CAD Experiment 2:
RF choke, Transformer and Attenuator (Pad)

Objective

Learn the principles and practical design of three basic MIC circuit elements in ADS.

Introduction

At microwave frequencies, realizations of some circuit components in the form of transmission line network become more attractive than lumped elements. In this experiment, RF choke, impedance transformer and pad will be used as illustrative examples.

Principles

A. RF choke

RF choke is a device that can be used to feed DC bias signal into a circuit but does not degrade the RF characteristics of the circuit. The circuit diagram of RF chock is shown in Fig. 1. In Fig. 1, point C is open when we look from the left side. After a quarter wavelength transmission line, point B behaves like a short circuit from left side. In a similar discussion, the right part of point A looks like an open circuit at point A, therefore will not affect the signal in the 50 Ω line.

B. Impedance transformer

A simple quarter wavelength transmission line can be used as impedance transformer or impedance inverter. Fig. 2 is the circuit diagram.
C. Pad (fixed attenuator)

Pad is an attenuator which attenuates the incoming signal but does not bring in residual VSWR. There are two types of resistor networks that can be used to design pads: T-type and \( \pi \)-type. Fig. 3 shows the circuit diagrams of the two types of pads. \( R_1 \) and \( R_2 \) should be designed to attenuate the incoming signal and match the system characteristic impedance simultaneously. The even and odd-mode excitation method can be used to analyze the circuit and derive the design equations for \( R_1 \) and \( R_2 \). Fig. 4 shows the procedures of obtaining the reflection and transmission coefficients using the even and odd mode excitation method.

Practices and Questions

A. RF choke

1. Fig. 5a and 5b show the circuit schematics and computed frequency response of 5GHz RF choke with an ideal transmission line model, respectively. Duplicate the result in ADS.

2. Change \( Z_1 \) (the 90 \( \Omega \)) to a lower impedance (35 \( \Omega \)) and \( Z_2 \) (the 35 \( \Omega \)) to a higher impedance (90 \( \Omega \)) and repeat the analysis as 1. Can you see the degradation of the performance (bandwidth)? Explain the reasons?

3. Now, change the ideal transmission lines in Fig. 5a to microstrip lines with the use of Linecalc and include the elements of microstrip's discontinuities (T-junction at A, step discontinuity at B, and open end effect at C) into the circuit design. Do the analysis and compare the results with Fig. 5b.

4. Change the center frequency to 10 GHz and repeat the analysis in part 3. Now, you can discuss the effects of discontinuities on the performance of RF choke and figure out how to compensate for them.

B. Impedance transformer

1. Fig. 6 shows the result of the transformation of a 50 \( \Omega \) resistor to 32 \( \Omega \) by a 40 \( \Omega \) quarter wavelength (5 GHz) line in the Smith chart. Duplicate the result in ADS
(compute from 4.8GHz to 5.2GHz). (Note: the input port is a 50 Ω termination.)

2. Fig. 7 shows the result of the quarter wavelength line inverting a capacitor into an inductor in the Smith chart. Duplicate the result in ADS. Replace the capacitor by an inductor, resonator (series and shunt types for 5 GHz resonant frequency) and see where they are in the Smith chart?

3. In your Lab report, indicate the place of each termination on the corresponding Smith chart, explain how the quarter wavelength transformer works on the Smith chart.

C. Pad (fixed attenuator)

1. Derive the design equations for \( R_1 \) and \( R_2 \) in terms of attenuation (A) for both T-type and \( \pi \)-type pad. The match condition should also be used (i.e., \( \Gamma = 0 \)).

2. Calculate \( R_1 \) and \( R_2 \) for 3, 10, 20 dB pads by the equations derived in 1, and check their performance by ADS (you are asked to do analysis on either T-type or \( \pi \)-type circuit, since the procedures are similar). Replace the resistors by thin film resistors (TFR) (50W/Box) and check it again (up to 20 GHz).

3. In practical circuit layout, conductors should be used to interconnect the thin film resistors (see Fig. 8). Choosing the width of the thin film resistors to be 16 mils, \( W_1 \) equal 24 mils, \( L_2 \) at least 15 mils, and putting the interconnect conductors (sections of transmission lines) into the circuit, do the analysis (plot S21 and S11) in frequency domain up to 20 GHz. (Note that the length \( L_1 \) is not important, WHY?)
Fig. 1 Circuit schematics of transmission line RF choke.

Fig. 2 Impedance transformer.

Fig. 3 (a) T-type pad (b) π-type pad.
\[ T = \frac{1}{\ell_2} \left( \Gamma_e - \Gamma_0 \right) \]
\[ \Gamma = \frac{1}{\ell_2} \left( \Gamma_e + \Gamma_0 \right) \]

Fig. 4 Analysis of T-type pad by even and odd-mode excitation method.

Figure 8. MIC layout of pad at 25 mils Al₂O₃.
Fig. 5 (a) Schematics of a 5 GHz transmission line RF choke circuit in ADS.
Fig. 5 (b) Frequency response of a 5 GHz transmission line RF choke
Fig. 8 The impedance of a 50 ohm resistance after a quarter wavelength 40 ohm transmission line.
Fig. 7 The impedance of a 3 pF capacitance after a quarter wavelength 40 ohm transmission line.