SLIM-GUIDE CIRCULATORS IN C, X, K AND U BANDS

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ABSTRACT

The performance is here discussed of circulators and switches using the evanescent mode approach. Units have been manufactured and tested from 4 GHz up to 50 GHz. The relevant results are likewise reported.

General

The technique of using below cutoff waveguide sections, as filtering elements, in microwave circuits was made popular by Craven in the first European Microwave Conference (London 1969).
Since that time an extended investigation was carried out in our company to evaluate the potential capabilities of such new technique.
As already reported in the literature, a section of rectangular waveguide, excited in the dominant mode TE10, when operated below cutoff, can be represented by a J inverter terminated with two inductive susceptances (fig.1).

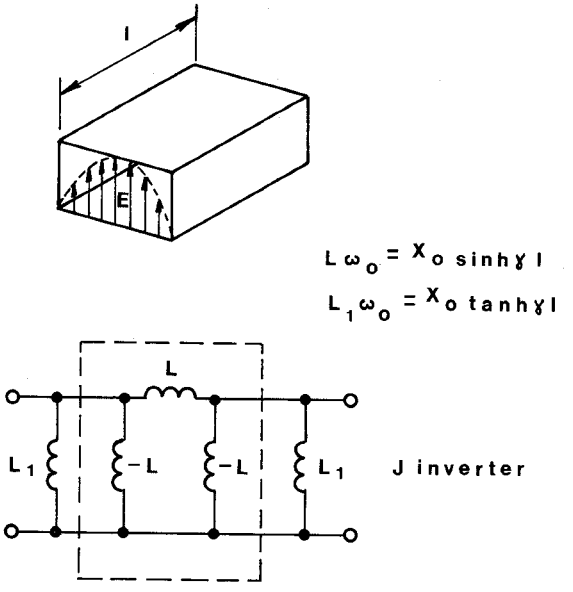

Fig.1

The filtering properties of the structure shown in figure 1 are self evident, and various papers (by Craven et al.) have extensively shown how to use these elements for the implementation of complex filtering structures.
Conversely, their use as coupling elements in different kind microwave circuits has been very little reported.
This contribution gives the results obtained in the implementation of ferrite circulators, as well as switches, by this technique.

Circulator layout

The first trial in implementing a slim-guide circulator was carried out while designing a parametric amplifier for the CTS satellite.
The other possible alternatives, propagating waveguide or microstrip, resulted respectively too heavy or too lossy.
An extensive investigation was therefore started, giving rise to an excellent output. The circulator showed an outstanding return loss over the prescribed band (500 MHz), a low insertion loss and a surprisingly good behaviour with temperature.

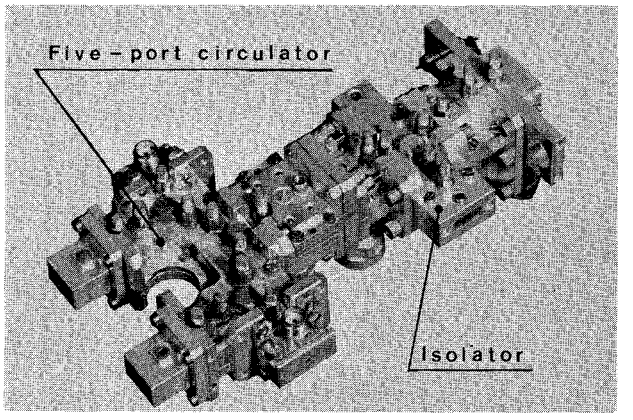

Fig.2

Fig.2 shows the microwave package of the parametric amplifier in which both a five port circulator and an isolator are clearly indicated.
The layout of a three-port structure typically consists of a cilindrical cavity, including a ferrite magnetized disc, and three slim-guide coupling filters. The resulting assembly is extremely compact and lightweight (fig.3).
The tuning of the junction is accomplished through a plunger opposite to the ferrite disc.
Its equivalent circuit, as seen from the coupling guides can be represented with a conductance in parallel with an inductive susceptance. The reactive part of the junction impedance can be tuned with a shunt capacitance (practically a screw), giving rise to a resonator of given Q. It is then straightforward to broadband the junction by adding suitable resonators so to have a prescribed insertion loss. The resonators are easily

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implemented by as many screws separated by proper slim guide sections.
In case of multiple circulators the connection between different junctions is accomplished directly in slim-guide, thus avoiding any transformer to propagating waveguides, with further advantages in terms of weight and volume.
By the way, through this method the interface between any two junctions can be advantageously optimized in terms of isolation.

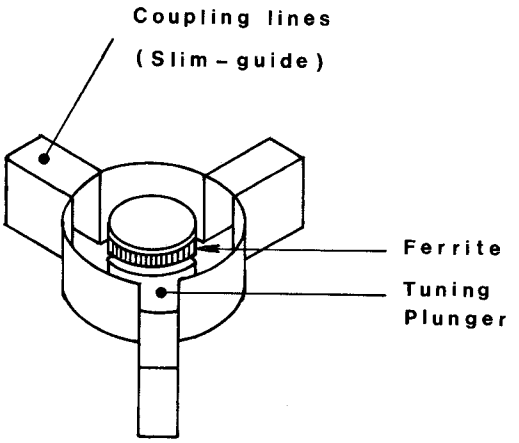

Fig.3

Experimental results

As a consequence of the successful work carried out with the paramp, a variety of similar devices was implemented, covering a wide frequency spectrum, from C band up to millimeter wavelengths.
Tabel I summarizes the results so far obtained :

Table I

Freq. range (GHz)	Isolat. (dB)	Band (GHz)	Insert. (dB)	Temp. range (°C)
4	35	0.5	0.05	0 to +40
11	30	0.9	0.1	-20 to +50
12	35	0.5	0.1	0 to +40
14	25	0.5	0.1	-40 to +70
20	20	2	0.25	-20 to +50
30	20	2	0.35	-20 to +50
50	20	3	0.5	-20 to +50

As regard applications, the above devices have been used according to the following list :

4 GHz : Low noise parametric amplifiers for INTELSAT Ground Station (fig.4) .
In this occasion the slim-guide circulator was used for its extremely low loss and high isolation (see Table I), which helped to obtain a low noise temperature (50°K) in a moderately Peltier-cooled system, even using a low pump frequency (44 GHz).
An additional advantage is represented by the filtering properties of the device, which allowed a correct operation without a transmit rejection filter.

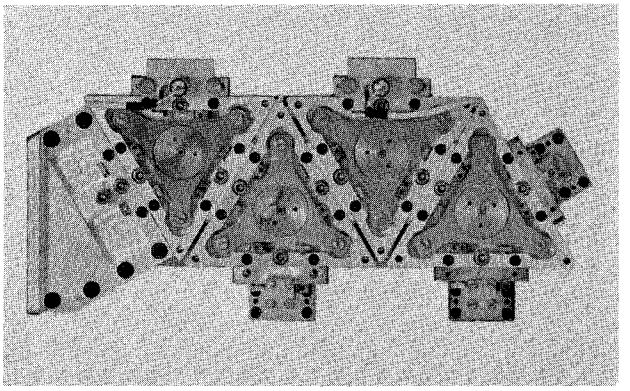

Fig.4

11 GHz : Low noise parametric amplifier for OTS and SIRIO satellite Ground Stations. It can also be used in INTELSAT Standard C stations.
In this case a multiple circulator was implemented including seven three-port junctions. It is shown in figure 5.
In this case too, advantage was taken of the filter-like transmission characteristics, in order to avoid a transmit rejection filter.

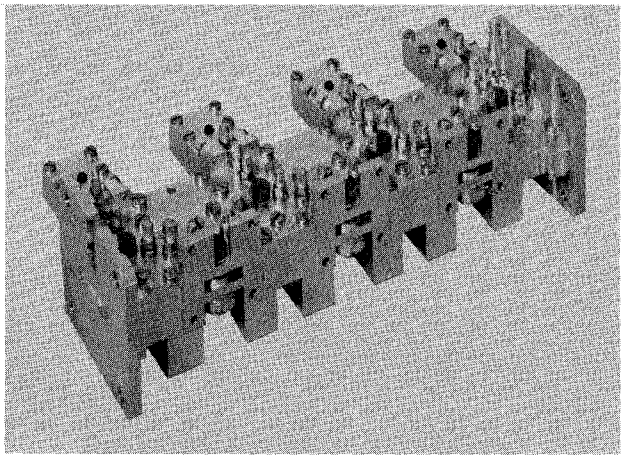

Fig.5

14 GHz : CTS (see fig.2), OTS and ECS satellite parametric amplifiers.

20 and
30 GHz : Three-port circulators were investigated in view of the 30/20 GHz transponders of the European Satellite H-SAT.
The units are still in development, and the figures reported in Table I refer to preliminary results.

53 GHz : This circulator is currently used as decoupling isolator in front of Gunn generators operated in that frequency range.
A slim-guide device was used due to its well defined out of band behaviour.

Comparison with different approaches

As shown in Table I the electrical performance of these circulators is at least comparable with present state-of-the art technology, as isolation and insertion loss are concerned.

As regards bandwidth, it may appear rather limited, but it should be remarked that, generally, it was imposed by the relevant application.
For instance the circulators at 11 and 12 GHz are essentially identical and their respective performances were obtained with a simple trade-off between band and isolation (acting on the Q's of the coupling filters).
Summarizing, apart weight and volume, the main advantages of this approach are :

- The insertion loss can be prescribed and its roll off closely follows theory up to the cutoff frequency of the feeding waveguides.
  In many cases this peculiarity can be exploited since the device, if properly designed, comes out to present the combined properties of a circulator and a filter in a single unit.
- The stability versus temperature and/or biasing field is surprisingly good.

Operation as latching switches

Tests have been made in X and K band on circulators operated as latching switches.
The only difference, with respect to the already described circulator, consists in a suitable coil coupled to the permanent magnet.
Particularly, one project was finalized to operate as output combiner in the ECS satellite.
Due to the high isolation requested, two cascaded circulators have been used in each path, so that the overall configuration is similar to a 5-port unit.
The switch is shown in fig.6 and the electrical characteristics are given hereunder :

- Bandwidth	:	10.95 to 11.7 GHz
- Insertion loss (two passes)	:	$\leqslant$0.25 dB
- Isolation	:	$\geqslant$56 dB
- Insertion loss in the transmit band (14 to 14.5 GHz)	:	$\geqslant$30 dB
- Switching time	:	$\leqslant$ 2 mS
- Switching power	:	11 W

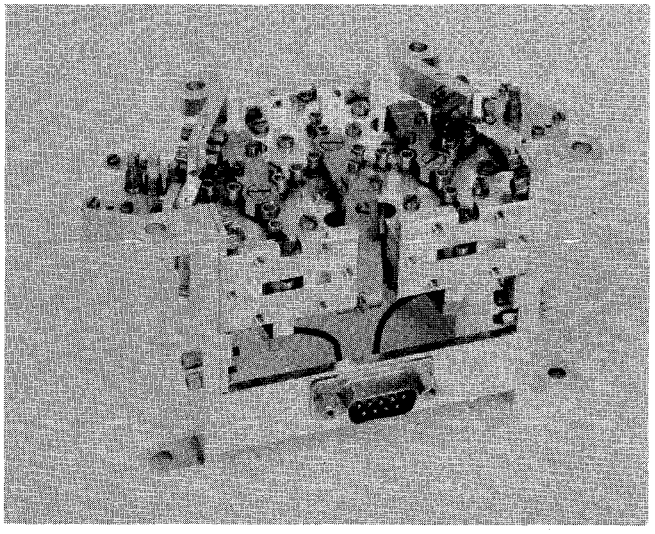

Fig.6

As regards switching time, it can be decreased down to 0.1 ms by changing the coil parameters.
It is estimated that a further decrease is possible , provided a higher resistivity metal is used for the circulator body.(Present switches have been realized in aluminum).

Acknowledgement

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