PERFORMANCE AND APPLICATIONS OF NOVEL TUNABLE OSCILLATORS UTILIZING FOCUSED-ION-BEAM-IMPLANTED GUNN-EFFECT DEVICES

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ABSTRACT

The RF performance of novel tunable voltage-controlled, injection-locked and dielectric resonator oscillators utilizing focused-ion-beam-implanted (FIBI) Gunn-effect devices is reported for the first time. By varying the bias voltage across the device a frequency tuning range from 5 to 25 GHz was achieved, which is the widest band exhibited to date by a single FIBI Gunn oscillator.

INTRODUCTION

Significant reductions in the complexity and cost of fixed- and swept-frequency signal sources are necessary for the implementation of microwave functions that incorporate built-in testing. In this paper we report on microwave sources of extreme simplicity that utilize focused-ion-beam-implanted (FIBI) Gunn-effect devices [1],[2]. Further, we describe the design approach and RF performance of injection-locked (ILO), voltage-controlled (VCO) and dielectric resonator oscillators (DRO). Oscillators utilizing devices with a linearly graded doping concentration exhibited swept frequencies from 6.5 to 13 GHz. With devices having two consecutive linearly graded doping concentrations, a wider frequency tuning range from 5 to 25 GHz was achieved. This result represents the broadest tuning range exhibited to date by a FIBI Gunn oscillator. These low-cost swept-frequency sources will facilitate the implementation of built-in-testing in microwave systems.

DEVICE EVALUATION

Details on the fabrication and characteristics of the Gunn Diode used in these experiments have been previously published [2]. The planar Gunn diode exhibits an active area 10 µm wide by 30 µm long. The current flow and doping concentration gradient are colinear in the longitudinal direction. Typical doping gradients range from 1 to 3 x 10^{17} cm^{-3} over a distance of 18 µm.

The design of the oscillators is based on the evaluation of the output impedance of the Gunn device. The device was mounted in shunt with a 50 Ω microstrip line. The real part of the output impedance was estimated from power measurements in which a circulator was used to separate the incident and reflected waves. The magnitude of the reflected waves at each oscillation frequency is shown in Fig. 1 for incident waves with power levels of -30, -20 and -10 dBm. From these results a variation of the real part of the negative resistance from 60 to 120 Ω can be in inferred. This variation is decreased by nonlinear effects associated with saturation at higher power level. The average negative resistance was estimated to be 70 Ω over the frequency range from 7 to 12 GHz.

INJECTION-LOCKED OSCILLATOR

The experimental apparatus used for the device evaluation was also employed for the ILO experiments. Frequency locking was achieved by adjusting the bias voltage across the device which, as previously reported [2], adjusts the transit-time frequency of the device. Locking was evidenced by the reduction of noise about the carrier. Typical injection-locking bandwidths were 1.8 GHz at 13 GHz and 50 MHz at 6.5 GHz. Frequency locking at injection signal levels as low as -30 dBm was demonstrated. In a low-cost implementation of the ILO, a broadband Lange coupler can be used to inject the locking signal.

VOLTAGE-CONTROLLED OSCILLATOR

In the operation of a free-running VCO, consisting of a Gunn device connected in shunt with a 50 Ω microstrip line, the variation of output power is due to standing waves established by impedance mismatch between the device and the output microstrip line. Matching the real part of the negative resistance of the Gunn device with a 50- to 70-Ω tapered microstrip line increases output power and decreases the variation of output power with frequency, as shown in Fig. 2(a). Output powers of -13 ± 2 dBm were measured over the frequency range from 6.5 to 13 GHz. Termination of second harmonics can decrease the variation to -13 ± 1 dBm from 6.5 to 12 GHz. The increase in output power and the reduction of standing waves confirm the estimated value for the real part of the negative resistance of the device. The relationship between the oscillation frequency and dc bias voltage across the free-running VCO is shown in Fig. 2(b). The output frequency varies monotonically from 6.5 to 13.5 GHz as the bias voltage is reduced from 12 to 7.2 V.

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In conventional VCOs the frequency tuning range is determined by capacitance variations produced by a varactor in the LC resonant circuit. By contrast, in the present oscillator the tuning range is determined by Gunn-domain transit times, which are controlled by doping concentration gradients and the longitudinal dimension of the device. Figure 3(a) shows the output power versus frequency curve of a VCO having an active region with two consecutive linearly graded doping concentrations: 1 to 2 x 10^{17} cm^{-3} over 5 µm and 2 to 2.5 x 10^{17} cm^{-3} over 11 µm. The corresponding tuning curve is shown in Fig. 3(b). The 5:1 tuning range of 5 to 25 GHz is the broadest band reported for a planar Gunn VCO utilizing a device fabricated with FIBI. This frequency tuning range is significantly higher than that of YIG-tuned oscillators, which is typically 3:1. Furthermore, the FIBI Gunn VCO is smaller and lighter and does not require bias currents associated with magnetic circuits.

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Further improvements of VCOs are possible. For example, the feasibility of redesigning the doping concentration gradient to achieve a linear tuning curve is being investigated. A redesign of the active area to decrease the real part of the negative output impedance to 50 Ω will further simplify the VCO and increase its output power. Additional increases of output power can be achieved with multiple devices connected to a power-combining circuit.

DIELECTRIC RESONANCE OSCILLATOR

The design approach of DROs utilizing tunable FIBI Gunn devices is to couple electromagnetic energy from the tapered microstrip line to a dielectric resonator. A photograph of such a DRO is shown in Fig. 4. Without redesigning the circuit, the VCOs described above can be stabilized for operation at the resonant frequency of any dielectric resonator, provided it is within the frequency tuning range of the FIBI Gunn device.

Seven DROs based on the same VCO were evaluated. The output frequencies, the dimensions of the dielectric resonators, the bias conditions, and the output power levels of these oscillators are summarized in Table 1. Output powers are in the range from -13.5 to -3.8 dBm for frequencies from 8.26 to 13.85 GHz. Also shown in the table are the corresponding power levels of the free-running VCOs, which vary from -14.8 to -13 dBm. The higher output powers exhibited by the DROs are due to conjugate matching to the output impedance of the Gunn device. In the wideband VCO design, an impedance match to the estimated average value of the real part of the device impedance was made. Typical output spectra exhibited by DROs using planar FIBI Gunn devices are shown in Figs. 5(a), (b) and (c). The phase noise is -80 dBc/Hz at 100 kHz from the 9 GHz carrier [see Fig. 5(c)]. At 5 MHz from the carrier the noise power level is 50 dB below that of the carrier. In the case of free-running VCOs, a comparable carrier-to-noise ratio occurs at 500 MHz from the carrier, as shown in Fig. 5(d).

The design of these novel DROs is considerably simpler than that of DROs using conventional Gunn diodes, in which the matching of low absolute values of negative resistance to 50 Ω is required at the resonant frequency of the dielectric resonator. The significance of these results is that the DROs can be implemented inexpensively and the nonrecurring engineering costs associated with customized designs are eliminated.

SUMMARY

Several results on VCOs, ILOs and DROs utilizing tunable FIBI Gunn devices are reported here for the first time. In our evaluation of the single-gradient FIBI Gunn device the real part of the negative resistance was in the range from 60 to 120 Ω. For ILOs utilizing this device, the injection bandwidths were 1.8 GHz at 13 GHz and 50 MHz at 6.5 GHz. Our VCOs using a single-gradient device demonstrated output powers of -13 ± 2 dBm over the tuning range from 6.5 to 13.5 GHz, and for devices with two linearly graded doping concentrations the tuning range was between 5 and 25 GHz. Finally, we have demonstrated a family of DROs based on a single VCO design that operate in the frequency range from 8.26 to 13.85 GHz, for which the phase noise was -80 dBc/Hz at 100 kHz from the 9 GHz carrier. These data represent a significant improvement in microwave device and component technology.

The primary importance of our work is the demonstration of a family of fixed- and swept-frequency sources of extreme simplicity. These signal sources are of wide interest for their impact on the low-cost implementation of military and commercial RF systems. In particular, swept-frequency sources have the potential for integration with planar detector diodes on GaAs MMIC wafers for built-in RF testing using dc probes.

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TABLE 1 - PERFORMANCE OF TUNABLE DROs UTILIZING PLANAR FIBI GUNN DEVICES

DIELECTRIC RESONATOR OSCILLATOR	OUTPUT FREQUENCY GHz	DIELECTRIC RESONATOR SIZE, IN	BIAS VOLTAGE V	BIAS CURRENT mA	DRO OUTPUT POWER dBm	VCO OUTPUT POWER dBm
1	8.26	D=0.279 H=0.125	9.48	7.5	-13.5	-14.8
2	9	OD=0.245 ID=0.080 H=0.100	9	7.5	-10	-13.3
3	9.93	D=0.235 H=0.110	8.35	7.5	-8.7	-13
4	11.03	D=0.215 H=0.095	8	7.5	-12	-14.5
5	11.71	D=0.215 H=0.095	7.82	7.5	-3.8	-13
6	13.75	D=0.185 H=0.080	7.45	7.5	-6.7	-12.8
7	13.85	D=0.185 H=0.080	7.45	7.6	-9.8	-13

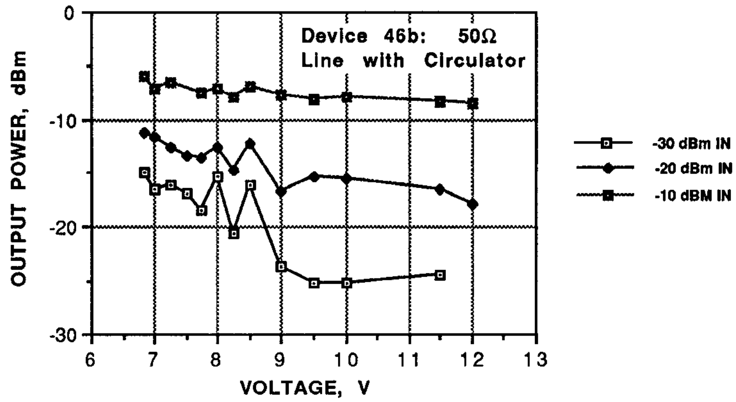


Fig. 1. Reflected power vs. bias voltage for the FIBI Gunn device.

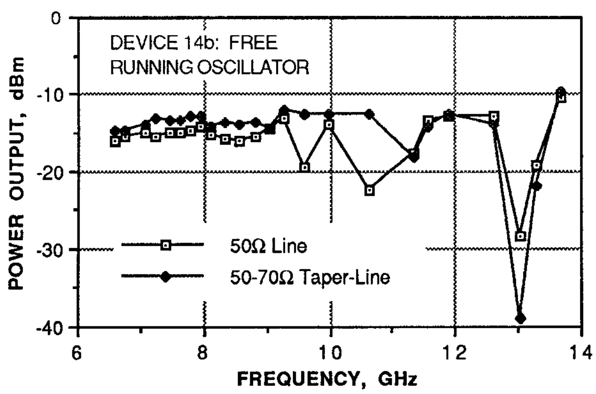


Fig. 2(a) Output power vs. frequency Curve exhibited by Free-running VCOs utilizing FIBI Gunn devices with a single linearly graded doping concentration, device 14.b

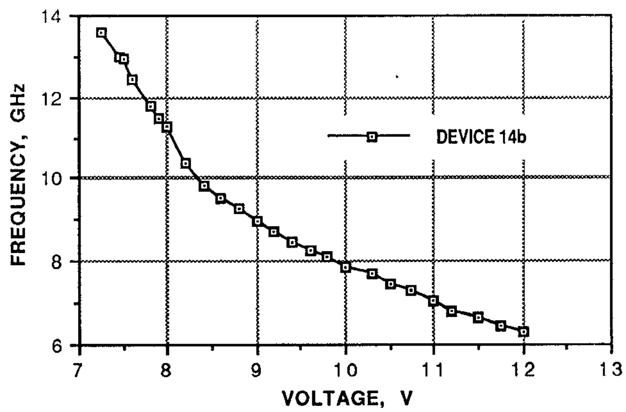


Fig. 2(b) Frequency vs. bias voltage exhibited by Free-running VCOs utilizing FIBI Gunn devices with a single linearly graded doping concentration, device 14.b

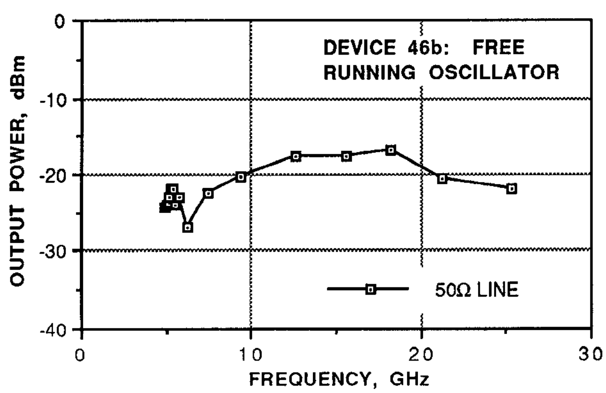


Fig. 3(a) Output power vs. frequency exhibited by free-running VCOs utilizing FIBI Gunn devices with two consecutive linearly graded doping concentrations, device 46b.

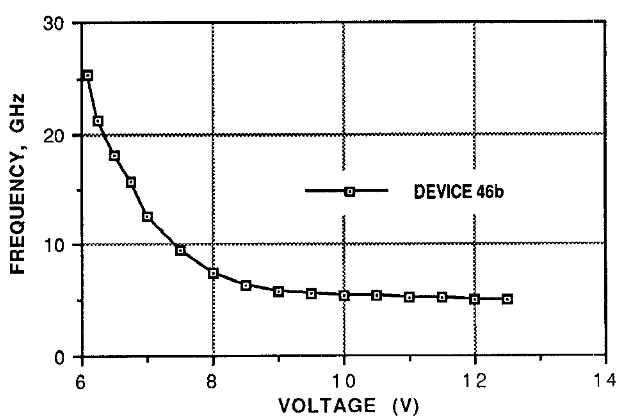
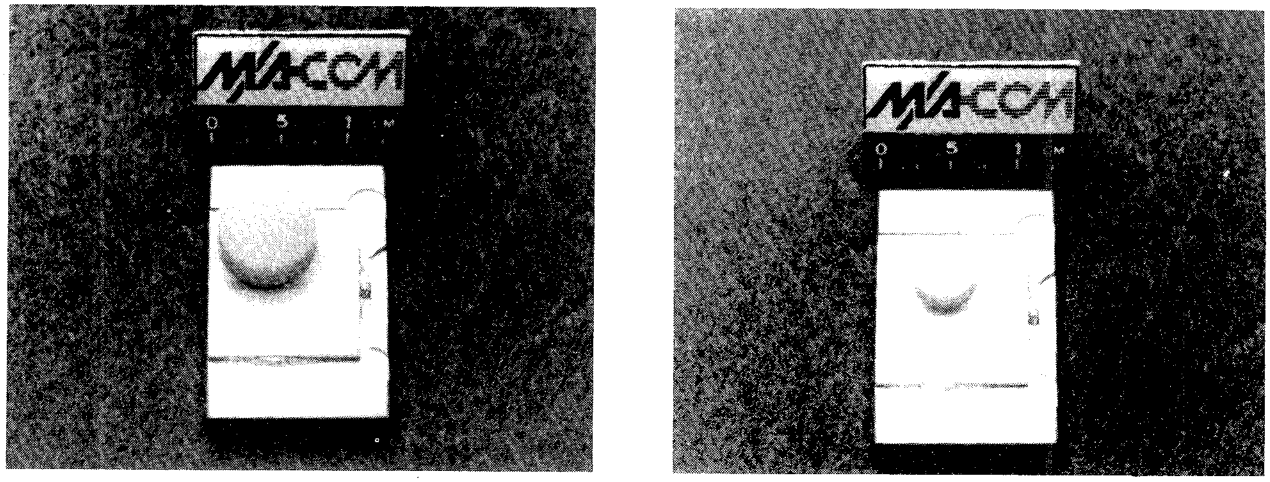
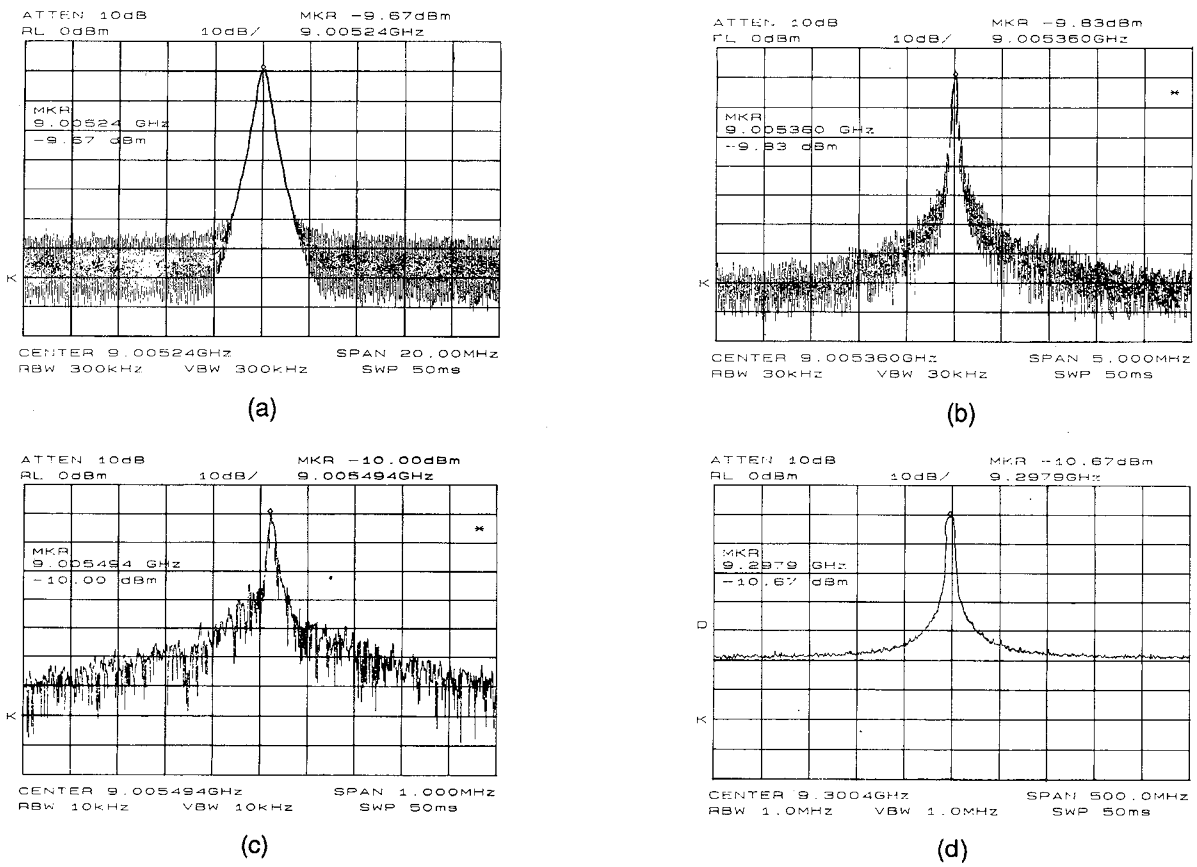


Fig. 3(b) Frequency vs. bias voltage exhibited by free-running VCOs utilizing FIBI Gunn devices with two consecutive linearly graded doping concentrations, device 46b



DIFFERENT DIELECTRIC RESONATOR DISC COUPLED TO TAPER LINE
OF GUNN OSCILLATOR CIRCUIT

FIGURE 4



SPECTRAL OUTPUT OF TUNABLE PLANAR GUNN DIODE USING MICROSTRIP TAPER LINE (a) WITH DIELECTRIC RESONATOR (D.R.),
SPAN 20 MHz (b) WITH D.R., SPAN 5 MHz (c) WITH D.R., SPAN 1 MHz (d)
FREE RUNNING WITHOUT D.R., SPAN 500MHz

FIGURE 5