LAB 4:TRANSMISSION LINE MODELLING

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Submission Date :23 May 2025
Due Date :23 May 2025
Lab Day(s) and Time:Friday 3-5pm
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DECLARATION

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Abstract

This experiment examines the effects of a 500-meter CAT5 transmission line on signal behaviour at different frequencies. Both square and sinusoidal waveforms were applied and observed at different points along the cable using a segmented 5-tap model. To investigate how signal amplitude and shape change with frequency and distance, measurements were made from 100 kHz to 1 MHz..

The data shows that, particularly with square waves, the signal experiences higher loss and shape distortion as frequency rises. This behaviour indicates that the transmission line functions similarly to a low-pass filter, with higher-frequency components getting more significantly attenuated. These findings highlight how transmission line impacts must be considered in high-speed communication systems to ensure signal integrity

Aims

The purpose of this experiment is to observe how voltage and waveform characteristics change as signals pass through a 500-meter transmission line model. It analyses the impact of frequency on distortion and attenuation, verifying theoretical predictions about transmission line behaviour.

Introduction

Maintaining signal integrity over physical media becomes crucial as data rates in contemporary communication systems keep rising. Signal quality is significantly affected at higher frequencies by the inherent resistance, capacitance, and inductance of transmission lines, such as CAT5 cables. To observe how signal characteristics change at each stage, this lab utilizes waveforms to simulate an extended transmission line that is divided into five segments. The experiment uses practical measurements to show how transmission lines function as low pass filters, highlights the significance of considering transmission effects in practical system implementation.

Background

Conductance (G), capacitance (C), inductance (L), and resistance (R) are distributed parameters required for generating transmission lines. These factors influence signal propagation, particularly in high-frequency scenarios. As frequency increases, reactive components (inductance and capacitance) dominate, causing signal distortion and amplitude reduction. Square waves are especially vulnerable due to their rich harmonic content, which is selectively attenuated, rounding sharp edges. This experiment uses a 5-tap CAT5 model to investigate this low-pass filtering effect.”

Distributed characteristics including as resistance (R), inductance (L), capacitance (C), and conductance (G), which are usually represented per unit length, control the behaviour of signals along these lines.

The waveform is greatly impacted by these characteristics as the signal frequency rises. Inductive and capacitive components introduce frequency-dependent impedance, which modifies the form of the signal, particularly at higher frequencies, while resistive and conductive losses lower the signal's amplitude. Square waves, which are made composed of many odd harmonics, are especially affected by distortion because high-frequency harmonics are attenuated, resulting in rounded edges.

A transmission line's characteristic impedance Z0, is a crucial statistic for estimating signal behaviour and is described as follows:

$$Z_o = \sqrt{\left(\frac{R+j\omega L}{G+j\ \omega C}\right)}$$

Here,
R = resistance per unit length (Ω/m)
L= inductance per unit length (H/m)
C = capacitance per unit length (F/m)
ω = angular frequency(rad/s)
J= imaginary unit
G= conductance per unit length (S/m) often negligible

In this experiment, a 5-tap design is used to represent a 500-meter CAT5 cable, and measurements are made at 100-meter intervals (TP1 to TP5). The arrangement is design to analyse how attenuation and waveform distortion changes over distance by applying square and sinusoidal waveforms at different frequencies. The theoretical idea that transmission lines operate as low-pass filters in high-frequency circumstances is supported by this practical model.

Equipment

1. Waveform generator
2. Digital Storage oscilloscope (DS0)
3. 5 tap transmission line (representing 500m of CAT5 cable)
4. BNC cables and probes
5. 100 Ω load

Procedure

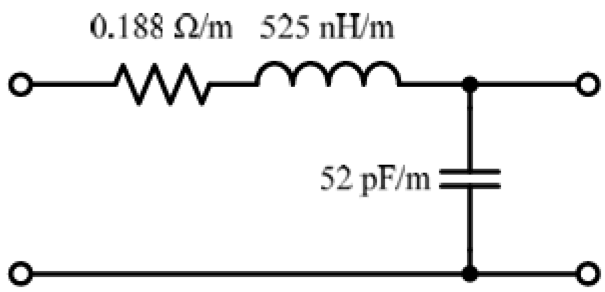

Figure 1 Transmission line model

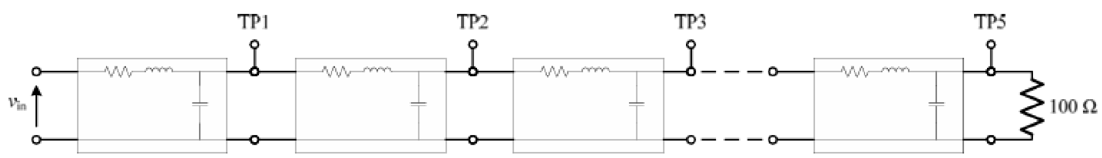

Figure 2 Transmission line model for 5 sections

- **<u>Attenuation along transmission line</u>**

1. Applying a 100 kHz 5 Vp-p sinusoidal waveform to vin of the transmission line model.
2. Now, recording the peak-to-peak voltage at each test point (TP1-TP2).
3. In this stage, changing the frequency to 1 MHz keeping the same peak-to-peak value to the input signal.
4. Repeating step 2.
5. Making a graph where peak-to-peak voltage is compared to distance for the two given frequencies.

- **Distortion of the waveform along the transmission line**

1. Applying a 100 kHz 5 Vp-p sinusoidal waveform to vin of the transmission line model.
2. Observing the waveforms at vin and all the other test points from TP1 to TP5.
3. Repeating step 2.
4. Now, taking snapshots of the waveforms
5. Repeating the experiment for a square waveform of 100kHz (5v with a 0V offset).

- **Effect of the transmission line at different frequencies**

1. First, applying a 100 kHz square waveform with 5v and 0 offset to vin of the transmission line model.
2. Observing the waveforms at vin and TP5.
3. Now, taking snapshots of the waveforms.
4. Increasing the frequency up to 1MHz by step of 100KHz at a time.
5. Repeating the measurements
6. Finally, Taking snapshots of the waveforms

Results and Observations

Prelab

Transmission parameters fro 100m of a CAT5 cable:

- Resistance: $R = 18.8\ \Omega$
- Inductance: L = 52.5 μH
- Capacitance : C =5200pF

Attenuation along the transmission line:

Test point/Equivalent Distance (m)	Vp-p at 100 kHz (Volts)	Vp-p at 1 MHz (Volts)
vin	3.6V	4.8V
TP1	3.31 V	642.5 mV
TP2	3.08 V	82mV
TP3	2.68 V	17.5V
TP4	2.33V	16.5V
TP5	1.97 V	16mV

This table shows the significant attenuation occurs along the transmission line when the signal frequency rises from 100 kHz to 1 MHz. The voltage drop across test points is constant and gradually at 100 kHz, indicating little signal loss over distance. But after TP1, the signal reduces significantly at 1 MHz, with the peak-to-peak voltage decreasing from 642.5 mV at TP1 to around 16 mV at TP5.

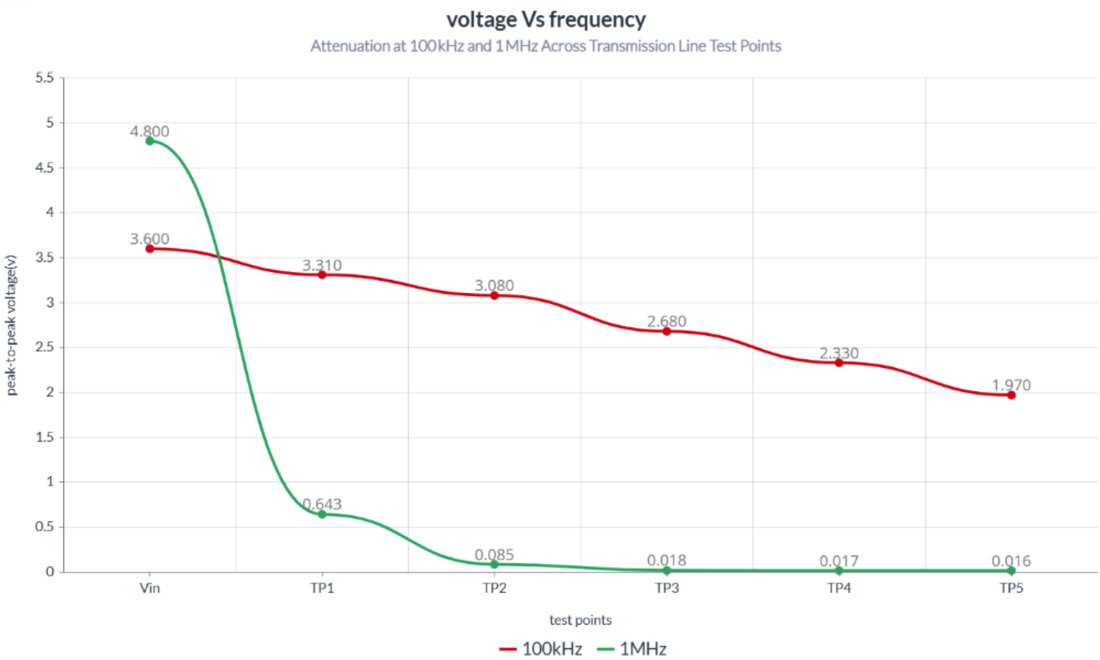

Figure 3: voltage Vs frequency across transmission line test point

The line graph displays the voltage from peak to peak at several test points along the transmission line for the 100 kHz and 1 MHz frequencies. The voltage levels decrease immediately after TP1 and approach zero by TP5, indicating a sharp and quick decline, as shown by the green line, which represents 1 MHz. On the other hand, the red line for 100 kHz shows a more continuous and gradual decrease, suggesting that the signal strength is comparatively constant across the same distance.

Calculations

Prelab

Transmission parameters from 100m of a CAT5 cable:

- ☐ Resistance: $R = 0.188\ \Omega/\text{m}$
  $= 0.188\ \Omega/\text{m} \times 100\text{m} = 18.8\ \Omega$

- ☐ Inductance: $\text{L} = 525\ \text{nH/m}$
  $= 525\ \text{nH/m} \times 100\text{m}$
  $= 52500\text{nH}$
  $= 52500\text{nH}/1000$
  $= 52.5\ \mu\text{H}$

- ☐ Capacitance: $\text{C} = 52\ \text{pF/m}$
  $= 52\text{pF/m} \times 100\text{m}$
  $= 52500\text{pF}$
  $= 52500\text{pF}/1000$
  $= 5.2\ \text{nF}$

Discussion

In this part,

- figure (4 to 9) is about the waveforms of vin, TP1 to TP5 at 100kHz
- figure (10 to 15) is about the waveforms of vin, TP1 to TP5 at 1MHz
- figure (16 to20) is about the square waveforms of vin, TP1 to TP5
- figure (21 to 30) is about the waveforms of vin, TP1 to ,TP5 at 100kHz with 5V ,0 v offset

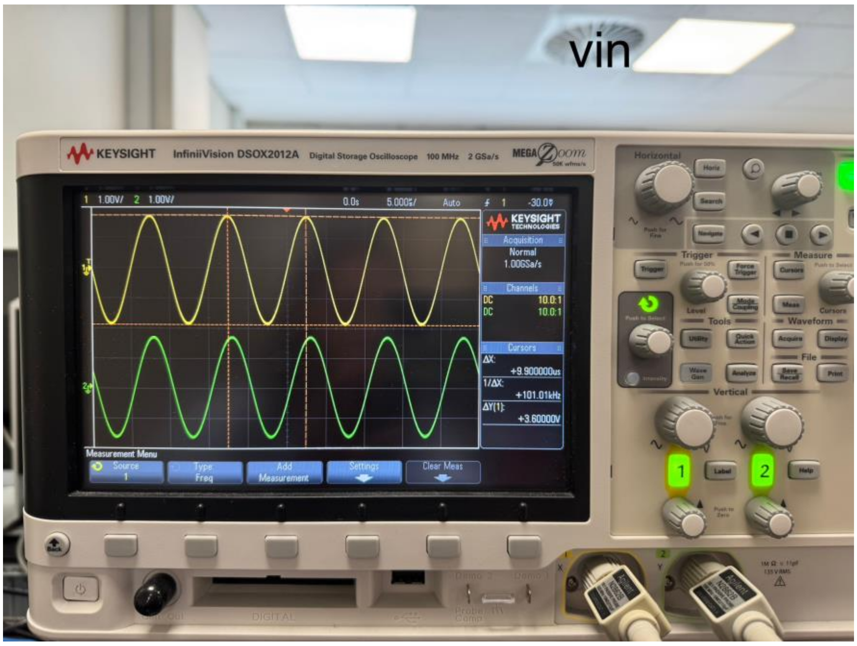

Figure 4: waveform of Vin at 100kHz

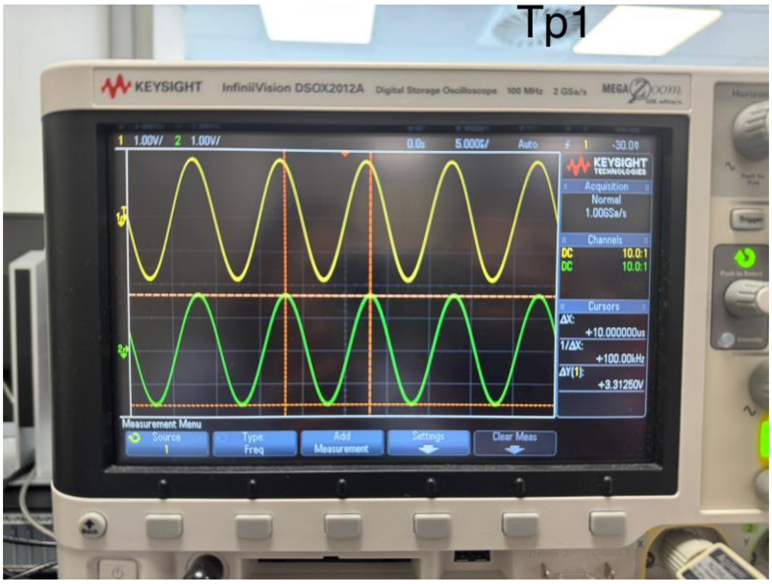

Figure5: waveform of Tp1 at 100kHz

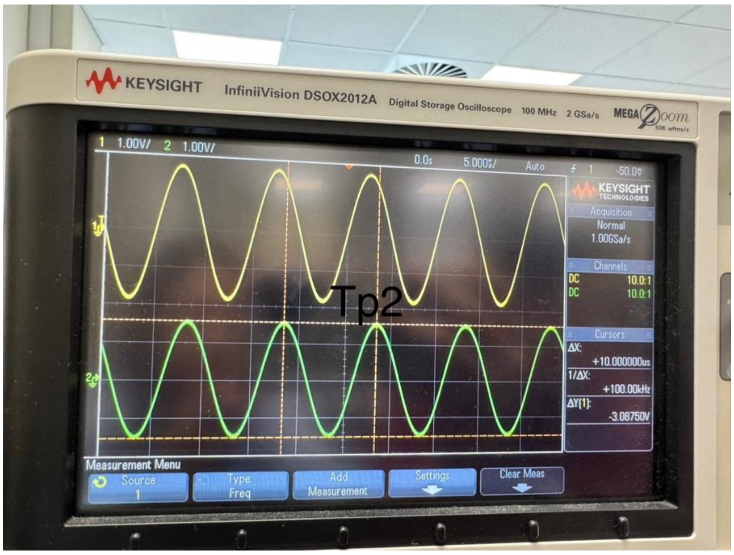

Figure 6: waveform of Tp2 at 100kHz

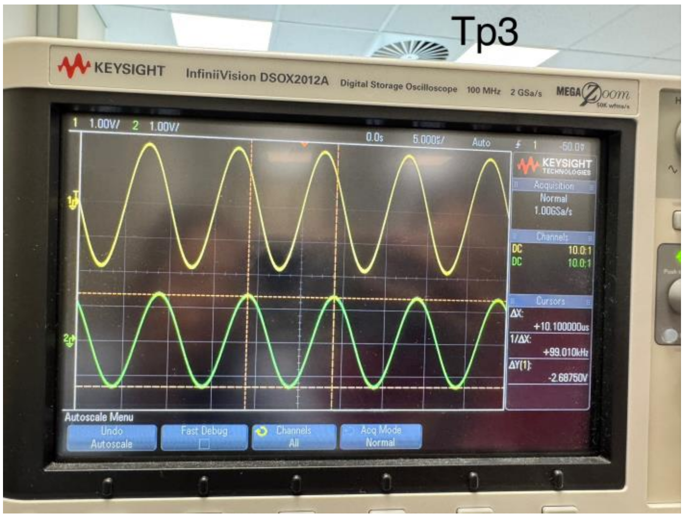

Figure 7: waveform of Tp3 at 100kHz

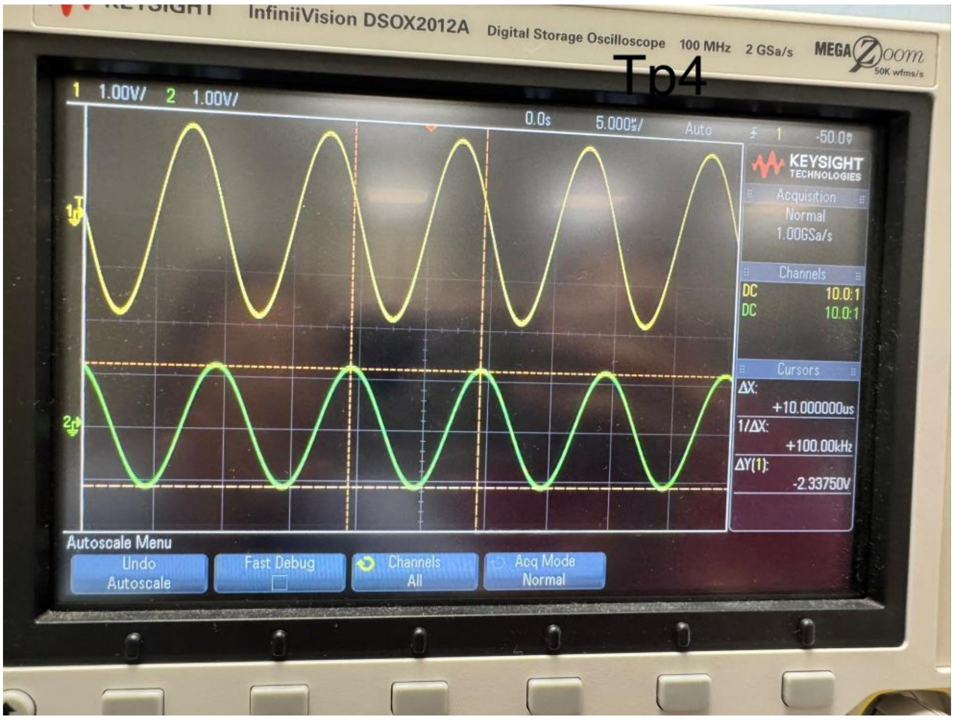

Figure 8: waveform of Tp4 at 100kHz

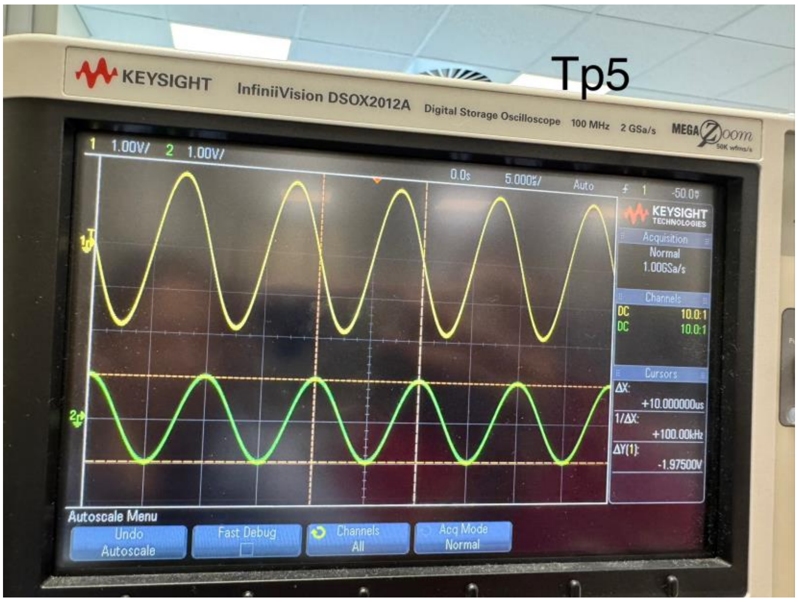

Figure 9: waveform of Tp5 at 100kHz

The signal was recorded at every test point from TP1 to TP5 (figure 4-9) after applying a 100 kHz, 5 V sinusoidal waveform to the input. The waveform was undistorted and smooth at the input. The green output signal began to gradually decrease amplitude as it travelled along the line, particularly from TP3 onwards. At every additional point away from the source, the waveform gradually moved to the right, displaying a noticeable phase shift. As the distance increased this change became more noticeable. Every waveform kept its clear sinusoidal form, indicating the absence of high-frequency distortion. At last, it can be said that the signal moves smoothly over the transmission line at 100 kHz with just small timing and amplitude variations.

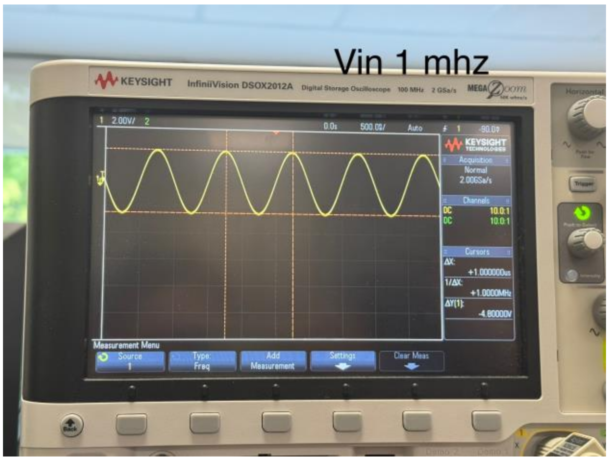

Figure 10: waveform of vin at 1MHz

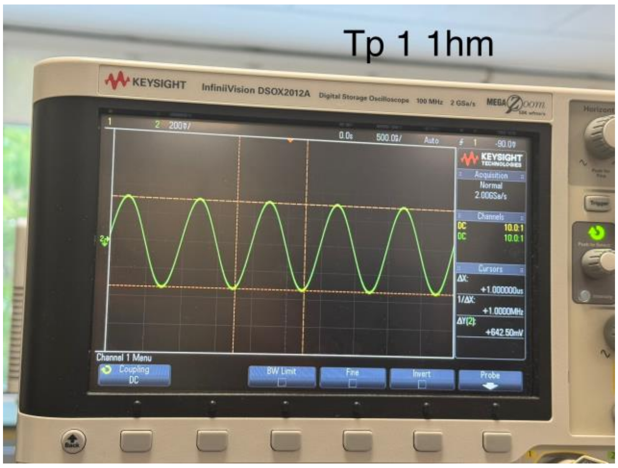

Figure 11: waveform of Tp1 at 1MHz

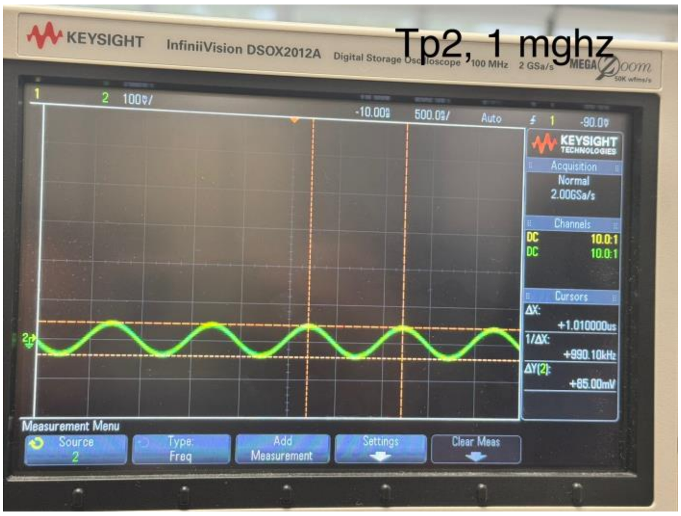

Figure 12 : waveform of Tp2 n at 1MHz

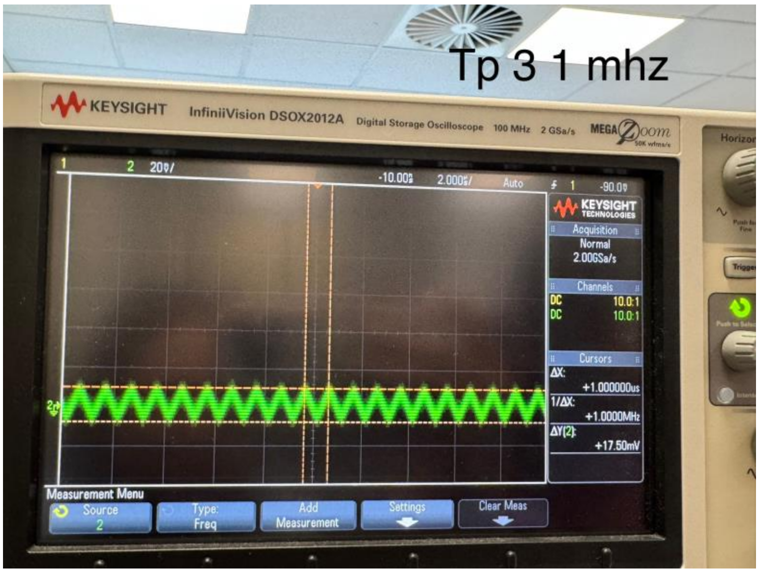

Figure 13: waveform of TP3 at 1MHz

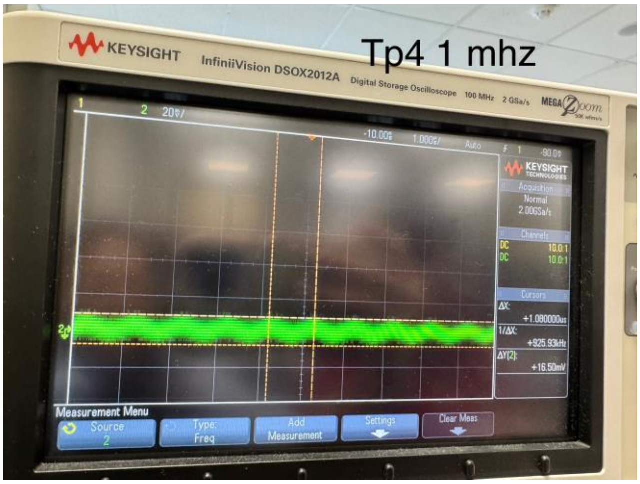

Figure 14: waveform of Tp4 at 1MHz

Figure 15: waveform of Tp5 at 1MHz

As the signal travelled through the test locations, noticeable signal degradation was observed when a 1 MHz sinusoidal waveform was delivered to the transmission line's input. The waveform was clean and

undistorted at Vin (Figure 10), suggesting a clean, strong signal. The signal had already lost a significant amount of amplitude by TP1 (Figure 11), and the waveform edges started turning round. The waveform started to appear significantly squeezed at TP2 (Figure 12), where the amplitude continued to drop off rapidly.
The signal was highly attenuated from TP3 to TP5 (Figures 13 to 15), showing up as low-amplitude ripples with hardly any waveform shape. The nearly flat output at TP5 demonstrated that the frequency-dependent loss of the transmission line had significantly reduced the 1 MHz signal.

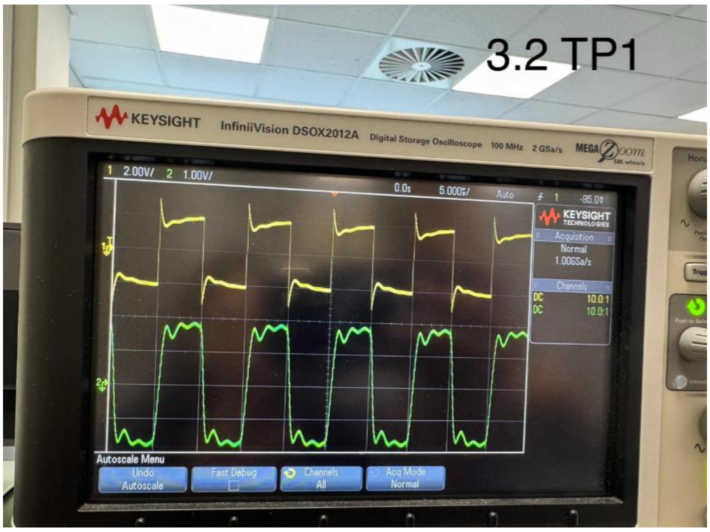

Figure 16: squre waveform of Tp1

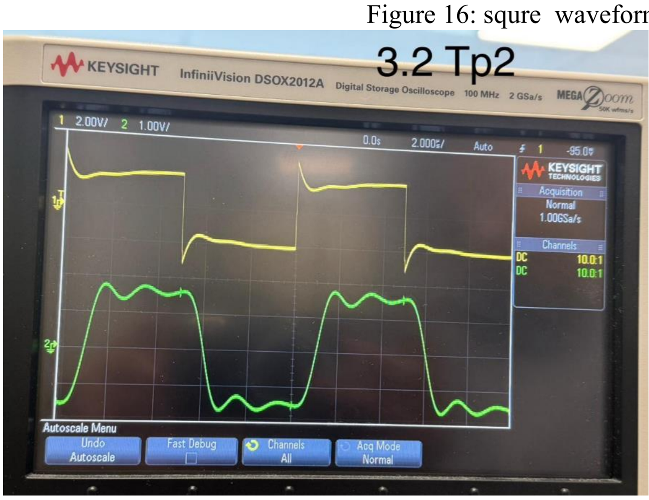

Figure 17: square waveform of Tp2

Figure 18: square waveform of Tp3

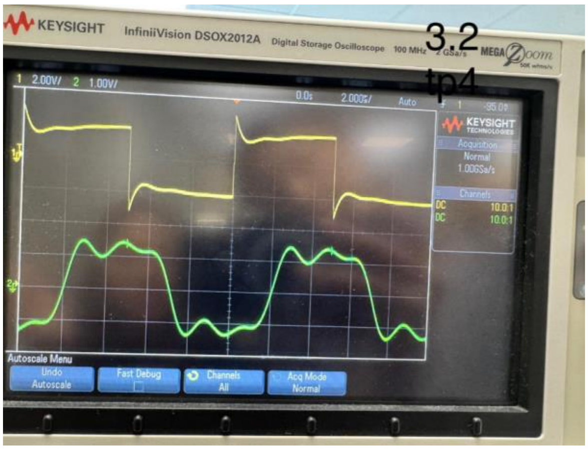

Figure 19: square waveform of Tp4

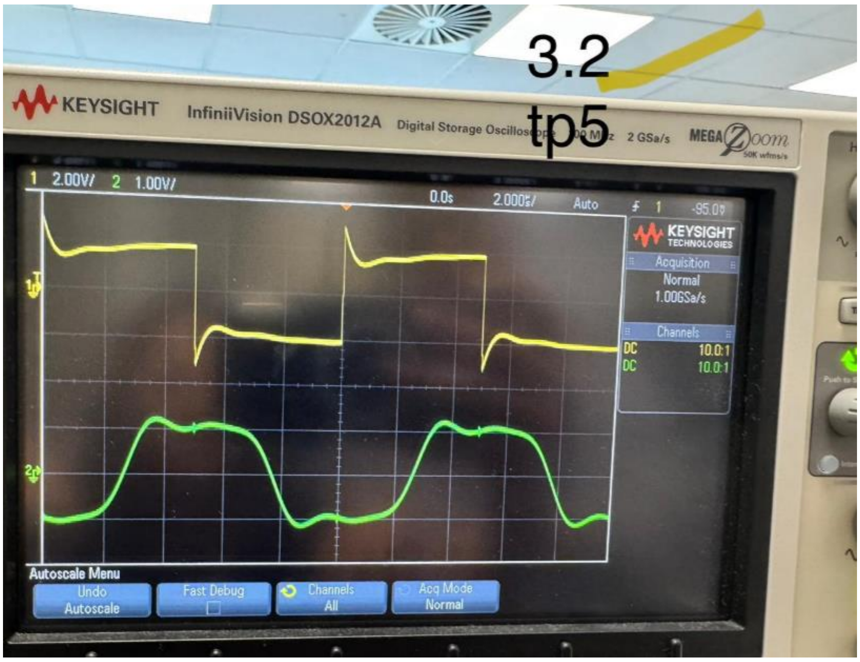

Figure 20: square waveform of Tp5

According to the figure (16-20), the sharp square wave seen at the test point was an indication of a signal that was not distorted. There were visible changes in the signal as it was tested at each test point from TP1 to TP5. At TP1, there was a slightly delay as compared to input, though the difference wasn’t significant. Starting in TP2, the waveform was no longer as sharp, the edges were rounded and the transitions moved more slowly as the high and low levels swapped. The precise edges were no longer noticeable as the signal distance increased Besides, the strength of the signal gradually went down which demonstrates that signal weakened as it moved further. The results suggest that the signal was reduced and delayed by the resistance and capacitance of the circuit’s wires.

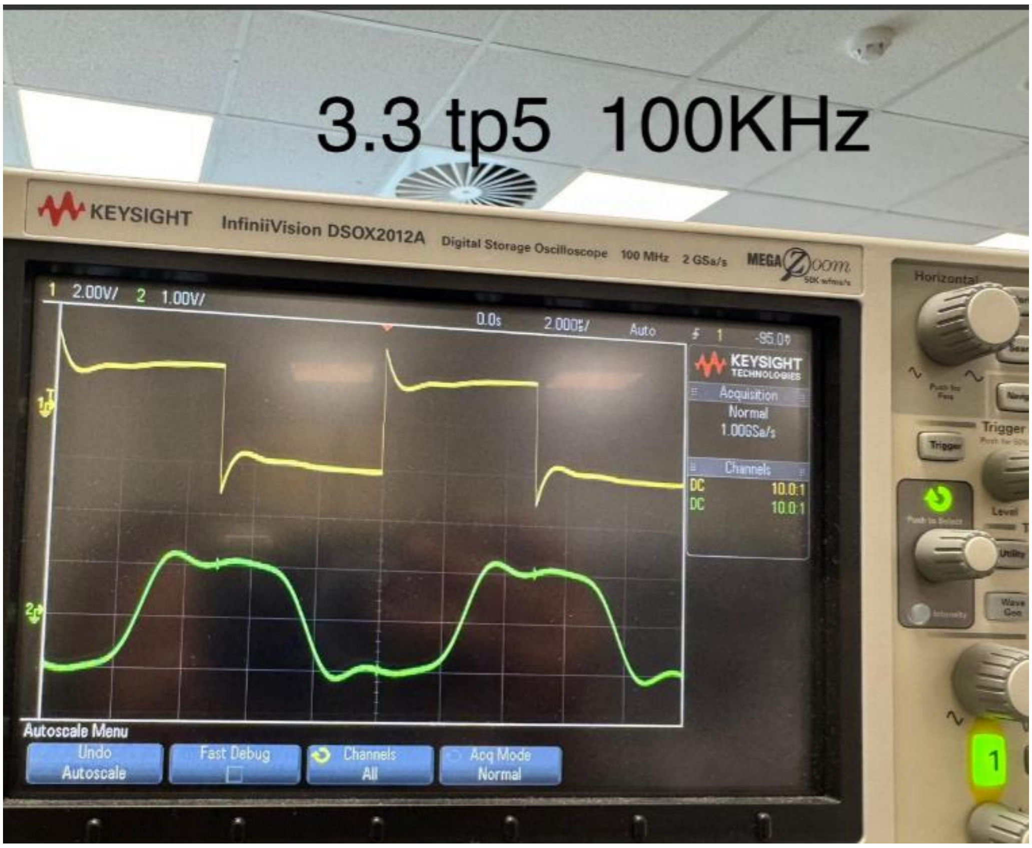

Figure 21: waveform of Tp5 at 100 kHz Input (5v, 0v offset)

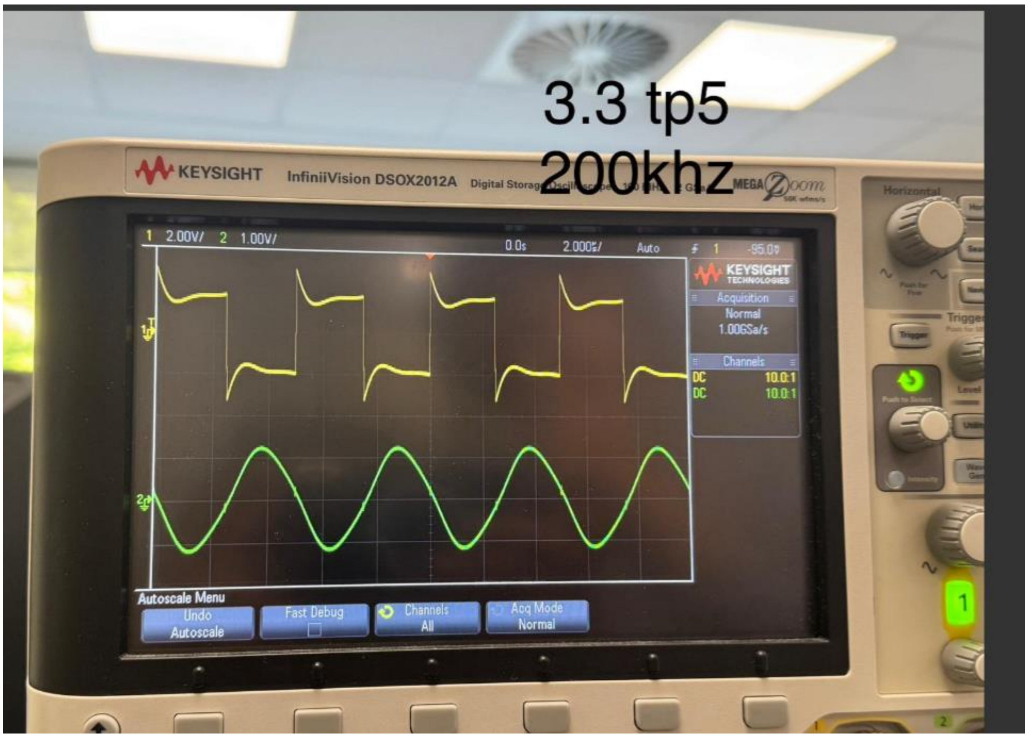

Figure 22 waveform of Tp5 at 200 kHz Input (5v, 0v offset)

Figure 23 waveform of Tp5 at 300 kHz Input (5v, 0v offset)

Figure 24: waveform of Tp5 at 400 kHz Input (5v, 0v offset

Figure 25: waveform of Tp5 at 500 kHz Input (5v, 0v offset)

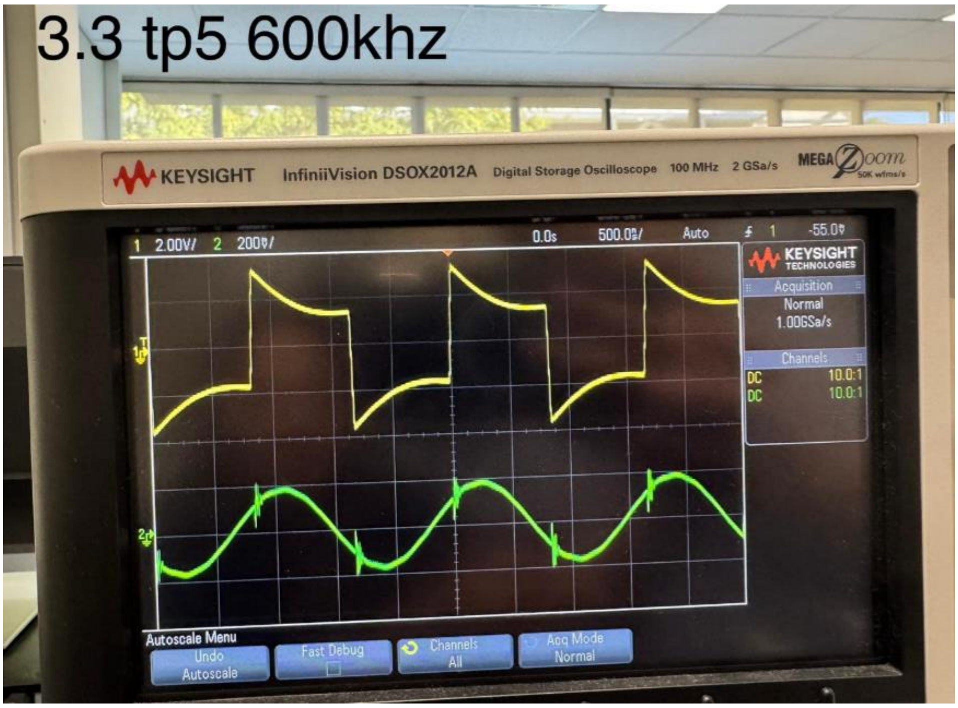

Figure 26: waveform of Tp5 at 600 kHz Input (5v, 0v offset)

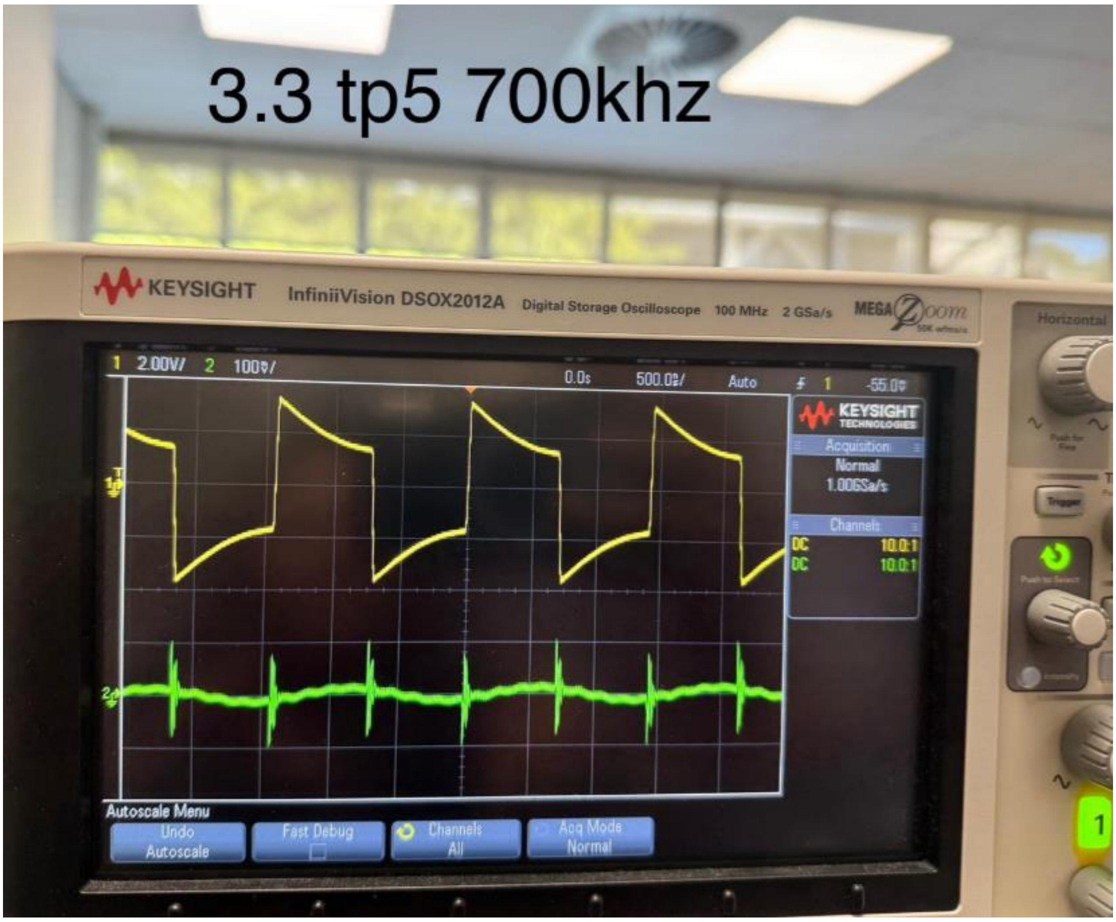

Figure 27 waveform of Tp5 at 700 kHz Input (5v, 0v offset)

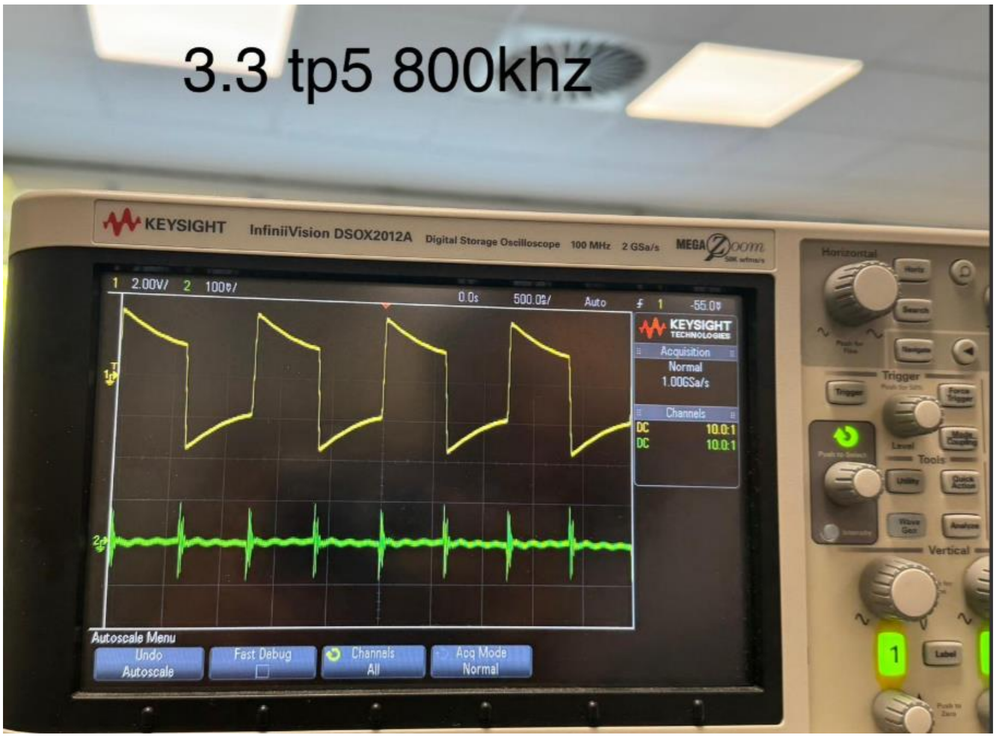

Figure 28: waveform of Tp5 at 800 kHz Input (5v, 0v offset)

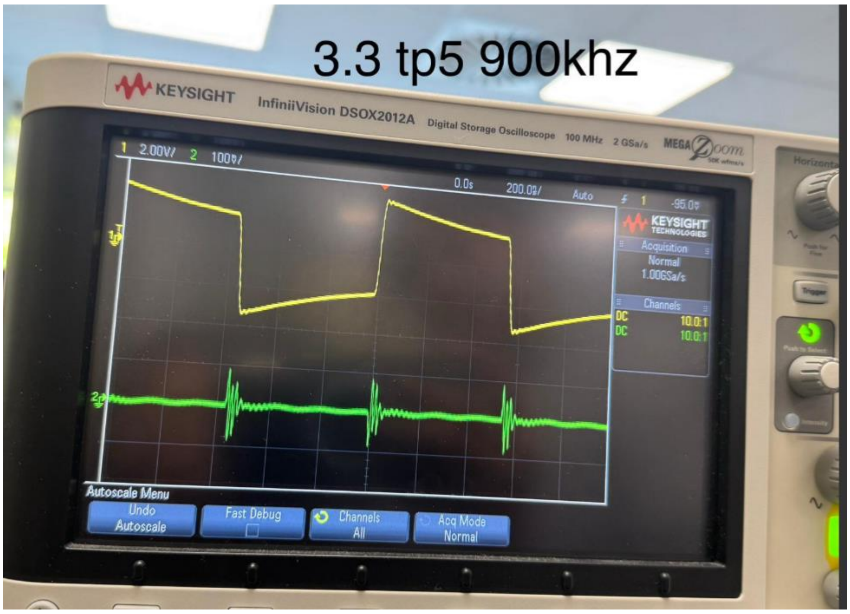

Figure 29: waveform of Tp5 at 900 kHz Input (5v, 0v offset)

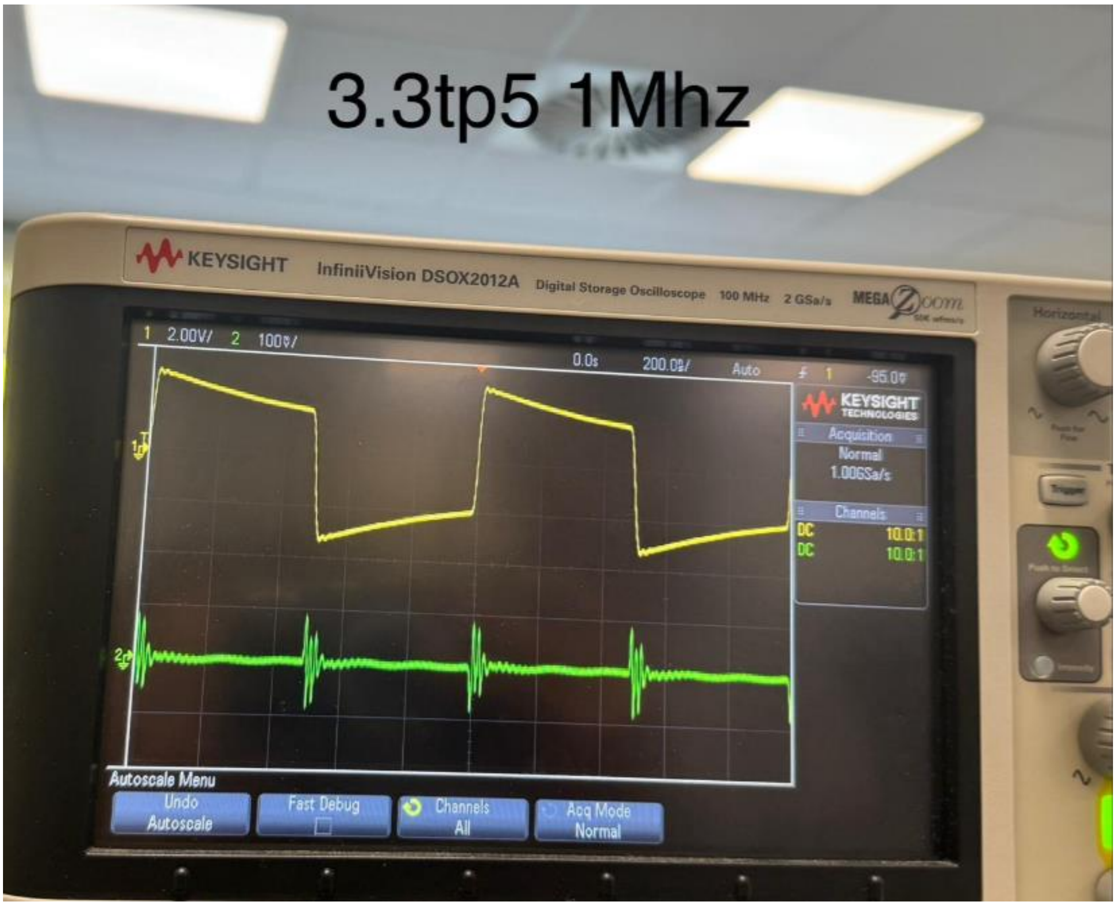

Figure 30 waveform of Tp5 at 1 MHz Input (5v, 0v offset)

The above figure displays the   waveform from Tp1 to Tp5 at 1 MHz Input with a 5v and a 0V offset. While the input was clear, the output at TP5 became more and more distorted with more frequencies .However, for frequencies ranging from 100 to 400 kHz, most of the waveform features remained unchanged. After 500 Hz, the readings showed less clear amplitude and well-coded edges. When the signal operated at 1 MHz, it lost most of its strength and appeared very low. It indicate that some of the higher frequencies are distorted more when traveling through the transmission lines.

Conclusions

Overall, the experiment demonstrated that frequency and distance influence signal quality in a transmission line. With the 500 m CAT5 model, showed that the shape of square waves became more distorted and their sine waves weakened, when frequency went from 100 kHz to 1 MHz. Moreover, the theoretical idea that transmission lines function as low-pass filters is supported by these. Finally, it is clear from the results that signal reliability in high-speed systems depends heavily on how frequently the signal changes.

References

[1]Venudhar Rao Hajari, Abhishek Pandurang Benke, Shalu Jain, Anshika Aggarwal, and Ujjawal Jain, "Optimizing Signal and Power Integrity in High-Speed Digital Systems," *Innovative Research Thoughts*, vol. 10, no. 3, pp. 99–116, Aug. 2024, doi: https://doi.org/10.36676/irt.v10.i3.1465.

[2]Visme, "Create Interactive Online Presentations, infographics, animations & banners in HTML5 - Visme by Easy WebContent," *Visme*, 2012. https://www.visme.co/

[3] Lecture notes and tutorial

Appendix

Nil