# THE DESIGN OF POWER COMBINED OSCILLATORS SUITABLE FOR MILLIMETRE-WAVE DEVELOPMENT

by

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# Abstract

The development of transistors with useful gain at frequencies up to 100 GHz has created prospects for more efficient power sources at millimetre wave wavelengths than those that are currently available using IMPATT or Gunn diodes. The power handling capability of all solid state devices that need to be physically small compared with the operating wavelength decreases with increasing frequency. For many systems applications, designed to operate in the millimetre wave part of the electromagnetic spectrum, power combined arrays of oscillators are needed to satisfy power source requirements. The research presented in this thesis addresses the problem of designing power sources for operation at millimetre wavelengths using transistors and distributed circuit elements that are all fabricated as a monolithic millimetre wave integrated circuit (MMIC) that is compatible with the physical constraints of current semiconductor materials technology and foundry practice.

Monolithic fabrication appears to be the only cost-effective way to make arrays of extremely small components. It is assumed in this research that the MMICs, on what are relatively fragile gallium arsenide (GaAs) or indium phosphide (InP) substrates, need to be at least 200 microns thick to be physically strong enough to be processed without excessive breakage rates. At 100 GHz the MMIC substrate will be electrically thick (thickness divided by wavelength in the dielectric near 0.25). In this thesis a completely new design for power combined transistor oscillator arrays on electrically thick MMICs is presented.

A review of both diode and transistor oscillator designs, including those that have been claimed to have prospects for monolithic fabrication as arrays at millimetre wave frequencies, reveals the designs that have been investigated in the past and the problems that have been encountered. The problems that arise are due to excitation of surface wave modes in thick substrates on the one hand or the increased losses and extreme fragility of very thin wafers or chips (50 microns or less) on the other.

The main concepts that form the basis of a new design include treating the MMIC rectangular substrate as a dielectric resonator with the transistor oscillators on the surface designed as shielded inverted microstrip component assemblies. The substrate partially fills a closed rectangular metal box. The air gap between the lid, and the surface of the substrate supports the quasi-TEM fields of the inverted microstrip oscillator components. The resonant mode of the partially filled cavity is energised by the output from each oscillator and the combined power output is fed to a load via a coupling structure in one wall of the resonator that is designed to be compatible with the constraints of monolithic fabrication. The transistor oscillators are positioned on the substrate surface so that only the output of each oscillator is coupled to the resonator although feedback within the oscillator circuit via the resonator can be designed.

Analytical methods for solving all of the design problems associated with this new combination of concepts are presented in detail. They include the design of transistor oscillators in shielded inverted microstrip, positioning of oscillator circuits on the surface of a large rectangular dielectric resonator, coupling between the oscillators and the longitudinal section magnetic (LSM) mode in the dielectric resonator and coupling combined power from the resonator into an output waveguide or radiating aperture.

The validity and accuracy of the overall design has been tested. The tests have been conducted on accurately scaled-up models that use packaged transistors in hybrid-type assemblies rather than monolithic assemblies. Technology and resource constraints that apply to most research efforts in this area of work, as revealed in the review, have forced most designers into scale model testing at microwave frequencies. Power combined outputs with good efficiency and spectrum characteristics have been demonstrated. It is concluded that this new design for power combined oscillators offers a means of creating millimetre wave power sources of significance for systems applications.