BROADBAND FIN-LINE CIRCULATORS

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Abstract

A novel configuration for fin-line circulators is introduced, with improved coupling to the ferrite resonator. It uses a unilateral structure and is well suited for integrated systems. Two devices in Ka-band and X-band show a 20 dB isolation bandwidth of 25% respectively 35%.

Background

Work on fin-line circulators has been reported only in the last year in [1] and [2]. These devices showed only moderate performance and could not compete with former waveguide or microstrip designs. Beyer[1] tried a quasi H-plane structure using an overlapping antipodal fin--line, which shows a field distribution between the fins similar to a microstrip line. Thus the coupling into the ferrite could take place in a similar way as in the microstrip circulator, which is well elaborated. The shortcoming, however, is the antipodal structure. Even with a better taper than the used $\cos^2$-shape, a broad--band transition to normal fin-line or empty waveguide will always cause difficulties. Hence, such a device is not very promising.

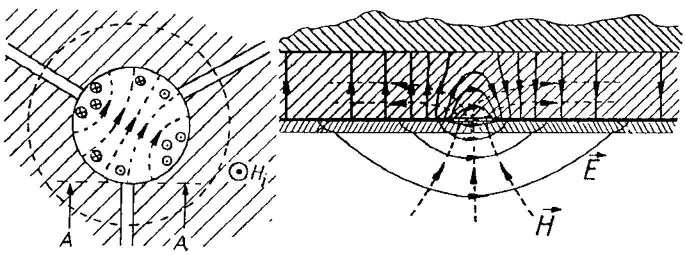

Fig.1 Former circulator design; a) Top view, b) cross-section AA

Our first approach to fin-line circulators[2] was based on a unilateral structure, which is well suited for integration and avoids problems with transition and manufacture. Its slot pattern is shown in Fig.1a, the corresponding electrical and magnetic fields in Fig.1b. Like in any E-plane circulator, the E-field has to be perturbed to match the $HE_{11\delta}$-resonator field required for circulation. The performance limitations of this junction are mainly due to the discontinuity caused by the abrupt ending of the fin-line at the ferrite and its electrical conducting ground plane. The desired perturbation of the fields can be advanced by a suitable slot profile in front of the ferrite disc and by a tuning plunger overtopping the ferrite, but even very elaborated set-ups having this geometry did not exceed 10 per cent bandwidth at 20 dB isolation.

Improved Design

To overcome these difficulties we tried to find a better way to adapt slot fields to resonator fields. A closer look to the field pattern of the $HE_{11\delta}$-mode shows that transverse E-field and longitudinal H-field coincide at

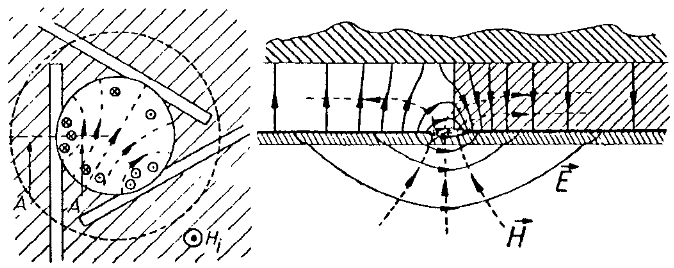

Fig.2 Improved circulator; a) Top view, b) cross-section AA

the sides of the ferrite disc, referred to slot-direction. As the electrical slot field can be erected under the influence of the high permittivity of the ferrite ($\varepsilon_r \approx 14$), coupling between slot and ferrite will be increased when the slots extend along its edges. This results in the arrangement shown in Fig.2a*. The ferrite disc clads part of the slots, and a cylindrical plunger, contacting the waveguide walls, forms its upper metallisation. The plunger contains a rare-earth permanent magnet which supplies the bias field.

As the ground plane of the plunger overlaps the ferrite disc, the slot line fields gradually develop to the field pattern shown by the cross-section in Fig.2b. The field distribution at the edges of the disc is very similar to that of common microstrip circulators with radial feed-lines lying perpendicular to our slots, hence the performance can be expected to be similar. The superiority of this geometry compared to [2] is based on the following facts:

(1) Tapering effect of the ferrite edge, which smoothly overlaps the fin-line slot.
(2) Arbitrary choice of the coupling angle by appropriate shape of the slot.
(3) Additional degree of freedom by varying the length of the by-passing stub slot.

These features shall be treated in detail. While the slot ends suddenly at the ferrite edge in the former device, now the fields can penetrate smoothly into the ferrite disc along its edge.

The coupling length can be chosen by a suitable shape of the feeding slots. Instead of a straight line, they may also be bended to the ferrite disc or away from it. Systematic investigations pointed out that straight tangential slots show the best results, the coupling angle, measured between the crossover points between ferrite and inner slot edge, being some 50°. By the way, this harmonizes with the calculated optimum, carried out by Wu and Rosenbaum[3] for microstrip circulators. The slot profile near the ferrite should be designed to support the coupling of the fields into the ferrite. Hence, it is worthwhile to enlarge the slot width in this region. Special attention must be paid to the shape of the short--circuited end of the slot. It must not couple to the slot of the adjacent port. This can be achieved either

* German patent filed

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by a sharp bending towards the waveguide wall or- if there is enough space left- by directing it perpendicular to the second slot. This has been approximately realized in Fig.2a.

The short-circuited end of the slots perform an additional shunt reactance to the junction. Its influence, however, turned out to be not decisive when strong coupling between slot and ferrite occurs, i.e. amid the circulation band, but it seemed to have a positive effect on the frequency response at the edges of the band by possibly compensating parasitic coupling reactances.

It is worth noting that there is no need for a matching structure in the feeding lines; the curves shown were measured with tapered transitions designed exclusively to match the wave impedance of the fin-lines to that of the empty waveguides used in our measuring equipment.

In the circulators in [2], bandwidths of more than about 5 per cent could be achieved only with quarter-wavelength impedance transformers. The lack of transformers is of great importance in designing integrated fin-line structures with several components on a single substrate. The one-sided structure is another important advantage for integration.

The step to the plunger inside the junction still remains as a discontinuity. It mainly deteriorates the reflection loss. To overcome this restriction, two possibilities may be considered:
Either, the waveguide step can be combined with a step in slot width, designed for the same wave impedance on both sides approximately. The steps will have a certain offset, thus compensating step reactances. The other method is a ramp in the waveguide housing, corresponding to a modified taper in slot width, thus avoiding any step discontinuity. The latter method is superior and has been realized in X-band. Further investigations will show, to which extent it can be replaced by the former one, which has the advantage of simpler housing and smaller size.

The measurement setup was carried out in standard waveguide. After obtaining a certain quality level of the circulator, its performance is only restricted by the taper transition. Their behaviour was calculated by the method of Saad/Schünemann[4]. After trying laws of exponents for the slot width with mediocre results, a rather sophisticated profile was found, which performs a VSWR of less than 1.15 all over the waveguide band being only one wavelength long. This subject will be treated in a future paper.

Results

Our investigations have been performed in X- and Ka-band. The substrate material is RT-duroid 5880 in all cases, 254 µm thickness, with 17,5 µm copper clad on one side. The structure is etched with usual photolithographic methods, and the ferrite puck is glued exactly in the center, using a low loss adhesive. Fig.3 shows photos of both devices.

In X-band, we use discs of RF2 from AEG-Telefunken ($\gamma\mu_o M_s$ = 230 mT) with circular or triangular basis. The triangle proved to be superior referred to achievable bandwidth. With 9.15 mm sidelength and 1.8 mm height the frequency band, in which isolation and reflection loss exceeds 20 dB, is 3.7 GHz, reaching up to the Ku-band (Fig.4c). The insertion loss is better than 0.6 dB, with a contribution of 0.3 dB due to the tapers.

In Ka-band, we have only tried cylinders of different materials (RF10 AEG-Telefunken, TT2-111 Trans. Tech., 5E1 Philips), all with a saturation magnetisation of about $\gamma\mu_o M_s$ = 500 mT. The differences between these materials are not significant. The measured results are given in Fig.4b. The isolation exceeds 20 dB from 28 to 36 GHz, with respect to the worst combination of ports. The dimensions of the ferrite puck are 2⌀ x 0.35 mm. In this device, the above mentioned ramps have not yet been established so that the reflection loss does not obtain the performance of the X-band device.

Control of the mechanical tolerances becomes very important with increasing frequency, which restricts the use of flexible substrates. To maintain symmetry, the ferrite planes have to be exactly parallel to the plunger surface, which can be ensured by a dielectric spacer of low permittivity. In this respect alumina substrate could be superior.

Conclusions

A fin-line circulator is presented, which shows performance similar to microstrip or waveguide devices, using a novel slot pattern. It is especially intended to be used in completely integrated fin-line systems, which suffered hardly from the lack of nonreciprocal fin-line devices until now. It can be realized using the well-known techniques of microstrip circulators.

Acknowledgement

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References

1 Beyer, A., Wolff, I.:" A Fin-Line Ferrite Isolator and Circulator for the R-band", Proc. of the 11th EuMC, Amsterdam 1981, pp. 321-326.

2 Braas, M., Schieblich, Ch.:"E-type Circulator for Fin-Lines", El. Letters, 1981, 17, pp. 701f.

3 Wu, Y.S., Rosenbaum, F.J.: "Wide-band operation of Microstrip Circulators", IEEE Trans. MTT-22, 1974, pp. 849-856.

4 Saad, A.M.K., Schünemann, K.: "Design of Fin-Line Tapers, Transitions, and Couplers", Proc. of the 11th EuMC, Amsterdam 1981, pp. 305-308.

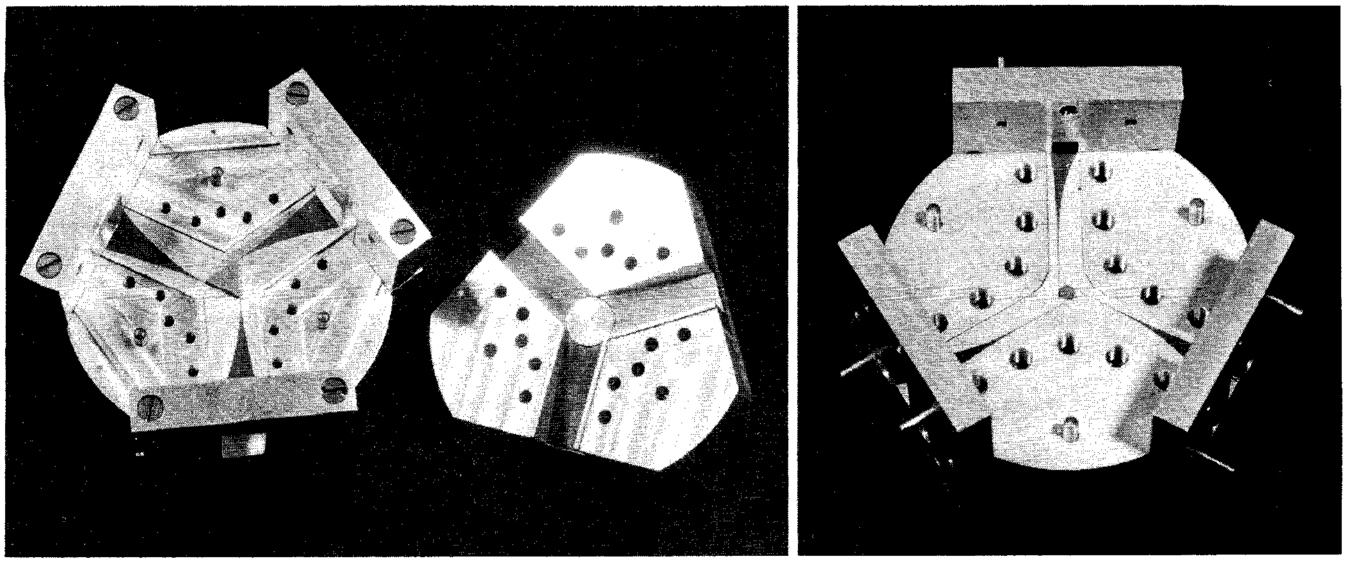
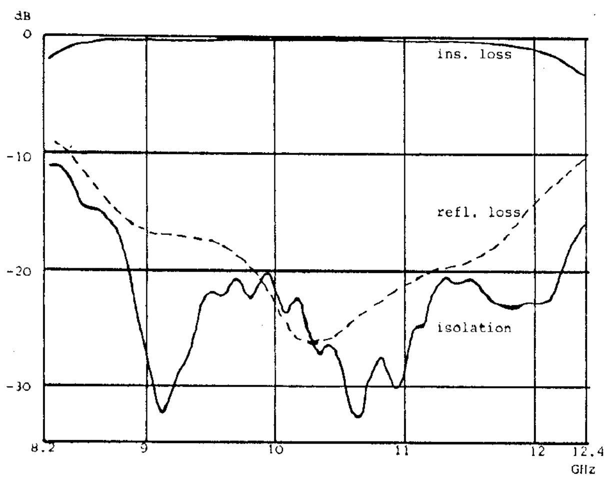


Fig.3 a) X-band circulator with linear ramps, b) Ka-band circulator



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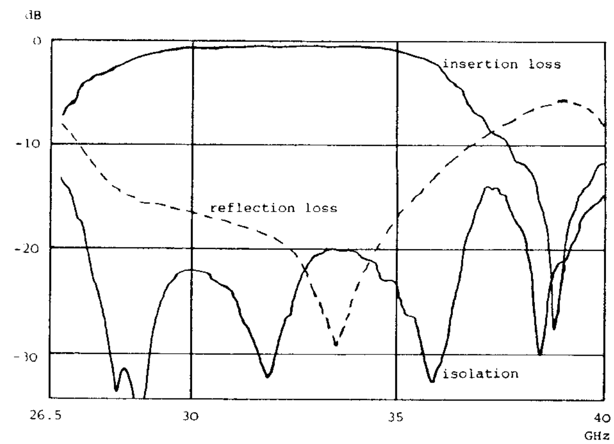

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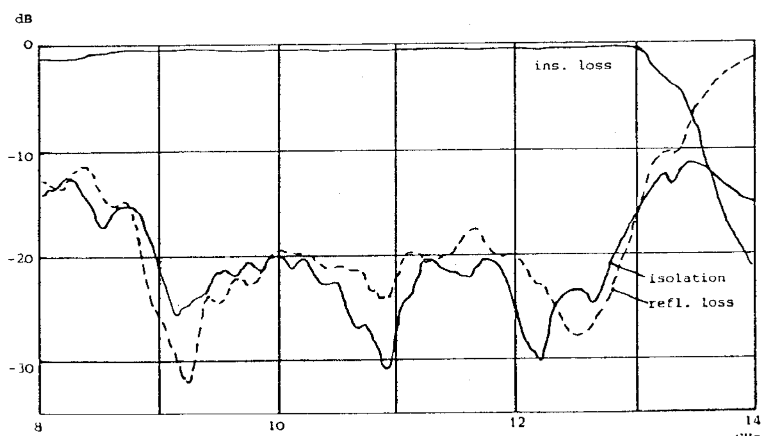

c)

Fig.4 Frequency responses

a) X-band without ramps

b) Ka-band without ramps

c) X-band with linear ramps and improved taper