Development of Field Probes for Measuring Ultra-wideband Electromagnetic Field Radiation

Evan Goldstein | Accelerator Operation and Technology – Applied Electrodynamics | Mentor: Quinn Marksteiner

Introduction

OBJECTIVES AND MOTIVATION

This project focuses on the development of electromagnetic (EM) field probes designed to operate in ultra-wideband RF frequency using principles derived from the electromagnetic theory of waveguides. By leveraging the transverse propagation modes of waveguides, the probes were calibrated for specific field applications. The desired results are broadband, high voltage far field probes for sub-nanosecond pulsed measurements. The methodology outlined in this work can serve as a model for similar probe development efforts in the future.

Design

PROBE FABRICATION

D-dot probes (dipoles) measure electric fields with capacitance and B-dot probes (loops) measure magnetic fields with inductance. These probes were modeled first before being fabricated from COTS parts. 3D modeling of the experimental ultra-high vacuum chamber assembly and the RF evaluation chamber lent to the design of the overall measurement system.

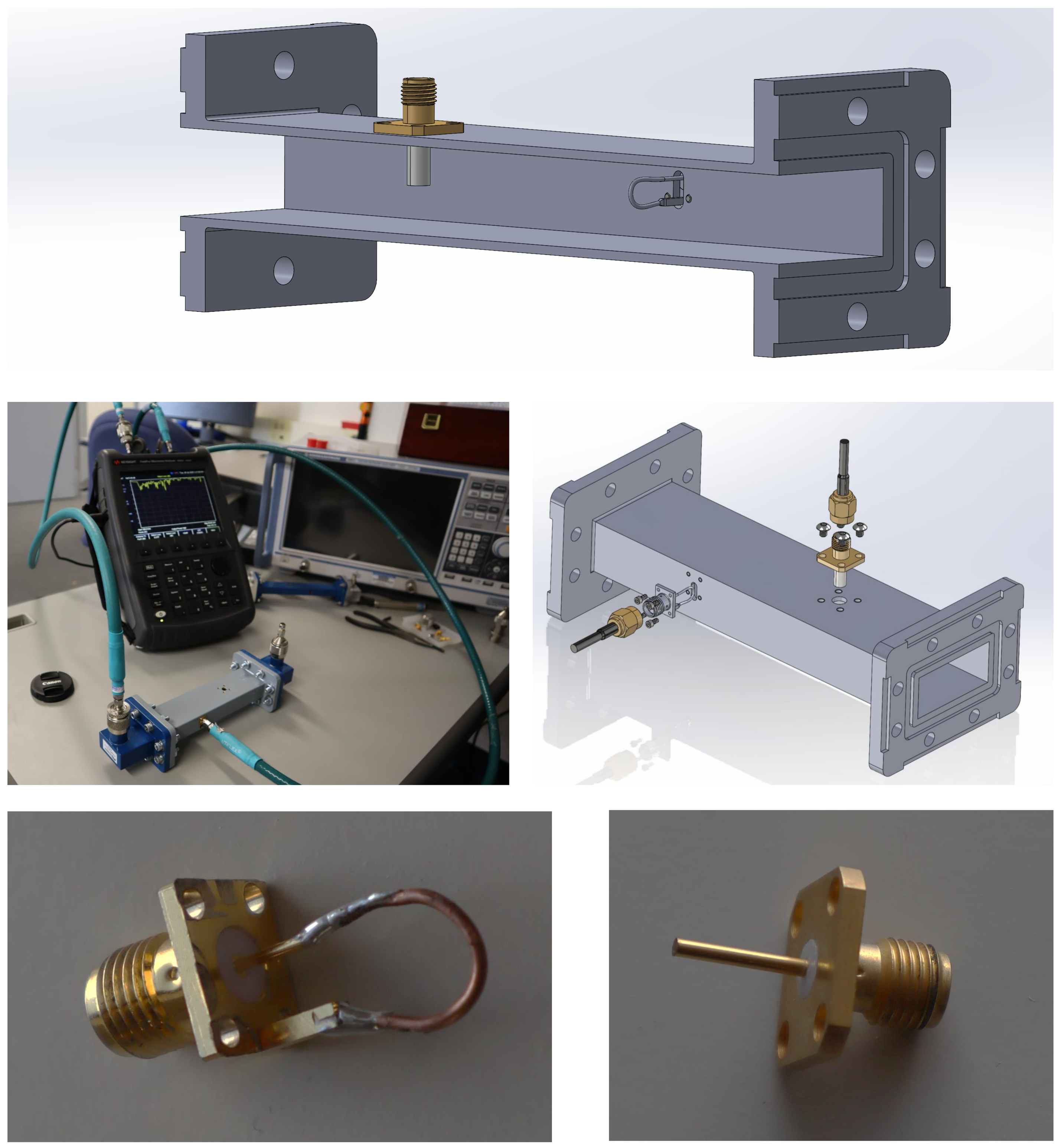


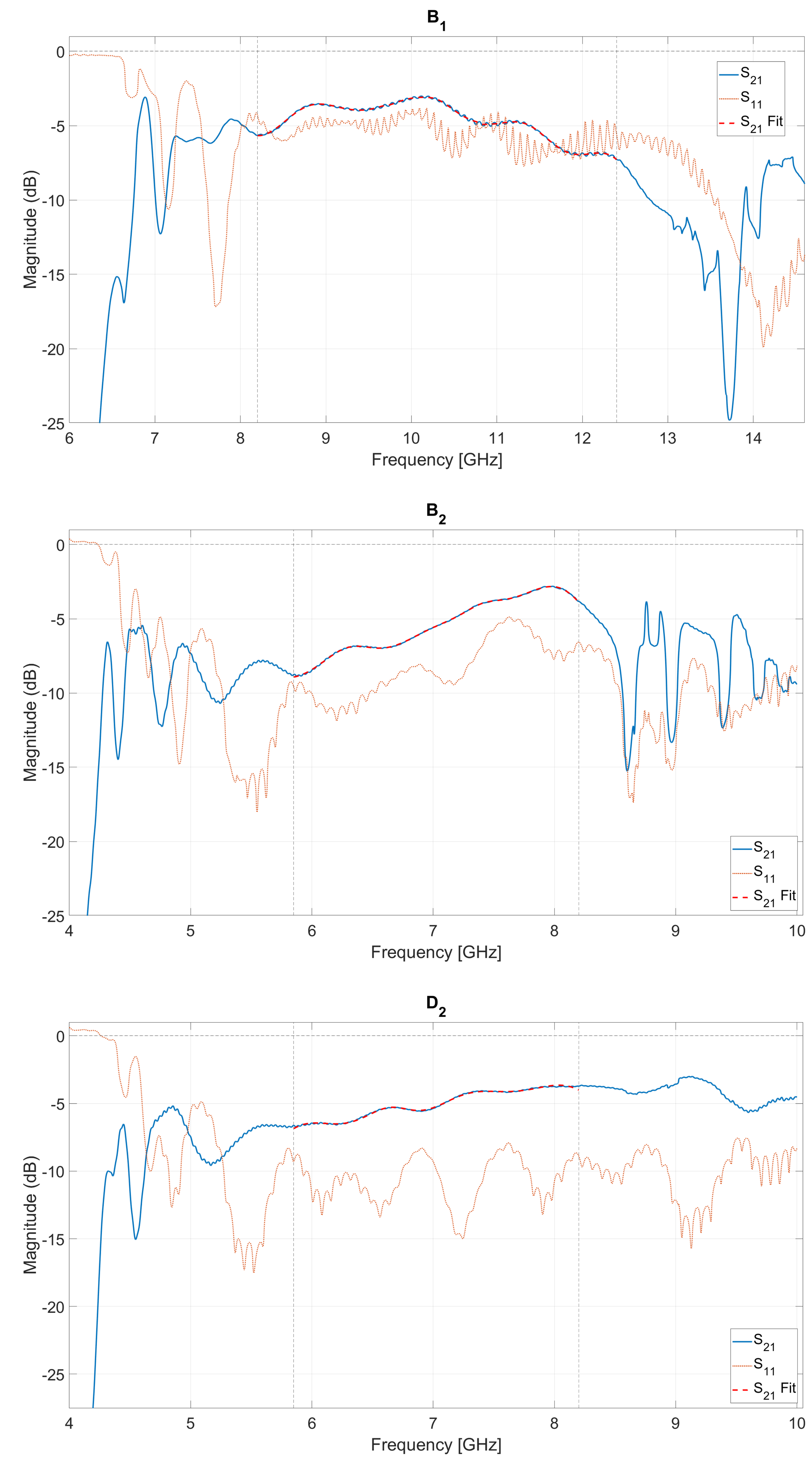
Figure 1. Fabricated D-dot and B-dot probes in waveguides and under test.

Experimental Setup

CALIBRATION

S-parameter measurements, taken using a microwave Vector Network Analyzer (VNA), record the power transmitted through the probe for a frequency range specific to each waveguide, averaged over 10 sweeps with smoothing to reduce noise. With MATLAB's RF Toolbox™ the frequency response data was analyzed by applying a rational function fit with *N* poles, selected to ensure a fitting error of < -40 dB. The average root-mean-square error (RMSE) was calculated to assess the quality of fit. This calibration approach allows each probe's behavior to be quantitatively understood within the relevant frequency band prior to use in the experimental system.

(a) (b) (c)



(d)

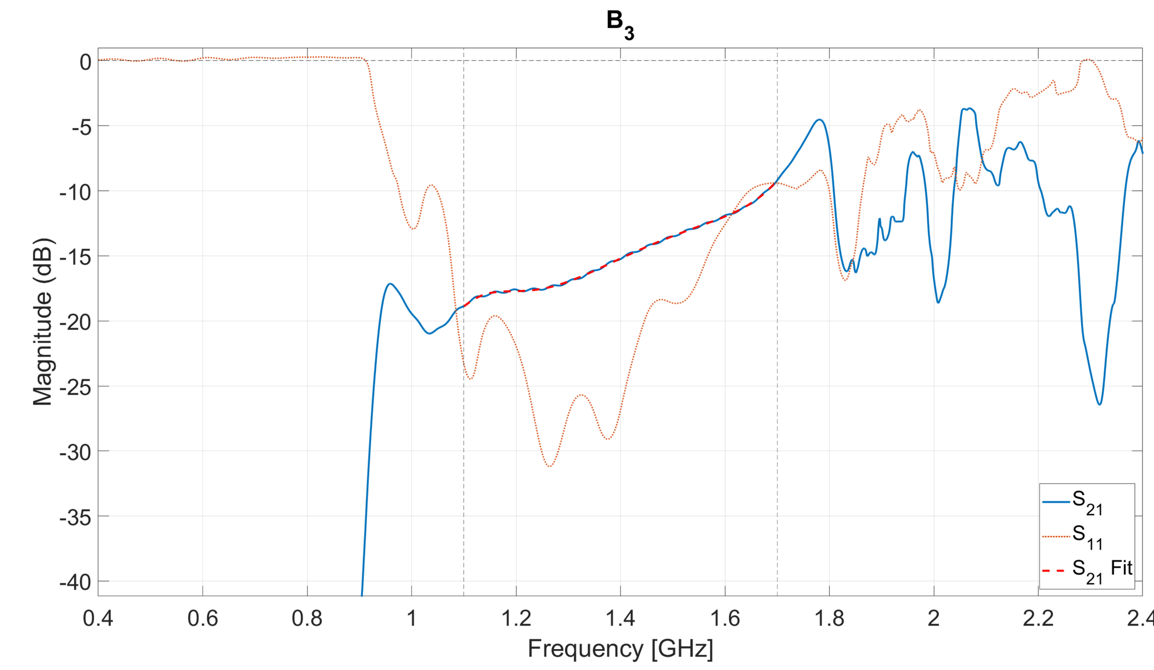


Figure 2. Magnitude of S_{21}, S_{11}, and the fitted function to the operational bandwidth of the waveguide for (a) B_1, (b) B_2, (c) D_2, and (d) B_3

SYSTEM POST-PROCESSING

Signal processing constructs the electric or magnetic field pulse from the raw probe output. This processes is shown in Figure 3. The transfer function from the calibration is applied to the data in the frequency domain to correct for the probe's unique frequency response. Cable and oscilloscope attenuations are accounted for before transforming the corrected signal back to the time domain.

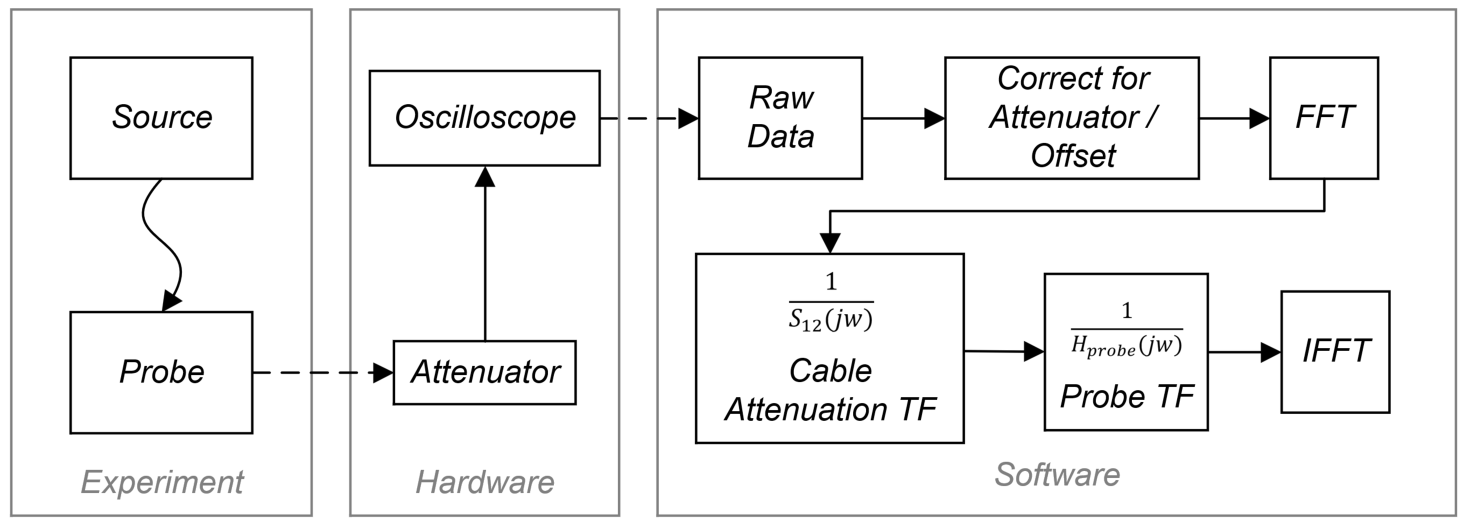


Figure 3. Diagram of the total experimental setup for probe measurements. This follows the signal path from collection in the experimental chamber through the software post-processing.

DISCUSSION

Next steps involve functional testing to verify the accuracy of the calibration and signal processing techniques across different voltage levels and time scales. Testing showed that the probes introduce reflections to the signals in the waveguides, seen as increased S_{11} values, which can impact calibration. Calibration uncertainty and functional testing can be carried out using a G-TEM Cell, a test chamber that creates far field EM radiation.

CONCLUSION

D-dot and B-dot probes were developed and calibrated to measure experimentally generated high-voltage, ultra-wideband pulsed fields. The combination of design, fabrication, and calibration brought these probes to life. Functional testing will validate their performance under simulated operating conditions and guide final implementation for experimental measurements.

REFERENCES

1. Huiskamp T., Beckers F.J.C.M., van Heesch E.J.M., Pemen A.J.M. B-Dot and D-Dot Sensors for (Sub)Nanosecond High-Voltage and High-Current Pulse Measurements. *IEEE Sensors Journal.*
2. W. Reed Edgel. PRODYN APPLICATION NOTE 1103A Functional Testing The Next Best Thing to Calibration
3. Wang, K., Duan, Y., Shi, L., & Qiu, S. (2019). Laboratory Calibration of D-dot Sensor Based on System Identification Method. *Sensors 2019, 19, 3255.*

Los Alamos NATIONAL LABORATORY

NNSA National Nuclear Security Administration

Managed by Triad National Security, LLC, for the U.S. Department of Energy's NNSA.

LA-UR-25-26601