circulators. No interstage matching is required between successive junctions.

The hardware derived from the basic design are depicted in Fig. 5; a summary of the circulator performance achieved is presented in Table I.

Summary

In summary, the design approach experimental results have been presented describing a rugged temperature-stable high-performance circulator design that has proved to be scalable. These circulators are being successfully utilized in the development of broad-band solid-state amplifiers.

References

[1] B. Owen and C. E. Barnes, "The compact turnstile circulator," *Digest of Technical Papers*, G-MTT 1970 International Microwave Symposium, pp. 388–392.

[2] J. Helszajn and F. C. Tan, "Design for radial-waveguide circulators using partial-height ferrite resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, p. 288, March 1975.

Varactor-Tuned Millimeter-Wave MIC Oscillator

DAVID RUBIN, MEMBER, IEEE

Abstract—**Varactor-tuned millimeter-wave MIC Gunn oscillators have been developed using packaged devices. A tuning range greater than 1 GHz was obtained in the 35-GHz range.**

I. Introduction

Recent papers have proven the feasibility of utilizing both Gunn [1] and IMPATT [2] diodes for millimeter-wave MIC oscillators. Wide-band varactor tuning has required unpackaged (low-parasitic) generating diodes. This has led to complications in the mounting of the small heat generating chips.

In this short paper, MIC oscillators using *packaged* Gunn diodes will be described. A varactor-tuned oscillator, operating in the 35-GHz region, had a tuning range in excess of 1 GHz. A graphical analysis will show the possibility of tuning ranges of 2–5 GHz.

II. Gunn Oscillator—Description

Fig. 1 is a diagram of a varactor-tuned microstrip-mounted Gunn oscillator. The Gunn diode is a commercially available 35-mW packaged device from Varian.[1] The varactor diode is in chip form, available from Alpha with gold ribbon leads attached.[2]

The oscillator operated in the region of 35 GHz; electronic tuning was over 1 GHz. The microstrip configuration includes a single-section quarter-wave edge-coupled filter, which acts as a low-loss dc block, and low-pass filters in both the Gunn and varactor lines to inhibit RF from being conducted along power supply lines. The oscillator is constructed on copper clad ($\frac{1}{2}$ oz) Duroid. This microfiber reinforced Teflon substrate has a dielectric constant of 2.3 and is approximately 0.010 in thick. The oscillator has an output power in excess of 5 mW over a gigahertz bandwidth, sufficient for many oscillator applications.

Manuscript received February 24, 1976; revised May 4, 1976.
The author is with the Naval Electronics Laboratory Center, San Diego, CA 92152.

[1] Varian VSA 9210.

[2] Alpha CVH 2045-96.

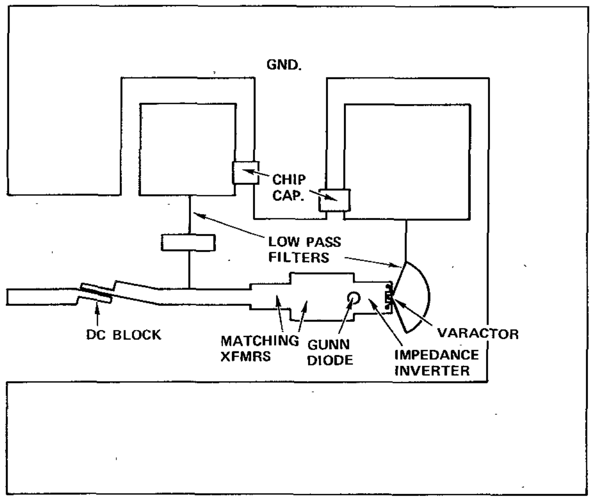

Fig. 1. Varactor-tuned microstrip oscillator.

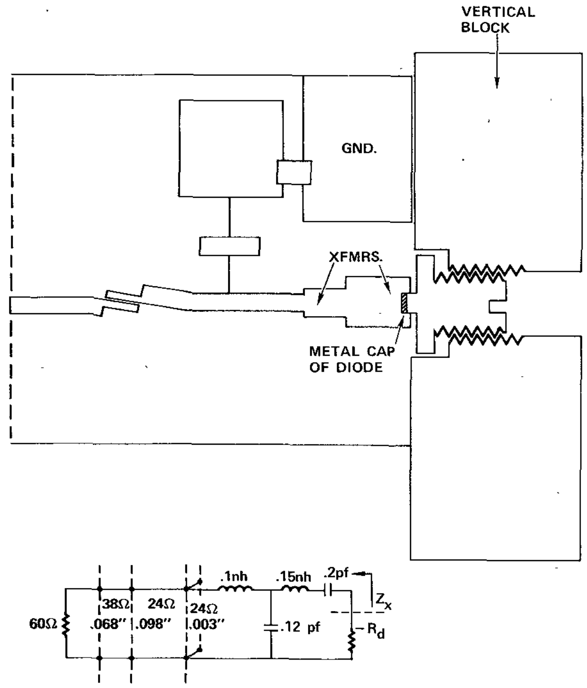

Fig. 2. Fixed-tuned microstrip oscillator. Last transformer section readily altered. Diode can be shifted slightly in position.

III. Gunn Oscillator—Design

Initially, a fixed-tuned microstrip oscillator was fabricated using a combination of experimental and analytical methods. Although a reasonable small-signal equivalent circuit of the packaged diode was available [3], the oscillator operated as a large-signal device, with a higher negative resistance and possible different dynamic capacitance, than given by the small-signal model. For the fixed-tuned oscillator, a series of various low impedance lines and matching quarter-wave transformers were constructed as in Fig. 2. The final lengths of these lines were easily altered by cutting. A Gunn diode, mounted slightly above and parallel to the line, made contact with the latter in various positions by screwing the diode heat sink more or less out of the block. In this manner, the small transmission line behind the short position was made to act as an open circuit capacitive stub, and a small amount of mechanical tuning was allowed. With very little experimentation, output powers of 30–40 mW were attained

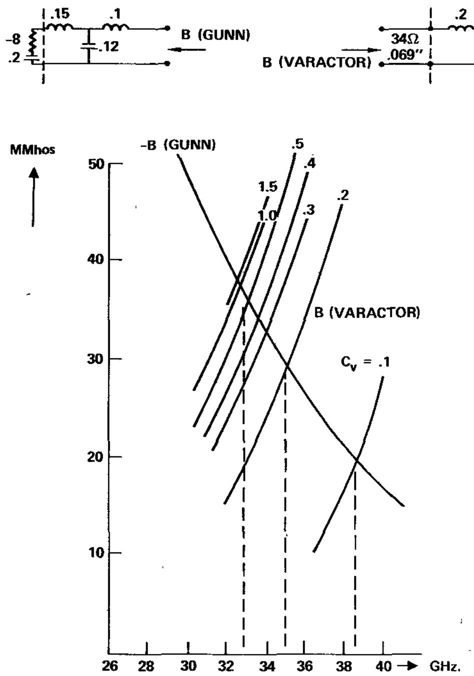

Fig. 3. Small-signal susceptance of Gunn diode and of ribbon leaded varactor diode with admittance inverter. Intersection of curves indicates theoretical resonance (with no additional components).

in the 38-GHz range. This was the same power that Varian obtained at 37.5 GHz using their standard waveguide mount. It was, therefore, apparent that experimentally a condition of approximate "best match" was obtained on microstrip. An equivalent circuit, neglecting discontinuities, is shown in Fig. 2. On the basis of this model, there are two frequencies within the 26–40-GHz range at which the impedance Z_x is purely resistive. At these frequencies (33.5 and 37.2 GHz) the circuit is capable of oscillating if the diode negative resistance can be made equal to the equivalent resistive load. It was possible to adjust the diode position and bias so that oscillations occurred at either 38 or 42 GHz, somewhat higher than predicted by the small-signal model.

In Fig. 3 a line is plotted showing the small-signal susceptance of the packaged Gunn diode. The package leads are responsible for a resonance somewhere below 26 GHz, above which the device appears inductive. In order to resonate the diode, it is necessary to provide a capacitive susceptance in parallel with the package. Varactor chip capacitors at millimeter-wave frequencies appear inductive when even the smallest bonding leads are used. To capacitively resonate the diode, an impedance inverter was used between the varactor bonding wire and the Gunn diode. The inverter consists of a quarter-wavelength distributed line, the impedance of which is optimized to give the largest frequency changes with change in varactor capacitance. In Fig. 3 the susceptance of varactor plus impedance inverter is plotted versus frequency for various values of varactor capacitance. The crossover points, where the susceptance is opposite and equal to that of the Gunn diode, represent the frequency of oscillation. This is true if the load appears resistive at the diode package when matched by the transformers. Varactor capacitance changes from 0.1 to 0.5 pF are within possibility representing a change of 5 GHz. More likely is a change between 0.2 and 0.5 pF, resulting in a 2-GHz change. Frequency-dependent matching components, such as the distributed transformers, may further decrease the tuning range.

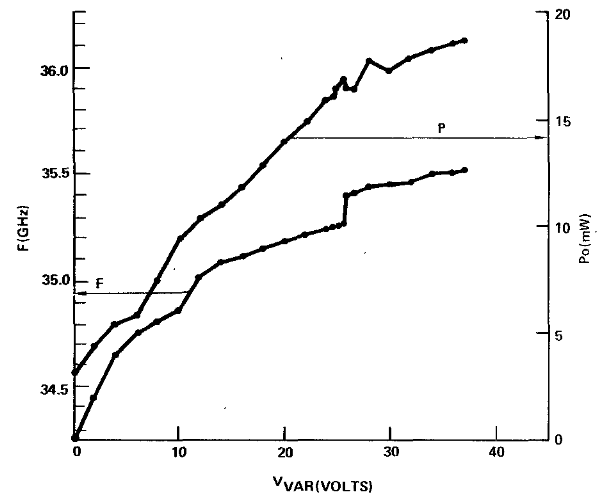

Fig. 4. Frequency and power output versus varactor reverse voltage.

Experimentally, as shown in Fig. 4, a 1.2-GHz tuning range was achieved near 35 GHz. With increasing bias voltage, the frequency increased. Since an increase in bias voltage on the varactor represents a decrease in capacitance, the admittance inverter functioned as described.

It should be apparent from Fig. 3 that if the external parasitic elements of the Gunn diode were reduced, the diode susceptance curve would tend to level, resulting in spreading of the crossover points and an increase in tuning range. This accounts for the fact that even at much lower frequencies wide-band solid-state oscillators almost all utilize unpackaged diodes.

IV. Conclusions

A millimeter-wave varactor-tuned Gunn oscillator was constructed on low-dielectric-constant microstrip. Output powers between 5 and 19 mW were obtained from a 40-mW diode over a 1-GHz bandwidth. It was shown how a 2–5-GHz bandwidth might be attainable using packaged diodes and how a further increase in tuning range would require diodes in chip form.

References

[1] B. Glance and W. Snell, Jr., "Low noise, integrated, millimeter wave receiver," *Bell System Technical Journal*, pp. 1321, 1328, Sept. 1974.
[2] E. J. Denlinger *et al.*, "Microstrip varactor-tuned millimeter wave IMPATT diode oscillator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 953–958, Dec. 1975.
[3] J. G. deKoning and R. E. Goldwasser, "A wide band, two-stage *Ka*-band Gunn effect amplifier," in 1974 Millimeter Wave Techniques Conf., Naval Electronics Laboratory Center, vol. 1, pp. A3-1–A3-13.

A Low-Noise Millimeter MIC Mixer

ALEXANDER J. KELLY, SENIOR MEMBER, IEEE, AND HERMAN C. OKEAN, FELLOW, IEEE

***Abstract*—This short paper describes a K_a-band integrated circuit mixer which, when integrated with a 2.5-dB-noise-figure IF amplifier, yields a 6-dB double-sideband noise figure over the band 36.5–38.5 GHz. A readily machinable low dielectric constant substrate has been utilized.**

Manuscript received February 2, 1976; revised May 10, 1976. This work was supported by the Naval Air Systems Command under Contract N00019-73-C-0250.

The authors are with LNR Communications, Inc., Hauppauge, NY 11787.