A Gunn Diode Based Surface Mount 77GHz Oscillator for Automotive Applications

Nigel Priestley, Keith Newsome, Ian Dale, Philip Norton

Marconi Applied Technologies, Lincoln, LN1 1SF, UK.

Abstract **— Gunn diode cavity oscillators are currently used in the majority of ACC 77GHz radar systems. These are bulky and normally require to be individually tuned. A substrate based voltage controlled oscillator has been developed, still using a Gunn diode; which has small size, is surface mount packaged and which retains the superior performance of a Gunn based oscillator over MMIC solutions. A good performance over temperature is achieved, due to the use of hot electron injection in the Gunn diode and the oscillator is voltage tuned by employing a varactor diode. The design, construction and performance are presented of a planar circuit based VCO which is suitable for high volume production.**

I. INTRODUCTION

The Gunn diode cavity Voltage Controlled Oscillator (VCO) has been the most favoured solution for high performance millimeter wave oscillators for many years. Over the last ten years, automotive radars in the 76 - 77GHz frequency range for adaptive cruise control (ACC) have put strong demands on the oscillator designer. The VCO must be manufacturable in quantities of thousands per month at low target cost, be as small as possible and work to a minimum performance specification. There are many good examples where this has been achieved in cavity VCO designs, but there is limited scope using this technique to gain further size reduction and remove the need for complex automatic production equipment in the assembly and tuning processes. For this reason we have departed from using a waveguide cavity and used a planar circuit instead.

This paper describes the patented design, realization and performance of a surface mount planar Gunn diode VCO for use in a 77GHz FMCW radar sensor. This represents a breakthrough for Gunn diode based VCOs and offers a solution where the key drivers of size, cost, performance and versatility may be satisfied simultaneously.

II. PLANAR VCO DESIGN

Initially an understanding of the operation of a waveguide VCO circuit was attempted. The usual arrangement was taken, Fig. 1, of a packaged Gunn diode on a heatsink with a small post above the diode package, a disc, a longer post connecting the disc and bias-line filter and finally the bias line filter itself.

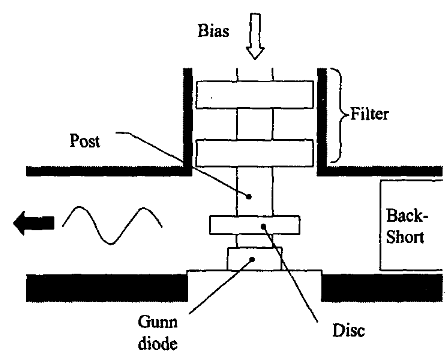

Fig. 1 Typical waveguide oscillator cross section

An equivalent circuit of the waveguide oscillator was drawn up and then entered into the circuit simulator, Ansoft Serenade. The results from this exercise were entirely consistent with expectations. A number of publications have specified the conditions for circuit controlled oscillations as:

1 Rdiode(f) + Rcircuit (f) = 0

2 Xdiode(f) + Xcircuit(f) = 0

Where R is the resistance and X the reactance of the respective element and f indicates the frequency. The serenade plot of this, Fig.2, shows how the circuit has two points (dotted) where the total phase including the diode capacitance is zero, satisfying condition 2. This occurs at 38 and 76GHz giving two potential oscillation points

Also at these points the circuit resistance is low (solid) and with a Gunn diode having a negative resistance of typically -2 or -3 ohms, oscillation will occur as this is greater than the circuit positive resistance.

0-7803-7239-5/02/$10.00 © 2002 IEEE

2002 IEEE MTT-S Digest

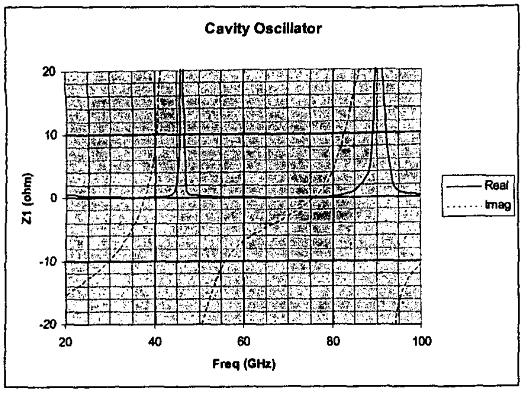

Fig. 2 Resistance and reactance as seen by diode in cavity oscillator

A varactor tuned Gunn diode VCO was chosen as the best configuration to use for the substrate based oscillator. Currently a number of cavity oscillator designs use bias pushing of the Gunn diode to sweep the oscillator frequency rather than to use a varactor. This places considerable demands on the Gunn diode design and more importantly, on the selection of suitable diode material which when used in the VCO meets the required performance specification. The rate of change of frequency with voltage, $^{dF}/_{dV}$, and the movement of this over temperature is critical to the overall performance of an ACC radar. Therefore it was decided to employ a varactor diode to tune the frequency output of the VCO. It is much easier to introduce a second microwave diode with a Gunn diode when both are chips in the planar design, than as a packaged device as used in a waveguide embodiment.

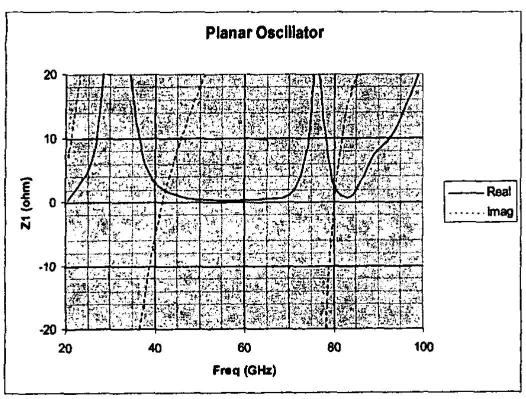

Fig.3 Resistance and reactance as seen by diode in planar oscillator

Ansoft serenade was used as the initial design tool for the substrate oscillator. Initially a simple L-C simulation was used to reproduce Fig 1 and this was then converted onto microstrip and optimized. Fig 3 shows that this design has the potential to provide oscillations at 42 and 80GHz.

Microstrip was chosen as the transmission medium for the oscillator circuit and fused silica as the substrate material. Previous component designs operating at 77GHz have used this route, for example the mm-wave front-end circuitry in an ACC radar sensor [3]. Fused silica has a dielectric constant, E_r =3.81, a dielectric loss Tan δ = 0.0004 at 30GHz and a coefficient of thermal expansion of 0.5 x 10^{-6} $^{o}K^{-1}$. It is readily available and is fully compatible with thin film processing.

A GaAs Gunn diode, with a graded AlGaAs injector, was selected as the millimeter wave power source so as to obtain good performance efficiency and the ability to operate over the broad temperature range that is required for automotive applications (-40°C to +85°C) [1], [2].

Thin film circuits were fabricated and the performance evaluated. At 80GHz the power produced was 5mW and it was found this was very dependent on the output match of the oscillator. However it was working as a second harmonic Gunn diode oscillator and achieved a respectable phase noise of -85dBc/Hz at 100KHz offset.

Further modifications to the circuit were made which resulted in improved performance and in particular an output power of >25mW. The schematic circuit design is shown in Fig.4. The circuit was designed to operate with a fixed positive voltage applied to the Gunn diode, and a variable positive voltage (0 to 5 volts) to the varactor diode to achieve a minimum of 300 MHz frequency tuning range.

A surface mount package was designed to provide the housing for the VCO circuit and to give excellent heat dissipation for the Gunn diode. The circuit is approximately 5mm x 7mm in size and features a microstrip launcher into a waveguide aperture in the base of the package. Gold plated copper was chosen for the base and the Gunn diode chip is mounted directly to this base which in turn is designed to be mounted directly with two screws to a metal housing which contains the rest of the radar module. A lid made from aluminum encloses the VCO circuit and naked semiconductor die and provides a hermetic package.

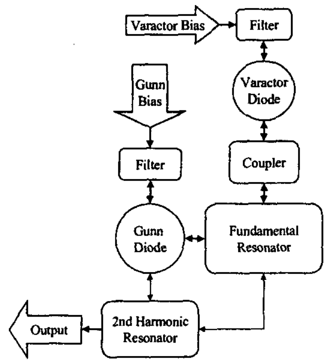

Fig. 4 Schematic Circuit Diagram

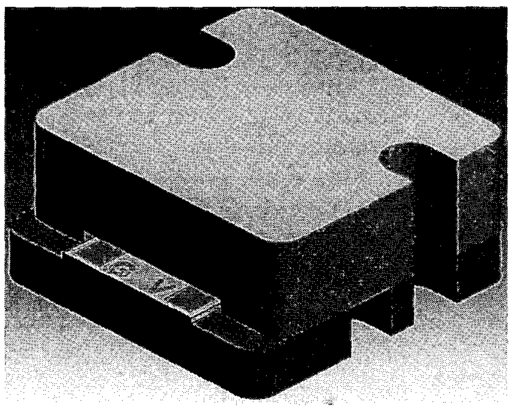

Fig. 5 Solid model illustration of VCO package. (WG output on lower surface)

III. COMPONENT CONSTRUCTION

The graded gap Gunn diodes were manufactured by Marconi Applied Technologies, incorporating an integral heat sink structure to ensure effective heat transfer directly to the base of the VCO package. The package for volume manufacture is fitted with ceramic feed-throughs and is capable of being hermetically sealed.

For the purposes of this work, the performance has been realized using the package shown in Fig. 5 & Fig. 6, which results in a WR12 output. However this concept is very easily adapted to provide the output in microstrip [4] which also may be configured to give two output ports; one for the transmitter and the other as a LO drive for a mixer.

Presently the Gunn diode is thermosonically mounted to the gold plated package floor; but alternative die mounting technologies are being developed including the use of solder eutectic. Epoxy is used to mount the varactor diode chip on to the floor of the package. Interconnection to the top contact on the Gunn diode is made using a solid gold Maltese cross structure which is bonded using a thermosonic wedge bonder. Gold wire is used to make a similar connection to the varactor.

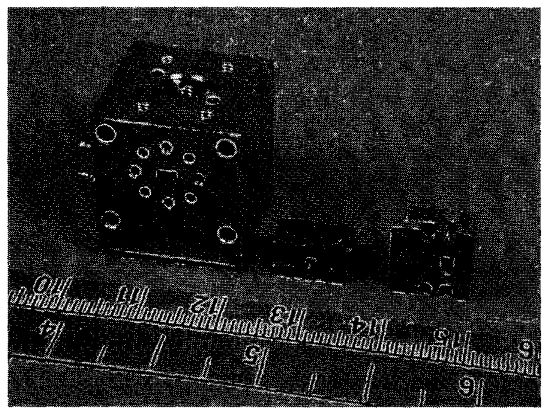

Fig. 6 Relative sizes, mm/inch, of VCO's. a) Cavity type, b) new VCO with microstrip output, c) new VCO with waveguide output.

TABLE 1

DESIGN SPECIFICATION COMPARISON WITH MEASURED RESULTS

Parameter	Target Specification	Performance Measured
Operating Temperature Range	-40 to +85 °C	-40 to +85 °C
Gunn Voltage	Fixed between +5 to +6 Volts	5.5 to 5.9 Volts
Varactor Bias Voltage	0 to +5 Volts	0 to + 5 Volts
Frequency Band	76.0 to 77.0 GHz	76.0 to 77.0
Frequency Tuning Range	> 300 MHz	300 to 1000 MHz
Output Power	> 25 mW (over temperature)	> 30 mW
FM Noise	< -80 dBc/Hz @ 100KHz offset	- 83 dBc/Hz @ 100KHz offset
Q	> 500	> 600
Size	15mm x 15mm x 5mm	Circuit 7mm x 5mm

IV. VCO PERFORMANCE

The VCO has been fully measured when feeding into a WR12 waveguide test bench. The center frequency, power, phase noise and frequency tuning range have been characterized over the operating temperature range of -40°C to +85°C. In most cases the measured performance exceeded the original target specification, and was achieved after manual tuning of the circuit; this has now been automated using a laser trimming system. A summary of the target design specification is shown in Table 1 along with a comparison of the results achieved to date.

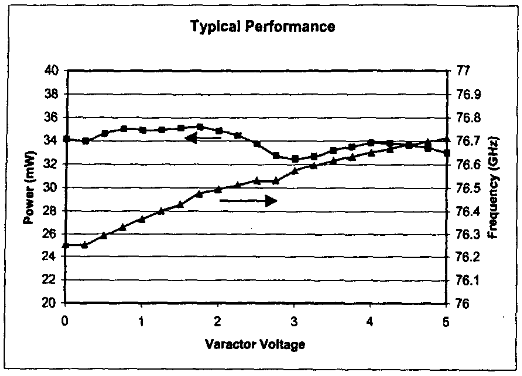

Fig. 7 Typical variation of output power and frequency with varactor bias voltage

A feature of the design is the flexibility offered with respect to the tuning range and associated varactor voltage. A tuning range up to 1 GHz can be obtained by using appropriate diodes, hence a high or low tuning range can be achieved to suit the radar system requirements.

Typical output power / frequency tuning curves and frequency with temperature curves are shown in Fig. 7 & Fig. 8.

The VCO has been successfully demonstrated within an FMCW ACC radar system where the system target parameters were met. In this application it replaced a cavity based Gunn diode oscillator

V. CONCLUSION

The challenge to move away from the usual cavity based Gunn diode source at 77GHz and opt for a planar surface

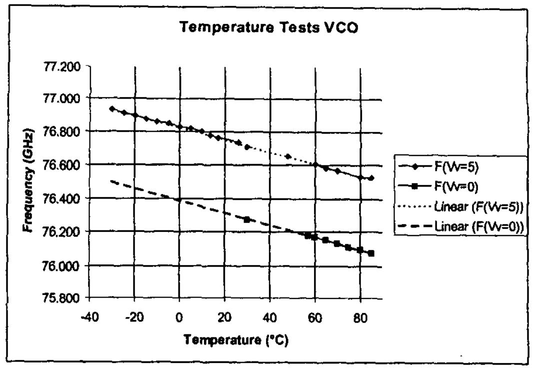

Fig. 8 Temperature variation of frequency F, with Varactor bias voltages Vv of 5V and 0V.

mount VCO has been met. The measured performance of VCOs made in production was comparable to cavity Gunn diode VCOs being made for current applications in ACC systems. Currently a second harmonic circuit design has been used but higher orders may be selected to serve higher frequency applications.

ACKNOWLEDGEMENT

The authors wish to acknowledge the work of the Marconi Applied Technologies semiconductor processing group for providing the Gunn varactor diodes, and thin film circuits.

REFERENCES

[1] N. R. Couch, H. Spooner, P. H. Beton, M. J. Kelly, M. E. Lee, P. K. Rees, and T. M. Kerr, "High-Performance, Graded AlGaAs Injector, GaAs Gunn Diodes at 94 GHz.", *IEEE Electron Device Letters.*, vol. 10, no. 7, pp. 288-290, July 1989.

[2] I. Dale, J. Stephens, and J. Bird, "Fundamental mode graded gap Gunn operation at 77 and 84 GHz," Microwaves 1994 Conference Proceedings, October 1994, London, p 248

[3] S. Redfern, C. Oxley, D. Dawson, J. Bird, G. Hilder, B. Prime, T. Brown, and D. Spencer, "An automotive 77GHz radar system designed for volume manufacture," Microwave Engineering Europe, pp. 29-33, December 1999 / January 2000

[4] T. Okumichi, S. Tomie and M. Fuji, "Development of Millimeter-wave Package for W-Band," 28th European Microwave Conference Proceedings, 1998 Vol 2, pp 135-140