W-BAND (75 TO 110 GHz) MICROSTRIP COMPONENTS

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ABSTRACT

Various microstrip components, including mixers, IMPATT oscillators, Gunn oscillators, doublers, and circulators, have been developed at W-band with state-of-the-art performance. The use of microstrip drastically reduces fabrication costs due to the less stringent machining tolerance. The design and performance of these components will be reported.

INTRODUCTION

Millimeter-wave components have been reported and used in many system applications. Most approaches use waveguide, suspended stripline, and finline. Fabricating these components at W-band generally requires stringent tolerance and is expensive; microstrip can alleviate this problem because no critical machining is needed in its fabrication. This paper reports many active and passive components fabricated in microstrip medium on Duroid substrate.

RAT-RACE BALANCED MIXERS

Microstrip rat-race mixers have been reported at W-band for very narrowband operation [1-3]. The rat-race mixer (Figure 1) consists of a ring type power splitter, two mixer diodes, two RF chokes, and a lowpass filter. The LO input is split equally into two mixer diodes. The RF input is also split equally, but 180 degrees out of phase at the mixer diodes. The LO and RF are mixed in these diodes which generate signals that are taken out through a lowpass filter. The RF choke provides the tuning mechanism and prevents the RF signal feeding into ground.

The dimensions of the ring are critical. It is 1.5 wavelength in circumference with four arms separated by 60 degrees of angular rotation. Two input and output arms are spaced from one another. At the center frequency, the input power from arm A will split equally into arms B and D. Because of the length of the electric path, the phase relationship between arms B and D will be 180 degrees out of phase. For the power input from arm C, the output will split equally in phase to arms B and D. The design of the ring requires that its impedance be equal to $\sqrt{2}$ times the characteristic impedance of each arm. For a 50-ohm system, this main ring impedance is equal to 70.7 ohms.

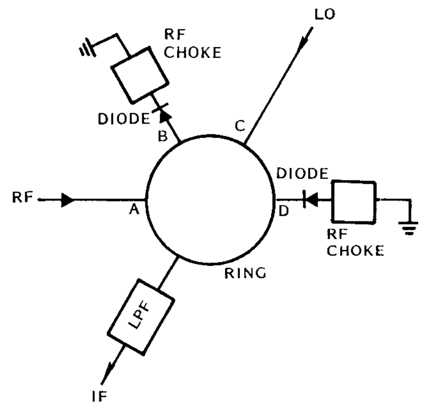

Figure 1. Rat-race mixer and ring.

A five-stage lowpass Chebyshev filter with 0.1 dB passband ripple is used in the mixer. The high impedance line in the filter is 100 ohms and the low impedance line is 20 ohms. The length of each section was optimized by the computer.

By carefully designing the ring size and the RF and IF matching, the bandwidth was improved considerably. A conversion loss of less than 7 dB was achieved for an instantaneous RF bandwidth of 9 GHz as shown in Figure 2. The circuit was built on 5-mil Duroid substrate. Broadband finline-to-microstrip transitions were connected to the mixer for RF and LO power coupling during mixer testing. The transition has an insertion loss of less than 0.5 dB over a 35 GHz bandwidth. The mixer without the transitions is shown in Figure 3.

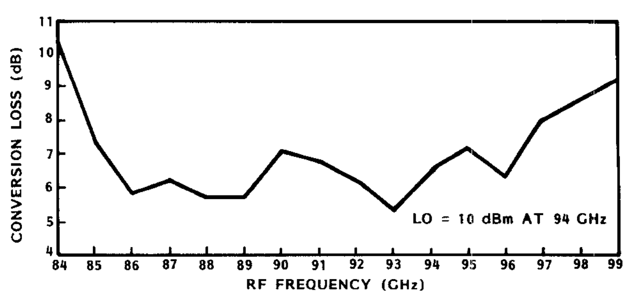

Figure 2. Performance of W-band rat-race microstrip mixer.

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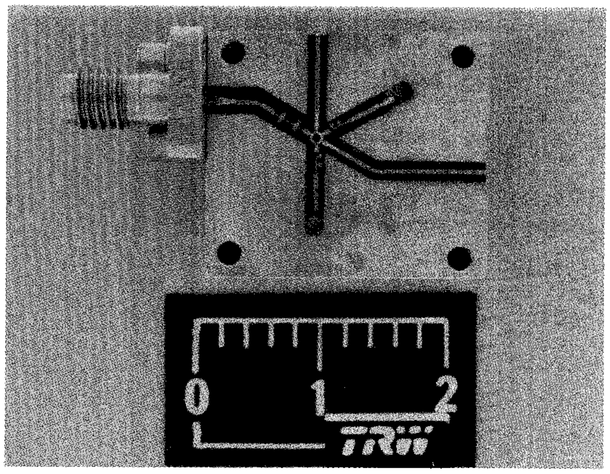

Figure 3. W-band microstrip rat-race mixer

IMPATT AND GUNN OSCILLATORS

Little work was reported on active microstrip components operating a W-band [4-6], and the output power was generally very low compared with their waveguide counterpart. By further optimizing the circuit reported in Reference 4, better power outputs for IMPATT oscillators were achieved. Figure 4 shows the performance for the CW operation. Over 90 mW at 100 GHz has been achieved, representing state-of-the-art performance using microstrip oscillators at W-band. The circuit used is shown in Figure 4.

For pulsed operation, a peak output power of 5 W at 92.75 GHz was achieved with a 50 kHz pulse repetition rate and 100-nsec pulsewidth using double-drift IMPATT diodes with capacitance of 6 to 7 pF and reverse breakdown voltage of 14 V. Figure 5 shows the bias current/voltage and video output of the RF signal.

The same circuit was used for Gunn oscillators. Typical power output is between +8 and +11 dBm.

FREQUENCY DOUBLER

The frequency multiplier is a viable approach to achieve low noise, stable, high frequency signals. All frequency multipliers reported at this frequency range use waveguide or suspended stripline [7-9]. A 46 to 92 GHz microstrip doubler is presented here with efficiency comparable to the suspended stripline multipliers.

Figure 6 shows the block diagram of the doubler. It consists of a dc block, an input matching and filtering circuit, a varactor diode, and an output matching and filtering circuit. Multiplication is accomplished with a GaAs varactor diode which has a cutoff frequency of about 500 GHz. The design began with the calculation of the diode impedance at input and output frequencies. Matching networks were then designed to match these impedance levels.

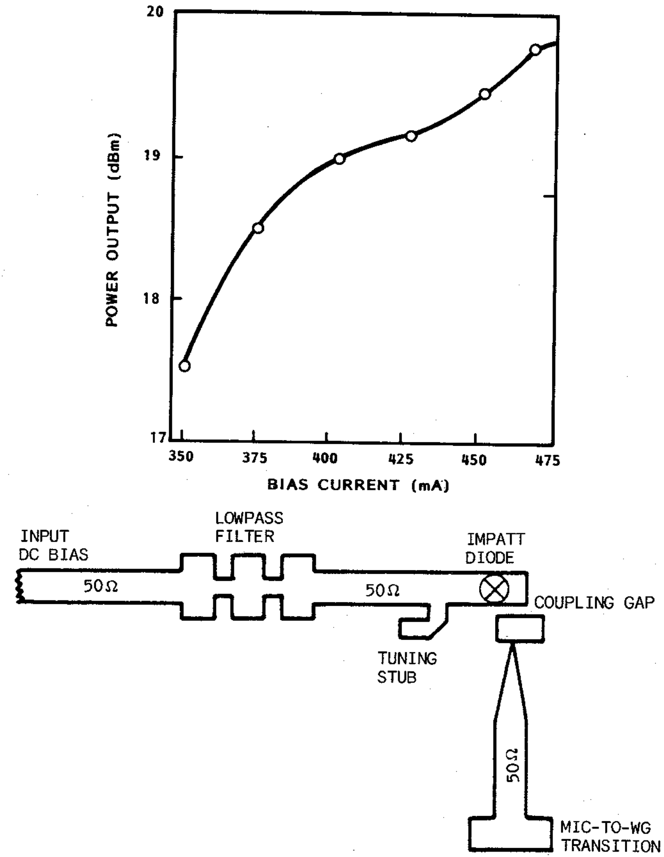

Figure 4. CW IMPATT oscillator performance and circuit schematic.

Figure 7 shows the actual hardware; performance is summarized in Figure 8. The conversion loss is about 8 to 9 dB over a 500 MHz output bandwidth.

CIRCULATORS

Circulators are important components for constructing oscillators and amplifiers using two terminal devices. At W-band, the ferrite disk becomes too small to support the lowest order mode; therefore, a relatively large ferrite supporting higher order modes is preferred to ensure producibility, repeatability of performance, and reasonable mechanical tolerance. The penalty for operating at higher-order modes is the slightly higher insertion loss.

As a dielectric resonator, the junction ferrite supports the propagation of a mode, controlled by the $X_{1,m}$ root of the Bessel function J'(x), and the ferrite radius is determined from:

$$R = \frac{X_{1,m}}{[(2\pi/\lambda_0)^2 \epsilon_r]^{1/2}}$$

where λ_0 is the free space wavelength at the design frequency and ϵ_r is the relative dielectric constant of the ferrite.

The ferrite disk operating at the first higher-order mode was selected with a diameter of 36 mils.

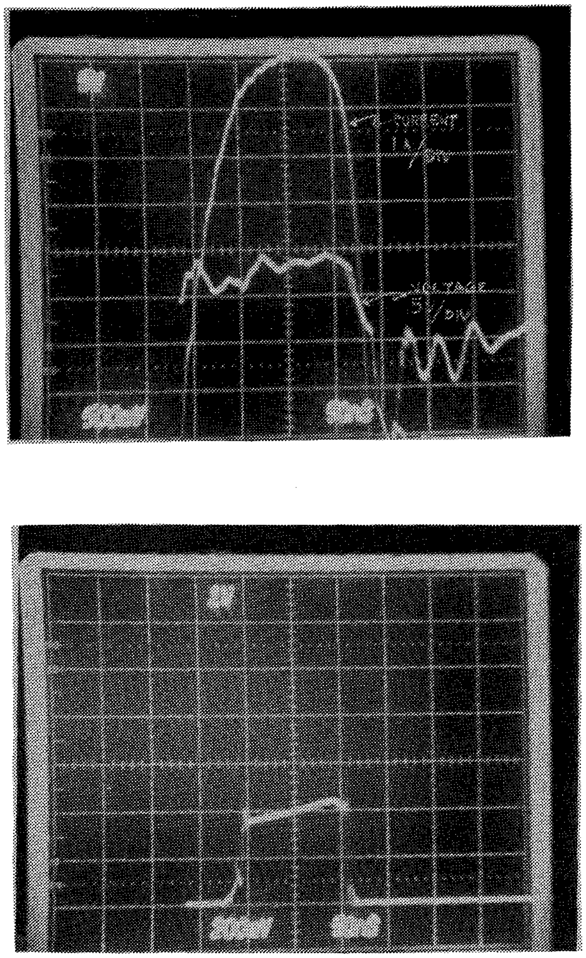

Figure 5. Performance of a W-band IMPATT oscillator in pulsed operation.

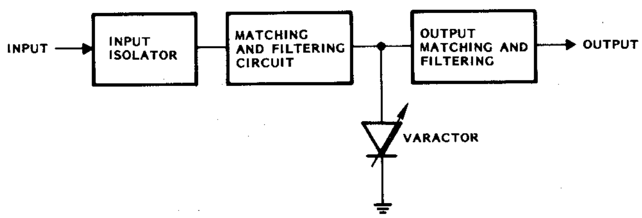

Figure 6. Block diagram of microstrip multiplier.

This large disk size has the advantage of less stringent mechanical tolerances and can thus be produced at lower cost.

The matching circuit design was based on impedance measurements using the network analyzer. The results of this impedance measurement for several frequencies are plotted on a Smith chart as shown in Figure 9. It can be seen that the circuit resonance occurs at 96.5 GHz, which is slightly higher than the designed operating frequency of 94 GHz. The center frequency can be easily adjusted by using a puck with 2 percent larger diameter. At the resonance, the ferrite puck becomes a pure resistance of

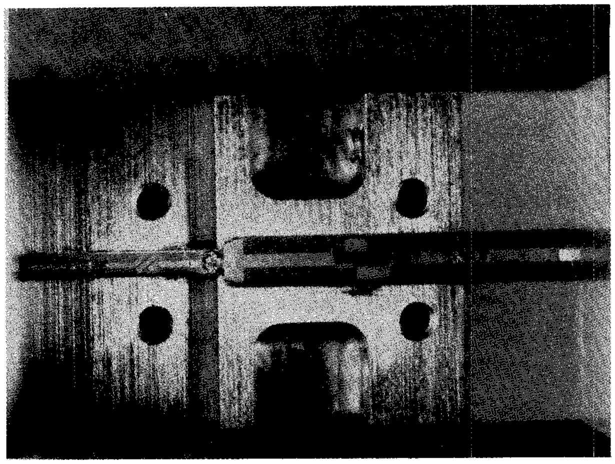

Figure 7. Photograph of 46- to 92-GHz microstrip doubler.

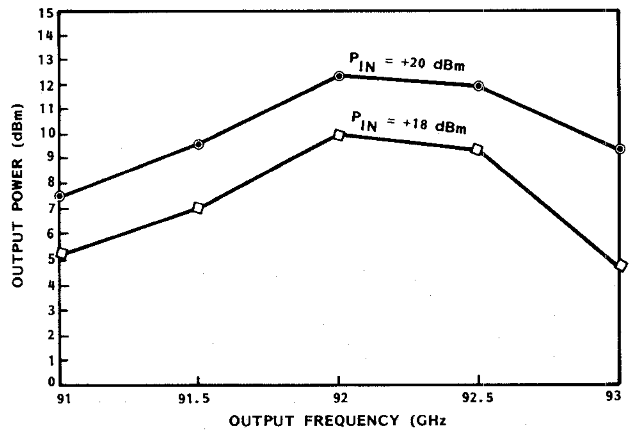

Figure 8. Performance of 46- to 92-GHz microstrip doubler.

70 ohms. The circulator provides the highest isolation and lowest insertion loss at the resonance.

Based on this measurement, a matching circuit was designed to match the 50-ohm line impedance to the ferrite impedance. The circuit is shown in Figure 10. The circulator has an insertion loss of less than 1.5 dB and an isolation more than 20 dB over a 2-GHz bandwidth (Figure 11). No external tuning stubs were required in the present circuit to improve the matching.

CONCLUSIONS

Many active and passive microstrip components have been developed at W-band with state-of-the-art performance. In contrast to the waveguide and suspended stripline approaches, the microstrip components can be manufactured at very low cost with comparable performance.

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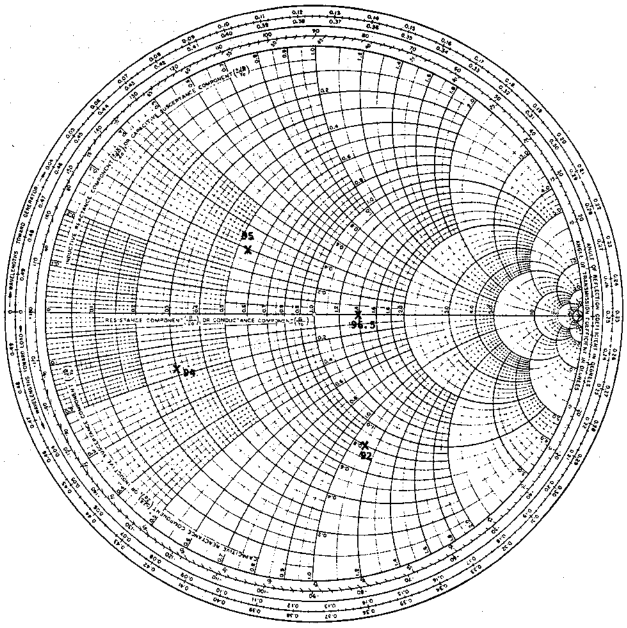

Figure 9. Circulator impedance measurement.

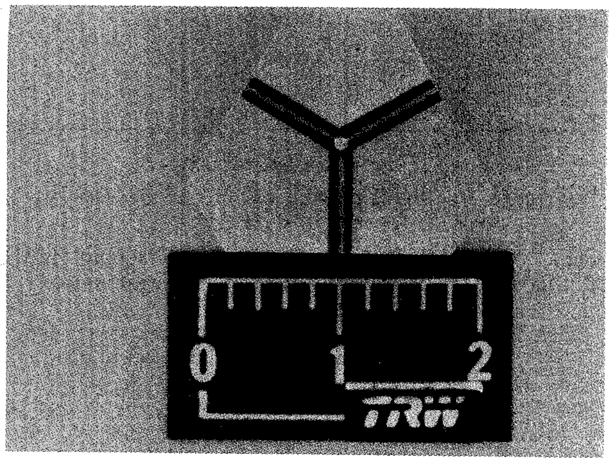

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Figure 10. Microstrip circulator with high impedance quarter-wavelength transformer.

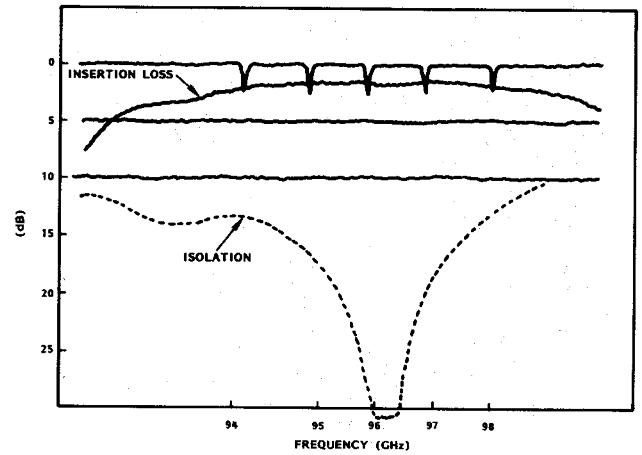

Figure 11. Insertion and isolation measurement of microstrip circulator.

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