MONOLITHIC 38GHz DIELECTRIC RESONATOR OSCILLATOR

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ABSTRACT

A 38GHz monolithic DRO incorporating a 0.3micron HEMT has been designed, using a small-signal design procedure. Following fabrication in-house, ten DROs have been tested, seven of which were found to be fully working at RF and gave ouput powers up to 0dBm. The temperature coefficient of the frequency of oscillation was -2.1ppm/°C and the phase noise was -68dBc/Hz @ 100kHz from carrier. The DRO is potentially inexpensive in high volume and suitable for a local oscillator in a broadband telecommunications system.

INTRODUCTION

A local oscillator was required for a 40GHz receiver downconverter in a broadband distribution system. As these downconverters are sited at domestic premises, this is a potential high volume application and must be affordable. The design requirements were;

- fo=38GHz.
- Output power >0dBm, i.e. sufficient to drive a HEMT mixer or a biased diode mixer.
- Frequency stability within ±3.5ppm/°C.
- Moderate phase noise (broadband systems are not unduly sensitive to phase noise).
- Easily manufacturable.
- Potential for low cost in volume production.
- Lightweight.
- Small size.

The most suitable type of oscillator to fulfil these requirements is a dielectric resonator oscillator (DRO). The dielectric resonator (DR) has typical dimensions of 0.8mm height x 2mm diameter at this frequency and so can be seen to meet the last two listed requirements easily. The DR can also be low cost in volume production if it is cast and does not require subsequent machining.

The resonator is a crucial DRO component and when coupled to a microstrip line it also has the necessary properties to assist in meeting the other performance requirements:

- it will provide the necessary reflection coefficient to ensure oscillation at 38GHz;

- an impurity deliberately introduced into the DR will give a positive temperature coefficient (TC) to partly nullify the negative TC of the active device and therefore improve the frequency stability;

- the DR increases the Q of the oscillator compared with varactor tuning or transmission line resonators, hence reducing the phase noise to the moderate levels required.

Previous work [1] has demonstrated the feasibilty of a FET DRO at 27.6GHz and this paper explores the feasibility of a similar DRO at 38GHz and above.

Simultaneously with the increase in frequency from 27.6GHz to 38GHz, it was a decided to move from a hybrid implementation to a GaAs microwave monolithic integrated circuit (MMIC). This will provide the following benefits: the potential for low cost in high volume; and a higher yield than hybrid techniques due to the reduced variability in components and their placement. Although MESFETs have been found to give adequate gain up to 30GHz, it was decided to incorporate a high electron mobility transistor (HEMT) to ensure adequate performance up to and beyond 40GHz.

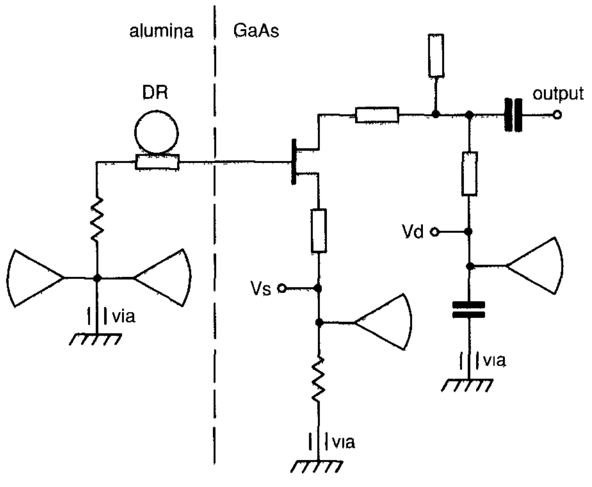

Figure 1 Circuit diagram of DRO

DESIGN OF 38GHz MONOLITHIC DRO

The topology chosen is that of a series feedback reflection stabilised DRO, and the circuit is given in Figure 1. The resonator circuit includes a terminated microstrip line of several millimetres length. This is more economically fabricated on alumina, due to the relatively high cost of GaAs real estate, hence the division of circuitry between the two substrates as shown.

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The design sequence closely followed previous work [1] at 27.6GHz. Firstly, on-wafer measurements provided data to derive a small-signal model for the 0.3micron x 75micron HEMT. This model was then used in the design procedure. The presentation page displayed by the CAD program is shown in Figure 2, and reference to this will confirm that it was possible to meet the design rules for stable oscillations at 38GHz, as listed in [1].

	input	input
FREQ	MAG_RHOr	PHASE_RHOr
38.00E+09	0.975	-179.493

HEMT	HEMT	HEMT	HEMT	output	output
mag(1/s11)	phase(1/s11)	Rfet	Xfet	Rop	Xop
0.320	179.510	-38.108	-113.688	9.421	115.671

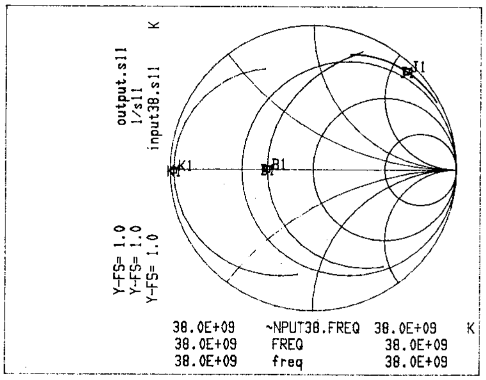

Figure 2 Results display from CAD program

For example, at the resonator/HEMT interface,

> the magnitude of 1/(reflection coefficient) for the HEMT is less than the reflection coefficient for the resonator, and the angles are equal at 38GHz,

and at the HEMT/output matching circuit interface,

> the output circuit provides a conjugate impedance match (at 38GHz) to the impedance at the HEMT drain, where the real part is assumed to be a third of the modulus of the negative resistance.

The chip layout is shown in Figure 3. The overall size is 1.25mm x 1.25mm. Features include:

- a 0.3micron x 75micron dual-fingered HEMT,
- two MIM capacitors,
- two through-substrate vias,
- one implanted resistor for self bias,
- two bias filters using radial line stubs.

FABRICATION

The GaAs process includes the following features:

- Starting material incorporating HEMT layers grown by MBE.
- Gate of dimensions 0.3micron by 75microns defined by E-beam direct write.
- Monolithic resistors using the as-grown epitaxial layers.
- MIM capacitors using a SiN_2 dielectric.

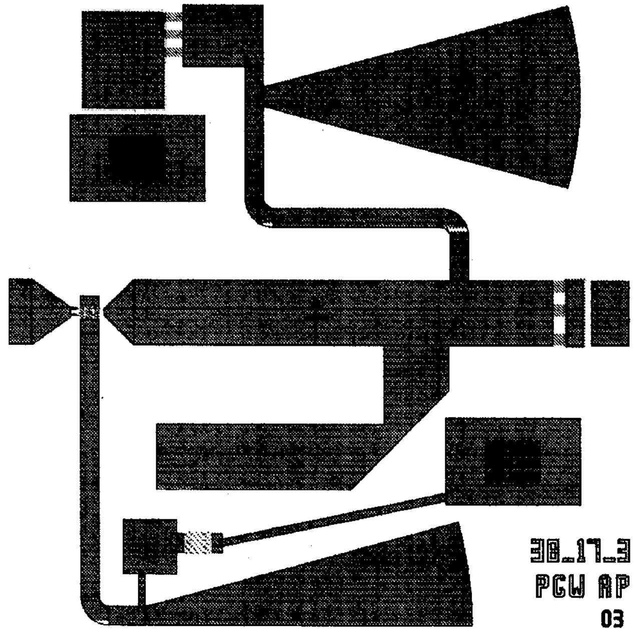

Figure 3 Oscillator chip layout

- Au-plated transmission lines.
- SiN_2 passivated components.

A copper-on-alumina interconnect substrate provides two functions: a 50ohm track from the chip output to the connector or mixer chip; and a 50ohm line terminated in a 50ohm thick film resistor and radial line stubs. This chip is dropped into a laser-cut hole in the alumina and both are tested in the housing shown in Figure 4. The cavity, formed in the lid, has dimensions to prevent box modes below 40GHz. The dielectric resonator is fabricated from Murata E-type material with a dielectric constant of 24.2.

Three measures have been taken to reduce the potential cost in high-volume manufacture:

- Use of a HEMT process close to those presently available from many foundries.
- The chip area has been carefully minimised during the design phase.
- The copper-on-alumina interconnect substrate is lower cost when compared with thin-film gold, and yet out-performs thin-film for a simple circuit such as a terminated microstrip line.

In addition the use of self bias will remove the need for a negative supply and reduce the complexity and cost of the power supply in the final receiver.

RESULTS

Ten oscillator chips were tested, of which seven were found to work fully at RF with an output power that can be increased from -7dBm to 0dBm, as the drain voltage is increased from 2.75V.

Phase noise at 100kHz from carrier was -68dBc/Hz. The methods of decreasing the phase noise produced by the HEMT were considered. One method is to increase the loaded Q of the resonator and this was investigated experimentally. The DR must be tightly coupled to the microstrip line to ensure oscillation and in these circumstances the external Q factor dominates over the dielectric Q of the DR, in the formula for loaded Q of the resonator circuit. This situation was found to have two consequences. Firstly, there was little scope to increase the external Q factor (and hence the loaded Q factor) by increasing the line to DR spacing. Secondly, increasing the dielectric Q by using a less lossy dielectric material for the DR had little effect on the loaded Q.

When temperature cycled from -20 to +40°C with a DR of TC=+4ppm/°C, the DRO exhibited a TC of -2.1ppm/°C, as plotted in Figure 5.

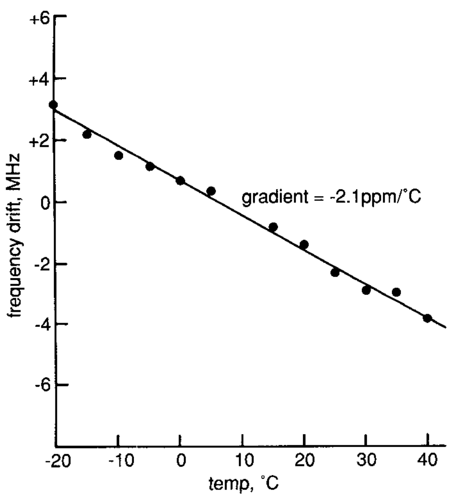

Figure 5 Temperature stability

Non-linear simulations have been carried out on the Microwave Non-linear Simulator part of the HP MDS™, predicting an output power of -8dBm with the drain voltage set to 2.75V. The frequency of steady-state oscillations is only 100MHz lower than the design frequency, of particular significance as the design procedure used *small-signal* scattering parameters.

APPLICATIONS

Transmitter sources and receiver local oscillators and LOs for broadband radio systems generally require moderately low phase noise, and a temperature stability of the order of 10 to 30ppm. This DRO (if followed by an amplifier) can therefore be used for this application. Narrowband systems, however will require higher frequency stability and lower phase noise in both transmitter and receiver.

In summary, the application for this DRO can be seen in the following table:

Method	**Feature**	**Application**
DRO	Limited freq. Limited power	LO for broadband (sensitive mixer)
DRO+amplifier	High power Limited freq.	Tx for broadband Higher power LO
Sub-harmonic DRO +multiplier	High frequency	LO for broadband
Sub-harmonic DRO +subharmonic mixer	Low cost sub-system Lossy	Upconverter in broadband systems
Harmonic Oscillator +amplifier	High frequency	LO for broadband
PLL+multiplier	High frequency Low phase noise High stability	LO and Tx for narrowband

FURTHER DEVELOPMENT OF THE DRO

The output power can be increased by using active devices with a higher gain and a wider gate.

As experiments have shown, the most promising opportunity for a further reduction in the phase noise of this free-running DRO at 38GHz lies in reducing the 1/f noise produced by the device. This involves a careful investigation into the physical origins of the noise, and optimisation of the features that exacerbate the low frequency noise in the HEMT.

It may be possible to extend this design to 60GHz with devices cabable of adequate gain, e.g. pseudomorphic HEMTs. However, the external Q factor of the resonator circuit will probably be lower leading to higher phase noise and lower output power.

CONCLUSIONS

A monolithic 38GHz DRO has been designed, fabricated and successfully tested, further verifying a previously published design method using a small-signal model and a linear CAD program. Output powers up to 0dBm were obtained, and the output power predicted by a non-linear simulation program is close to that measured. The monolithic DRO is easily manufacturable at low cost in high volume, and is suitable for use as a LO in broadband telecommunication systems. The alternative configurations for other applications have been discussed.

REFERENCES

[1] P G Wilson and R D Carver, "An easy-to-use FET DRO design procedure suited to most CAD programs", IEEE MTT-S International Microwave Symposium Digest, pp1033-1036, 1989

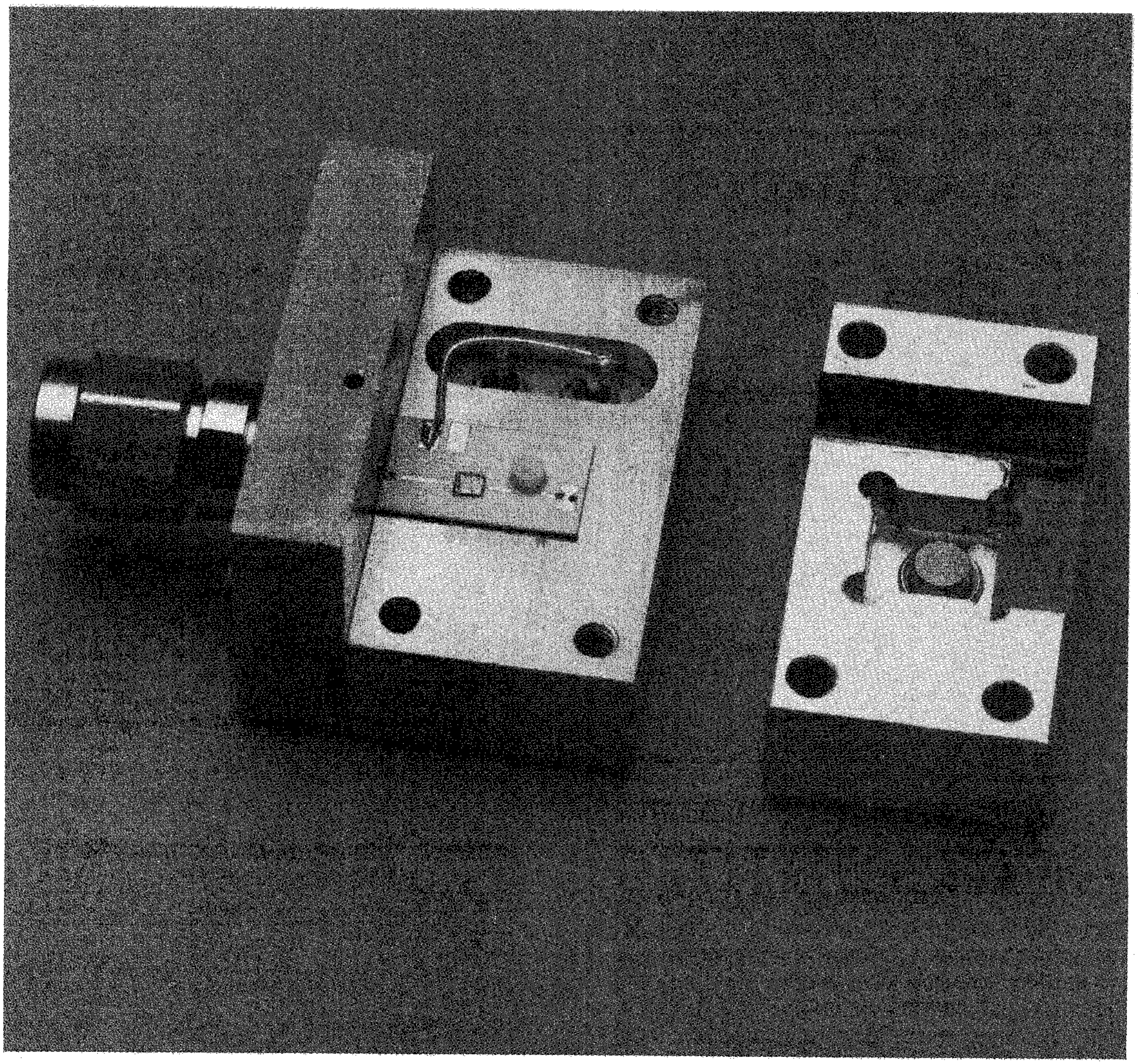

Figure 4 Photograph of monolithic DRO in test housing