BROADBAND DIELECTRIC WAVEGUIDE COUPLER AND SIX-PORT NETWORK

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Abstract

A new structure of dielectric waveguide coupler and power divider has been descrived which has merits such as simple construction, flat frequency response, good repeatablity and stability. The theoretical and measurement data are given in the paper. The six-port network in which the same technique is used has been developed. The design and performance data are also presented.

Directional Coupler

The directional coupler which has compact y type structure is shown in Fig.1. It is made of two identical dielectric waveguides, coupled each other by sidewall. There is no gap between two guiders, so they can be tied up together with binder to get good repeatability and mechanismic stability. The coupling factor Kc is

$$Kc=(\beta_1-\beta_2)/2 \qquad (1)$$

where β_1, β_2 are the propergation constants of symmetrical and antisymmetrical mode respectively, or, the fundamental and second mode if we regard the two waveguides as one.

The coupling length of 3dB coupler is:

$$L_{3dB}=\pi/Kc \qquad (2)$$

Because of large aspect ratio of the guides, the effective dielectric constant approach can be used for enough accuracy.

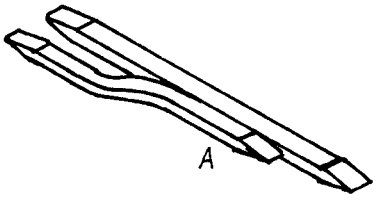

Fig.1 Directional Coupler

We can make the frequency response of coupler flatter by methods as described following:

1) Select optimal structure parameters of coupler such as dielectric constant ε_r, or cross section of waveguides. The strong coupling where the gap between waveguides is zero can offer broadband performance, because it's coupling doesn't depend on evanenscent field. In strong coupling, if we select proper cross section, we can get flatter frequency response. In Fig.2 are shown several calculated curves of different cross section, their dielectrical constant ε_r is 2.5 (Polystrene) Among these curves, curve (1) is a satisfied one.

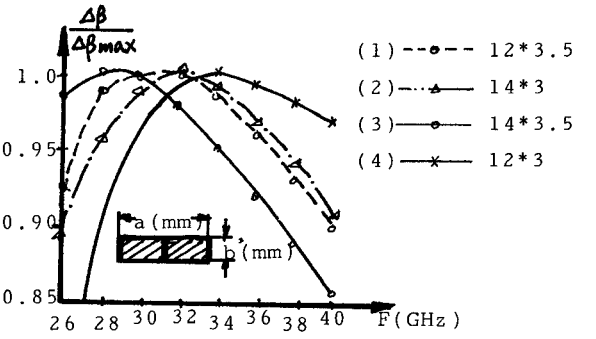

Fig.2 Normalized coupling factor Kc

2). Take y type structure.

The part A in Fig.1 is a port of coupling waveguide, which take the shape of taper in E-plane. It acts as a matched load. So we can save a connecting arm which usually makes frequency response worse.

3). Taper in E-plane.

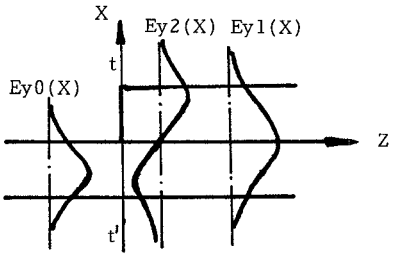

Fig.3 The modes of a coupler

When input wave comes to the taper A, the fundamental mode in single waveguide becomes symmetrical and antisymmetrical mode in coupled waveguides as shown in Fig.3. The abruptly change of shape in t-t' plane can stimulate enough antisymmetrical mode to get correct coupling. The numerical analysis can be carried on by mode matching technique. The taper in E-plane can

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reduce the reflection to a level that can be neglected.

The measurement performance of 3dB coupler is shown in Fig.4 The cross section and coupling length of this coupler is same as curve (1) in Fig.2. In the frequency range from 28 to 38 GHz, the coupling unflatness is less than 1dB.The loss of launching, mode transforming and loss of dielectric waveguide is about 1dB.

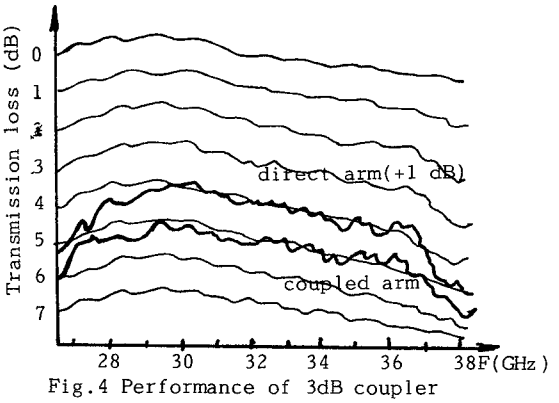

Fig.4 Performance of 3dB coupler

The coupling coefficient of a coupler can be changed by changing its coupling length, not necessary to change its cross section, so the frequency response can be kept unchanged almostly. In Fig.5 is shown the performance of 6dB coupler.

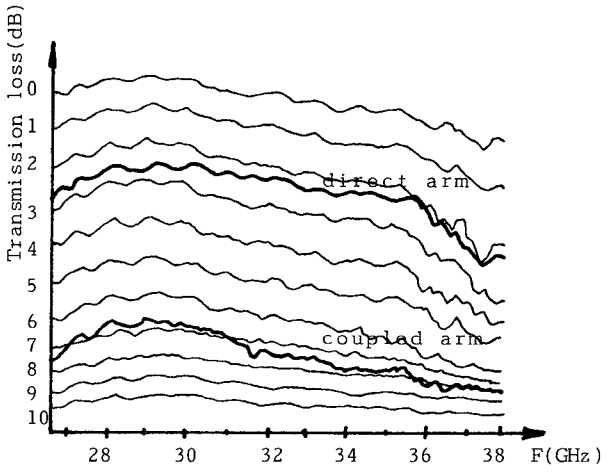

Fig.5 Performance of 6dB coupler

When coupler is used in 6-port network, the phase relationship of two output arms is very important.

If we take assuming that field distribution is sine-shaped in the dielectric and exponential-shaped in the air as shown in Fig.6, the phase-relation can be formulized as following:

The field on coupling area can be expressed as:

$$Ey(x,z)=C_1 Ey_1(x)*\exp(j\beta_1 z)+C_2 Ey_2(x)*\exp(j\beta_2 z) \quad (3)$$

where z is the distance from t-t' plane, C_1, C_2 are mode's amplitudes. So the phase of each point in x,z plane is (when z fixed, $z=z_0$):

$$\varphi(x,z_0)=\tan^{-1}\left(\frac{C_2 Ey_2(x)\sin(\beta_1-\beta_2)z_0}{C_2 Ey_2(x)\cos(\beta_1-\beta_2)z_0+C_1 Ey_2(x)}\right)-\beta_1 z_0 \quad (4)$$

When coupling is weaky, we assume that

$C_1 \doteq C_2$, $|Ey_1(x)| \doteq |Ey_2(x)|$

so that,

$$\varphi(x,z_0)=\tan^{-1}(1/(\mathrm{ctan}(\beta_1-\beta_2)*z_0 \pm 1))-\beta_1 z_0 \quad (5)$$

The phase distribution va.distance from center of coupling waveguides is shown in Fig.7.

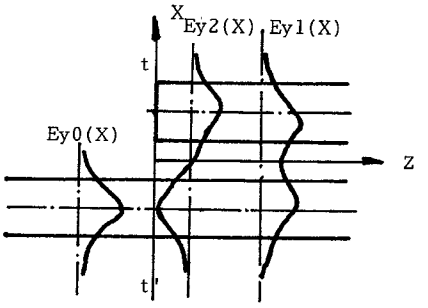

Fig.6 Field distribution on the coupler

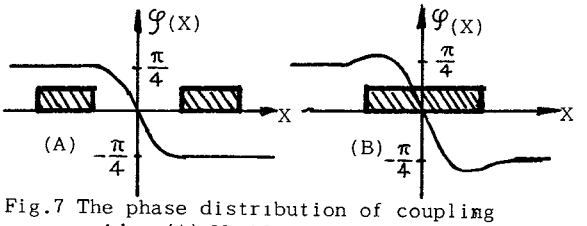

Fig.7 The phase distribution of coupling waveguides (A) Weakly coupling (B) Strong coupling

The phase difference between two output arms is (weak coupling):

$$\Delta\varphi=\tan^{-1}\left(\frac{\sin((\beta_1-\beta_2)l)}{\cos((\beta_1-\beta_2)l)+1}\right)-\tan^{-1}\left(\frac{\sin((\beta_1-\beta_2)l)}{\cos((\beta_1-\beta_2)l)-1}\right)$$

$$=\pi/2 \quad (6)$$

In strong coupling case, the phase difference is approximate 90°,which is identified by measurement as shown in Fig.8.

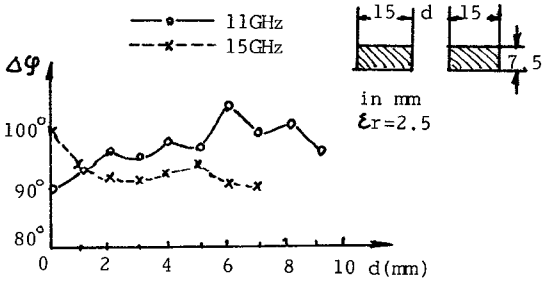

Fig.8 Phase difference between two output arms vs. distance d

Power Divider

Compact Y type power divider is sketched in Fig.9. It is composed of three identical rectangular dielectric waveguides. Both gaps between them are zero, so we can regard the three coupling guides as one.

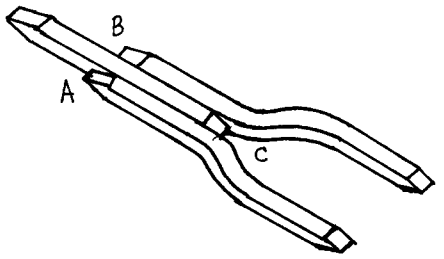

Fig.9 Power Divider

The field on the coupling area can be decomposed into fundamental and third mode, the transverse distribution of them are shown in Fig.10.

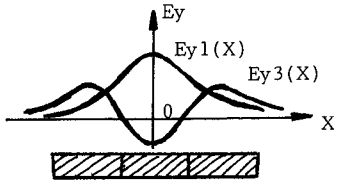

Fig.10 Fundamental and third mode of coupling dielectric waveguides

The field in coupling erea is:

$$Ey(x,z)=C_1 Ey_1(x)\exp(j\beta_1 z)+C_3 Ey_3(x)\exp(j\beta_3 z) \quad (7)$$

The sketch of measured field distribution of power divider is shown in Fig.11. If we properly select the coupling lenth,we can get the desired coupling.

The coupling factor Kd is:

$$Kd=(\beta_1-\beta_3)/2 \quad (8)$$

where β_1,β_3 are the fundamental and third mode's propergation constants, which can be calculated by effective dielectric constant method. Some results are shown in Fig.12.

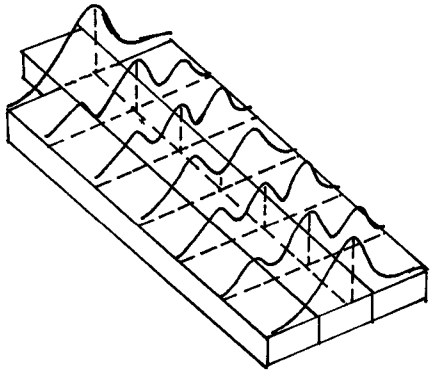

Fig.11 Distribution of Ey(X,Z) of power divider

For the similar reasons as in the case of coupler,this structure is also a broadband one. If we let power divider as the structure as in Fig.9 , where tapers A,B,C act as matched loads, we can make the frequency response flatter.

The coupling length of divider,different from coupler, is:

$$L_{3dB}=2\pi/Kd \quad (9)$$

In this length the loss of divider is minimum.

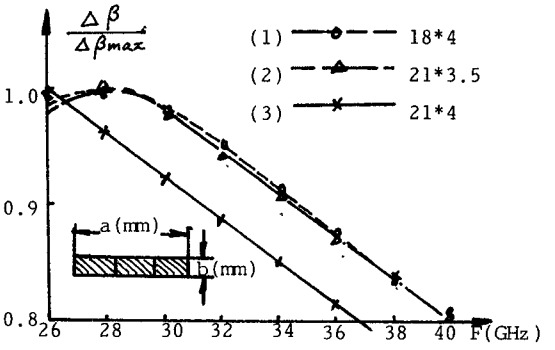

Fig.12 Normalized coupling factor Kd

Six-port Network

The circult of six-port network is shown in Fig.13, the prototype of which is recommend by Engen[4] .The dielectric material is polystrene, the cross section is $3.5*6mm^2$. The launchers are metal rectangular horns, the ends of waveguide are tapered, and inserted into the horn. Because of strong coupling, the length of coupler becomes shorter, so the size of six-port network becomes smaller, all of the devices can be linked up together and putted in a box of size $180*300*30mm^3$,suported by foam polystyrene.

The Q-point of six-port network is depended on coupling of each coupler and power divider, because it is very easy to change the coupling coefficient, namely, only changing the coupling length of the coupler,we can adjust them to proper values, and get desired Q-point distribution easily.

The measured data of Q-point are shown in Table 1.

Acknowledgment

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An Altemative Network Analyzer"
IEEE MTT-25,No.12,1977

Freq.(GHz)	Q1	Q2	Q3	Q4
31	3.95∠-37°	4.43∠120°	3.23∠204°	114∠157°
32	2.99∠90°	2.69∠225°	1.90∠-63°	12∠226°
33	2.04∠190°	3.44∠-33°	2.72∠54°	15∠210°
34	2.31∠-15°	3.18∠132°	2.30∠199°	53∠54°
35	2.02∠85°	2.79∠227°	2.10∠270°	16∠243°
36	1.62∠220°	2.61∠14°	2.65∠64°	6.2∠18°

Table 1 Q-point of Six-Port Network

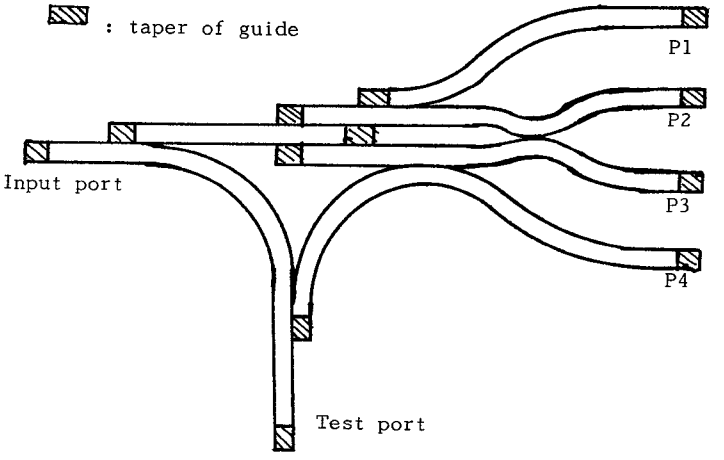

Fig.13 The six-port network