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ANALYSIS OF THE INPHASE FERRITE -LOADED POWER COMBINER/DIVIDER

by

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ABSTRACT

Transmission line analysis of the inphase ferrite - loaded power combiner/divider (PC/D) is given culminating in several conclusions which are useful in the design of such devices. It is also concluded that, when the electrical length of the circuit equals half a wavelength of operation, it can be used as a directional coupler. Furthermore, a modification of the said combiner/divider is reported to offer encouraging performance characteristics.

1.0 INTRODUCTION

Ferrite-loaded power combiners have been used in providing high powers for transmitters for long but little on the analysis of such devices has been reported. Recently (1-5) it has been shown that transmission line transformers, constructed in the same way as ferrite-loaded power combiners, behave as ordinary transmission lines at high frequences where the self inductance and the interwinding capacitance of the windings form tha primary constants of the transmission line.

In the analysis of the transmission line transformers, the distributed parmeter approach has been effectively used to give an indepth understanding of their behaviour.

In this paper, the transmission line analysis is therefore used for tha inphase ferrite-loaded PC/D (Fig.1) with the following assumptions :-

1. the reactance of the two bifilar windings for each transmission line $X_L >> R_L$ (where R_L is the resistance of the input ports)
2. the referred equivalent core resistance $R_m >> R_L$
3. at the analysis frequencies, the transmission line is lossless (i.e. the copper and the dielectric losses are negligible).

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As a result of the analysis several conclusions are made.

A modification to the combiner/divider is suggested in section 3 consisting of a cascade of two transmission lines with different characteristic impedances. The performance characteristics of this network are also compared to those of the parent network.

For both the two cases, plots of insertion loss and isolation characteristics of the combiners/dividers will be given in the frequency range from 0./01 fmax to fmax, where fmax is the maximum frequency of operation.

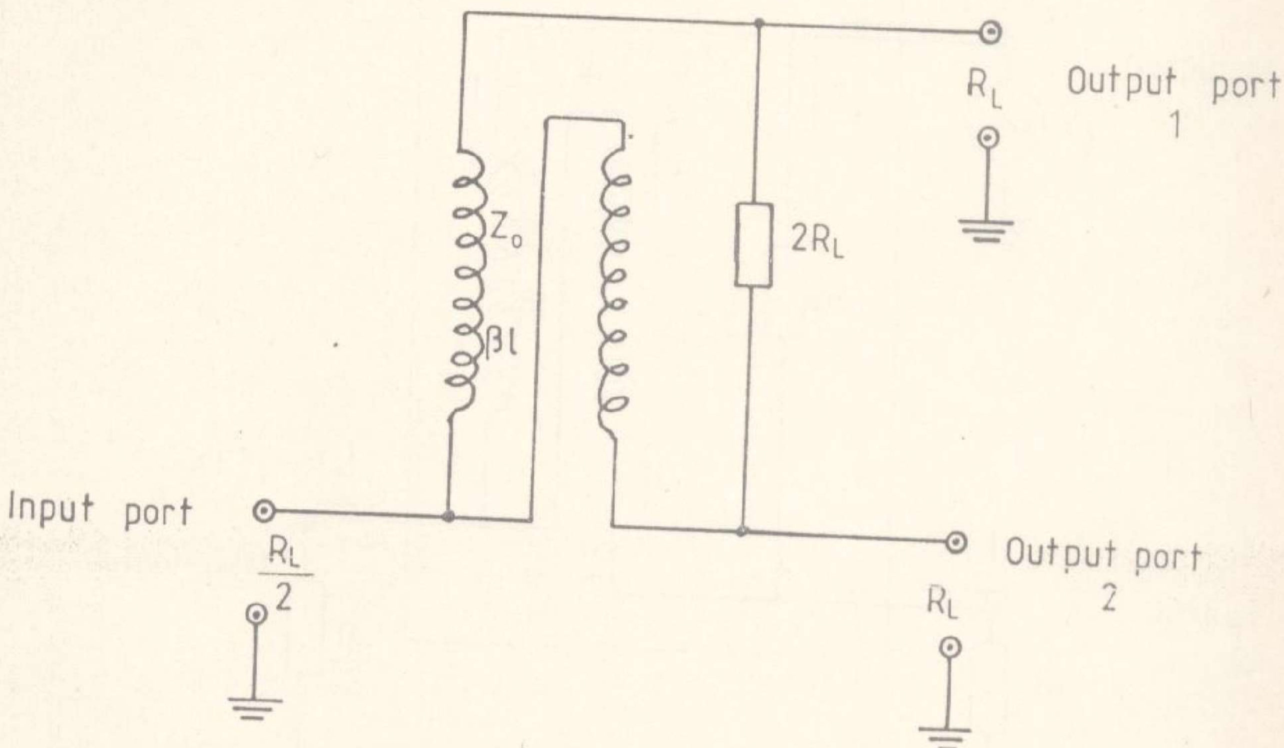

Fig. 1: Inphase Ferrite Loaded PC/D Circuit arrangement

2.0 ANALYSIS OF THE BASIC INPHASE FERRITE-LOADED PC/D

Fig. 2 shows the circuit arrangement of the PC/D drawn to determine the isolation between the output ports.

Referring to the above mentioned figure, by inspection, the network is fully described by the following five equations:-

$$V_g = V_1 + (I_1 + I_2)R_L/2 \qquad (1)$$

$$0 = (I_1 + I_2)R_L/2 - V_2 - (I_3 - I_2)R_L \qquad (2)$$

$$V_g = I_3(2R_L) + (I_3 - I_2)R_L \tag{3}$$

$$V_1 = V_2 \cos\beta l + j(J_2/Z_0)\sin\beta l \tag{4}$$

$$I_1 = I_2 \cos\beta l + J(V_2/Z_0)\sin\beta l \tag{5}$$

where Z_0 - characteristic impedance of the line

$\beta = 2\pi/\lambda$ - phase constant of the line,

λ - wavelength of operation,

l - length of the line.

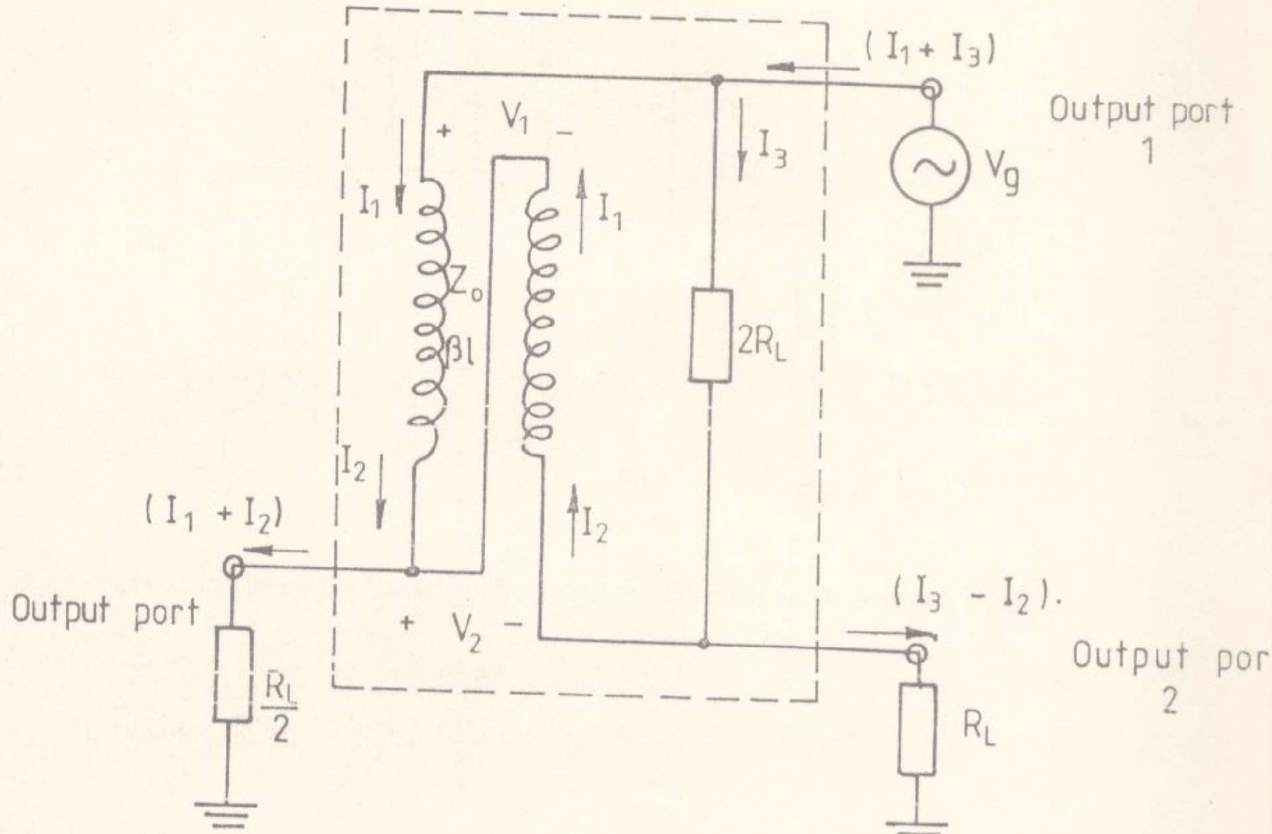

Fig.2: Basic Inphase-Loaded PC/D: circuit arrangement for determining isolation.

From the above five equations, the isloation of the PC/D can be easily found to be :

$$\text{Isolation} = 20\log_{10} \left| \frac{V_g}{(I_3 - I_2)R_L} \right| =$$

$$= 10\log_{10}\left[\frac{(3+5\cos\beta l)^2 + (R_L/Z_0 + Z_0/R_L)^2\sin^2\beta l}{(1-\cos\beta l)^2 + (R_L/Z_0 + Z_0/R_L)^2\sin^2\beta l}\right] \tag{6}$$

The insertion loss of the PC/D can be found using Fig. 3, whereby the following equation can be written by inspection :-

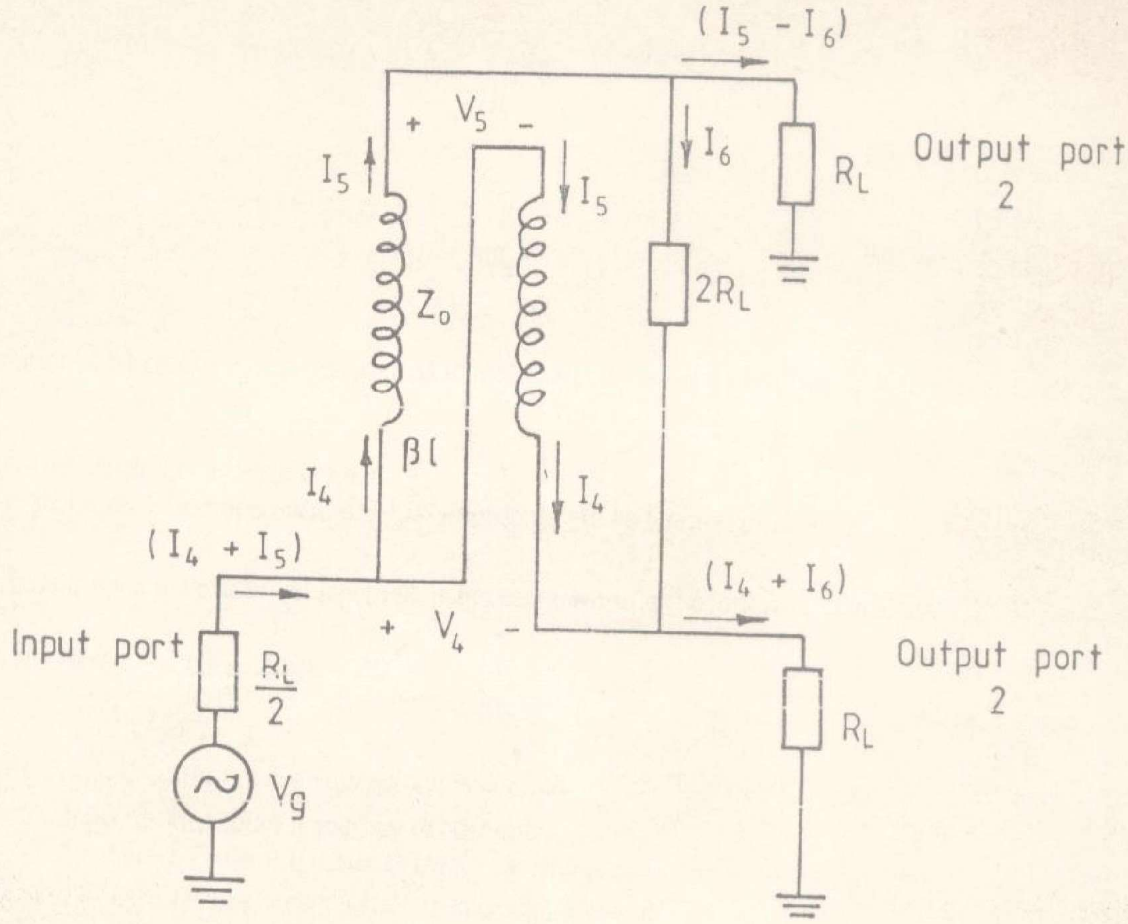

Fig.3: Basic Inphase Ferrite-Loaded PC/D: circuit arrangement for determining insertion loss.

$$V_g = (I_4 + I_5)R_L/2 + V_4 + (I_4 + I_6)\ R_L \qquad (7)$$

$$V_g = (I_4 + I_5)R_L/2 - V_5 + (I_5 - I_6)R_L \qquad (8)$$

$$0 = (I_4 + I_6)R_L + I_6(2R_L) - (I_5 - I_6)R_L \qquad (9)$$

$$V_4 = V_5 \cos\beta l + jZ_0\ I_5 \sin\beta l \qquad (10)$$

$$I_4 = I_5 \cos\beta l + j(V_5/Z_0)\sin\beta l \qquad (11)$$

Using equations (7) to (11) the insertion loss can be easily found to be :

$$\text{Insertion Loss} = 10\log_{10}\left[\frac{\left(\frac{V_g}{2}\right)^2 \cdot \frac{R_L}{2}}{|I_6^2 R_L| + |I_4^2 R_L|}\right]$$

$$= 20\log_{10} \left| \left[1 + j \left(\frac{Z_o}{2R_L} \right) \tan \left(\frac{\beta l}{2} \right) \right] \right|$$

$$= 10\log_{10} \left[1 + \frac{Z_0^{\ }}{4R_L^2} \tan^2 (\beta l/2) \right] \qquad (12)$$

Equations (6) and (12) have been used to plot the isolation and insertion loss characteristics of the PC/D as functions of :

(a) line lengths (values of m) and
(b) characteristic impedance -to- load impedance ratios (values of Z_0/R_L)

In these graphs the electrical length βl is broken down into the following components 3 (5)

$$\beta l = 2\pi \frac{l}{\lambda} = 2\pi \frac{l}{\lambda_{min}} \frac{\lambda_{min}}{\lambda} = 2\pi \frac{l}{\lambda_{min}} \frac{f}{f_{max}} = 2\pi mn$$

where λ_{min} - minimum wavelength of operation
fmax - maximum frequency of operation
m - l/λ_{min} - fractional length parameters
n - f/fmax - normalised frequency parameter

Fig. 4 - 6 show the isolation and insertion losss characteristics of the PC/D for different values of Z_0/R_L.

The following conclusions can be made from the plots :-

(1) The transmission line lengths of the PC/D[5] should be made as short as possible compared to the wavelength of operation in order to achieve acceptable insertion and isolation characteristics in the design frequency bandwidth.

(2) The optimum condition for isolation and insertion loss characteristics is achieved when the characteristic impedance of the transmission line equals the impedance at each of the input ports (for the case of the combiner).

(3) The PC/D has theoretically zero isolation when the length of the transmission line equals half the wavelength of operation.

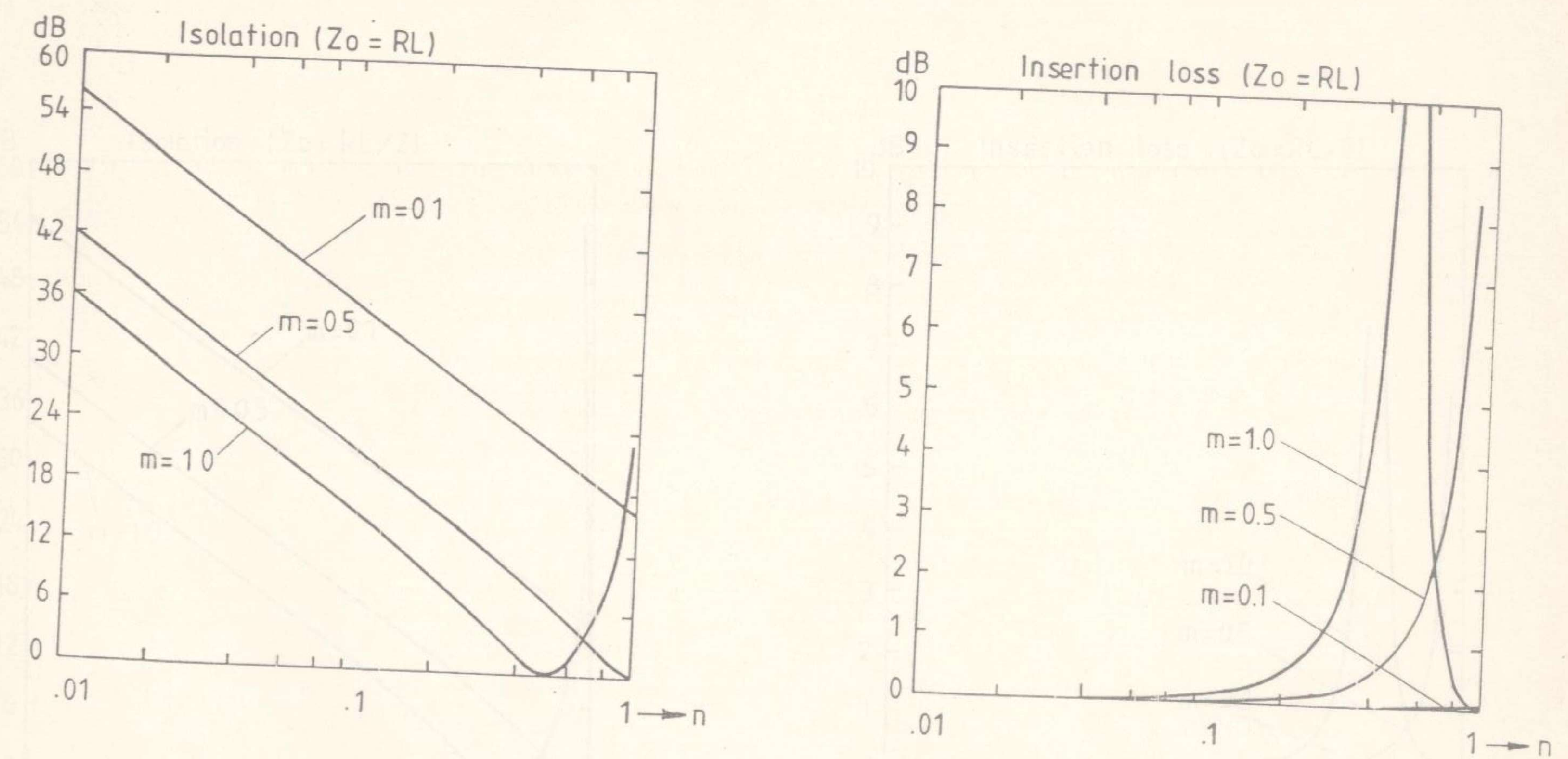

Fig. 4 Isolation and insertion loss characteristics for the inphase ferrite-loaded PC/D when $Z_0 = R_L$

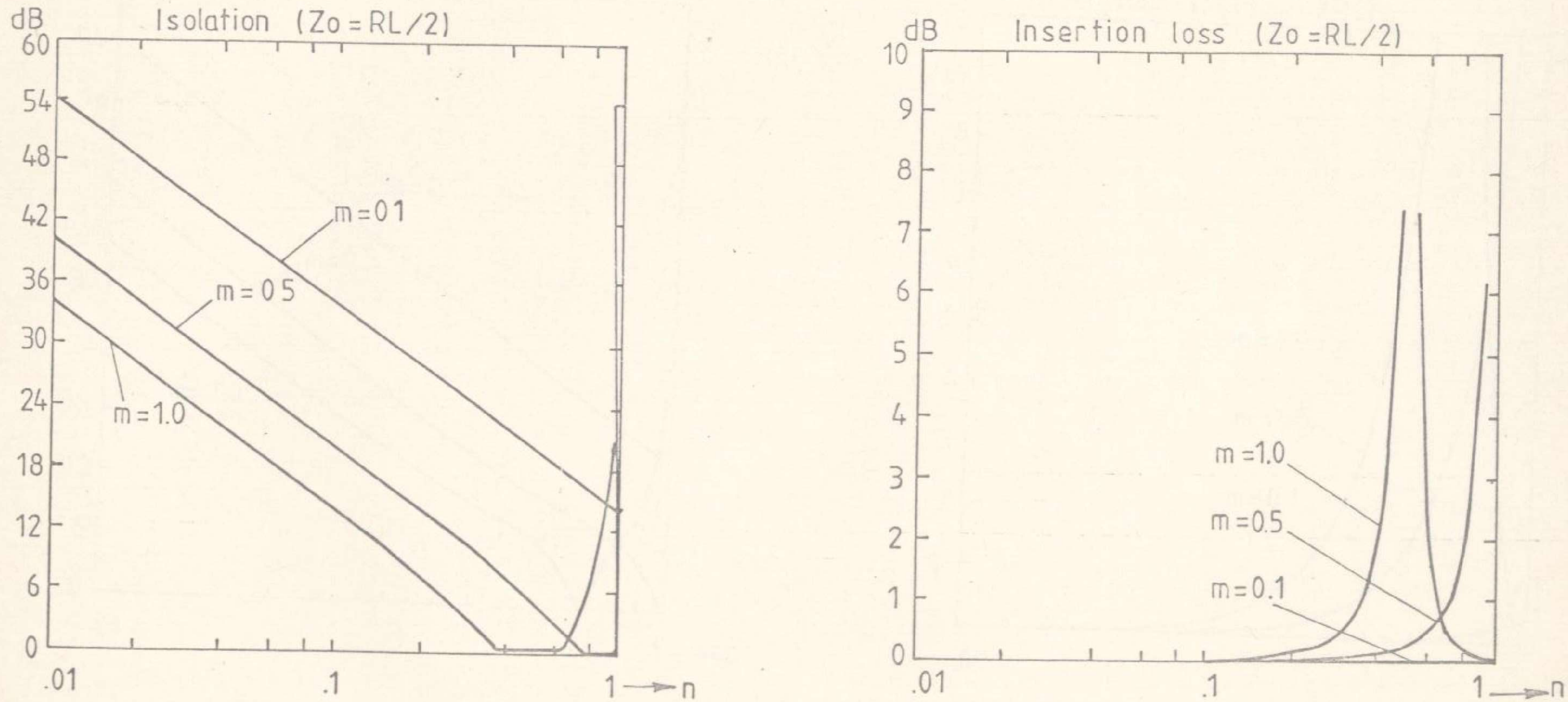

Fig. 5 Isolation and insertion loss characteristics of the inphase ferrite-loaded PC/D when $Z_0 = R_L/2$.

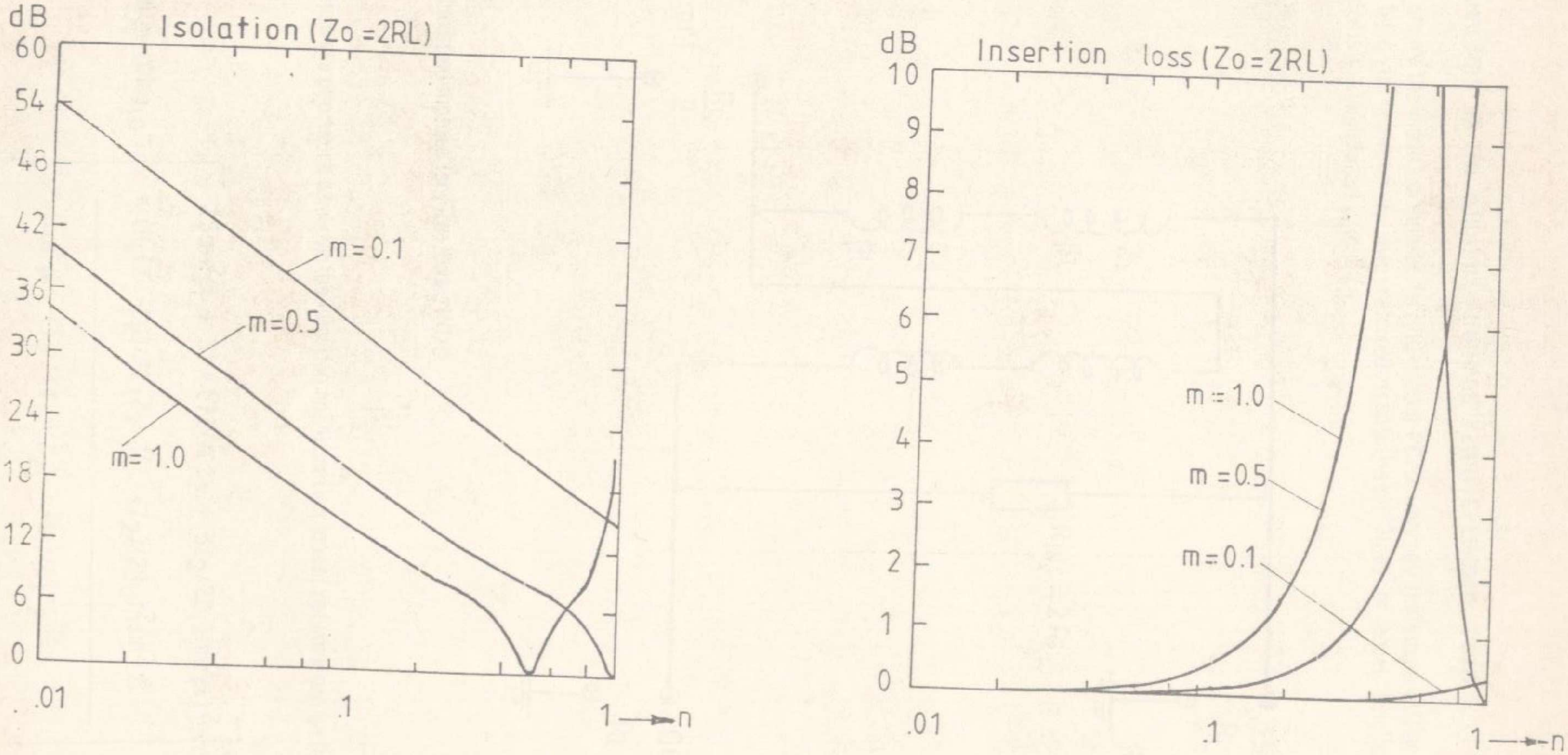

Fig. 6 Isolation and insertion loss characteristics of the inphase ferrite-loaded PC/D when $Z_0 = 2R_L$

3.0 ANALYSIS OF THE MODIFIED INPHASE FERRITE-LOADED PC/D

Fig. 7 shows the modified inphase ferrite-loaded PC/D whereby the single bifilar line of the basic form is replaced by two cascaded transmission lines of equal lengths but with characterisitcs impedances Z_1 and Z_2.

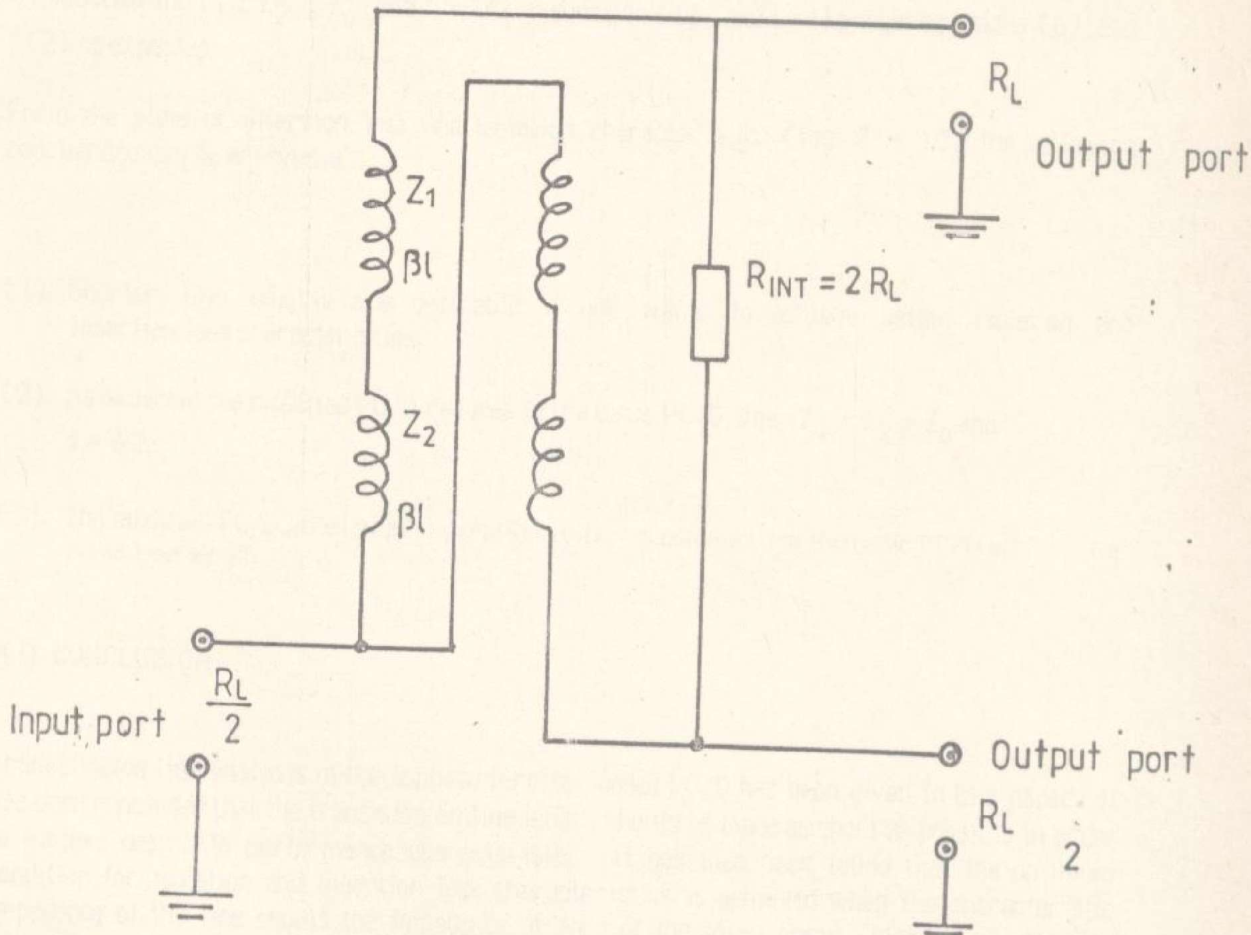

Fig.7: Modified inphase ferrite-loaded PC/D

Using the same procedure as above the isloation and insertion loss of network can be found to be:-

$$\text{Isolation} = 10\log_{10}\left[\frac{\left((5\cos^2\beta l + 3) - (7Z_1/Z_2 + 3Z_2/2Z_1)\sin^2\beta l\right)^2 + \left(R_L(Z_1+Z_2)/2Z_1Z_2 + 3(Z_1+Z_2)/2R_L\right)^2\sin^2 2\beta l}{\left((\cos^2\beta l - 1) - ((Z_1 + Z_2 \ldots{}^2\beta l)/Z_1Z_2\right)^2 + \left(R_L(Z_1+Z_2)/2Z_1Z_2 + (Z_1+Z_2)/R_L\right)^2\sin^2 2\beta l}\right] \qquad (13)$$

$$\text{Insertion loss} = 10\log_{10}\left[\frac{2-((Z_1+Z_2)\sin^2\beta l/Z_1)^2+(Z_1+Z_2)^2\sin^2\beta l)/4R_L}{(2-((Z_1+Z_2)\sin^2\beta l)/Z_1)^2}\right] \quad (14)$$

By substituting $Z_1 = Z_2 = Z_0$ and $l = \lambda/2$ in equation (13) and (14) we get equations (6) and (12) as expected.

From the plots of insertion loss and isolation characteristics (Fig. 8 - 10) the following conclusions can be arrived at :

(1) Shorter line lengths are desirable if one wants to achieve better isolation and insertion loss characteristics.

(2) As expected the modified PC/D reduces to the basic PC/D when $Z_1 = Z_2 = Z_0$ and $l = \lambda/2$.

(3) The modified PC/D gives higher isolation values as compared to the basic PC/D of the same line length.

4.0 CONCLUSION

Transmission line analysis of the inphase ferrite-loaded PC/D has been given in this paper. It has been concluded that the transmission line length should be made as short as possible in order to achieve desirable performance characterістics. It has also been found that the optimum condition for isolation and insertion loss characteristics is achieved when the characteristic impedance of the line equals the impedance at each of the input ports. Moreover, when the transmission line equals half the wavelength of operation, the PC/D has been found to have theoretically zero isolation. This implies that because of circuit imperfections, the network may be used as a directional coupler.

A modification to the PC/D has been suggested, which uses a cascade of two transmission lines with diffeent characteristic impedances. This network has been found to offer better isolation characteristics as compared to the basic PC/DS.

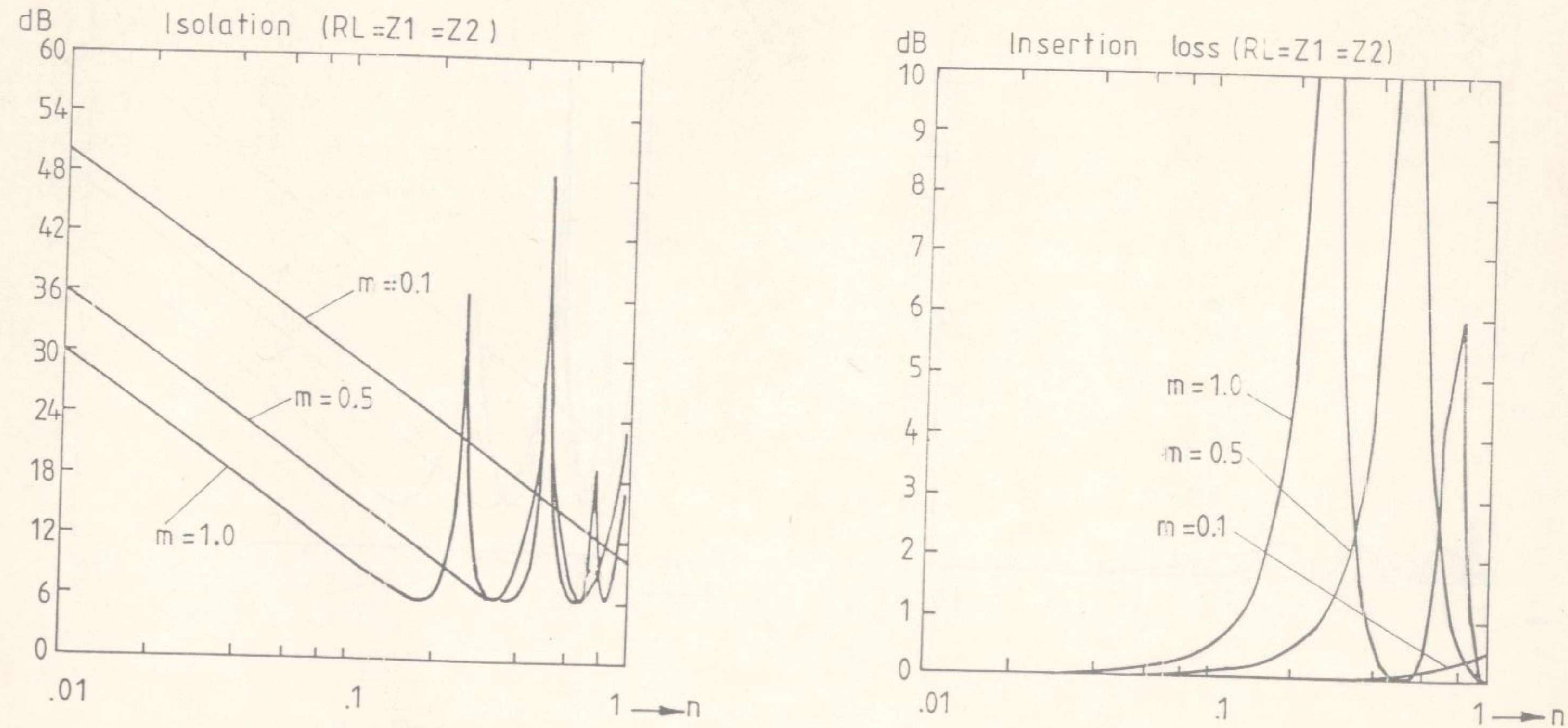

Fig. 8 Isolation and insertion loss characteristics of the modified PC/D with $R_L = Z_1 = Z_2$.

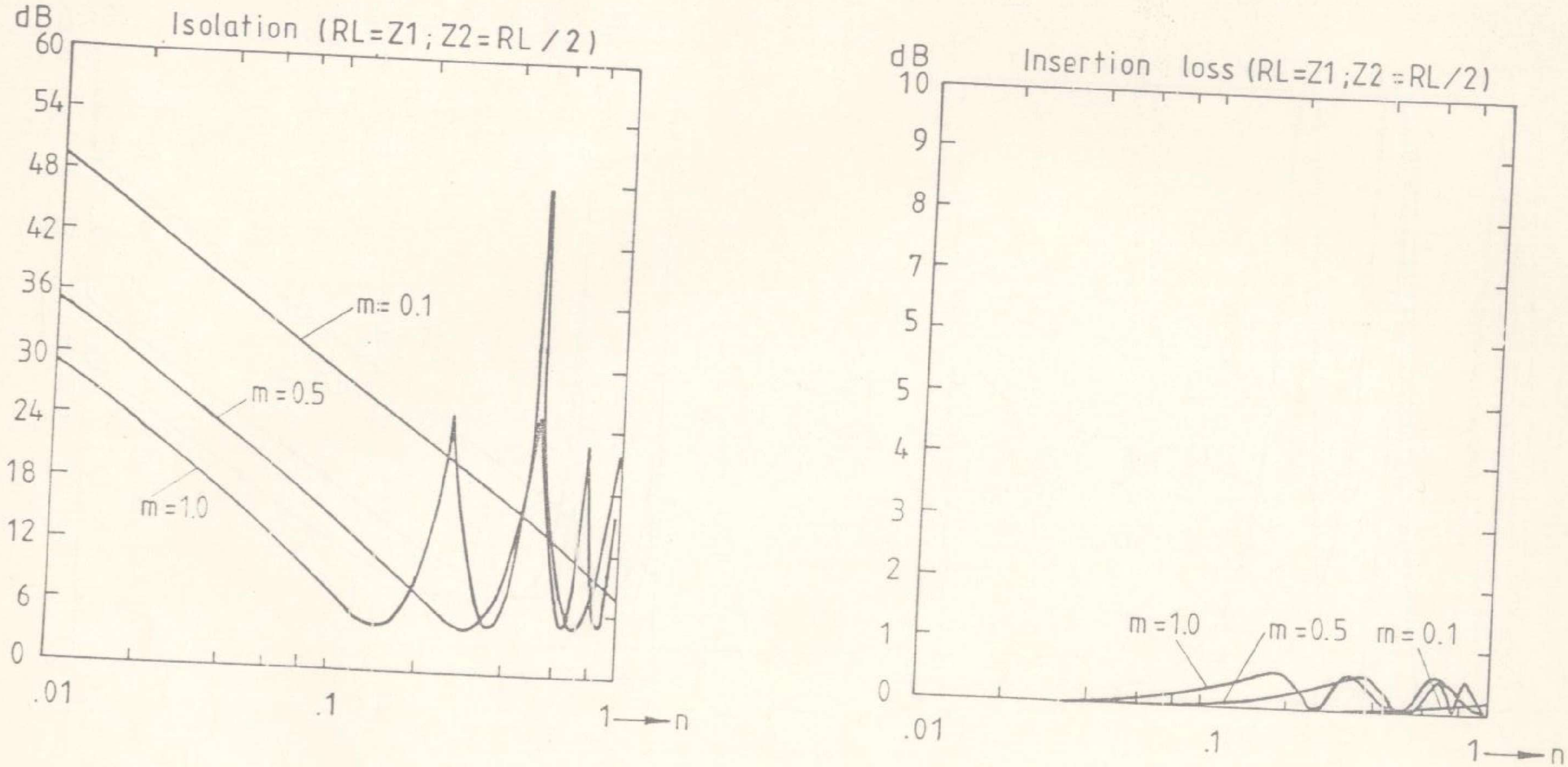

Fig. 9 Isolation and insertion loss characteristics of the modified PC/D with $R_L = Z_1$, $Z_2 = R_L/2$.

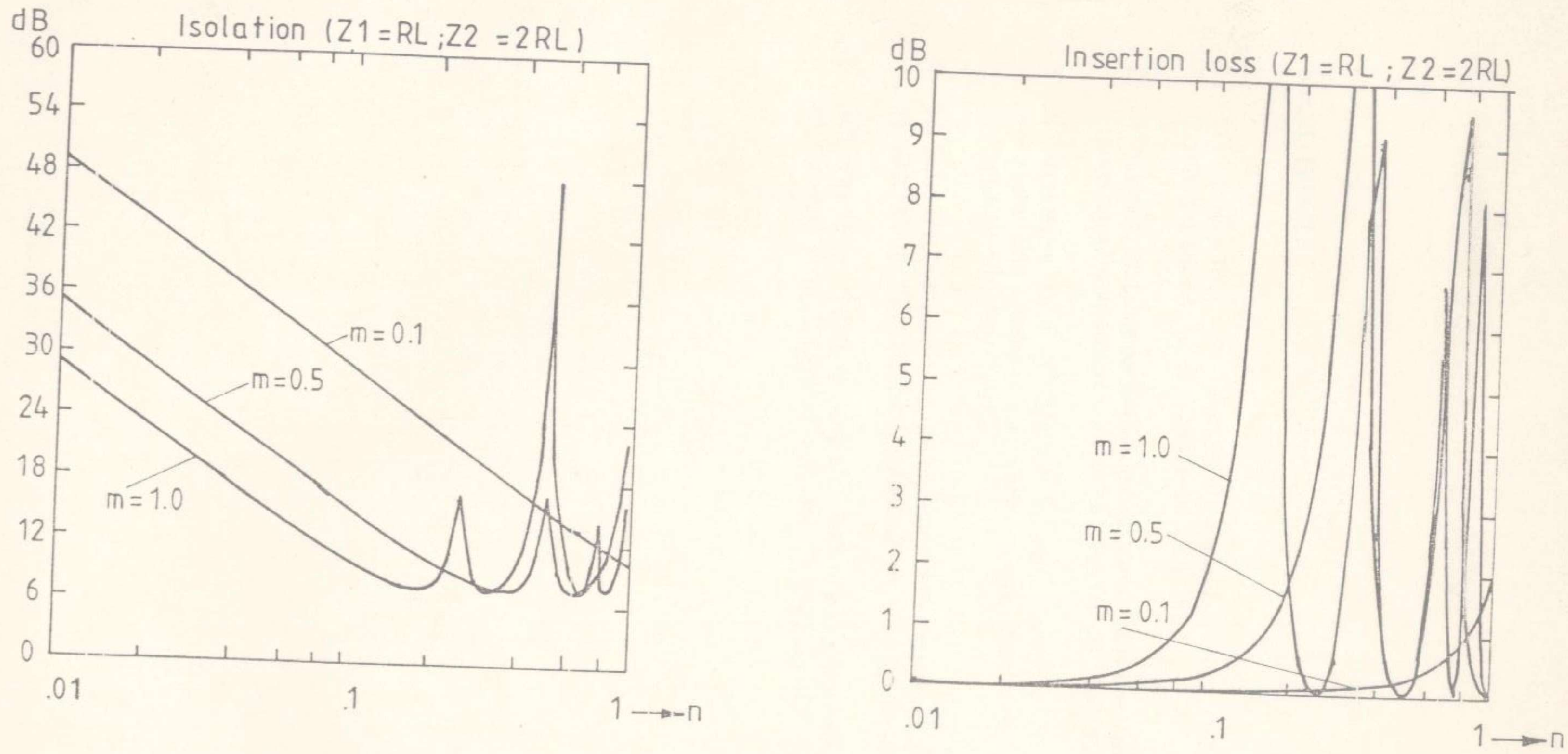

Fig. 10 Isolation and insertion loss characteristics of the modified PC/D with $Z_1 = R_L$; $Z_2 = 2R_L$

5.0 REFERENCES

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