MILLIMETER-WAVE IMPATT SOURCES FOR COMMUNICATION APPLICATIONS

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Abstract

FM transmitter oscillator of 400 mW output power at 60 GHz and 275 mW at 94 GHz using silicon double-drift IMPATT diodes and varactor-tuned local oscillators were developed for data transmission at 100 megabits/sec data rate.

I. Introduction

Millimeter wave solid state devices have been evolving rapidly from laboratory development into practical system applications. For secure and adverse weather communication at 60 and 94 GHz respectively, silicon double-draft IMPATT devices are the best choice as transmitter oscillators because of their output power capability and efficiency better than other solid state devices[1, 2]. The highest output power of the IMPATT devices can best be utilized by direct bias current modulation to achieve either AM (on-off) or FM data transmission, since any other modulation schemes (i.e. the use of varactor or PIN diodes) would result in excessive power loss (in the order of 2 to 3 dB) at these high frequencies.

This paper[3] describes our effort of developing silicon double-drift IMPATT oscillators at these frequencies for FM data transmission at 100 megabits per second data rate using bias current modulation. Varactor diode tuned silicon single-drift IMPATT local oscillators have also been developed at these frequencies and the system performance evaluation of these oscillators has been accomplished by incorporating these oscillators into an FM transmitter-receiver.

II. Transmitter Oscillators

For transmitter oscillators, silicon double-drift p^+-p-n-n^+ doping profile IMPATT diodes were fabricated using multiple-epitaxial growth technique. A flat diode concentration of 8.7×10^{16} per cm^3. The total epilayer thickness equals 1.0×10^{-4} cm. For the 94 GHz diodes, flat doping profile with effective dopant concentration of 2.0×10^{17} per cm^3 and total epithickness of 0.72×10^{-4} cm was used. The 60 GHz diodes were thermal-compression bonded onto copper heatsinks, and the 94 GHz diodes were mounted on type II diamond heatsinks, which yielded a thermal impedance about 30% less than the use of copper heatsinks. The diodes were in quartz ring sealed packages and placed in reduced height waveguide circuit as shown in Figure 1a. The length a, and L in the coaxial section of the circuit can be adjusted to provide tuning in conjunction with the tuning short. Details of the circuit tuning characteristics will be reported elsewhere[3].

Bias tuning characteristics of a 60 and a 94 GHz transmitter oscillator are shown in Fibure 1b, and 1c respectively. The 60 GHz oscillator achieved output power of 400 mW with 6% efficiency at diode junction temperature below 266°C for long life reliable operation. A similar oscillator was singly tuned and achieved 480 mW and 8.6% efficiency at 250°C junction temperature. The 94 GHz oscillator has a frequency tuning range of 1 GHz with maximum output power of 275 mW and 4.5% efficiency at low junction temperature above ambient of 215°C. The oscillators were modulated up to 100 MHz using specially designed regulator/modulator circuits. Noise characteristics of the oscillators were measured. Figure 2 shows and AM noise characteristics of the 94 GHz oscillator shown in Figure 1c. AM noise at 1 KHz to 100 KHz from carrier was continuously measured and shows 1/f (f = frequency) dependance. However, at 1 to 2 GHz away from carrier, the increase in noise was possibly caused by insufficient rf choke design which allowed the current in the bias circuit to be modulated at those frequencies.

III. Varactor Tuned Oscillators (VTOs)

Varactor tuned IMPATT local oscillators were developed at 60 and 94 GHz for use in the FM receivers. Figure 3a shows the reduced height waveguide circuit for the VTOs. A varactor diode was placed near a quarter wavelength from a packaged silicon single-drift (p^+-n-n^+) IMPATT diode. A metal short provided tuning. Figure 3b is the tuning characteristics of a 60 GHz VTO. The varactor diode was a quartz ring packaged GaAs mesa diode of total (diode plus package) zero bias capacitance of 0.23 pf, and 9.0 volts breakdown voltage. The IMPATT diode was biased at 217°C junction temperature. The VTO achieved 1 GHz tuning range with +18 dBm maximum output power. Figure 3c is the tuning characteristics of a 94 GHz VTO. An IMPATT diode of 0.67 pf in zero bias capacitance was used as varactor. The VTO achieved 1 GHz tuning at low junction temperature of 200°C. Noise performance of VTOs are in general improved over current biased IMPATT oscillators because good bias current regulation can be provided for the VTOs. Shown in Figure 4a and 4b are the noise characteristics of the VTOs shown in Figure 3b and 3c respectively. Since the receiver operated at an i.f. centered at 1.5 GHz, the VTO AM noise at 1.5 GHz from carrier shown in Figure 4b indicates that the VTOs can be used with balanced mixers with 27 dB LO noise suppression without generating excess receiver noise figure which can be easily achieved.

IV. System Performance Evaluation

The FM transmitter oscillators and the VTOs were evaluated in a FM transmitter-receiver. Figure 5a shows the system block diagram. A comparator circuit was provided following the frequency discriminator to improve the post-detection sensitivity. Detected video data pulses output operating at 94 GHz are shown in Figure 5b, at 100 megabits per second data rate with non-return-to-zero (NRZ) mode. Spectral output of the data are shown in Figure 5c for 100 megabits NRZ and in Figure 5d for 200 megabits NRZ. Good data and spectral results were obtained up to and near the receiver FM threshold.

Figure 6 shows the measured bit-error-rate (BER) for the 94 GHz unit. BER of 10^{-7} at signal-to-noise ratio (S/N) of 13 was obtained. The BER measured fits the expression of (½)EXP(-kγ), where k = 0.771. Since most FM receivers have k between 0.5 (non-coherent FSK) and 1.26, the performance of these oscillators fell between the theoretical values.[4]

V. Conclusions

This work proves the feasibility of developing high power solid state transmitter oscillators and low noise VTOs as local oscillators for high data rate FM communication system applications at 60 and 94 GHz. With the continuous improvement on devices and heat-sinks techniques, we expect to achieve FM cw transmitter power of 1 W at 60 GHz and ½ W at 94 GHz in the near future for military and commercial communication applications.

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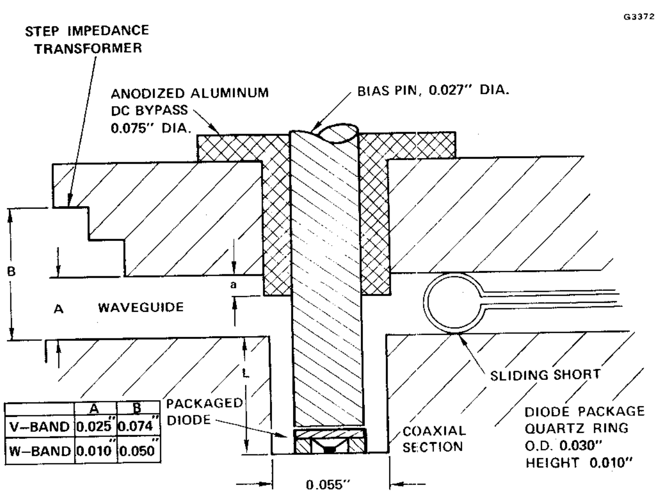

Figure 1a Coaxial coupled reduced height waveguide circuit.

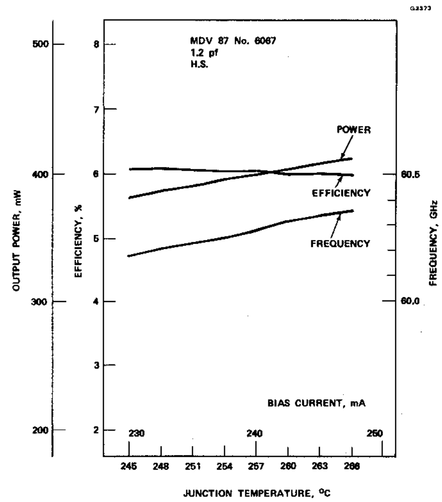

Figure 1b Bias current tuning characteristics of a 60 GHz oscillator.

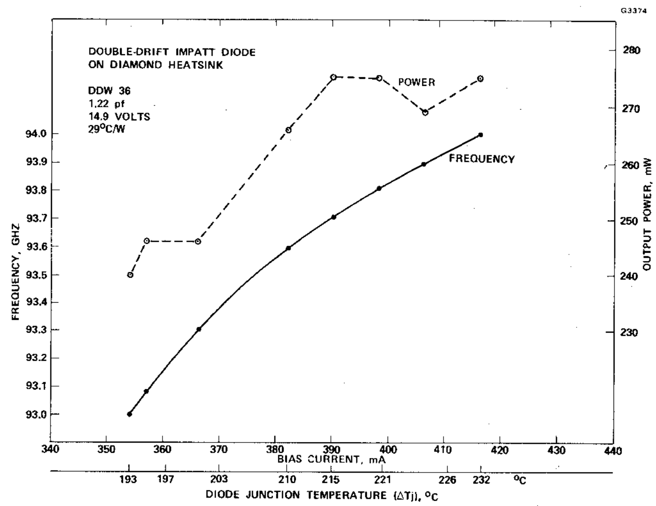

Figure 1c Bias current tuning characteristics of a 94 GHz oscillator.

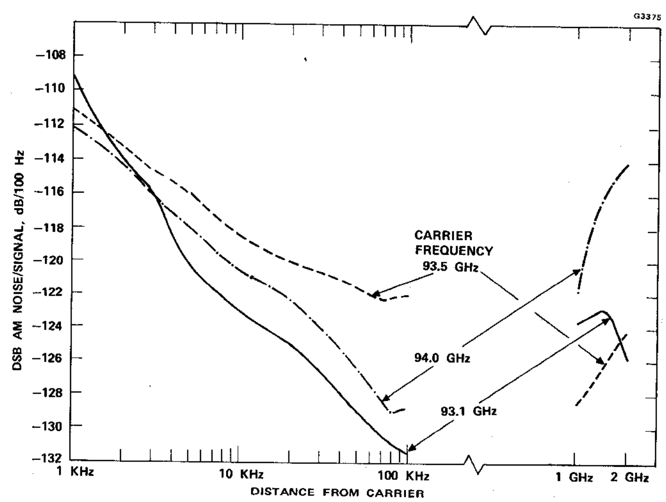

Figure 2 AM noise characteristics of the 94 GHz oscillator shown in Figure 1c.

	Dimensions, Inches		
	A	B	C
V-BAND	.074	.025	.060
W-BAND	.050	.010	.060

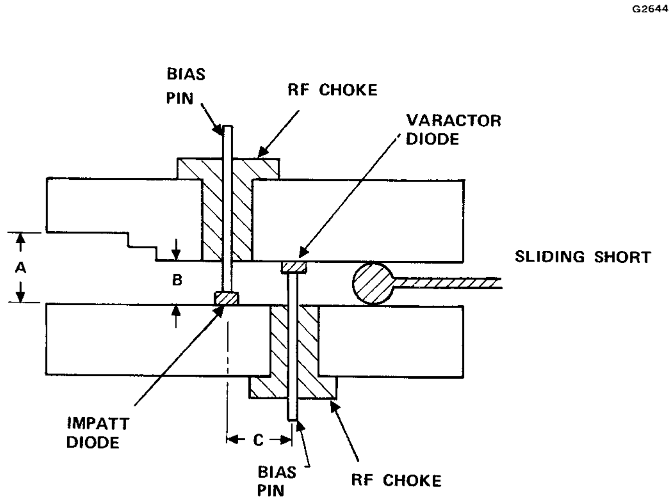

Figure 3a VTO reduced height waveguide circuit.

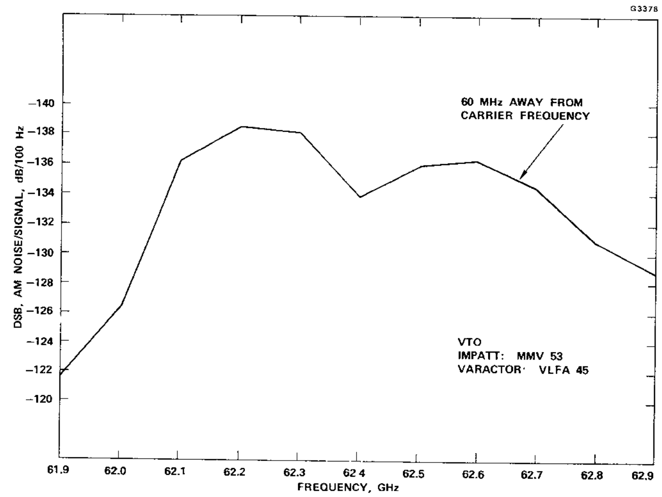

Figure 4a 60 GHz VTO.

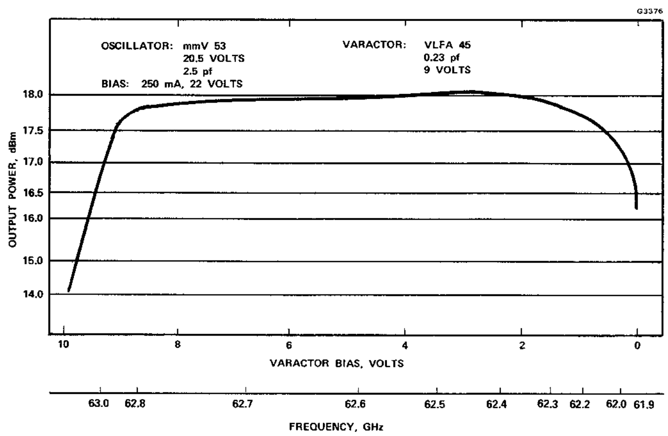

Figure 3b Tuning characteristics of a 60 GHz VTO.

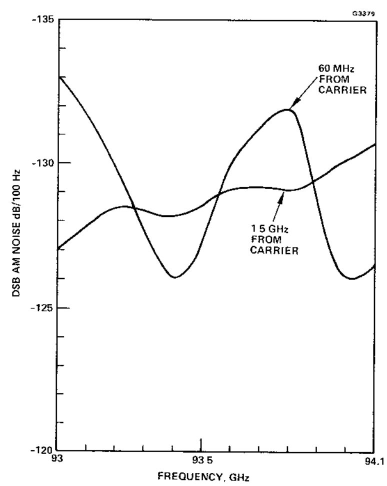

Figure 4b 94 GHz VTO.

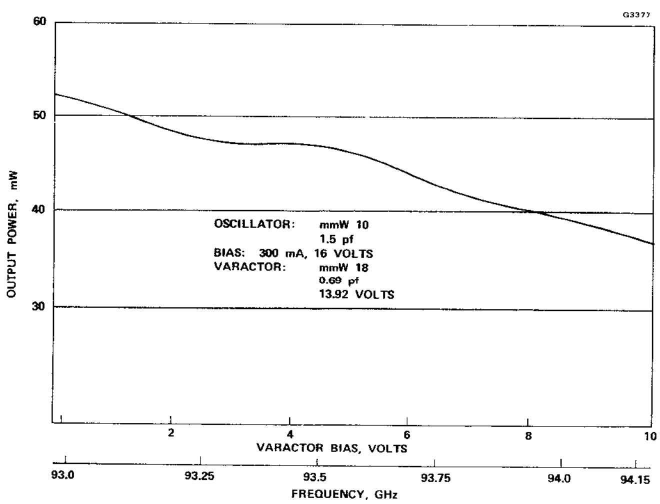

Figure 3c Tuning characteristics of a 94 GHz VTO.

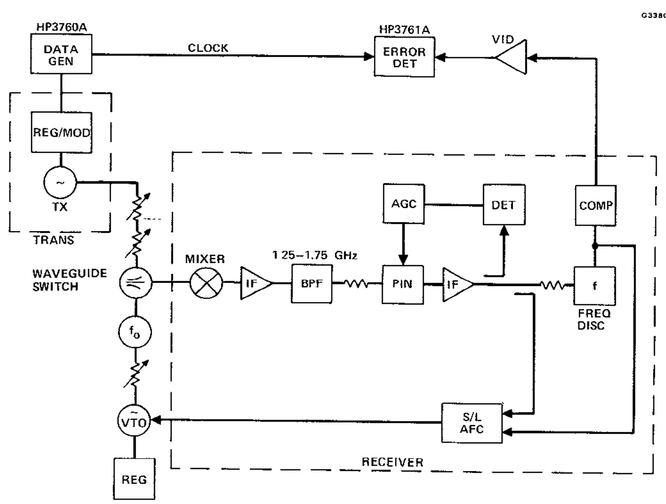

Figure 5a System block diagram.

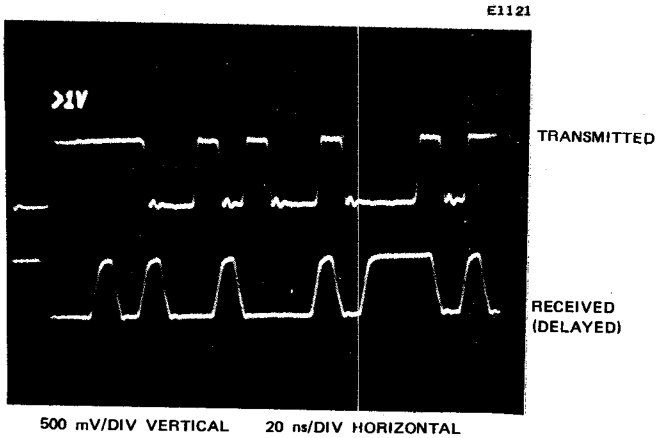

Figure 5b Detected data output, 100 megabits per second-non-return-to-zero (NRZ).

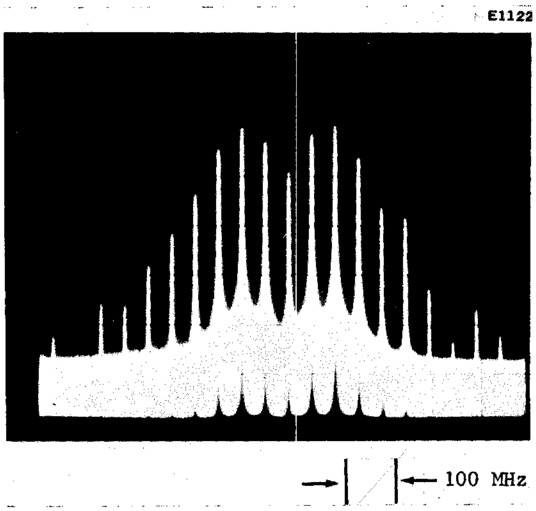

Figure 5c Spectral output, 100 megabits/ sec., NRZ. (1010 world pattern).

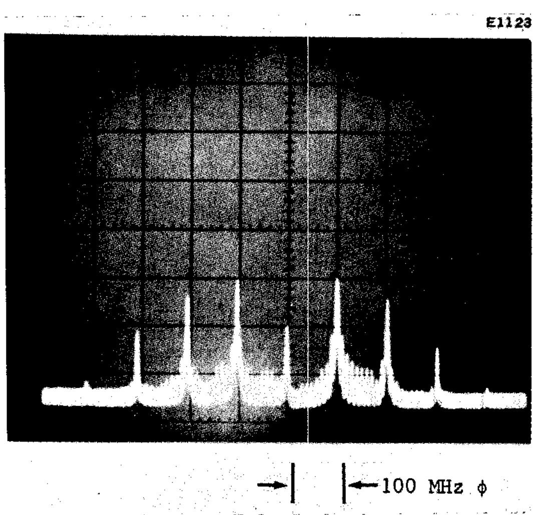

Figure 5d Spectral output, 200 megabits/ sec., NRZ. (1010 world pattern S/N = 17 dB).

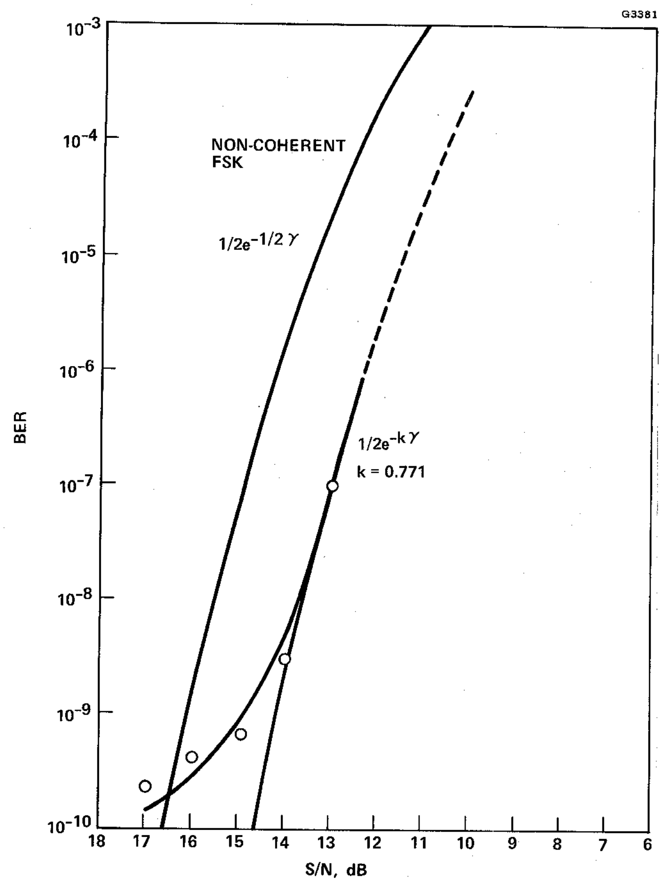

Figure 6 Bit-error-rate (BER).