Analytical Study of Reflection and Transmission Coefficient of Planar Structures Using Transmission Line Models

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ABSTRACT - An ideal microstrip directional coupler makes use of the basic features that power flowing in one direction in the main microstripline induces a power flow in the second line in the forward direction or in the reverse direction. The coupling characteristics & reflected waves depend on the microstrip width, spacing between two microstrip and operating frequency. In the coupler some power flowing in the system gets reflected back. So it is necessary to calculate reflection coefficient & hence VSWR & its variation with stripwidth, spacing & frequency which is the aim of the present paper.

KEYWORDS: MSL, VSWR, MICROWAVE

I. INTRODUCTION

Natural coupling exists when two transmission lines are placed in close proximity parallel to each other. Such coupling is possible in varieties of transmission structures like transmission lines, waveguides or striplines, microstriplines, slotlines or any other planar transmission structures are placed with their sides parallel to each other, mutual coupling exists between them. Power flowing in one line will be coupled to each other line & vice-versa. When the coupled power flows in the direction of incident power in the same phase the coupling is forward and when the coupled power flows in the direction opposite to the incident power, the coupling is backward. The forward coupling is treated as propagation of power in the even mode of wave propagation and the backward coupling as the odd-mode of wave propagation. [1-4]. Such coupled transmission lines are used in various microwave circuits such as (i) Directional coupler (ii) Filters and (iii) Impedance transformers etc. The present chapter is devoted to the study of characteristics of microstripline coupler or directional coupler, reflection coefficient and hence the voltage standing wave ratio (VSWR) and their variations with strip geometries, spacing & operating frequency [5,6].

II. MICROSTRIPLINE DIRECTIONAL COUPLER

It is a four port network commonly used for sampling a known fraction of microwave power flowing in a particular direction. Fig 1 depicts a block diagram of the directional coupler [7-9].When a wave travels from port-1 to port-2, a fixed fraction of this power appears at port-4 and there is no power at port-3. Port-4 is coupled, called desired (coupled) port & port-3 is called isolated (undesired) port. Conversely, if the wave travels from port-2 to port-1, a fraction of this signal appears at port-3 (called coupled port) & no signal will appear at port-4 (called isolated port).

III. MULTIHOLE DIRECTIONAL COUPLER

The most common type of the wave guide directional coupler is made of two wave guides placed adjacent to each other with one wall common as shown in fig 2. There are two holes A & B in the common wall. If a signal is pressed at port-1 of the one waveguide some fraction of the signal will be coupled to the side waveguide. The distance between two holes is $\lambda/4$. Each of the holes excites two waves, one traveling towards left and other towards right. Because of $\lambda/4$ spacing between two holes, the two waves traveling towards left are out of phase by 180^0 and cancel each other. On the other hand the two waves traveling towards right are in phase and reinforce each other. Thus out power appears on right hand side at port-4 called coupled port and no power appears at port-3 on left hand side. This port -3 is called isolated port. The power coupled to the port-4 depends on the size and the position of the holes in the common wall of the directional coupler. The two holes coupler described above works satisfactorily only at a single frequency corresponding to quarter wave spacing between the holes. The band width of the directional coupler can also be enhanced by using multi pairs of coupling holes. The characteristic of the directional coupler can be expressed through S-matrix.When all four ports of the directional coupler are matched the scattering matrix for the network is expressed as

 DOI : 10.18231/2454-9150.2018.1277

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix} \quad \text{--------------- (1)}$$

In writing equation-1 complete isolation between ports 1 & 3 and ports 2 & 4 has been considered. Also the reciprocal nature of the network has been taken into account. By considering the unity property of S-matrix for lossless network we have

$$S_{12} S_{12}^* + S_{14} S_{14}^* = 1 \quad \text{--------------- (2)}$$
$$S_{12} S_{12}^* + S_{23} S_{23}^* = 1 \quad \text{--------------- (3)}$$
$$S_{23} S_{23}^* + S_{34} S_{34}^* = 1 \quad \text{--------------- (4)}$$
$$S_{14} S_{14}^* + S_{34} S_{34}^* = 1 \quad \text{--------------- (5)}$$

From equation (5.3.2) & (5.3.3) we get

$$|S_{14}| = |S_{23}| \quad \text{--------------- (6)}$$

From equation (5.3.4) & (5.3.5) we get

$$|S_{12}| = |S_{34}| \quad \text{---------------- (7)}$$

At this stage we make use of an artifice which is commonly implied to change the phase angle of the coefficients of S-matrix. The phase angle of S_{mm}'s may be changed by adding a section of the wave guide at various ports. By choosing reference plane of port-1 with respect to reference plane of port-2 we can make S_{12} real. In the similar manner S_{34} can be made real by selecting suitably the reference plane of port-3 with respect to that of port-4.

$$S_{12} = S_{34} = \alpha \quad \text{--------------- (8)}$$

Also the characteristic of a loss less network is expressed as

$$S_{12} S_{23}^* + S_{14} S_{12}^* = 0 \quad \text{--------------- (9)}$$

Since S_{12} is real

$$S_{23}^* + S_{14} = 0 \quad \text{-------------- (10)}$$

Also we can further select plane of port-4 with respect to port-1 such that S_{14} is real. In this case we write

$$S_{23} = -S_{14} = \beta \quad \text{-------------- (11)}$$

Thus euation-1 can be written as

$$S = \begin{bmatrix} 0 & \alpha & 0 & -\beta \\ \alpha & 0 & \beta & 0 \\ 0 & \beta & 0 & \alpha \\ -\beta & 0 & \alpha & 0 \end{bmatrix} \quad \text{--------------- (12)}$$

Here coefficient α and β are related by the equation

$$\alpha^2 + \beta^2 = 1 \quad \text{---------------- (13)}$$

Further α is called transmission factor and β is called coupling factor of the directional coupler.

IV. DIRECTIVITY (D) OF MICROSTRIPLINE COUPLER

It is the measure of discrimination of a directional coupler between forward and backward waves and is defined as the ratio of the voltage coupled to the desired port-4 and the voltage coupled to the undesired port-3 i.e.

$$D = V_4 / V_3$$
$$D = P_4 / P_3 \quad \text{--------------- (14)}$$

= Power at desired port-4 / Power at undesired port-3

D is measured in dB & then expressed as

$$D_{(dB)} = -20\log_{10}[V_4 / V_3]$$

Or $$D_{(dB)} = 10\log_{10} [P_4 / P_3] \quad \text{-------------- (15)}$$

 DOI : 10.18231/2454-9150.2018.1277

For an ideal forward directional coupler D is infinity i.e. voltage at port-3 should be zero. The signal is coupled only to port-4. Port-2 and port-4 are perfectly matched.

V. Coupling Co-efficient of the Coupler

It is defined as the ratio of voltage (or power) at input port-1 to the voltage (or power) at output (desired) port-4 and is written as

$$C = V_1/V_4$$

Or $C = P_1/P_4$ --------------- (16)

It is also expressed in dB.

$$C = -20\log_{10}[V_1/V_4]$$

$$C = 10\log_{10}[P_1/P_4]$$

C and D are the two characteristic factors of directional coupler.

The other factors of the coupler are reflection co-efficient and transmission coefficient which will be discussed in the following section 6.

VI. Reflection and Transmission Coefficient of the Coupler

The phenomenon of setting up of a reflected wave at the load due to improper termination or due to impedance irregularity in a line is called Reflection.Reflection co-efficient is defined as the ratio of reflected voltage or current to the incident voltage or current. It is usually denoted by 'k' while dealing with voltage, we called voltage reflection-coefficient and while dealing with current we called as current reflection co-efficient.

$k = V_r / V_i$ --------------(18)

$k = - I_r / I_i$ -------------(19)

where,

V_r and I_r be the reflected voltage and current and V_i and I_i be the incident voltage and current.

Expression for the reflection and transmission coefficient

From the fundamental equations of the transmission line at any point is given by

$$V = A e^{-Px} + B e^{Px}$$

$$I = \frac{1}{Z_0} [\underset{I}{A e^{-Px}} - \underset{II}{B e^{Px}}]$$

First term I represent the incident wave and second II term represent the

reflected wave. Let y be the distance measured from the terminated load impedance Z_R then above equation can be expressed in terms of the y by putting $x = -y$

$$V = A e^{Py} + B e^{-Py}$$

$$I = \frac{1}{Z_0} [A e^{Py} - B e^{-Py}]$$

When $y = 0$ i.e. at receiving end

$$V = V_R \text{ and } I = I_R$$

$$V_R = A + B$$

$$I_R = A - B / Z_0$$

$$Z_0 I_R = A - B$$

And hence

$$A = (V_R + Z_0 I_R) / 2$$

And $B = (V_R - Z_0 I_R) / 2$

By definition of reflection coefficient

$$k = V_r / V_i$$

$$k = B e^{-Py} / A e^{Py}$$

$$k = (B/A) e^{-2Py}$$

At the termination Z_R , $y = 0$, therefore,

$$k = B / A$$

$$k = \frac{V_R - Z_0 I_R}{V_R + Z_0 I_R} \quad \text{---------(17)}$$

$$k = \frac{Z_R - Z_0}{Z_R + Z_0} \quad \text{------(20)}$$

Hence reflection coefficient can be calculated if the load impedance Z_R and characteristic impedance Z_0 is given.

VII. Formulation of the Reflection and Transmission Coefficient in Case of Even and Odd-Modes

During the propagation of wave through the transmission coupled structure some part of wave coupled in same phase and some in opposite phase. Hence there are two modes of wave propagation known as even and odd-mode respectively. The wavelengths have different values in these modes and these play an important role in determining the reflection and transmission coefficients. If λ_{ge} and λ_{go} are the wavelengths in even and odd-modes respectively then Z_{oe} and Z_{oo} are the respective impedances and Z_o denotes the characteristic impedance of the isolated microstripline structure then λ_{ge} is given by (300/f) x (Z_{oe} / Z_o) and λ_{go} is given by (300/f) x (Z_{oo} / Z_o)[7].

The reflection coefficient for even-mode propagation is given by

$K_{re} = Z_{oe} - Z_o / Z_{oe} + Z_o$ -----(21)

and The reflection coefficient for even-mode propagation is given by

$K_{ro} = Z_{oo} - Z_o / Z_{oo} + Z_o$ ----(22)

Transmission coefficient for even and odd-modes are given by

$K_{te} = 2.Z_{oe} / Z_{oe} + Z_o$ ------------- (23)

and

$K_{to} = 2.Z_{oo} / Z_{oo} + Z_o$ ------------- (24)

respectively. Where,

$Z_o = \sqrt{(Z_{oe} \text{ x } Z_{oo})}$ -------------- (25)

The characteristic impedance for even and odd-modes have all ready been studied. The values of characteristic impedances are employed for the study of reflection and transmission coefficients which will be studied in following sections.

DOI : 10.18231/2454-9150.2018.1277

VIII. STUDY OF DEPENDENCE OF REFLECTION COEFFICIENT AND TRANSMISSION COEFFICIENT ON STRIPWIDTH

As per definitions of the reflection and transmission coefficients the characteristic impedance for even and odd-modes of propagations and their geometric mean play an important role for the study of these coefficients. Evidently these are the functions strip geometries, substrate permittivity and operating frequencies. We have concentrated our study of dependence of reflection and transmission coefficients on the stripwidth and spacing between two metal strips. The results of chapter 4 have been also used here. On the basis of computed results various manual calculations have been carried out for different stripwidth keeping spacing between two strips fixed. The results have been placed in table 1 and graphs have been plotted keeping stripwidth on x-axis and reflection and transmission coefficients on y-axis as shown in graph 1. The results shows that as metal stripwidth increases reflection coefficient both in even-mode and odd-modes decreases where as transmission coefficient increases with increase of metal stripwidth. This shows concentration of flux is larger in case of wider strip than that for thinner strips and flow of power through the strip in the forward direction both for even and odd-modes is larger than in the reverse direction. As a result transmissivity is always greater than the reflectivity for all metal stripwidth. The result is also converging both in case of even and odd-modes for wider strips.

IX. STUDY OF DEPENDENCE OF REFLECTION AND TRANSMISSION COEFFICIENT ON SPACING BETWEEN TWO METAL STRIPS

Reflection and transmission coefficient for even and odd-modes are related with characteristic impedance of the transmission structures which are the functions of the geometry of the structures such as metal stripwidth, height of the substrate and the spacing between two metal strips. In section 1 dependence of these coefficients on stripwidth was studied. Now dependence of these coefficients on spacing between two metal strips is to be dealt with. For these purpose exhaustive manual calculations have been carried out for different values of spacing. Results obtained have been placed in table 2. Keeping spacing on x-axis reflection and transmission coefficients for even and odd-modes both on y-axis graphs have been plotted as shown in graph 2. It is obvious that reflectivity decreases with increase of spacing between two metal strips in case of even-mode and odd-mode both. Whereas, transmission coefficient increases with increase of spacing between two metal strips for even and odd-mode both. It is also noted that reflectivity for odd-mode is greater than that in even-mode for a given stripwidth and spacing. Further it has been observe that for higher value of spacing reflection and transmission coefficient are almost identical for even and odd-mode both.

X. STUDY OF DEPENDENCE OF REFLECTION AND TRANSMISSION COEFFICIENT ON PERMITTIVITY

Reflection and transmission coefficients of the transmission structure are dependent on characteristic impedance for even and odd-modes of propagation. These coefficients are thus basically dependent on the nature of the substrate material. For the study of dependence of these coefficients on permittivity exhaustive manual calculations have been carried out for different substrates and the results have been placed in table 3. Taking the relative dielectric permittivity on x-axis and reflection and transmission coefficients on y-axis graphs have been plotted as shown in graph 3. From the result it is obvious that reflection coefficients decreases with increase of relative permittivity both for even and odd-modes of propagation, where as transmission coefficient increases with increase of relative permittivity for a given values of metal strip width and spacing between two metal strips of the given coupled structure. Thus the flux linked with the transmission structures in the reflected part is smaller where as that linked with the transmitted part is greater both for even and odd-modes and become larger and larger as relative permittivity used is higher.

XI. DISCUSSION AND CONCLUSION OF THE RESULT

As above discussion we concluded that the characteristic parameters such as characteristic impedance, phase velocity and guide wave length are the functions of geometries of the structures and the relative permittivity of the substrate used. This discussion concludes that the energy flux linked with the coupled structures is greater for wider stripwidth and wider spacing in case of even-mode than that in odd-mode. On the basis of these studies reflections and transmission coefficients have been studied in this paper. The variation of theses coefficients with metal stripwidth, spacing between two metal strips and relative permittivity have been studied and discussed. The discussion shows that reflection coefficients for narrow metal strips and narrower spacing is greater than that in wider stripwidth and spacing which shows that energy flux is greater in the reflected part than that of wider strip and spacing. The transmission coefficient both for even and odd-modes are greater in case of wider strip and spacing. This concludes more and more power get transmitted in wider metal strip and spacing. These studies are more useful for the design of different microwave components such as microstrip isolator, circulator and directional coupler etc. With the help of

 DOI : 10.18231/2454-9150.2018.1277

this study the power flow can be also be controlled by suitable choice of the design structure, and substrate material and frequency. There is better scope of study of microwave components and their characteristics in future.

Table No. 1 Dependence of reflection and transmission coefficient on strip width

f = 2GHz, t = 0.05 mils, s = 10 mils, ϵ_r = 9.6

w	Even-mode		Odd-mode	
	K_{re}	K_{te}	K_{ro}	K_{to}
10	0.26	0.74	0.27	0.73
30	0.23	0.77	0.25	0.75
50	0.22	0.78	0.24	0.76
70	0.21	0.79	0.22	0.78
90	0.20	0.80	0.20	0.80

Table No. 2 Study of dependence of reflection and transmission coefficient on spacing between two metal strips

f = 2GHz, t = 0.05 mils, w = 10 mils, ϵ_r = 9.6

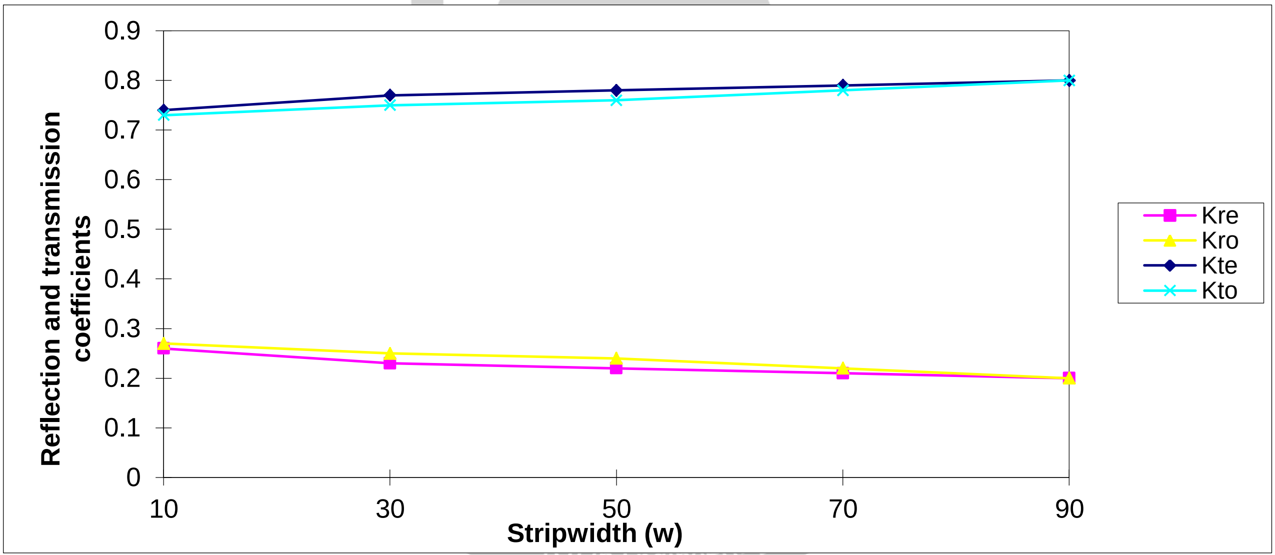
s (mils)	Even-mode		Odd-mode	
	K_{re}	K_{te}	K_{ro}	K_{to}
10	0.26	0.74	0.27	0.73
20	0.22	0.78	0.25	0.75
50	0.13	0.86	0.15	0.85
100	0.06	0.94	0.07	0.93

Table No. 3 Dependence of reflection and transmission coefficients on permittivity

f = 2GHz, t = 0.05 mils, w = 10 mils

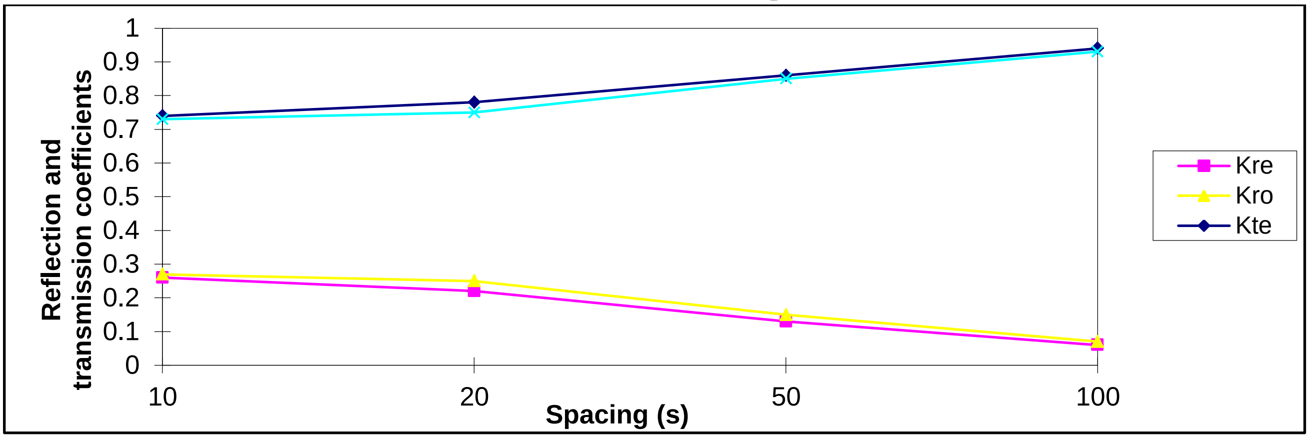
ϵ_r	Even-mode		Odd-mode	
	K_{re}	K_{te}	K_{ro}	K_{to}
2.5	0.084	0.916	0.086	0.914
9.6	0.075	0.925	0.078	0.922
16	0.067	0.933	0.070	0.930
18	0.060	0.940	0.063	0.937

Graph No. 1 Dependence of reflection and transmission coefficient on strip width



Graph No. 2

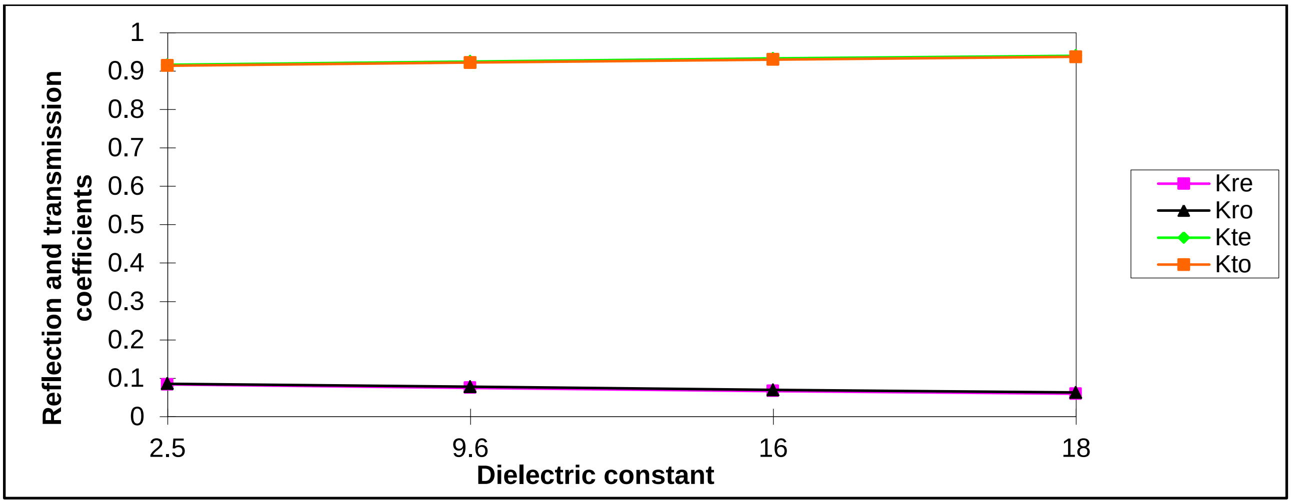
Study of dependence of reflection and transmission coefficient on spacing between two metal strips



Graph No. 3

Dependence of reflection and transmission coefficients on permittivity

 DOI : 10.18231/2454-9150.2018.1277



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 DOI : 10.18231/2454-9150.2018.1277