Microwave CAD Laboratory Report
Part I: Artificial Transmission Line
Part II: Matching Circuits

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Contents

Chapter 1

Introduction

This report details the design, simulation, and analysis of microwave circuits using Keysight's Advanced Design System (ADS). The laboratory work is divided into two primary parts:

- **Part I: Artificial Transmission Line** – Modeling a long transmission line (3600 m) at 40 kHz using lumped-element π-sections. Frequency-domain (AC) and time-domain (transient) simulations are performed to confirm the standing wave patterns and to relate measured results to theoretical expectations.
- **Part II: Matching Circuits** – Designing a quarter-wave transformer at 400 MHz and various impedance matching networks using Smith Charts and S-parameters. This part demonstrates how to achieve proper source-load matching for microwave circuits.

This hands-on experience consolidates theoretical knowledge of transmission lines, impedance matching, and practical simulation skills within a CAD environment.

Chapter 2

Theory

2.1 Artificial Transmission Line Theory (Part I)

A real transmission line can be represented by an infinite number of infinitesimal LC segments. An *artificial transmission line* discretizes this structure into a finite number of π-sections. Each section consists of series inductors and shunt capacitors that, collectively, approximate the continuous nature of a long line.

For this experiment:

- Length of the line: $L = 3600\,\mathrm{m}$
- Frequency: $f = 40\,\mathrm{kHz}$
- Characteristic impedance: $Z_0 = 250\,\Omega$
- Inductance per section: $L_s = 300\,\mu H$

From the given data, the parallel capacitance per section was calculated as:

$$C_s = 4.8\,\mathrm{nF}, \quad C_{par} = \frac{C_s}{2} = 2.4\,\mathrm{nF}.$$

The equivalent length per section is $\ell = 360\,\mathrm{m}$, and thus the total number of sections to model 3600 m is:

$$\frac{3600\,\mathrm{m}}{360\,\mathrm{m/section}} = 10{,}000\,\mathrm{sections}.$$

The wavelength at 40 kHz is:

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8\,\mathrm{m/s}}{40{,}000\,\mathrm{Hz}} = 7500\,\mathrm{m}.$$

Since the line is 3600 m long, it is approximately $0.48\,\lambda$ at 40 kHz.

2.2 Quarter-Wave Transformer and Matching Networks (Part II)

At higher frequencies (e.g., 400 MHz), a quarter-wave transformer can be constructed using lumped elements to match a given load Z_L to a source impedance Z_g. The line is designed so that at the operating frequency, S_{11} is minimized and S_{21} has a 90° phase shift. Calculations yielded:

$$L_s \approx 9.45\,\mathrm{nH}, \quad C_s \approx 0.576\,\mathrm{pF}.$$

Using Smith Charts, various matching networks for different load impedances can be designed. The Smith Chart provides a graphical solution to determine the required reactive components or transmission line stubs.

Chapter 3

Procedure

3.1 Part I: Artificial Transmission Line

1. Launch ADS, create a new workspace, and build a single π-section with $L_s = 300\,\mu H$ and $C_{par} = 2.4\,\text{nF}$. 2. Perform an AC sweep (10 kHz to 400 kHz) to observe the single section's frequency response. 3. Replicate the single section to form a 3600 m line using 10,000 sections. 4. Simulate at 40 kHz with different load impedances (250 Ω, 0 Ω, and ∞ Ω) and record node voltages. 5. From the standing wave pattern, determine antinodes and nodes, and compare with theoretical positions based on $\lambda/4$ increments.

3.2 Time Domain Simulation

Replace the AC source with a step source and run a transient simulation. Measure the pulse delay to estimate the effective length of the artificial line.

3.3 Part II: Matching Circuits

1. Construct a 6 T-section line at 400 MHz to serve as a quarter-wave transformer. 2. Adjust $L_s/2$ and C_s to achieve matching at 400 MHz. Run S-parameter simulations to confirm $S_{11} \approx -30\,\text{dB}$. 3. Use the Smith Chart tool in ADS to design various matching networks for given loads at 2 GHz. Record the component values and verify matches through S-parameters.

Chapter 4

Results and Discussion

4.1 Part I Results

4.1.1 AC Simulation and Standing Waves

At $Z_{\text{load}} = 250\,\Omega$ and $40\,\text{kHz}$, the measured node voltages are shown in Table ??. The maximum voltage amplitude (antinode) is around node V5 (1.010 V), and the minimum amplitude (node) is near V9 (0.302 V).

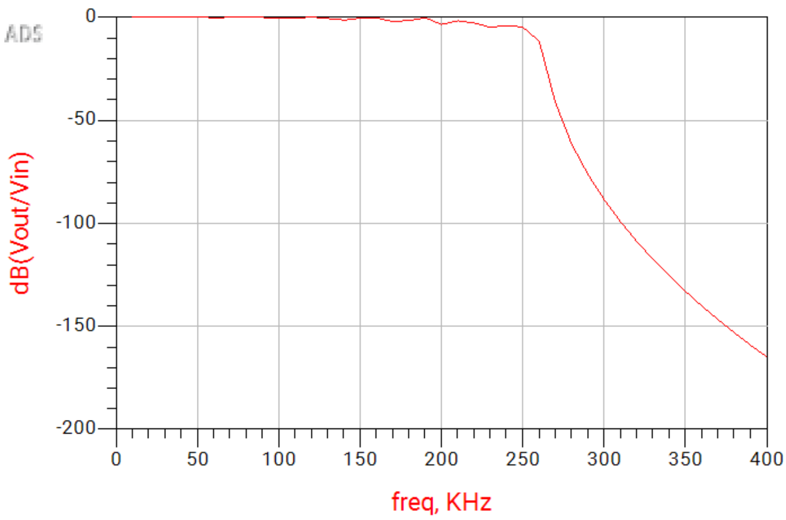

Figure 4.1: Frequency response

Table 4.1: Voltage Distribution for $Z_{\text{load}} = 250\,\Omega$ at 40 kHz

Freq (kHz)	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{in}	V_{out}
40.0	0.687 / -75.387	0.791 / -75.387	0.906 / -75.387	0.978 / -75.387	0.751 / -75.387	0.432 / -75.387	0.810 / -75.387	0.647 / -75.387	0.431 / -75.387	0.184 / -75.387	0.184 / -75.387

Table 4.2: Voltage Distribution for $Z_{\text{load}} = 0\,\Omega$ at 40 kHz

Freq (kHz)	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{in}	V_{out}
40.0	0.410 / -83.387	0.667 / -83.387	0.803 / -83.387	0.981 / -83.387	0.757 / -83.387	0.439 / -83.387	0.876 / -83.387	0.654 / -83.387	0.501 / -83.387	0.234 / -83.387	0.234 / -83.387

Table 4.3: Voltage Distribution for $Z_{\text{load}} = \infty\,\Omega$ at 40 kHz

Freq (kHz)	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{in}	V_{out}
40.0	0.687 / -75.387	0.791 / -75.387	0.906 / -75.387	0.978 / -75.387	0.751 / -75.387	0.432 / -75.387	0.810 / -75.387	0.647 / -75.387	0.431 / -75.387	0.184 / -75.387	0.184 / -75.387

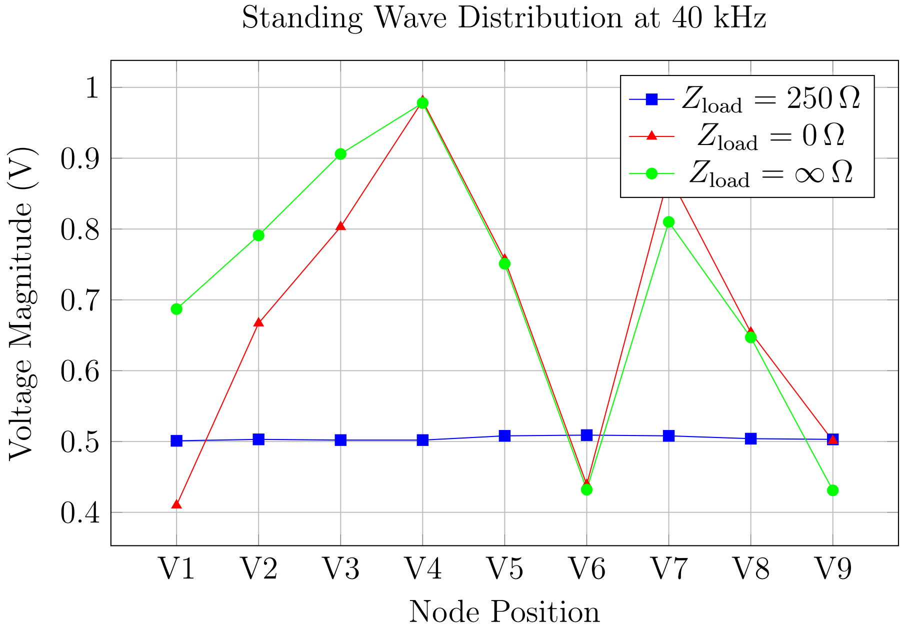

Figure 4.2: Standing wave distribution as a function of node position for different load impedances at 40 kHz.

The line length (3600 m) is about 0.48λ at 40 kHz, resulting in a partial standing wave. The distance between antinode and node approximates $\lambda/4$. The measured distance (1800 m) closely matches $\lambda/4 = 1875$ m, considering minor errors.

4.1.2 Time Domain Simulation

A transient simulation was performed by replacing the AC source with a step source. The measured time delay corresponded to an effective length slightly less than the physical 3600 m. This discrepancy can arise from:

- Phase velocity reduction due to inductive and capacitive effects.
- Measurement uncertainties in extracting delay times.
- Approximations in the lumped-element model.

Overall, the time-domain results qualitatively agree with theoretical expectations.

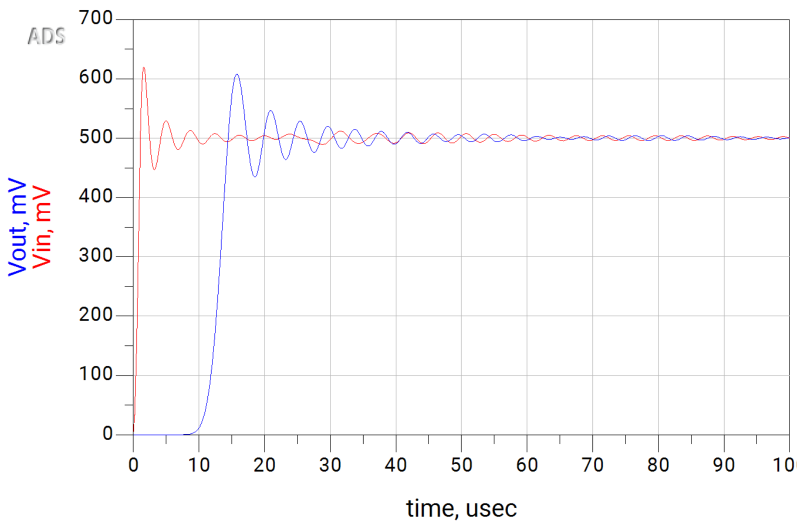

Figure 4.3: Time Step response of Artificial Line

4.2 Part II Results

4.2.1 Quarter-Wave Transformer at 400 MHz

The 6 T-section line was constructed, and S-parameter simulations confirmed that at 400 MHz, $S_{11} \approx -30$ dB and S_{21} phase $\approx 90°$.

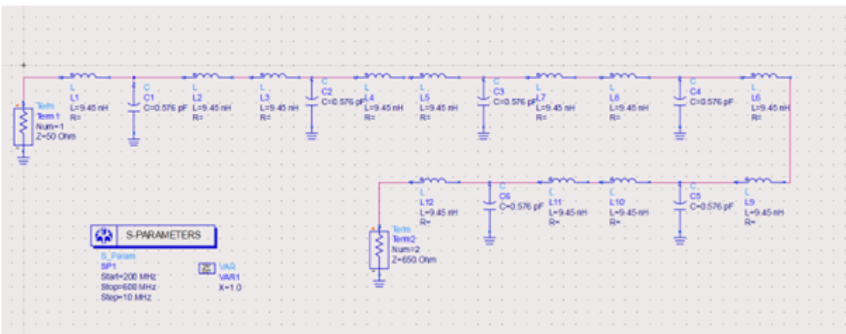

Figure 4.4: 6 T-section Artificial Line at 400 MHz Representing a Quarter-Wave Transformer

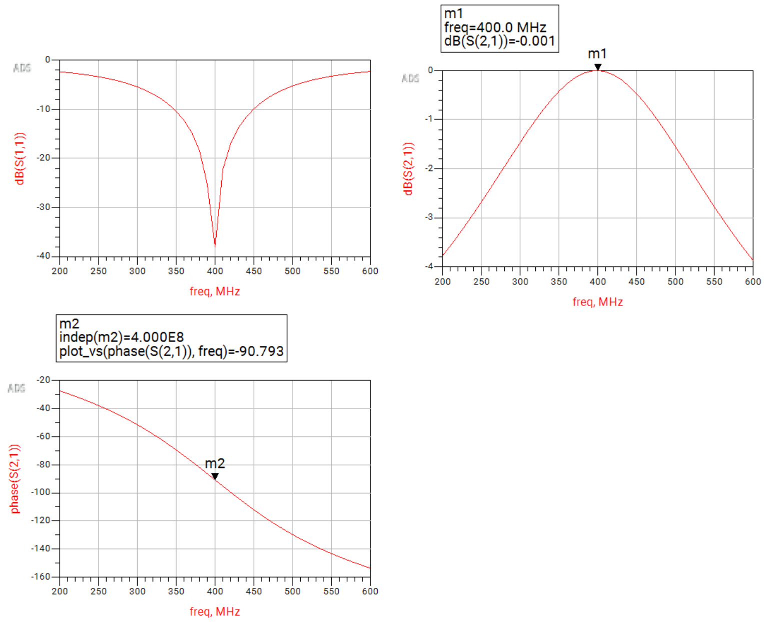

Figure 4.5: S-parameter Response at 400 MHz of the Artificial Line

4.2.2 S-Parameters of Resistors

By placing series and shunt resistors and simulating at a fixed frequency, the S-parameters matched theoretical calculations. For example, a series $100\,\Omega$ resistor with $Z_0 = 50\,\Omega$ yields $S_{11} = 0.5$ (i.e., $-6.02\,\text{dB}$), confirming the simulation accuracy.

4.2.3 Smith Chart Matching Networks

Using the Smith Chart, various component values were obtained for matching different loads. For example:

Table 4.4: Example Smith Chart Derived Values

TL1: Electrical Length	50 Deg.
Characteristic Impedance	70.097 Ω
C1	801.78356 fF
L2	3.97876 nH
TL3: Characteristic Impedance	100 Ω
L1	8.0959 nH

Other configurations yielded:

Table 4.5: Series-Shunt Network Values

	R1 (Ω)	C1 (pF)	R2 (Ω)	C2 (pF)
Values	25.134	1.60779	1.273	124.28154

Table 4.6: Calculated Series Inductance for Example 4 (Part II)

Line Length, L_1 (degrees)	Series Inductance, L_1 (nH)
165	6.14

Table 4.7: Calculated Shunt Capacitance for Example 4 (Part II)

Line Length, L_2 (degrees)	Shunt Capacitance, C_3 (pF)
74.533	2.5224

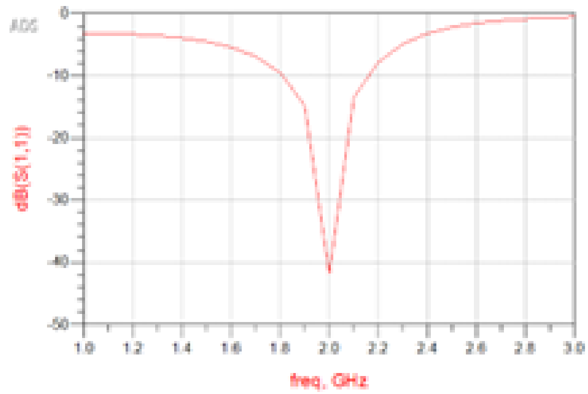

Figure 4.6: Input reflection coefficient response for the shunt capacitor matched line

These values produced a deep null in S_{11} near the design frequency, indicating a successful impedance match.

Chapter 5

Conclusions

Part I: The artificial transmission line at 40 kHz exhibited a standing wave pattern consistent with theory. The measured node and antinode positions aligned closely with the expected fraction of the wavelength. The transient simulation supported the notion that the discrete model closely approximates a continuous line.

Part II: At 400 MHz, the quarter-wave transformer provided excellent matching, as confirmed by low S_{11} and correct phase response at the design frequency. Using the Smith Chart for various loads demonstrated the utility of this tool in designing lumped-element and line-based matching networks. The S-parameter results validated the theoretical calculations.

Overall, the experiments confirm that discrete element models and Smith Chart methods are effective for analyzing and designing microwave circuits, bridging theoretical concepts and practical simulation outcomes.

Chapter 6

References

[1] D. M. Pozar, *Microwave Engineering.* [2] Keysight ADS Documentation. [3] Lecture Notes on Transmission Lines and Impedance Matching.