THE DIELECTRIC RESONATOR POWER COMBINER OSCILLATOR: A NEW DESIGN FOR MICRO- OR MILLIMETER-WAVE DEVELOPMENT

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ABSTRACT

Field effect type transistor oscillators are formed on the surface of a shielded rectangular dielectric resonator and synchronised via the dielectric LSM-mode resonance. Their combined outputs are coupled via a monolithic-compatible structure into a standard output line or guide. Measured DC-to-RF conversion efficiencies up to 35% validate the new concepts and design method.

INTRODUCTION

A completely new approach to the design of a dielectric resonator oscillator (DRO) is to build the oscillator circuit on the surface of a rectangular dielectric resonator (DR) and couple the output through the resonator to a standard line or guide that feeds the load. More than one oscillator may be formed on the surface of the resonator and coupled to it so that they synchronise at the resonant frequency and power combine in the load as illustrated in Figure 1. This is in contrast to the conventional DRO that adds the resonator to the oscillator circuit as a lumped element at microwave frequencies rather than using it as the foundation for forming an integrated assembly. Not only is a synchronisation and power combining function added to those that may be performed by the DR but the new combination of concepts that form what is a planar design may be exploited to produce oscillators at any frequency in the microwave and millimeter wave bands using appropriate technology (hybrid or monolithic) and materials. Furthermore, designs may be executed with performance objectives as diverse as, maximum conversion efficiency power combined output for one application, or low phase noise output for another.

The research presented here is proof of concept work and the test results that are for hybrid microwave assemblies, designed to produce maximum DC to RF conversion efficiency power output, validate both the concepts and the design methods that have been developed. This may be regarded as a solution to the design impasse [1] for grid oscillators due to the effects of surface waves in the substrate used in those oscillator arrays once it becomes electrically thick at millimeter wave frequencies.

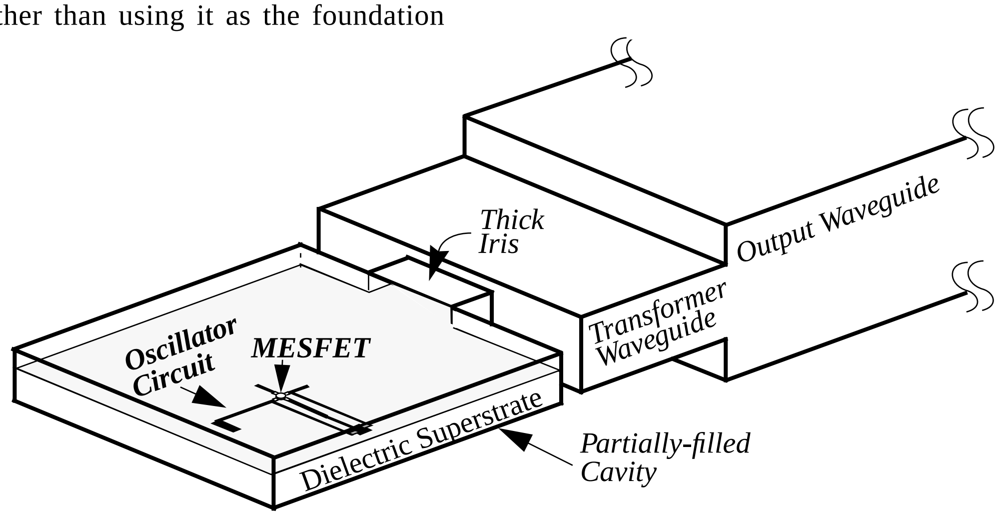

Figure 1. Outline view of substrate mode power combiner with standard air filled rectangular waveguide output (only one of an array of oscillators in the cavity is shown).

EFFICIENT POWER OUTPUT DESIGN

A dielectric resonator power combiner oscillator designed as an efficient power source is shown in outline in Figure 1. It is a planar integrated assembly within a metal package that forms the walls that enclose the dielectric resonator, the coupling iris and the air-filled output waveguide. The components that form the integrated assembly perform distinctly different functions and require separate design treatment as summarised below.

MESFET oscillators are formed on the surface of a high dielectric constant rectangular slab that may be gallium arsenide in the case of monolithic fabrication. The dielectric slab within the metal cavity can be analysed as a length of rectangular cross-section waveguide that is partially filled by the dielectric material. The normal modes of propagation are longitudinal section magnetic (LSM) and longitudinal section electric (LSE) [2] with the LSM modes of direct relevance to the design of an oscillator. Metal walls at each end of the length of waveguide turns it into a resonator with properties that can be calculated accurately. Figure 2 illustrates the way in which as many as four oscillators may be combined by a DR designed to be a LSM_{303} resonator at the oscillation frequency. The LSM mode has electric field components in all three cartesian directions in the dielectric. The electric field at the surface of the slab shown in Figure 2 must be calculated accurately so that the metal strips and the transistors that form each oscillator can be positioned precisely. A circuit with series feedback at the source is chosen so that, with the transistor at a position of zero surface electric field, the metal strips connected to the electrodes cross the field at right angles as shown in Figure 2. Thus the oscillators are not coupled to the DR except through a probe strip at the end of a phasing line from the transistor drain. This strip is the oscillator load. The top wall of the cavity, separated from the DR by an air space, acts as the ground plane for all of the metal strips that form the oscillator circuits. They are designed as lengths of quasi-TEM mode shielded inverted microstrip transmission line with the dielectric slab acting as a shielded superstrate. This TEM mode is separate from the LSM mode. Established oscillator design procedures can be used depending upon which transistor parameters are known, i.e., either small or large signal.

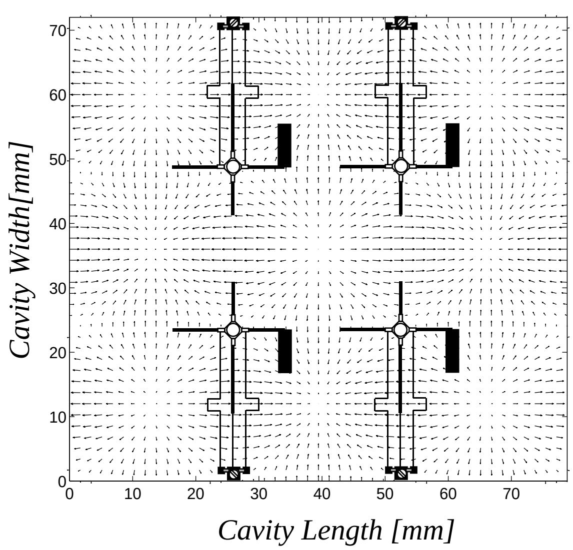

Figure 2. The required placement of oscillator circuits in the electric field on the surface of the dielectric slab for a LSM_{303} resonance.

The dielectric resonator with an air space above it is assumed to be fully enclosed by the metal walls of the cavity except at the input plane of the thick iris output coupling structure. This structure is needed to provide overcoupling of the load (coupling factor, $\beta > 1$) so that power lost in the DR is small compared with that fed to the load. The boundary conditions, together with the equivalent current representation of the oscillator probe strips, allow refinement of the design of the LSM mode resonance in terms of physical dimensions, oscillation frequency, coupling factor of the load and the surface electric field distribution for positioning the oscillator circuits and designing the oscillator output coupling probe for correct oscillator loading.

The thick iris output coupling structure of Figure 1 is a short length of rectangular metal pipe coaxial with the cavity and partially dielectric filled in the same height proportions but only one third as wide so that the LSM_{10} mode propagates through it with the same cutoff frequency as the LSM_{30} mode in the DR. Mode matching analysis of the junction at each end of this thick iris together with evaluation of the reaction parameters between the two junctions yields an admittance at the junction with the DR. From this analysis a correction to the DR resonant frequency follows and the coupling factor to the load is easily

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derived. The coupling factor can be altered by changing the thickness of the iris, i.e. the length of LSM_{10} mode waveguide, and also the height of the transformer waveguide shown in Figure 1, to optimise the oscillator DC to RF conversion efficiency from particular transistors and construction materials.

VALIDATION TESTING

A single transistor oscillator on the surface of a LSM_{303} mode DR was designed following the procedure summarised above and the design software developed for each component. Details of the oscillator circuit layout and the dimensions of the DR and thick iris dielectric filling are shown in Figure 3. The output spectrum for this oscillator, conservatively biased, is shown in Figure 4(a) and plots of the power output and DC to RF conversion efficiency as a function of drain voltage are shown in Figures 4(b) and (c). The design was executed with the small-signal S-parameters for the transistor which is an inexpensive MESFET. The test frequency is within one percent of the design value and the maximum efficiency is 35%. This is an excellent result that validates the concepts and accuracy of the design methods that have been developed.

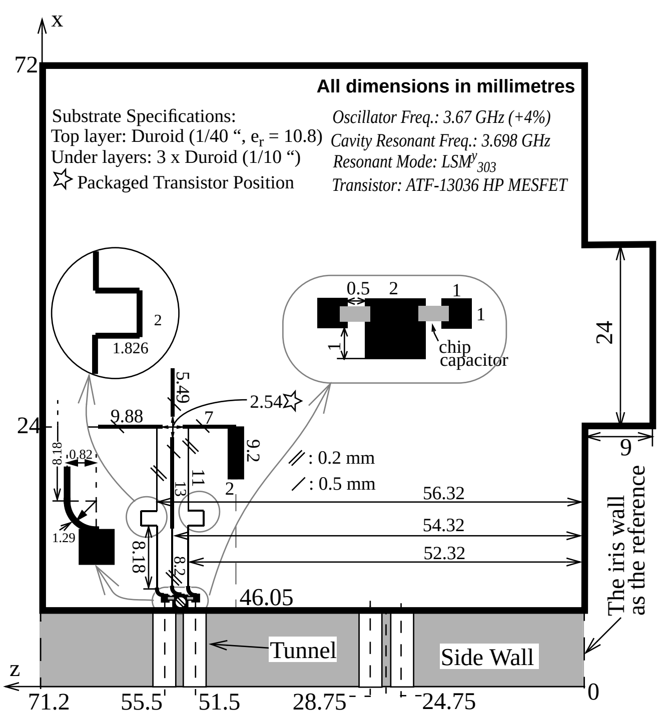
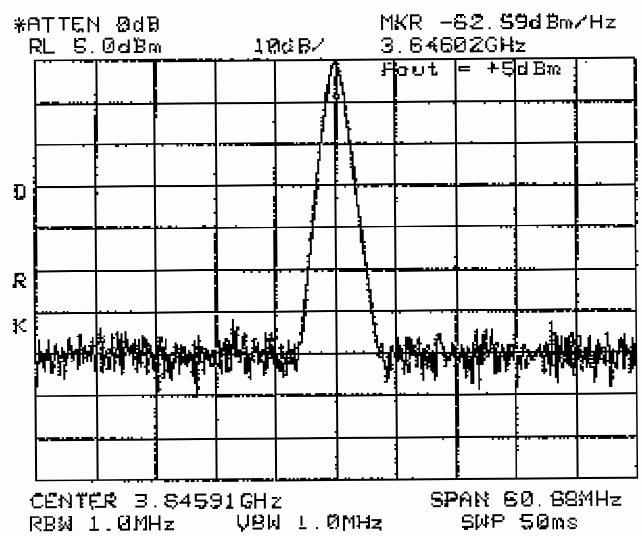
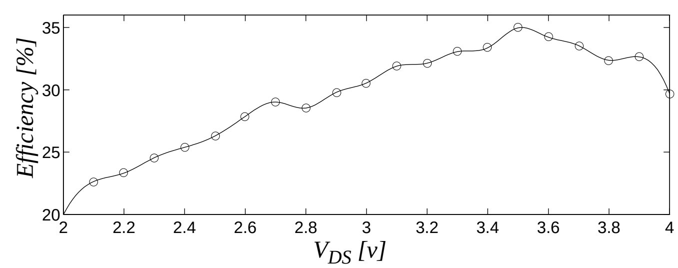


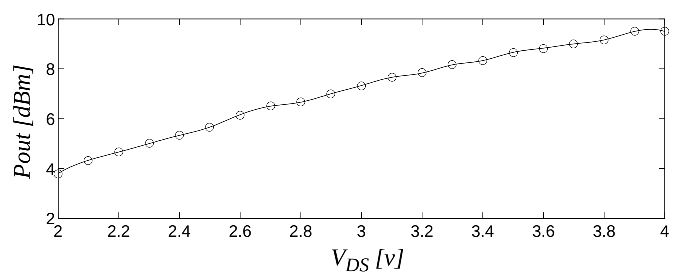
Figure 3. Dielectric resonator and thick iris layout for single transistor oscillator



(a) Spectrum for $V_{DS} = 2.44$ V, $I_D = 5$ mA and external $V_{GS} = 0$.



(b) DC to RF Conversion Efficiency as a Function of Drain



(c) Measured Output Power as a Function of Drain Voltage

Figure 4. Measured output spectrum, efficiency and power for the oscillator design shown in Figure 3 .

Two transistor oscillators on the surface of a LSM_{303} mode DR when tested gave comparable results for frequency and efficiency. The LSM_{303} mode DR has provision for separately biasing each oscillator. Comparison of results for individual and simultaneous operation clearly demonstrated the synchronisation and power combining effects produced by the direct interconnection of the oscillators through the DR. The design optimises power output for the case where both oscillators are operating and as a consequence it is 7 to 8 dB greater than the power output when only one of the oscillators is operating. Synchronisation and correct phasing is due to the direct connection of the oscillators to the DR and the high level injection locking that results. Injection locking analysis is only valid for loosely connected oscillators [3] and cannot be used here. In all cases of directly interconnected oscillators synchronisation design is possible by means of load pulling analysis with the aid of a Rieke diagram representation of each oscillator and the DR [4].

LOW PHASE NOISE DESIGN

The design method for low phase noise is similar to that set out above but the targets for oscillator circuit, DR and output coupling are different if minimum phase noise is to be achieved with the available materials including the transistors to be used. The design trade-offs set out in reference [5] are relevant when applied to the MESFETs or HEMTs favoured in this DRO work.

PROSPECTIVE APPLICATIONS

Power oscillators may be designed with heat sinking metal posts placed beneath each transistor through the dielectric slab because the electric field of the desired LSM resonance is zero at these locations. Because the posts will tend to suppress unwanted resonant modes relatively large arrays may be designed. A limit to the number of oscillators in an array for power generation is imposed by the quality of the materials used in fabricating the DR because this affects the unloaded Q and the maximum coupling, given that there is a minimum value of loaded Q below which moding may occur. Larger arrays are possible without moding than appear practical in a Kurokawa type resonant combiner because this design involves narrowband oscillators whereas Kurokawa assumed wideband negative resistors.

Note that the externally applied gate-to-source voltage in Figure 4(a) is zero. Under oscillating conditions gate current flows at the peak of the gate voltage swing and self bias develops. Together with the DRO functioning as a tank circuit the potential exists for the oscillator to be designed to operate as a classical class C type oscillator [6]. However details of the nonlinear large signal characteristics of the transistor including those for a positive gate under dynamic conditions at the proposed oscillation frequency are needed. Efficiencies well over 50% may be realised.

Millimeter wave DRO power combiners may be designed. For operation at 100 GHz a gallium arsenide DR would be about 300 microns thick and therefore physically strong enough to have sufficient area to accommodate several oscillators as a monolithic millimeter-wave integrated circuit DRO.

ACKNOWLEDGEMENT

Australian Research Council funding for this research is gratefully acknowledged.

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