RECENT DEVELOPMENTS IN BROADBAND DIRECTIONAL COUPLERS ON MICROSTRIP

F.C. de Ronde

Philips Research Laboratories
Eindhoven-The Netherlands

Abstract

Introduction of lumped elements in the microstrip itself proved to be a rather simple way to overcome the difficulties encountered by achieving tight coupling (3 dB) and high directivity ($>$ 20 dB) for proximity couplers on plain microstrip.

Three couplers were made as proof; two 3 dB proximity couplers: a distributed-lumped and an octave-flat lumped one, and a 8.34 dB decade-wide asymmetric coupler of the DuHamel & Armstrong type.
It is evident that application of the new technique is not restricted to couplers.

Introduction

Directional couplers covering several octaves or even a frequency decade are usually built up from cascaded proximity couplers. If a tight coupling is necessary it proves to be very difficult to develop one in microstrip. Due to its planar structure even a single-section 3 dB coupler can hardly be made without overlay[1], overlap[2] or interdigital[3] technique. Moreover the inhomogeneity of the medium restricts the directivity to a rather low value. Although Podell's wiggling method[4] has solved the latter problem, a tight coupling is still difficult. Due to the different places of the even- and odd mode currents it proved possible to influence the even-mode inductance practically independent of the odd-mode one. Transversal slots in the outer edges of the coupled strips raise the even--mode inductance, whereas those in the inner edges enlarge the odd-mode one. It will be evident that the inductance and capacitance of a microstrip can be influenced by slots and/or holes of different form, dimension and position as such to give Z_o and β a desired value, even frequency dependant. As a first application three couplers were made, showing the possibilities of the above--mentioned distributed-lumped technique.

I. The distributed-lumped proximity coupler

There is no rigorous theory on the microstrip proximity coupler (see FIG. 1) available. This is not only due to the inhomogeneity of the medium.

The transition regions - providing accessible ports - form non-uniform transmission lines, which even for a homogeneous medium, sofar give rise to unsolved problems. Nevertheless this need not be a reason to deter us from realizing a tight coupler; an understanding of the basic underlying principles might help.

Although we are not dealing with TEM waves, it is still possible to work with the even- and odd mode, which can be regarded as separate transmission lines, being uncoupled as long as the coupler has a symmetry plane along the guiding axis. It is well-known that the coupling between two microstrips is due to reflection for both modes while entering and leaving the uniform region.

For ideal directivity (D) the jump in characteristic impedance for both modes must be equal in magnitude and opposite in phase, so

$$Z_{oe}/Z_o = Z_o/Z_{oo} \qquad (1)$$

Moreover the phase constants must be equal, so

$$\beta_e = \beta_o \qquad (2)$$

Introducing the even- and odd-mode capacitance and inductance per unit length, these conditions can be written as

$$L_e = C_o Z_o^2 \quad (3) \quad \text{and} \quad L_o = C_e Z_o^2 \qquad (4)$$

The coupling (C), being determined by the ratio Z_{oe}/Z_{oo}, can now be written as

$$\frac{L_e C_o}{L_o C_e} = k^2 \text{ or simply } k = L_e/L_o \qquad (5)$$

This unusual approach has been chosen in order to see more directly which factors govern the directivity and the coupling. Since Podell proposed his wiggly method, the directivity needs no longer be a problem for the uniform region. The influence of the non-uniform regions on both quantities will be treated at the end of this section, leaving the behavior in the uniform region as most important for investigation at present. How can a tight coupling, and therefore a high value of k, be achieved? A narrow slot(s) results in a low value for L_o, being minimum for broad strips. The width (w) of the strips follows directly from condition (4), usually resulting in a value for L_e being too low for a tight coupling like 3 dB. If the slot width has been reduced already to its minimum, determined by the technology, the value of L_e must be raised. As the currents of both modes are concentrated at different places, this can easily be achieved without changing L_o by making transverse slots in the outer edges of the strips as indicated in FIG. 2. If for large values of L_e, C_o proves to be too low, wiggling can be applied. So for a given minimum slotwidth, the coupling is almost determined by condition (3). It is evident that the period of the transverse slots has to be small with respect to the smallest wavelength used, in order to avoid a normal periodic structure. The most broadband directivity can be obtained if the lumped elements are actually distributed along the strips in order to fulfill conditions (1) and (2) at nearly every position. The couplers to be described have $D > 20$ dB (1-12 GHz); the utmost value depends on a lot of minor details, especially the configuration of the non-uniform regions. For tight coupling, these regions have large discontinuities, resulting in the excitation of higher-order modes. These modes, contrary to TEM, give rise to forward coupling which spoils the directivity. The configuration as given in our figures, proved the ability to lead to directivities over 30 dB even at 12 GHz.

II. Octave-flat lumped proximity coupler

Up-to-now the only solution for a broadband or even octave-flat 90° coupler is a multi-section symmetrical structure[5] in stripline because a single-section is too frequency-dependent, due to the reflections at a quarter-wavelength distance.

Decade-wide coupling can be achieved if one reflection is eliminated, see next section, however, at cost of the phase relation between the coupled ports.

If the length l can be made small with respect to the wavelength used, a lumped coupler can be obtained, but a configuration is needed allowing for $L_e \gg L_o$, which was possible with a microstrip, - slot coupler[6]. Two drawbacks regarding integration are: first, the configuration is no plain micro-strip; second, the overall size of the coupler is even larger than a normal micro-strip coupler due to the open areas to prevent the slot from shortcircuiting. More-over the frequency-dependency is almost identical to that of a microstrip coupler, so only tight coupling and good directivity has been solved this way.

Another approach is to compensate for the quarter-wavelength influence by making both reflections frequency dependent. In FIG. 3 L_e and C_o are made frequency dependent by special slots in the strips. L_e has been replaced by an inductance L_e' shunted by a capacitance C, whereas C_o is composed of C_o' in series with an inductance L. Both L and C are small enough to prevent resonances below 12 GHz. This way each reflection goes down when frequency goes up, whereas normally the overall coupling goes up below center frequency f_o. As a result a rather flat coupling, at least over an octave, could be achieved together with a gain in coupling and compactness (see FIGS. 2 and 3). From the above it is evident that lumped does not mean automatically a larger bandwidth, but it offers more possibilities.

The length of the coupling region can be reduced by increasing the inductances and capacitances. For a certain coupling we have the restriction given by condition (5). Now we may write:

$$L_e = kL_o;\ C_e = L_o/Z_o^2 \text{ and } C_o = kL_o/Z_o^2 \qquad (6)$$

which means that a coupler can be made more lumped by enlarging L_o and k. If k is smaller than the maximum coupling which can be made, L_o can be enlarged by making transverse slots in the inner edges of the strips.

III. Decade-wide asymmetric coupler

An almost frequency independent coupling can be achieved if one of the abrupt transitions can be substituted by a con-tinuous taper, preferably without reflection in order to obtain a coupling as flat as possible (see FIG. 4). As the coupler needs a minimum length to behave as a transmission line, it has a high-pass behavior[7,8,9,10]. In order to keep the overall size of the coupler limited, the actual length of the taper should take up most of the available coupler ending in a narrow slot.

Due to the inhomogeneous medium the forward coupling, destroying the directivity, will be enormous if no special provisions are made. Wiggling seems to be the solution, although application in a tapered slot is not attractive. Moreover backward coupling must be prevented, preferably by raising L_o instead of C_o. Transverse slots in the inner edges of the strips can easily be made, even in the tapered slot.

For a strong coupling transverse slots in the outer edges of the strips have been applied. If the slot proves too narrow to be made, wiggling can be applied. In order to prevent reflections these transverse slots and the wiggly part have both been tapered. The slot(s) is formed by two large identical arcs touching each other at the end of the wiggly part, so as to prevent reflections. These might, however, occur at the open end of the taper, where they can be compensated over a frequency decade. As the backward coupling is also to be neglected at this point a good directivity was obtained even for a coupler of 50 mm length.

References

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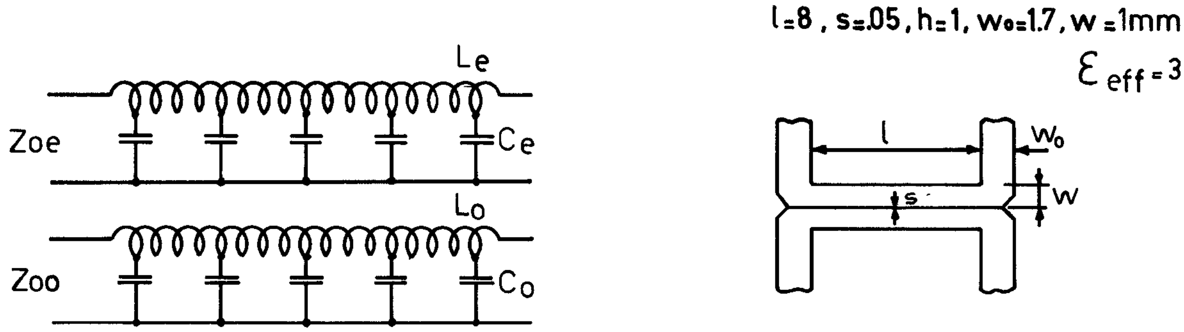

Fig.1 DISTRIBUTED 3.2 - 6.4 GHz 6 ± 0.6 dB

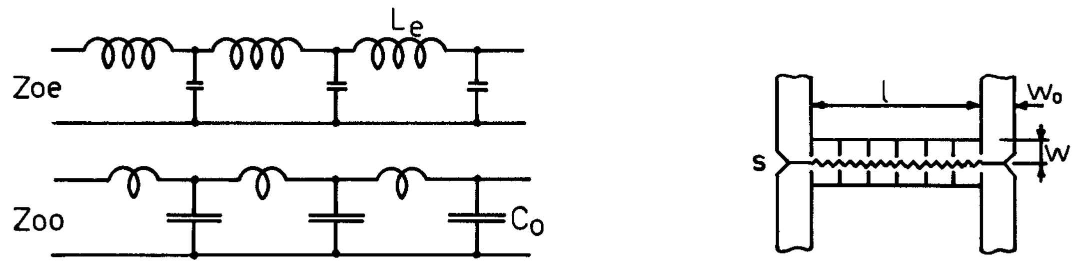

Fig.2 DISTRIBUTED-LUMPED 2.9 - 5.8 GHz 4.5 ± 0.4 dB

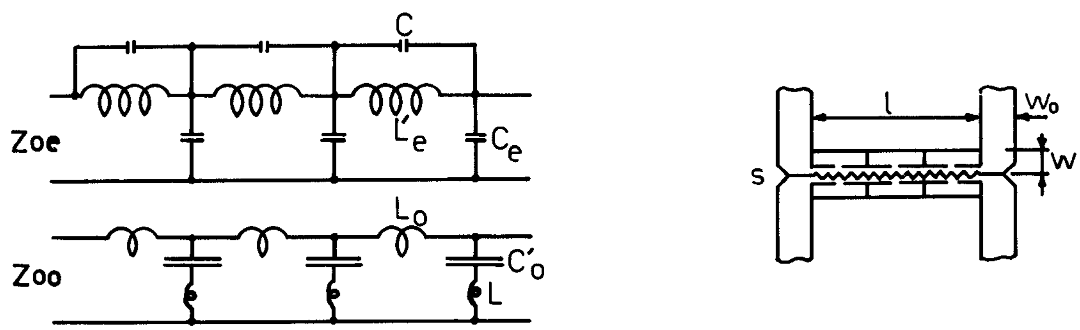

Fig.3 OCTAVE-FLAT LUMPED 2 - 4GHz 3 ± 0.2 dB

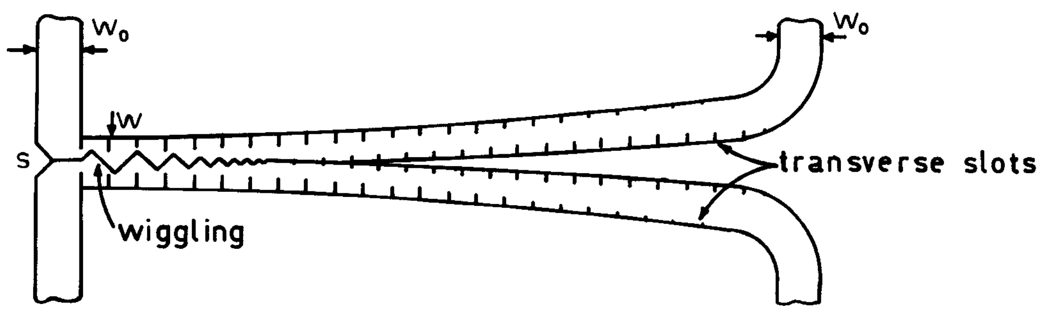

Fig.4 DECADE - WIDE ASYMMETRIC 1 - 12GHz 8.34 dB