NEW FORMULAE FOR THE INITIAL DESIGN IN THE OPTIMIZATION OF T-JUNCTION MANIFOLD MULTIPLEXERS

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ABSTRACT

We present an effective criterium for the choice of the starting point in the optimization of T-manifold multiplexers. Given N separately designed channel filters, the method provides the expressions for their locations with respect to the manifold as well as the spacings between the junctions forming the manifold itself.

By inspection of the results it is seen that the proposed formulae perform considerably better than the standard ones based on stub models. In fact, in the non-contiguous case, the design is almost complete when the junctions forming the manifold have certain characteristics.

In the contiguous case, a further optimization is required but the initial choice is very close to the final solution.

INTRODUCTION

Nowadays, the most common method for the design of microwave multiplexers is based on optimization [1], [2]. The entire configuration, i.e. manifold and filters, is determined by minimizing a proper objective function, that often depends on hundreds of variables.

It is evident that the choice of the starting point, i.e. the initial multiplexer configuration, is crucial in view of reducing the optimization time and avoiding local minima traps, which frequently occur in minimizations over a number of variables.

On the other hand, the criteria appeared in literature are either extremely intuitive, as those based on the assumption that a filter in its outband can be taken as a stub [1], or quite sophisticated, as those where the filter prototypes are modified in order to account for the interaction with other channels [3], [4]. In both cases, however, the junctions forming the manifold are treated as ideal, at the initial step.

This work was partially supported by MURST.

In this contribution, we propose quite a general criterium for the choice of the starting point of an optimization-based design approach. The method takes advantage from the knowledge of both the actual response of the filters and of the specific junctions forming the manifold, as they are simulated by full-wave analyses.

The resulting formulae are expressed in closed form in terms of the scattering parameters of the filters and junctions. They do not take into account of the interaction via higher order modes possibly occurring between junctions and filters. At the first step of the design, however, such an interaction can be neglected, as it will be taken into account in the further optimization of the functional deriving from the full-wave analysis of the whole device.

We will specialize our design method to the significant case of a T-junction manifold multiplexer.

DIPLEXER DESIGN

Let us consider a three-port junction **J** of scattering matrix **S**. It can be proved that, at a given frequency f, it is always possible to minimize the reflectivity of the two-port junction obtained by closing an arm of a reciprocal and lossless three-port junction, say port 2, on a reactive load jX, provided that the load is positioned at the distance:

$$l(f) = \frac{\psi - \phi}{2\beta} \qquad (1)$$

where $e^{j\psi}$ is the reflection of the reactive load, β the propagation constant of the feed waveguides

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and

$$\phi = 2\tan^{-1}\frac{-b+\sqrt{a^2+b^2-c^2}}{c-a} \qquad (2)$$

The real quantities a, b and c depend on the scattering parameters of the junction and assume the following expressions:

$$a = \frac{a_{33}}{a_{11}}(1+a_{22}^2)\sin(\phi_s-\phi_{11}-\phi_{33}) - a_{22}(1+(\tfrac{a_{33}}{a_{11}})^2)\sin\phi_{22}$$

$$b = \frac{a_{33}}{a_{11}}(1+a_{22}^2)\cos(\phi_s-\phi_{11}-\phi_{33}) - a_{22}(1+(\tfrac{a_{33}}{a_{11}})^2)\cos\phi_{22} \qquad (3)$$

$$c = 2\frac{a_{33}}{a_{11}}a_{22}\sin(\phi_{11}+\phi_{22}+\phi_{33}-\phi_s)$$

where $S_{ii} = a_{ii}e^{j\phi_{ii}}$ are the scattering matrix diagonal parameters and $e^{j\phi_s}$ is the determinant of the scattering matrix of the three-port junction computed at the frequency f.

The corresponding value of the minimum reflectivity is given by:

$$\rho_{min} = a_{11}\left|\frac{1-\frac{a_{33}}{a_{11}}e^{j(\phi+\phi_s-\phi_{11}-\phi_{33})}}{1-a_{22}e^{j(\phi+\phi_{22}}}\right| \qquad (4)$$

Note that $\rho_{min}=0$ only if $a_{11}=a_{33}$. Now, we want to realize a diplexer using such a junction and two given filters F_1 and F_2.

Noting that a filter in its out-band is an almost reactive load, formula (1) gives the criterium we are looking for. This is to connect the filters to ports 1 and 2 of the junction at the distances l_1 and l_2, respectively, in such a way that the two-port obtained by closing arm 1 of the junction on filter 1 has minimum reflection at the midband frequency of the second filter (f_2) and vice versa. Note that ψ appearing in (1) must be chosen as $\angle S_{11}^{F_1}(f_2)$ and $\angle S_{11}^{F_2}(f_1)$ respectively.

It is also worth noting that this approach is quite general, as it applies to junctions realized by any technology, its derivation being based only on the reciprocity and losslessness of the junction.

Of course, the perfomance of the diplexer will depend on the specific junction employed. In this regard, the Y-junction seems to be the best solution, because $S_{11}=S_{22}=S_{33}$ and its response is almost flat on the whole band, as discussed in a previous paper [5].

For a T-junction (Fig. 1) at a given frequency, the minimum reflection of the two-port obtained by closing port 1 on F_1 at the distance given by (1) is still zero, since $S_{33}=S_{22}$ at any frequency, provided that F_1 is in its outband. Conversely, when F_2 is placed at port 2, we can just reach a minimum of reflectivity, but not zero, since $a_{11}\neq a_{33}$. Therefore the resulting diplexer performace will be perfect at the midband frequency of the filter loading port 2, while it will deteriorate somewhat at the midband frequency of the filter loading port 1, being still acceptable in many practical cases.

MULTIPLEXER DESIGN

The above idea can easily be extended to the design of a multiplexer, as indicated in the case of Y-junction manifolds [6]. N filters F_i of scattering matrices $\mathbf{S}^{F_i}$, ordered in such a way that $f_i < f_{i+1}$, where f_i is the midband frequency of F_i, are connected to N identical T-junctions of scattering matrix S_T as indicated in Fig. 2. The distances l_k and ls_k are calculated as follows:

i) l_k is calculated so as to obtain a matched two-port between ports 3 and 2 of the $k-th$ junction at frequency f^* (where f^* is the arithmetic mean of f_1, f_2,...,f_{k-1}), when port 1 is closed on F_k; in this case $e^{j\psi} = S_{11}^{F_k}(f^*)$;

ii) ls_k is the distance between port 3 of the $k-th$ junction and the reactive load jX that minimizes the reflection of the resulting two-port at the frequency f_k; for $k>1$, jX is the input impedance seen to the right of port 2 of the $(k-1)-th$ junction calculated at the frequency f_k; for $k=1$, $jX=0$, being the input impedance of a short-circuit.

Formula ii) is valid provided that filters F_1, F_2, ..., F_{k-1} appear as reactive loads at the frequency f_k, as always occurs in practice.

RESULTS

Formula 1 was validated by considering several three-port junctions both in rectangular waveguide and in microstrip technology. Regarding the T -junction, we considered the E-plane case and calculated the optimum distances at which a short must be placed in order to obtain the maximum return loss at port 3, at 10 GHz, when the short loads either port 2 (T_2) or port 1 (T_1). The scattering parameters employed in expression 1 were computed by full-wave analysis. By means of 1, the theoretical optimum positions are: $l_1 = 38.222\,mm$ and $l_2 = 35.498\,mm$. The experiment, performed by means of a commercial E-plane T-junction in WR90 waveguide, was carried out by moving the short until minimum reflection was found. We measured the optimum distances $l_{e1} = 38.38mm$ and $l_{e2} = 35.62mm$. The slight deviation is probably due to the mechanical tolerances of the T-junction ($\pm 0.050mm$). The input reflection of the junction loaded as above is shown in Fig.3.

Regarding the multiplexer, we can show at the moment just theoretical results concerning the simulation of an E-plane T-manifold multiplexer employing E-plane septate filters. Although the simulations of both filters and junctions, separately considered, are very accurate [7], the model does not take into account the interaction between junction and filters via higher order modes. On the other hand, the single mode assumption was validated by an inspection of the final dimensions of the sections, always longer than $\lambda_g/4$, and, besides, the results obtained are to be taken just as starting point for a full-wave multiaccessible mode optimization. Moreover there is great practical effectiveness in simple formulae, a fact that depends strongly on the above single mode assumption. In order to appreciate the usefulness of formula (1), we compared the initial responses of many multiplexers designed as illustrated above with those designed according to the existing formulae (3.5.8-12) of [1]. The latter give the initial lengths usually employed as starting design of T-junction manifold multiplexers. Of course, in both cases final design requires an optimization step, but the comparison is very interesting in order to evaluate how close the initial design comes to the final solution. As a first example, we considered a 9-channel non contiguous multiplexer, employing Tchebysheff 7-poles 50 MHz bandwidth E-plane filters and E-plane T-junctions; the spacing between channels is 60 MHz. As can be seen, the reflection keeps lower than -12 dB for all channels (Fig. 4). In the contiguous case, results deteriorate a little. As an example, Fig. 5 shows the response of a 6-channel contiguous multiplexer employing Tchebysheff 7-poles 50 MHz bandwidth E-plane filters and E-plane T-junctions. Channels are separated by 5 MHz. Even in this case, the advantage of the proposed solution with respect to the standard one is evident.

CONCLUSIONS

An analytical and simple criterium for the choice of the initial guess in the optimization of T-junction manifold multiplexers has been presented. It provides closed form expressions giving the positions at which filters have to be placed and the distances separating the junctions in the manifold. The approach is quite general, being based on the analysis of the scattering matrices of the three-port blocks forming the manifold.

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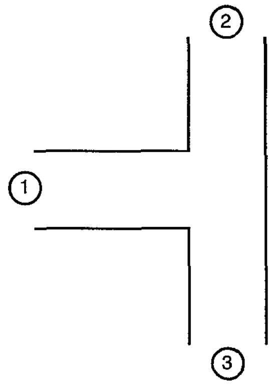

Fig. 1. Transverse section of a T-junction

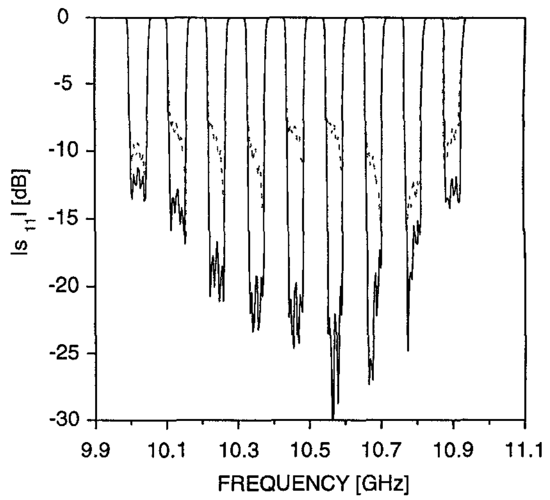

Fig. 4. Reflection at the common port of a un-optimized 9-channel not contiguous multiplexer, employing septate E-plane filters and an E-plane T-junction manifold. The dashed line is obtained by spacing junctions and channel filters according to formulae (3.5.8-12) of [1]; The continuous line refers to our method

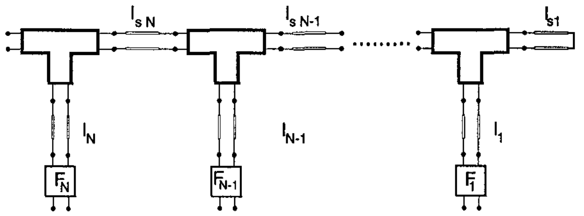

Fig. 2. Layout of the T-manifold multiplexer

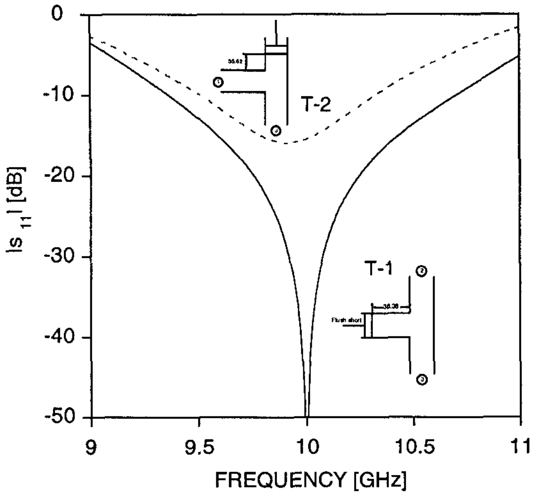

Fig. 3. Reflection at the port 3 of the T-junction, when T-1) a short loads port 1; T-2) a short loads port 2. Shorts are placed at the distances which minimize the input reflection at 10 GHz

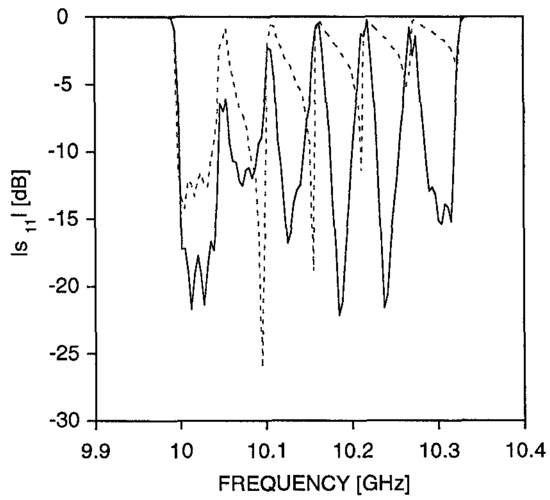

Fig. 5. Reflection at the common port of a un-optimized 6-channel contiguous multiplexer, employing septate E-plane filters and an E-plane T-junction manifold. The dashed line is obtained by spacing junctions and channel filters according to formulae (3.5.8-12) of [1]; The continuous line refers to our method

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