THERMOSTABLE STRIPLINE LUMPED ELEMENT CIRCULATOR FOR UHF APPLICATIONS

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ABSTRACT

The paper reports on the design features and development of thermostable stripline lumped element circulator operating in the above resonance mode. Improvements in insertion loss and temperature stability were achieved by virtue of a new integral topology for the conductors' crossover and a novel arrangement of the dc magnetic circuit. Circulator prototypes demonstrated excellent performance in the frequency range 70-400 MHz.

INTRODUCTION

Stripline lumped element circulators have been in use for more than 30 years [1] but are still challenging designers and manufacturers. The problems of thermal stability, low insertion loss, power handling capability and size remain at the focus of recent developments [2,3].

Objective of this work was to develop a low loss thermostable circulator with a power rating over 200W for operating in the UHF band.

The implementation of such a device is associated with various conflicting requirements to the physical layout. For example, circulator thermal stability crucially depends upon the efficiency of heat sink from ferrites, known as poor thermal conductors. However ferrite elements are normally enclosed in a dc magnetic circuit which obstructs heat transfer. Massive ground conductors adjacent to the ferrite surfaces might mitigate the latter problem but would upset uniformity of the biasing magnetic field and complicate locating and bonding the driving lines to ground. On the other hand, optimisation of the circulator layout is seriously limited by the constraints of the available theoretical models employed for analysis of lumped element circulators [1,4]. Although rigorous simulation looks an enormously difficult task, the equivalent network models [1,4] predict only qualitative behaviour of a 3-port ferrite junction and barely allow subtle effects of various topological factors to be evaluated.

This paper addresses to the aforementioned problems and offers some new solutions. The concepts presented in the paper were successfully applied to designing low loss medium power circulators [5].

RESULTS

In a view of the objective of this work, both the arrangement of the dc magnetic circuit and the layout of the RF network were thoroughly reviewed.

1. *Magnetic circuit.* It was experimentally observed that insertion loss in circulator critically depends on the uniformity and vertical alignment of the internal dc magnetic field in ferrite disks [6]. Therefore it seemed desirable to position the magnet as close as possible to the ferrite, in

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order to diminish the effects of the demagnetising field [7]. However measurements of commercially available disk shaped permanent magnets demonstrated very strong magnetic field inhomogeneity which substantially exceeded the non-uniformity caused by the demagnetising field of the ferrite disks themselves. Pole pieces of special shape which serve as "magnetic lenses" were proposed in this work to compensate for the non-uniformity of the magnetic field generated by the permanent magnet. Then the ferrite disks deployed beside the pole pieces were exposed to a nearly uniform dc magnetic field. At the same time the demagnetising field inside the ferrites was essentially suppressed due to the closeness of the pole pieces. Another important feature of such an arrangement was that the ferrite disks became a substantially integral part of the magnetic circuit.

A closed form approximate solution for the respective magnetostatic problem has been obtained. It enables one to explicitly express the ferrite Polder tensor $\underline{\mu}$ in terms of the saturation magnetisation $4\pi M_s$ of the ferrite and the residual induction B_r of the permanent magnet. The latter solution is essentially employed to optimise thermal performance of circulator.

2. *Conductor crossover*. In order to minimise the insertion loss and enhance a power handling capability of the circulator, a new integral topology of the stripline conductor layout was devised. The crossover pattern may be easily fabricated simply by folding the segments of an etched sheet conductor (Fig 1). High Q ceramic chip capacitors may immediately be embedded under the strips to facilitate matching of the output ports. The proposed integral formation of the conductor layout has several advantages. Ferrite disks are not wrapped by the strips but inserted in the locating compartment in the folded conductor. Such an assembly enables one face surface of each ferrite disk to be exposed to direct contact to the housing body which provide the ground connection. It eliminates a number of soldered joints and precisely locates strip lines that enables the topological symmetry of the structure to be consistently reproduced. The geometry of crossover (strip width and separation) is optimised for the best impedance matching between the output ports and ferrite filled strip lines.

3. *Thermal stabilisation.* An ideal thermostable circulator requires that the tensor $\underline{\mu}$ be constant across the specified temperature range. However the latter requirement is physically unrealisable. Therefore minimisation of temperature drift for the specific circulator characteristics is the only opportunity. Extensive analysis of the temperature stabilisation issues for lumped element circulator has been made in [8]. But it is limited to a particular circulator model and configuration of external dc magnetic field which proved to be inapplicable to our arrangement. For that reason our analysis makes use of a different criteria of temperature stability - the impedance of the ferrite filled stripline is required to be constant. In the UHF band the latter condition can effectively be replaced by another one: $\mu(T)$=const, where $\mu(T)$ is a diagonal component of the tensor $\underline{\mu}$. Temperature drift $\delta\omega$ of the circulator central frequency ω was estimated under the latter condition for Knerr's model of ferrite junction [4] and the model of dc magnetic circuit described in the previous section. For some combinations of materials our calculations predicted small temperature deviations of w across the temperature range 0-70°C and the feature of self-thermostabilisation (Fig. 2).

4. *Experimental results.* The circulator prototypes based on the discussed concepts demonstrate excellent performance and temperature stability in the frequency range 70-400 MHz. An example of experimental performance is presented in Fig. 3. The results of

measurements are in close agreement with calculations.

CONCLUSIONS

The features of thermostable stripline lumped element circulator operating in the above resonance mode have been discussed. The new layout comprising an integral topology of the conductor crossover and novel arrangement of dc magnetic circuit with improved uniformity of internal biasing magnetic field in ferrite disks has been proposed. Circulator prototypes demonstrate excellent performance and enhanced power handling capability in the frequency range 70-400 MHz.

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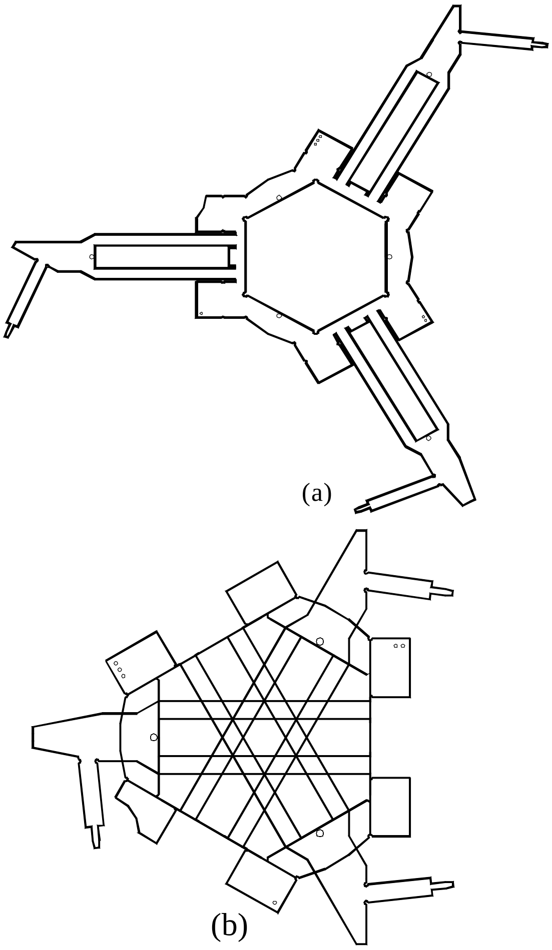

Fig. 1. Layout of the unfolded strip conductor (a) and a folded crossover assembly (b).

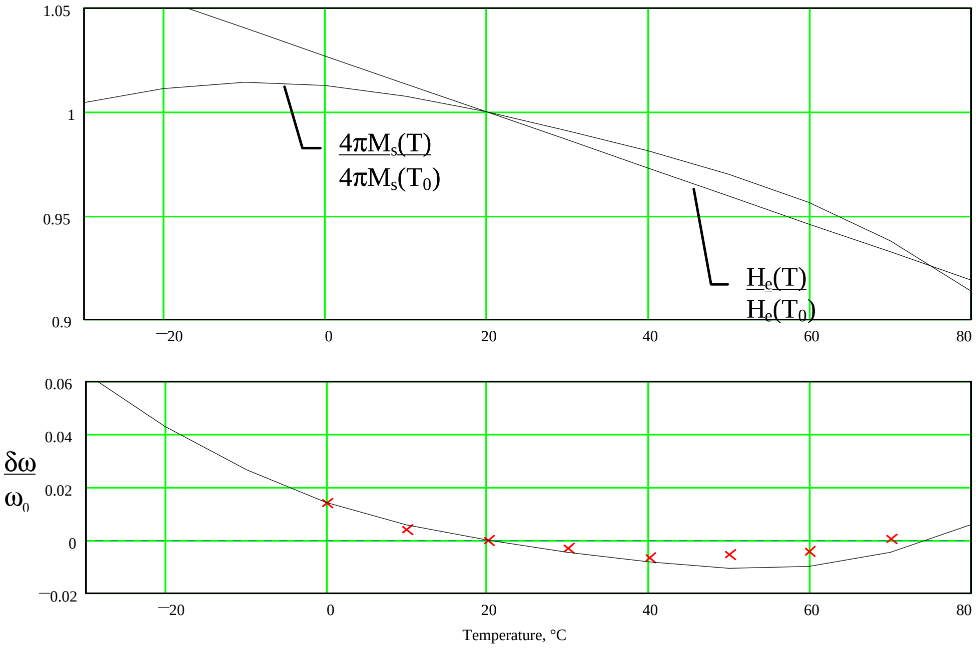

Fig. 2. Normalised temperature dependencies of $4\pi M_s$, external magnetic field H_e and respective variations of the circulator central frequency (calculation - solid lines, measurement - crosses)

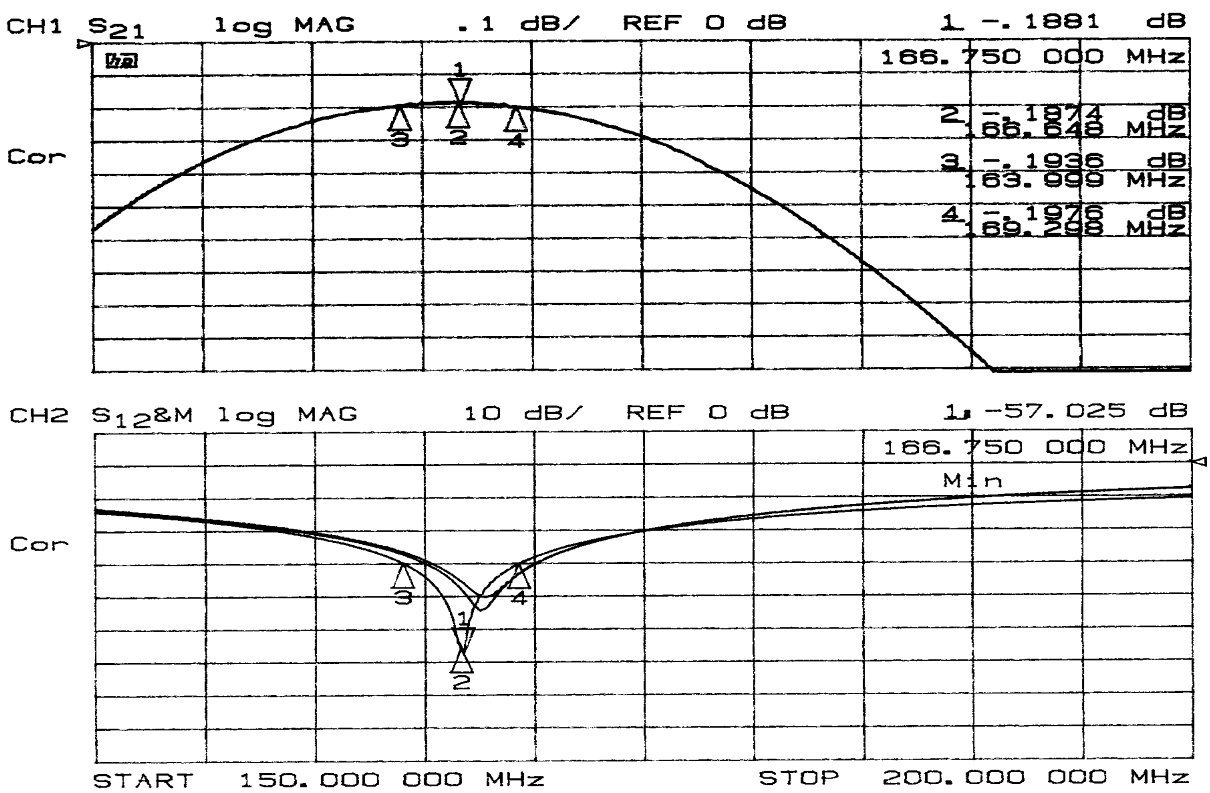

Fig. 3. Performance of the circulator experimental prototype.