Characterization of Coaxial Cables Using a Vector Network Analyzer for the Calibration of a Radio Interferometer for Lightning Study

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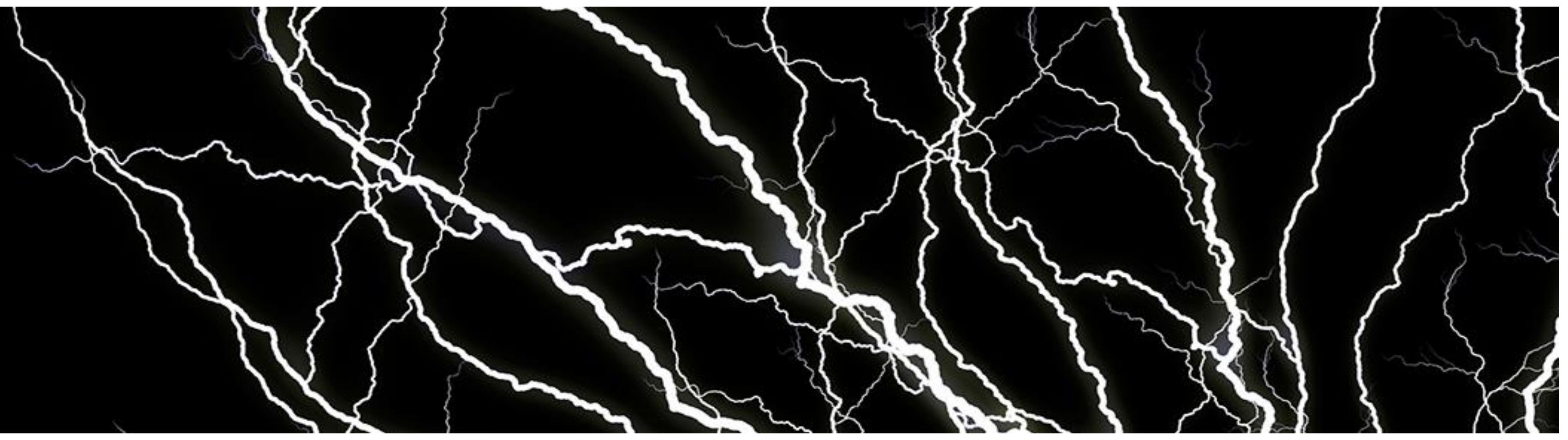
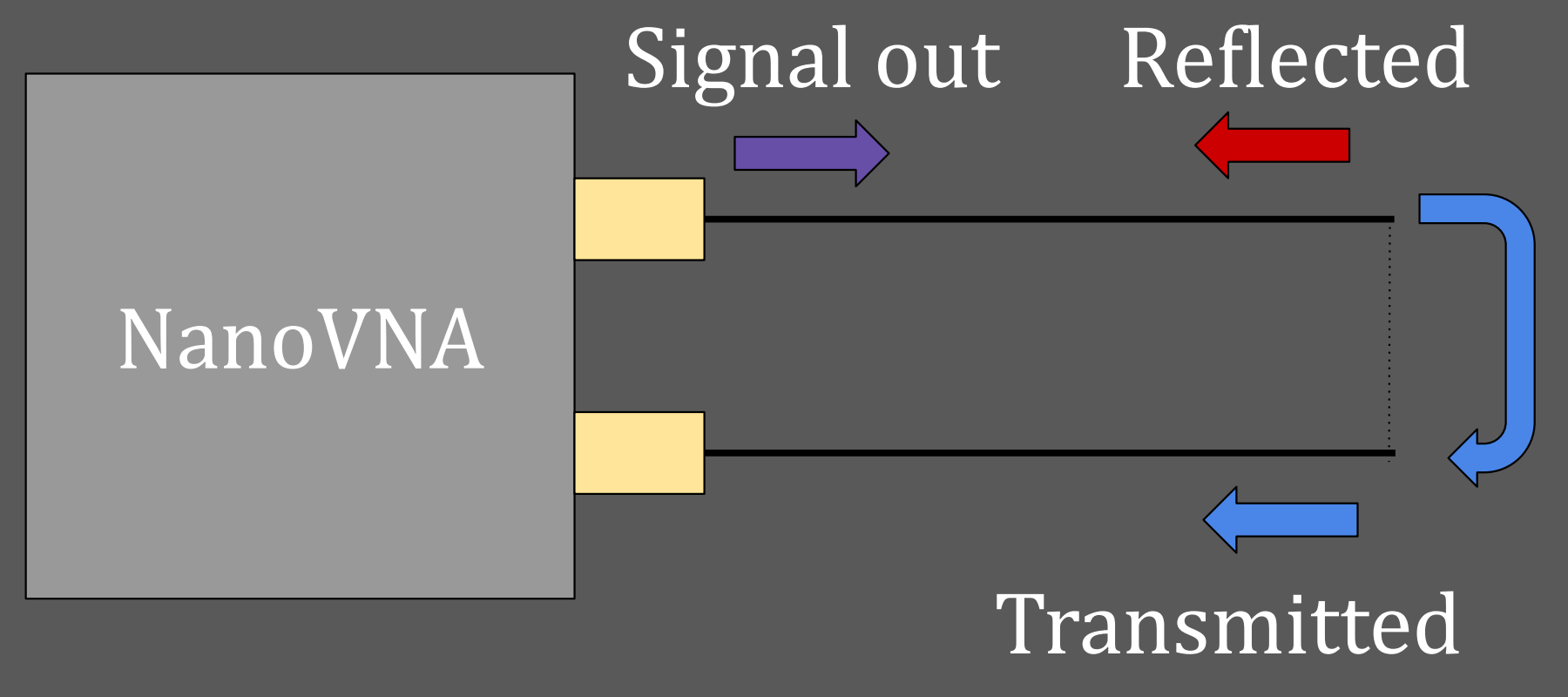


Introduction

- The study of lightning will allow for better aircraft protection and weather prediction.
- Our research lab is constructing an array of radio antennas to image lightning at high speeds [3].
- Each antenna needs to be synced together in time with very low error.
- Characterizing the cable delay to high precision is necessary to sync the antennas in time.

How to measure cables?

Measurements are taken with the NanoVNA portable network vector analyzer.



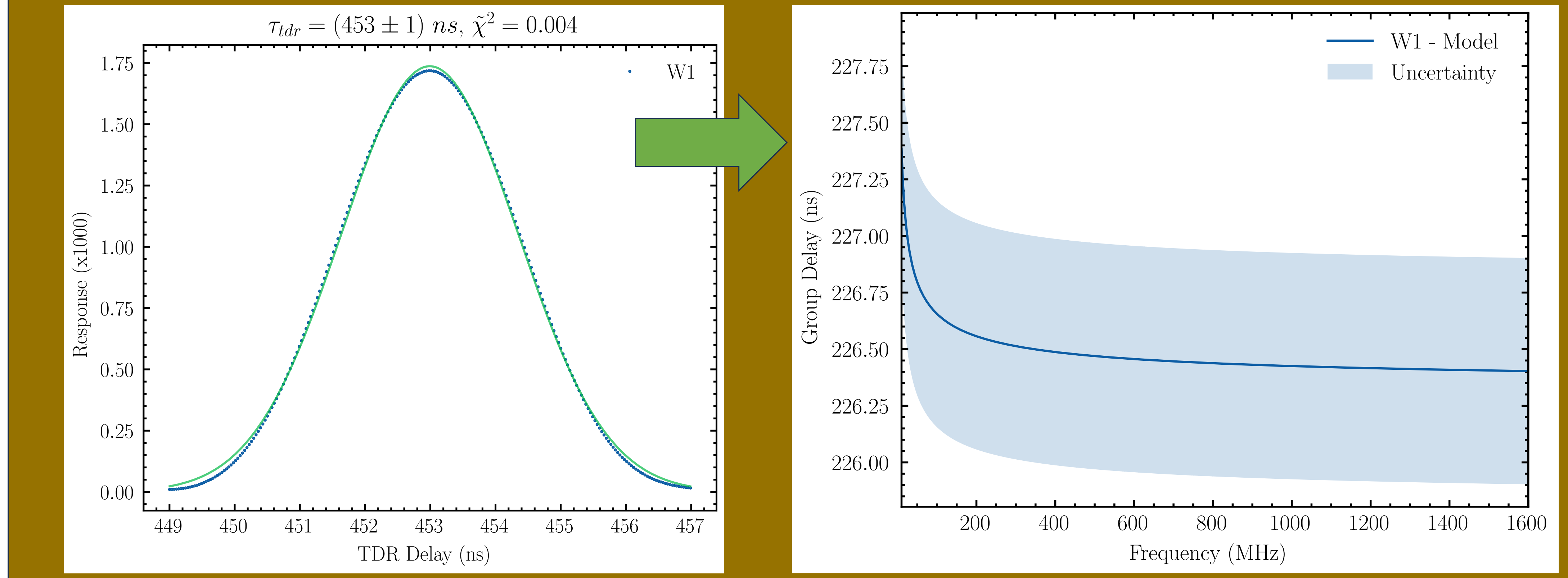
This instrument sends out a sweep of increasing frequencies. By comparing the outgoing and ingoing signals we can preform both **transmission** and **reflection** measurements [1].

Since the cables are (100-300ft) long, out in the field we can only do reflection measurements. However, transmission measurements are the only way to measure delay as a function of frequency. Therefore, I created a method to relate these two measurements.

Reflection Measurements *TDR*

Reflection measurements are done by connecting one end of the cable to the NanoVNA and leaving the other cable end open. This measurement gives an approximate value for the cable length. This process is a form of Time Domain Reflectometry (TDR) [4].

I created a method to model signal delay through coaxial cables.


Reflection Measurement
Transmission Delay Model

Both group delay parameters a and τ_∞ depend linearly on length. In lab we measured multiple TDR lengths (delay) and group delay parameters and showed that there is a constant relationship between them. This relationship allows us to make a transmission model of the cable from a reflection measurement.

Sources of Uncertainty

Type of Uncertainty	τ_{tdr} (ns)	a (ns $\sqrt{MHz}$)	τ_∞(ns)
Discretization	1	X	x
Systematic	x	0.51	0.045
Temperature	0.023	0.076	0.015
Random Variation	0.001	0.006	0.001

Name	τ_∞/τ_{tdr}	a/τ_{tdr} ($\sqrt{MHz}$)
24P1	0.4995	0.007516
24P2	0.4995	0.007354
24P3	0.4996	0.007529
24W1	0.4995	0.007406
24W2	0.4996	0.007247
24W3	0.4995	0.007490
ST	0.4996	0.007530
Average	0.4996	0.007439

- Systematic uncertainty is determined by comparing NanoVNA Measurements to a lab grade E5063A VNA..
- Frequency discretization is due to device digitization step size.
- Utilized a chiller/oven to take measurements at varying temperatures between -10 and 40°C
- Random variation comes from measuring the same cable on different days.

Conclusion

It is viable to use reflection measurements in order to model the group delay of coaxial cables. The dominant uncertainty comes from discretizing the frequency. Other effects such as temperature and random variation are small enough to be ignored. For a given cable our total uncertainty is within 1%. This is within the error budget originally given for this project. The error can be reduced in the future by increasing the number of discretization points.

Transmission Measurements *GD*

In a transmission measurement both ends of the cable are connected to the two distinct ports on the NanoVNA.

Dispersion Coefficient

Group Delay

$$\tau = \frac{a}{\sqrt{f}} + \tau_\infty$$

Delay at infinite frequency (no dispersion)

Frequency

For cylindrical waveguides, the group delay takes the form of the equation above, which we fit to our transmission data [2]. Signals undergo dispersion and therefore move at a different speeds depending on frequency.

$$a = A \cdot L \qquad \tau_\infty = T \cdot L$$

Both parameters depend linearly on the true length of the cable. K is a collection of physical constants which is the same for each cable. T is analogous to the speed at an infinite frequency, also the same for all cables. We replace length with the TDR measurement.

$$\tau = \tau_{tdr}\left(\frac{(a/\tau_{tdr})}{\sqrt{f}} + \left(\frac{\tau_\infty}{\tau_{tdr}}\right)\right)$$

The constants can be determined statistically by dividing a and τ_∞ by τ_{tdr} . We write the constants as A = (a/τ_{tdr}) and T = (τ_∞/τ_{tdr}).

References & Acknowledgments

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