LOSS CALCULATION IN PARALLEL COUPLED LINES

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Abstract

A method to calculate dissipation loss in any number of parallel coupled lines is presented. The method is an extension of Wheeler's technique (1) for a single transmission line. The results can be used to calculate performance of lossy transmission line network using parallel coupled lines.

Introduction

A method to calculate ohmic losses in any number of parallel coupled lines is presented. This enables one to calculate dissipation losses in interdigital, comb line and side coupled filters using a microwave network analysis program such as described in Refs. (2) & (3). By varying the parameters of the filter one can then find optimum designs.

Ohmic attenuation coefficients in parallel coupled lines

A basic method to calculate the ohmic losses due to the skin effect in conductors is given by Wheeler(1). Wheeler and Cohn (4) showed that the attenuation is proportional to the rate of change of characteristic impedance (or admittance) with recession of each of the conductor surfaces, in direction of field penetration for the lossless case.

Kolker (5) and Horton (6) calculated losses in two symmetric parallel coupled lines with rectangular inner conductors.

This method is general and does not require symmetry or a particular cross section (7).

The method for loss calculation requires two steps. The first step is to calculate the attenuation coefficients which are proportional to the rate of change of the even and odd mode characteristic impedances with recession of each of the conductors surfaces. The equation for the attenuation coefficients is given by:

$$\alpha_{c_x}^{\ y} = \frac{R_s\sqrt{\varepsilon_r}}{2\eta}\cdot\frac{1}{Z_{0x}^{\ y}}\cdot\frac{\delta Z_{0x}^{\ y}}{\delta n}$$

where: x - either E or O for the even and odd modes.
y - either A or B corresponds to Fig.1
R_s - surface impedance.
ε_r - relative dielectric constant.
η - space impedance.
Z_o - characteristic impedance.
δn - the recession of conductors surfaces in direction of field penetration.

The impedance matrix for two coupled lines (see Fig.1) is then found. The impedance elements are given in appendix.

A method to analyze many parallel coupled lines is based on division of the self capacitances of the interior lines into two parts (as shown in Fig.2). It is known that for the lossless case the devision of the self capacitances in any arbitrary ratio has no effect on the results. This was checked also for the lossy case and again the devision of the self capacitances in any arbitrary ratio has no effect on the results.

After the devision, the odd and even impedances of each "pair" are calculated. All the conductors are then changed by δn in direction of field penetration and the new self and mutual capacitances found. The conductors are again devided into "pairs" and the odd and even impedances calculated for each "pair". Then the attenuation coefficients and the Z matrix calculated for each "pair".

Applications

The ability to calculate the losses enables us in the design of filters using parallel coupled lines (interdigital, comb line and side coupled filters) a preliminary calculation of the performance. We can take into account the effect on bandwidth, power dissipated in passband or stopband, VSWR etc. For example in Fig.3 is shown the frequency response of an interdigital filter with and without losses. The design was worked out using n = 9 reactive element Tchebyscheff prototype with 0.1 Db ripple, a fractional bandwidth of 0.043 centered at 600 MHz. Input and output impedances of 50 ohms, relative dielectric constant of 2.32, ground planes spacing 6.35 mm and inner conductors realized using printed circuit (0.02 mm thickness). The internal impedance level as defined by (8) was 70 ohms. The shrinkage in the 3 Db bandwidth was 8% so the designed bandwidth must be greater in 8%. The comparison between the calculation and measurements shows good agreement.

Loss calculations were performed for interdigital filters using round rods, rectangular bars and printed circuit, and different internal impedance levels. The design was worked out using n = 4 reactive element Tchebyscheff prototype with 0.1 Db ripple, a fractional bandwidth of 0.043 centered at 1000MHz. Input and output impedances of 50 Ohms, relative dielectric constant of 1.00 (for the printed circuit relative dielectric constant of 2.32) and ground planes spacing 6.35 mm.

The results are ploted in Fig. 4. An important result is that for a filter where the inner conductors are rectangular, the minimum losses occurs at low internal impedance levels. For a filter where the inner conductors are round rods the minimum losses occurs at 73 ohms internal impedance level.

Conclusions

A method to calculate losses in parallel coupled lines has been presented. The method is not limited by the number of the parallel coupled lines or the construction method.

The ability to calculate the performance of lossy networks using parallel coupled lines should help in the better design of these networks.

Apendix

The impedance matrix for two non-symmetric, lossy parallel coupled lines:

This is an extension of Z matrix given by 9 and (10).*

$$Z_{11} = Z_{44} = \frac{Z^A_{OE}}{2\ S_{EA}} + \frac{Z^A_{OO}}{2\ S_{OA}}$$

$$Z_{12} = Z_{43} = \frac{Z^A_{OE}}{2\ S_{EA}} - \frac{Z^A_{OO}}{2\ S_{OA}}$$

$$Z_{13} = Z_{42} = \frac{Z^A_{OE}}{2\ SS_{EA}} - \frac{Z^A_{OO}}{2\ SS_{OA}}$$

$$Z_{14} = Z_{41} = \frac{Z^A_{OE}}{2\,SS_{EA}} + \frac{Z^A_{OO}}{2\,SS_{OA}}$$

$$Z_{21} = Z_{34} = \frac{Z^B_{OE}}{2\,S_{EB}} - \frac{Z^B_{OO}}{2\,S_{OB}}$$

$$Z_{22} = Z_{33} = \frac{Z^B_{OE}}{2\,S_{EB}} + \frac{Z^B_{OO}}{2\,S_{OB}}$$

$$Z_{23} = Z_{32} = \frac{Z^B_{OE}}{2\,SS_{EB}} + \frac{Z^B_{OO}}{2\,SS_{OB}}$$

$$Z_{24} = Z_{31} = \frac{Z^B_{OE}}{2\,SS_{EB}} - \frac{Z^B_{OO}}{2\,SS_{OB}}$$

where:

$S = \text{TANH}\ (\gamma L)$

$SS = \text{SINH}\ (\gamma L)$

$\gamma = \alpha + j\beta$

$\alpha = \alpha_d + \alpha^y_{c_x}$

y - either line A or B

x - either odd or even modes

α_d - attenuation in dielectric

$$\alpha^y_{c_x} = \frac{R_s\sqrt{\varepsilon_r}}{2\eta}\,\frac{1}{Z^y_{0x}}\,\frac{\delta Z^y_{0x}}{\delta n} = \frac{-R_s\sqrt{\varepsilon_r}}{2\eta}\,\frac{1}{Y^y_{0x}}\,\frac{\delta Y^y_{0x}}{\delta n}$$

R_s - surface resistance

η - space impedance

* It should be noted that:

1. In the Y matrix the signs of Y_{11}, Y_{21}, Y_{34}, Y_{43}, Y_{14}, Y_{41}, should be inverted.
2. In calculations replace $\frac{\sqrt{1-S^2}}{S}$ by $\frac{1}{\text{SINH}\ (\gamma L)}$

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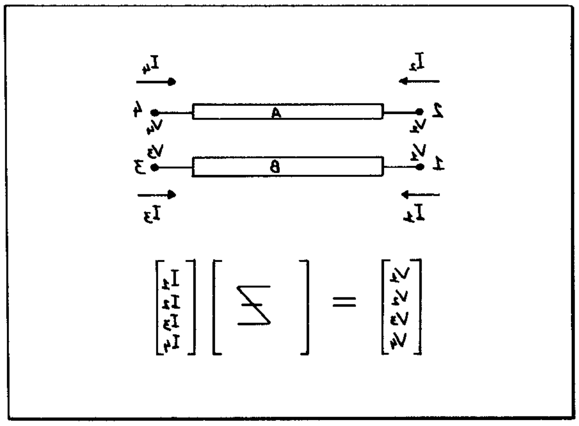

FIG. 1: TWO COUPLED NON-SYMMETRIC LINES AND THE FOUR PORT IMPEDANCE MATRIX.

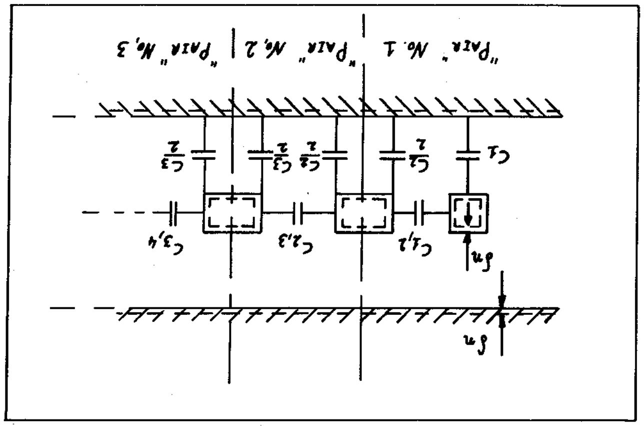

FIG. 2: CROSS SECTION OF A LARGE NUMBER OF PARALLEL COUPLED LINES AND DIVISION OF INTERIOR SELF CAPACITANCES INTO TWO EQUAL PARTS.

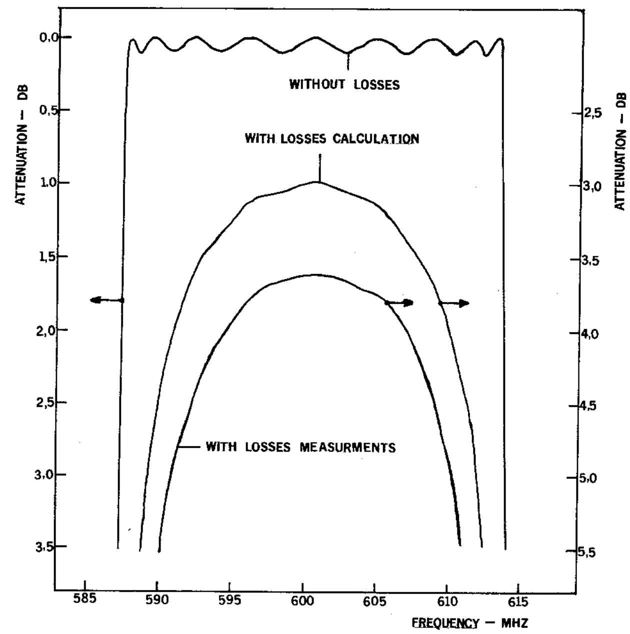

FIG. 3: FREQUENCY RESPONSE OF AN INTERDIGITAL FILTER WITH LOSS AND WITHOUT LOSS.

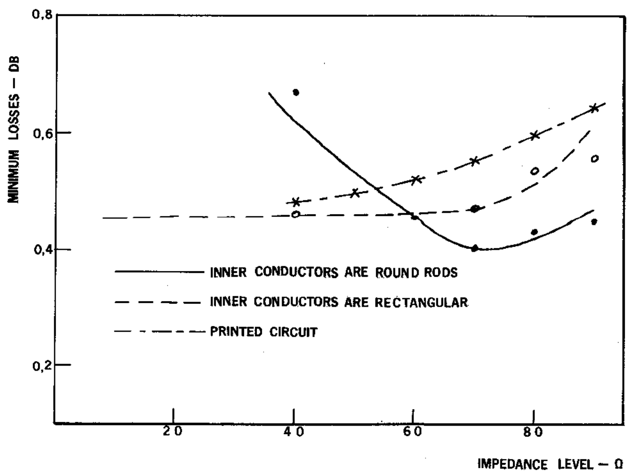

FIG. 4: MINIMUM LOSS IN THE FILTER AS A FUNCTION OF IMPEDANCE LEVEL.