HIGH DIRECTIVITY RF COUPLER

Paolo Antoniazzi has developed a method of producing couplers usable at gigahertz frequencies using standard low-cost fibreglass printed circuit.

At the beginning of the 1950's, a transmission line corresponding to a flattened coaxial with the sides removed was described[1]. While yielding configurations that were somewhat simpler to fabricate, this approach still required that close tolerances be maintained as in the case of coaxial construction. The relative simplicity of the parallel-line system – or stripline – suggested further study of this type or of some equivalent open system.

This work has resulted in an interesting variation of the parallel-line system which avoids the requirements for extreme accuracy and dimensional symmetry. Because of the ease of manufacture and the apparent similarity to conventional wiring, the generic name of microstrip has been given to this transmission system[2]. A cross section of the wire-above-ground system, as well as a cross section of the variation using a strip conductor – microstrip in place of the round wire – are shown in **Fig. 1**.

In the idealised case using a simple uniform dielectric and a lossless conductor, the type of transmission corresponds to the TEM mode[3,4]. This has been confirmed approximately by theoretical work and by measurements performed on practical microstrip circuits comprising composite dielectrics and finite conductor dimensions.

As the frequency is increased, however, the dispersion effect becomes more obvious, and the characteristic impedance and the phase velocity defined under the quasi-TEM analysis, **Inset 1**, must be modified.

Inset 1. TEM – Transverse-ElectroMagnetic waves. These waves are characterised by the fact that both the electric vector (E vector) and the magnetic vector (H vector) are perpendicular to the direction of propagation. This is the mode commonly excited in coaxial and open-wire lines. It cannot be propagated in a waveguide.

An important characteristic of the microstrip circuits is the power-flow distribution between the conductor and ground plane. **Figure 2** gives the calculations of the ratio of power-flow in a particular cross section to the total flow of power for a given b/h (b=width of the microstrip conductor, h=thickness of dielectric substrate).

While the distribution shown is approximate, it is possible to conclude that most of the power-flow is adjacent to the conductor. Essential characteristics necessary to design a microstrip system are shown in the box, **Figs. 3-5**. In particular using the information in Fig. 4 it is possible to design the correct length of the near λ/4 coupler, for fibreglass material about 0.5 referred to air.

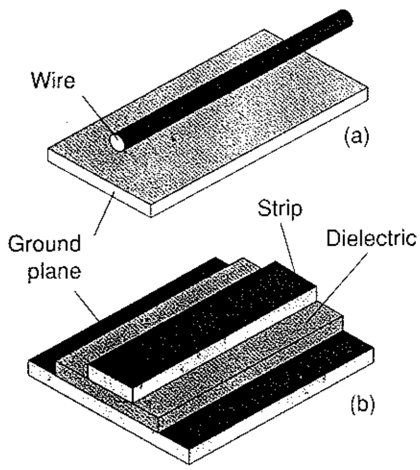

Fig. 1. Cross section of transmission systems: (a) shows the wire above ground and (b) illustrates the microstrip.

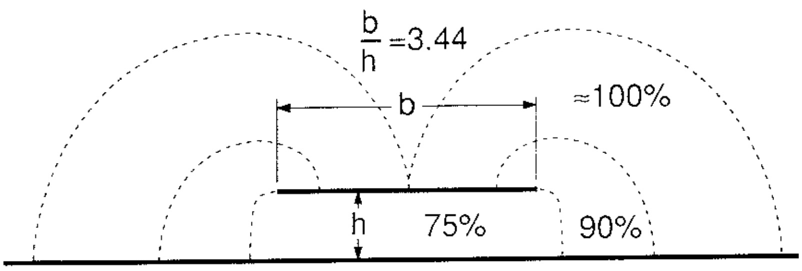

Fig. 2. Power-flow distribution in a microstrip system.

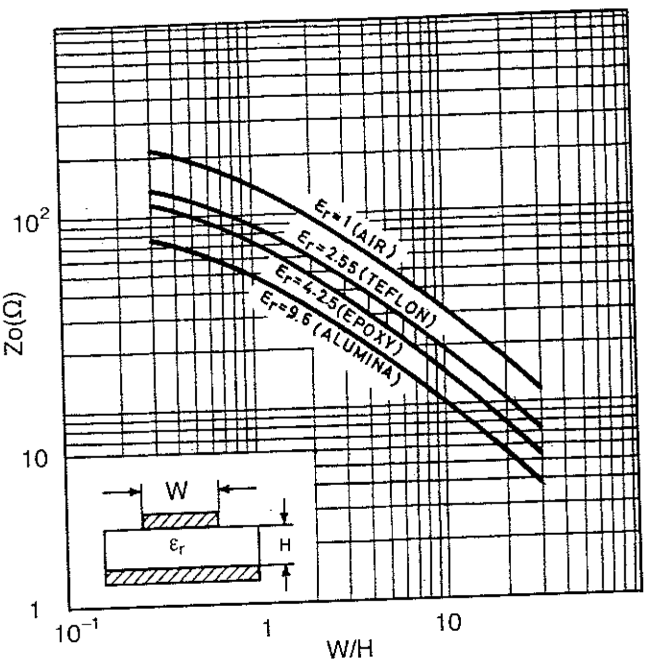

Fig. 3. Characteristic impedance versus E and W/h.

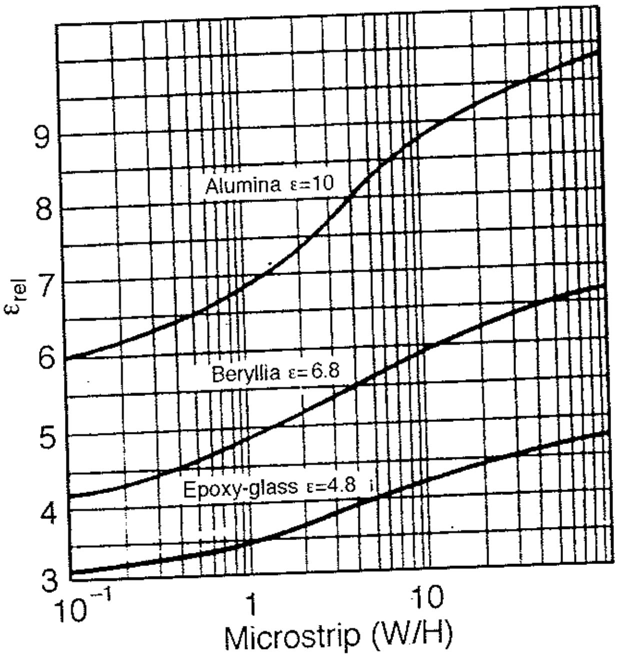

Fig. 4. Effective dielectric constant.

The directional coupler

A directional coupler is ideally a lossless reciprocal four-port device. It normally provides two unequal amplitude outputs when a signal is fed to one of its inputs. Depending on which port is fed, the outputs may be in-phase or out-of-phase (90° or 180°).

Directional couplers are usually described by indicating the coupling ratio of the low signal level output. Thus a 20dB directional coupler will provide a 'coupled' output which is 20dB below the input, while the through path (main line) has only a little loss, 0.04dB in this case. Naturally the main line loss increases for lower coupling ratios as indicated in **Table 1**.

Directional couplers can be used effectively in systems to monitor power or match, branch signals, feedback power in amplifiers and for signal injection. Designer who understand the unique features of directional couplers will find many other applications where coupler properties can solve particular system problems.

Table 1.

Coupling ratio (dB)	Coupled output (dB)	Main line loss (dB)
3	–3	3.00
6	–6	1.25
10	–10	0.46
20	–20	0.04

A directional coupler has the ability to separate and sample signal components based on the direction of signal flow. Referring to **Fig. 6**, the diagram shows a 20dB directional coupler with a signal source at Port (1).

Ports (2) and (3) are terminated in Z_o while Port (4) is loaded with an unknown impedance Z_l. We can see that if Z_l=Z_o the return loss of Z_l becomes infinite and no signal reaches Port (3). This, of course, should follow from the consideration that Ports (1) and (3) and (2) and (4) are isolated when the directional coupler is terminated with Z_o.

Practical directional couplers have finite isolation and this introduces an error in the comparative levels at Ports (3) and (2). Directional coupler directivity is a limiting parameter in the ability to accurately measure the return loss of a unknown load. As an example, if isolation (S31) is 43dB and coupling (S21) is 13dB, then directivity is 43–13, or 20dB.

The calculated error limits for a given directivity of coupler are shown in **Fig. 7** and the following Table[5]. For example, if a coupler with 25dB directivity is used to measure the return loss of an antenna for wireless LAN systems and the measured value is 22dB, then the true return loss value can be anywhere between 17.3 and 32.7dB. Inserting different lengths of cable between the coupler and the antenna quickly shows that the match is not perfect, since the readings will change. The need for higher values of directivity by simple

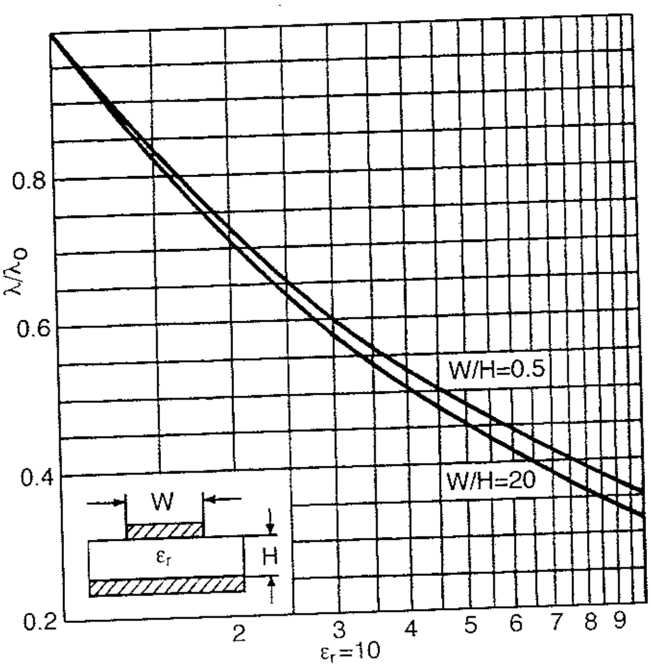

Fig. 5. Ratio of line wavelength to free space wavelength.

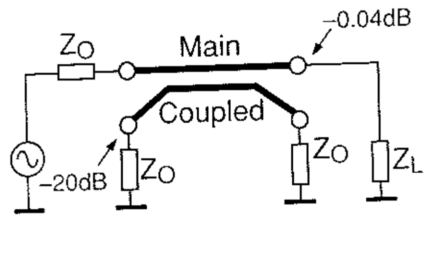

Fig. 6 Incident and reflected signal flow for a 20dB directional coupler.

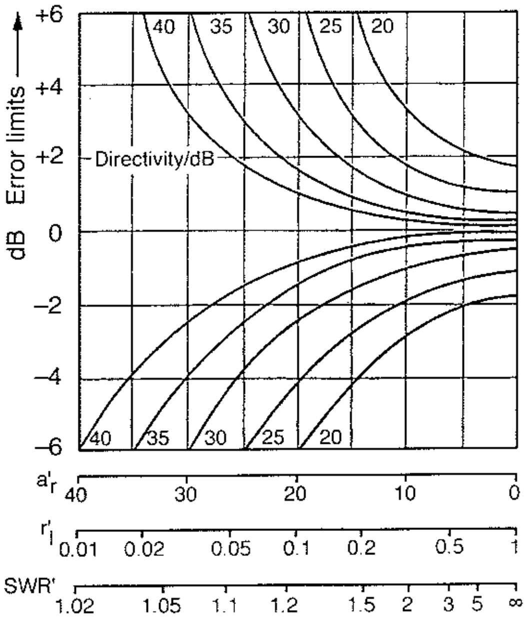

Fig. 7. Error limits due to insufficient directivity.

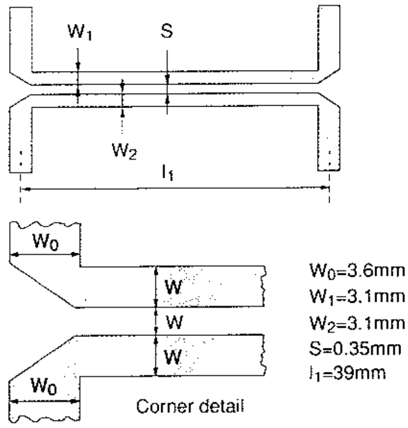

Fig. 8. Layout of the side coupled 13dB directional coupler realised with standard 1.6mm fibreglass printed circuit – dual sided.

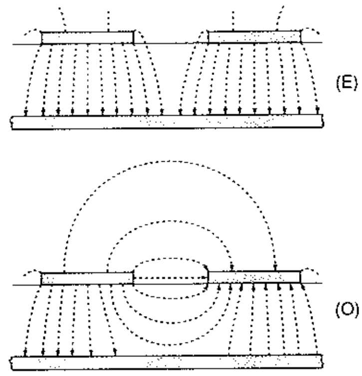

Fig. 9. Even mode (E) and odd mode (o) propagation. Electric field of the two modes.

couplers was the starting point for our experiments.

Measured return loss (dB)	Range of true return loss (dB) with 20dB Directivity	with 25dB Directivity
10	7.6 to 13.3	8.6 to 11.7
14	10.5 to 20.0	11.8 to 16.9
18	12.9 to 31.7	15.0 to 23.1
22	15.0 to 33.7	17.3 to 32.7

High directivity via standard pcb

A difficulty with stripline couplers in homogeneous dielectric, where the centre board has a lower dielectric constant than the outer boards, is that the even-mode circuit will be electrically longer than the odd-mode circuit. For side coupled microstrip directional couplers of the type shown in **Fig. 8**, the well known even-and-odd-mode theory shows different phase velocity for the even mode (E) and odd mode (O) of propagation[6].

Figure 9 shows the electric field of the two modes. The system has different values of E for the different modes of propagation, since their fields are not distributed in the same way between air and dielectric. In this way, the two modes have different phase velocity.

Taking this effect into account, we can design simple high directivity couplers. A conventional microstrip 13dB directional coupler has only 26 to 28dB of isolation (directivity of 13 to 15dB) according to our tests at 900–1200MHz, **Fig. 12**.

The measured values are in good agreement with the theory. More expensive directional couplers realised with triplate techniques or meander-folded coupled lines[7] have better directivity because of symmetrical distribution of the electric field. However, for microstrip circuits that also contain other passive or active components, this design is not practical.

The improved directivity of the coupler described in this article, with the layout of Fig. 8 and shown in photos of **Figs 10, 11**, is obtained simply by covering the central coupler structure with an unmetallized dielectric layer that consists of the same material as the microstrip substrate. This assumes standard 1.6mm fibreglass copper-clad circuit board.

Owing to this 'overlay substrate', of about 12×50mm, the electric field propagates almost entirely in an homogeneous dielectric and therefore the even and odd modes show nearly the same propagation velocity.

A comparison between conventional and 'overlay' couplers (with the same layout) is shown in Fig. 12. The reverse coupling was plotted against frequency after various adjustments of the side coupling space (s) and linewidth in the coupling zone (W_1 and W_2).

The final optimised 'overlay' coupler design shows high directivity, with reverse coupling better than 35dB in the range 950–1200MHz. The four type-N connectors – used only to permit a special high-power test – passed through the ground plane and made contact to the microstrip conductor. Compensation aluminum transitions are used in the mounting of the 'big' connectors. ■

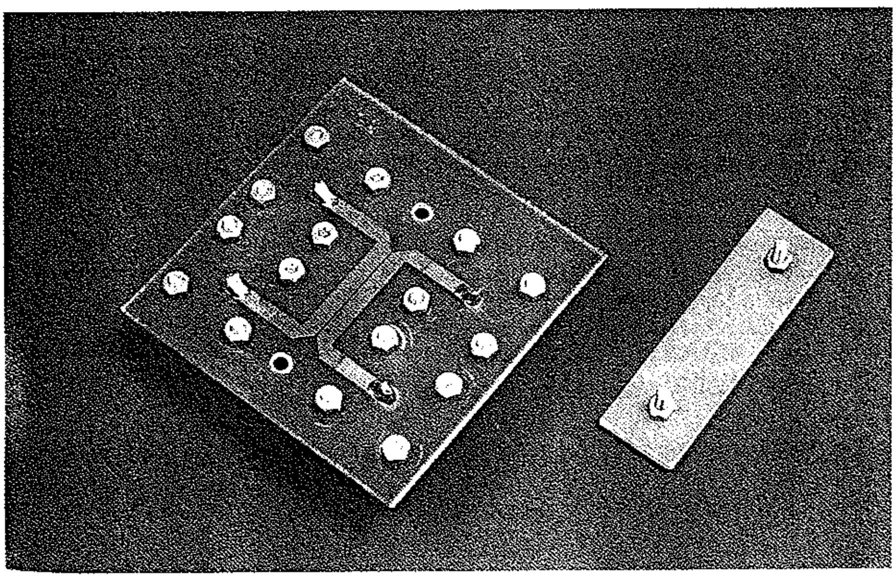

Fig. 10. Improved coupler – track side.

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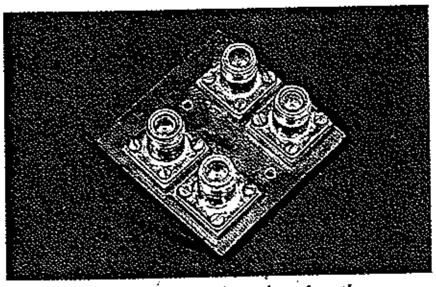

Fig. 11. Improved coupler, showing the connector layout.

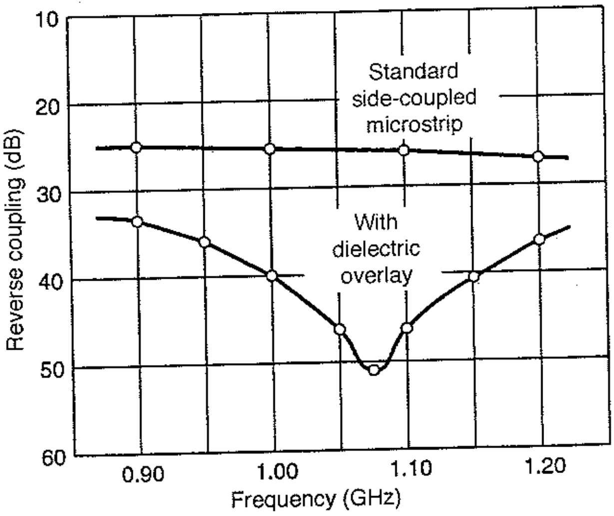

Fig. 12. Comparison between standard and 'overlay' coupler (1.6mm fibreglass, layout of Fig. 8.).

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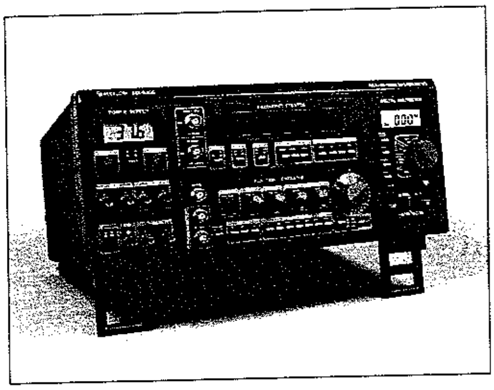

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