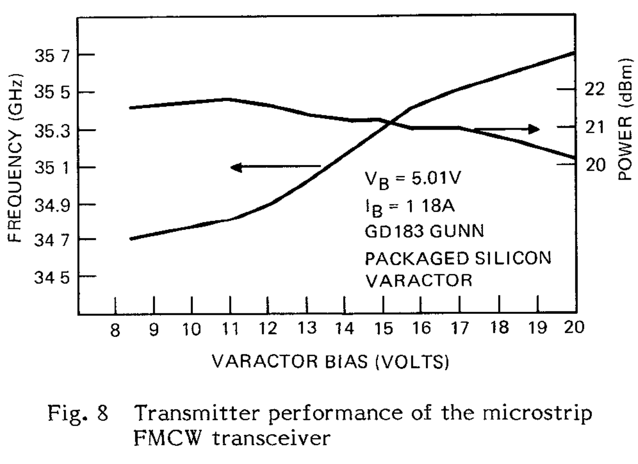

Fig. 8 Transmitter performance of the microstrip FMCW transceiver

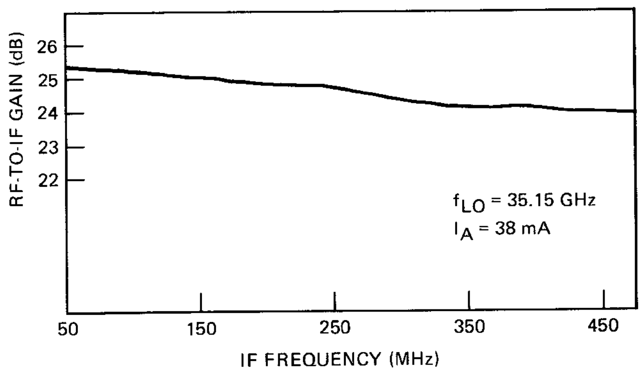

Fig. 9 RF-to-IF gain of the transceiver using a monolithic amplifier

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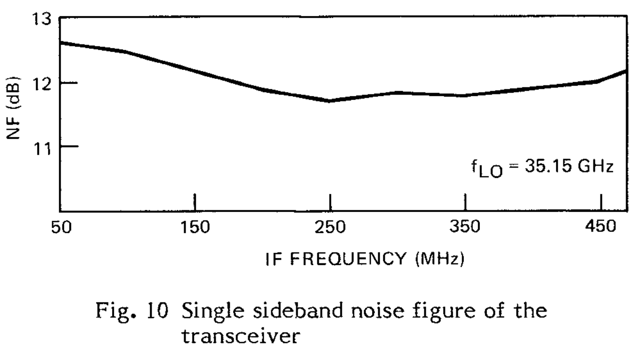

Fig. 10 Single sideband noise figure of the transceiver