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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Modeling Method of circuit exposure to UWB Pulse

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- Objective
- Directed Energy Effects
- Modeling Method
- Electrical Circuit Testing
- Future Work

- The objective of this project is to develop a method of analyzing an electrical circuit or electrical component while under exposure of a non-lethal Directed Energy (DE) threat.

- Provide detailed analytical understanding of non-lethal DE threats affecting electronic systems.

- Provide data to help with the design DE countermeasures

- Provide an alternative to costly field testing

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• This project uses the far field response of a system that transmits an Ultra-Wideband (UWB) pulse. This pulse is similar to an EMP.

• Differs from HPM (High Powered Microwaves), which are typically CW signals.

• There are two ways for an UWB pulse to effect an electronic system:

• First is the "front door" in which the DE signal couples through the receiver antenna of the electronic system.

• The second is the "backdoor" in which the DE signal couples through the seams, cracks, or cabling of the electronic system.

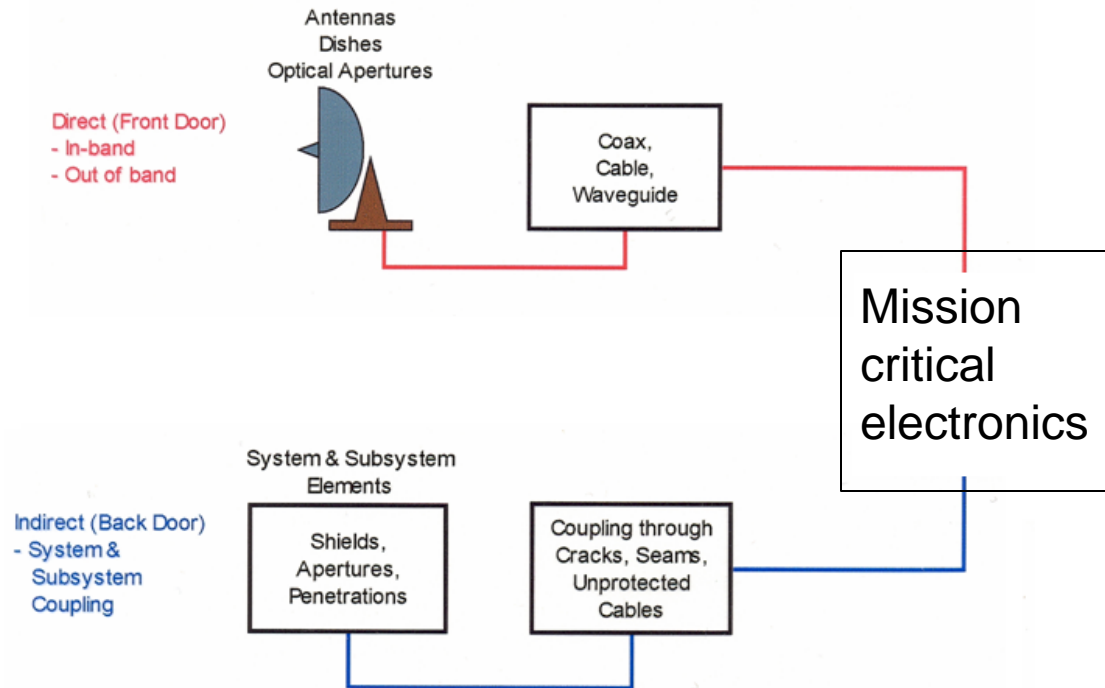• This project utilizes the "backdoor" scenario.

Antennas
Dishes
Optical Apertures

Direct (Front Door)
- In-band
- Out of band

Coax, Cable, Waveguide

Mission critical electronics

System & Subsystem Elements

Indirect (Back Door)
- System & Subsystem Coupling

Shields, Apertures, Penetrations

Coupling through Cracks, Seams, Unprotected Cables

Diagram courtesy of George H. Baker "High Powered Electromagnetic Weapons" August 2011

- Existing modeling and simulation methods of "backdoor" approach consider EM waves coupling on PCB traces and components. These techniques are executed in CAD modeling environments using FEM.

- Existing methods alone can not determine the culprit component (resistor, capacitor, inductor, transistor, etc). A combination of modeling methods utilizing nodal analysis and FEM is presented here to mimic a "backdoor" approach.

- With most modern electrical components being SMD, the UWB pulse couples into the PCB traces of circuit.

- The presented modeling method requires two inputs: the far field response from the UWB pulse system for determining the voltage response on each trace of the circuit, and the PCB trace layout of the circuit for determining the mutual coupling between all the traces

- The PCB trace layout is entered into Sonnet software, which outputs the mutual coupling (S21) between all the traces.

- Sonnet analyzes the PCB layout in MoM with a full wave frequency sweep.

- Sonnet uses the top traces, dielectric dimensions, and ground plane to calculate the mutual coupling between traces

- The output mutual coupling data in the frequency domain is exported to a MATLAB script for inverse FFT.
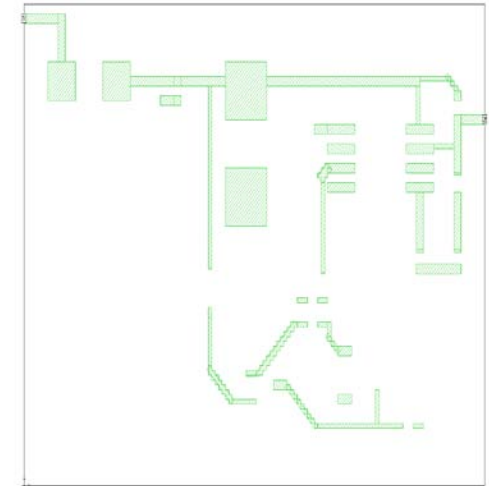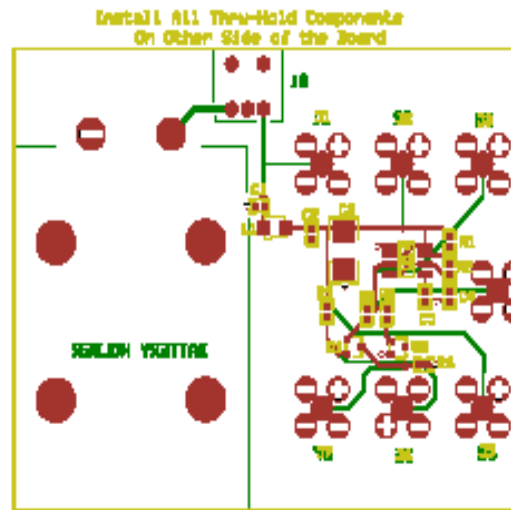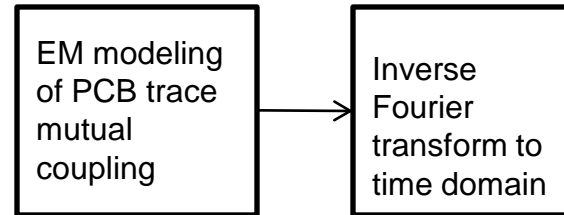
- MATLAB modeling software is used to develop a script that will calculate voltage response on each trace from the input of the far field transient pulse response.

- In the script, the pulse is converted to the frequency domain using FFT for voltage calculation; then, the voltage is converted back to time domain using inverse FFT.

- The dimensions of each trace and dielectric dimensions are known values in the script.

- The script outputs time vs. amplitude (which include imported S21) data that will link to SIMULINK environment.

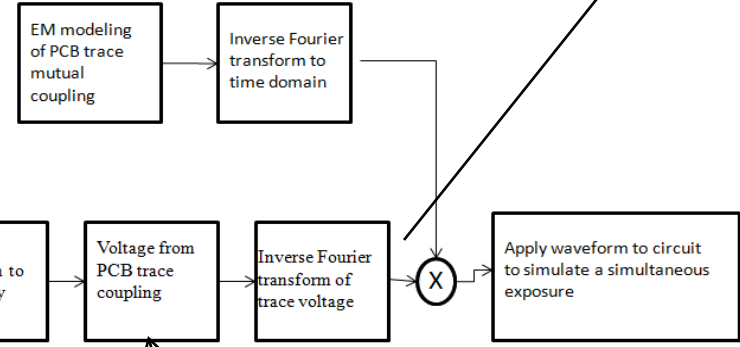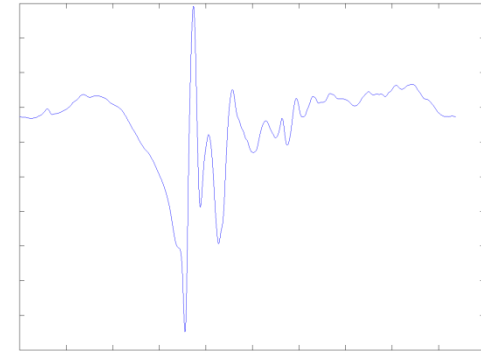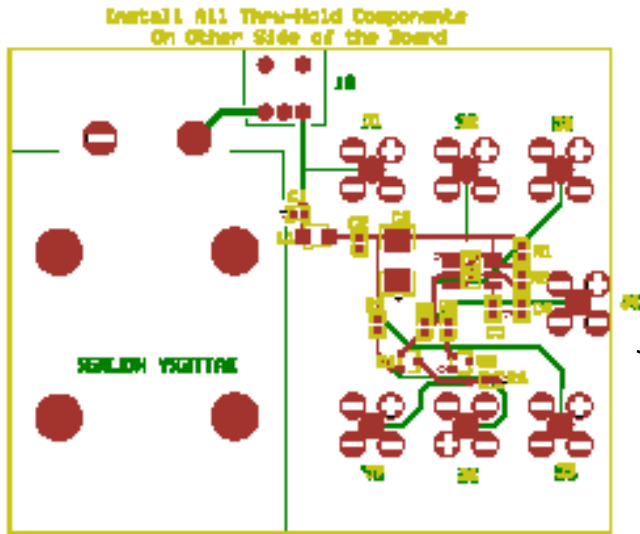Fourier Transform to Frequency domain → Voltage from PCB trace coupling
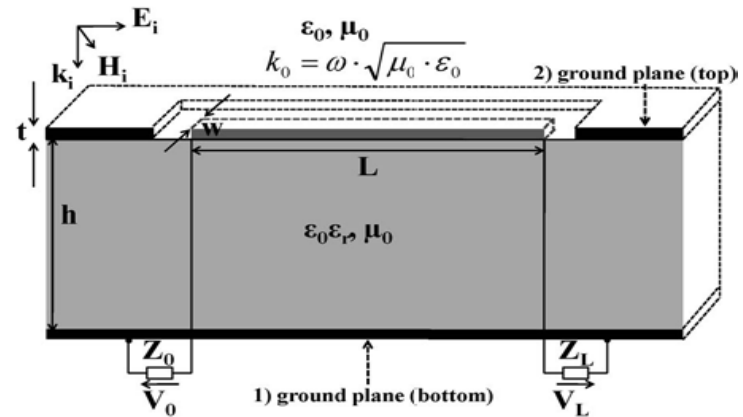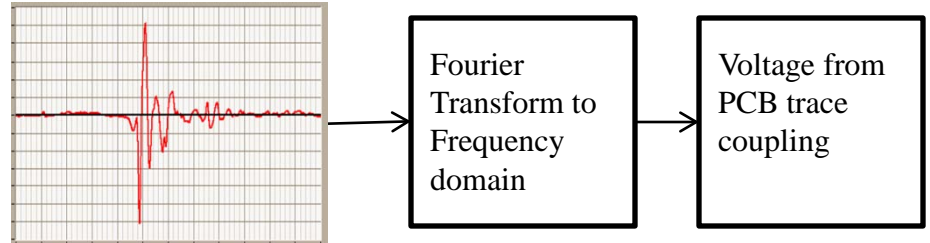
"The Influence of Different PCB Materials on the Coupling Behavior of High Power Electromagnetics" IEEE 2009 978-1-4244-4108-2

$$k_0 = \omega\sqrt{\mu_0 \varepsilon_0}$$

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\sqrt{1 + \frac{10h}{w}}\right)^{-1} - \frac{\varepsilon_r - 1}{4.6}\left(\frac{t}{w}\right)$$

$$|V_{0,L}| \approx k_0 h L E_i \left(1 + \frac{\sqrt{\varepsilon_{r,eff}}}{\varepsilon_r}\right)$$

DISTRIBUTION STATEMENT A

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

EM modeling of PCB trace mutual coupling	Inverse Fourier transform to time domain

UWB pulse boundary conditions	Fourier Transform to Frequency domain	Voltage from PCB trace coupling	Inverse Fourier transform of trace voltage	✕	Apply waveform to circuit to simulate a simultaneous exposure

$$k_0 = \omega\sqrt{\mu_0 \varepsilon_0}$$

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\sqrt{1 + \frac{10h}{w}}\right)^{-1} - \frac{\varepsilon_r - 1}{4.6}\left(\frac{t}{w}\right)$$

$$|V_{0,L}| \approx k_0 h L E_t \left(1 + \frac{\sqrt{\varepsilon_{r,eff}}}{\varepsilon_r}\right)$$

DISTRIBUTION STATEMENT A

*TECHNOLOGY DRIVEN.* **WARFIGHTER FOCUSED.**

- The circuit to the right is a sample analog circuit with p and n-type MOSFETs that handle the square wave output of the 555 timer.

- The J ports are pickoff nodes to monitor the function of the different sections of the circuit.

- This circuit was created to include several common electrical components in a typical circuit.
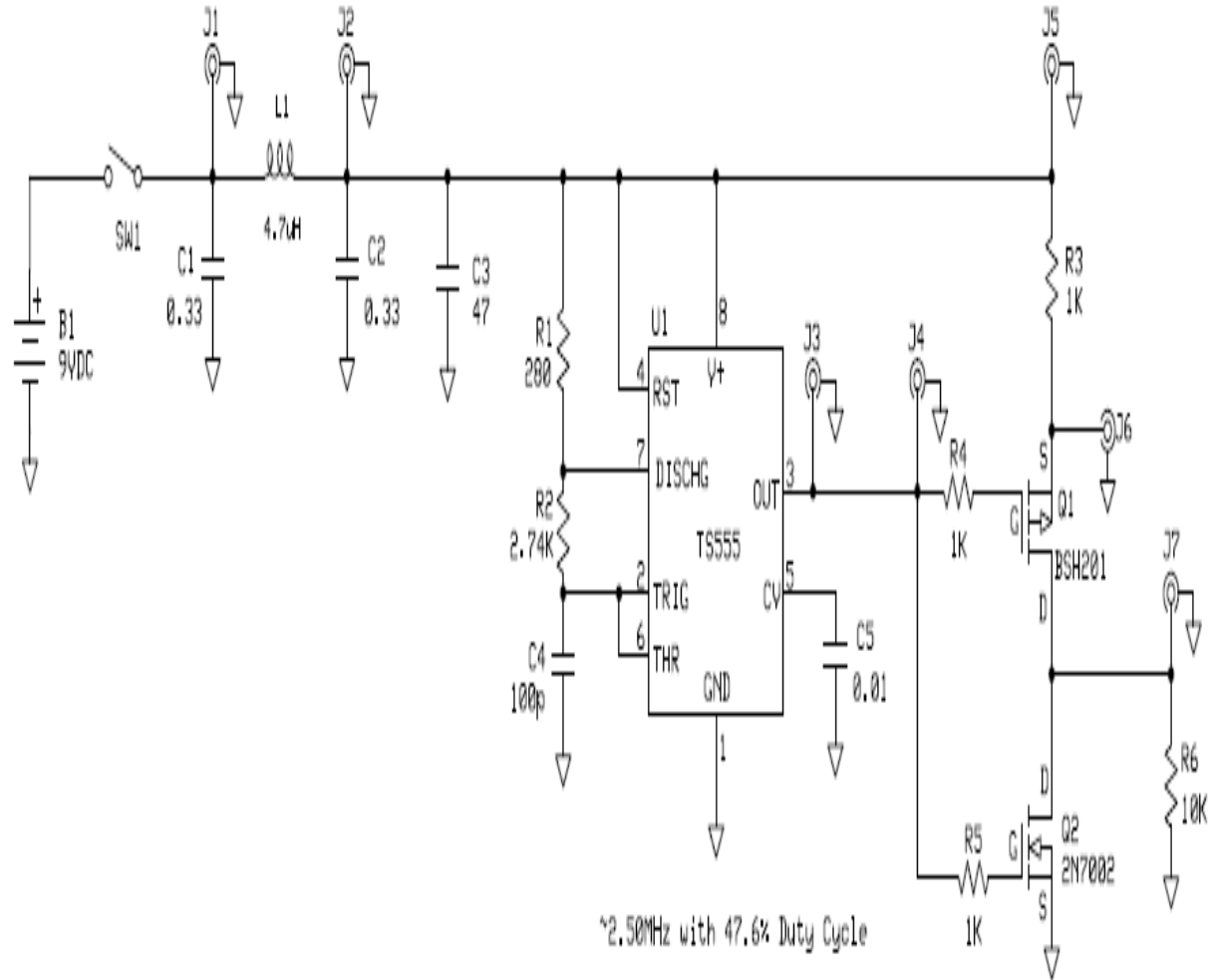
- The circuit board was fabricated with J pickoff points from the back of the board to prevent UWB pulse interference.

- The pickoff connects are right angle SMAs and the battery is connected on the bottom.

- There is a ground plane on the top layer surrounding the circuit to shield the pickoff cables.

- The red lines are the top traces and the green are the bottom traces for pickoff points only.
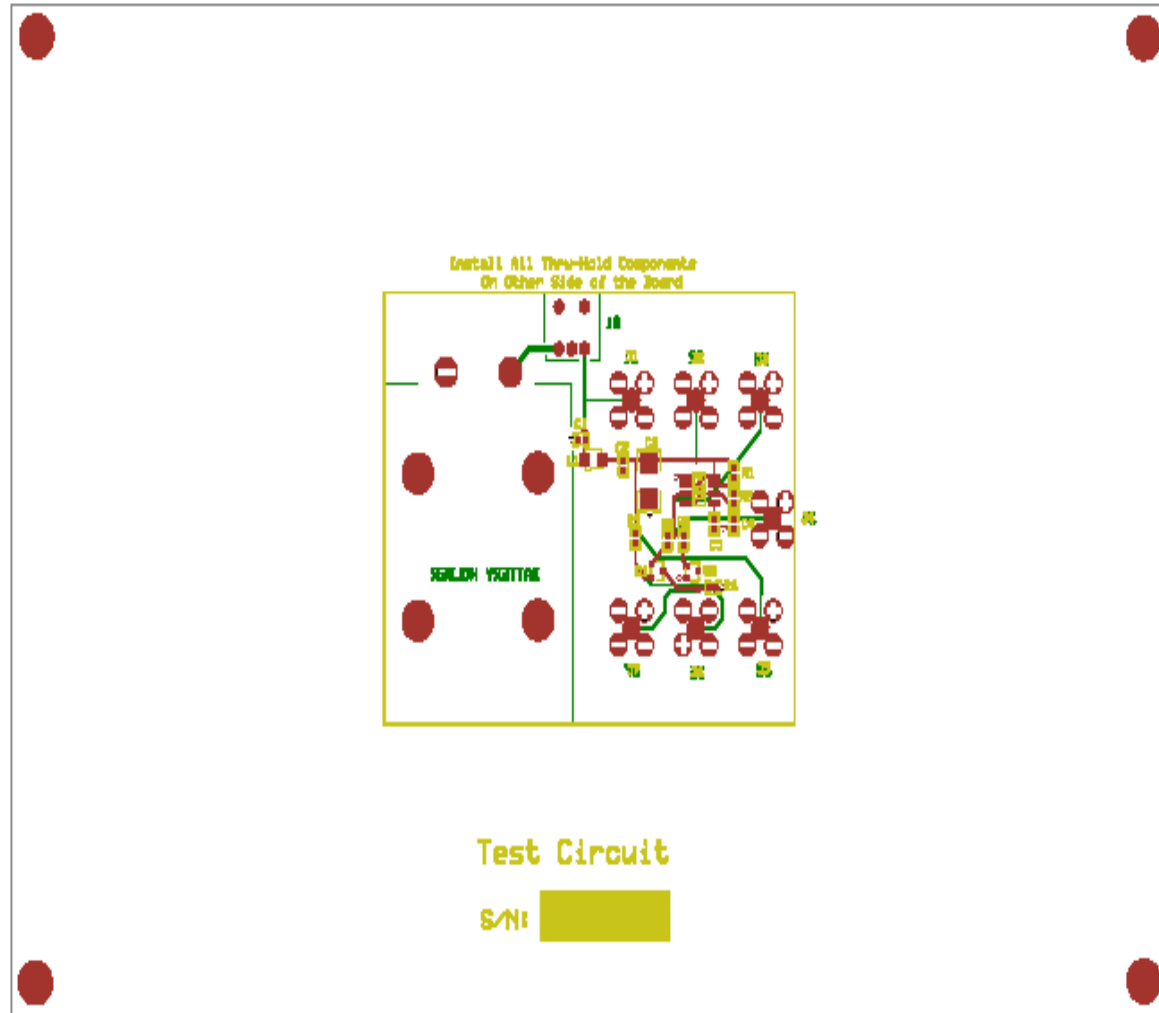
- This is a SIMULINK version of the circuit

- Voltage probes are used as pickoff nodes for detecting the responses at different sections of the circuit.

- All pickoffs are converted from physical electronics data to SIMULINK data.

- SIMULINK has the capability to import data from MATLAB scripts.
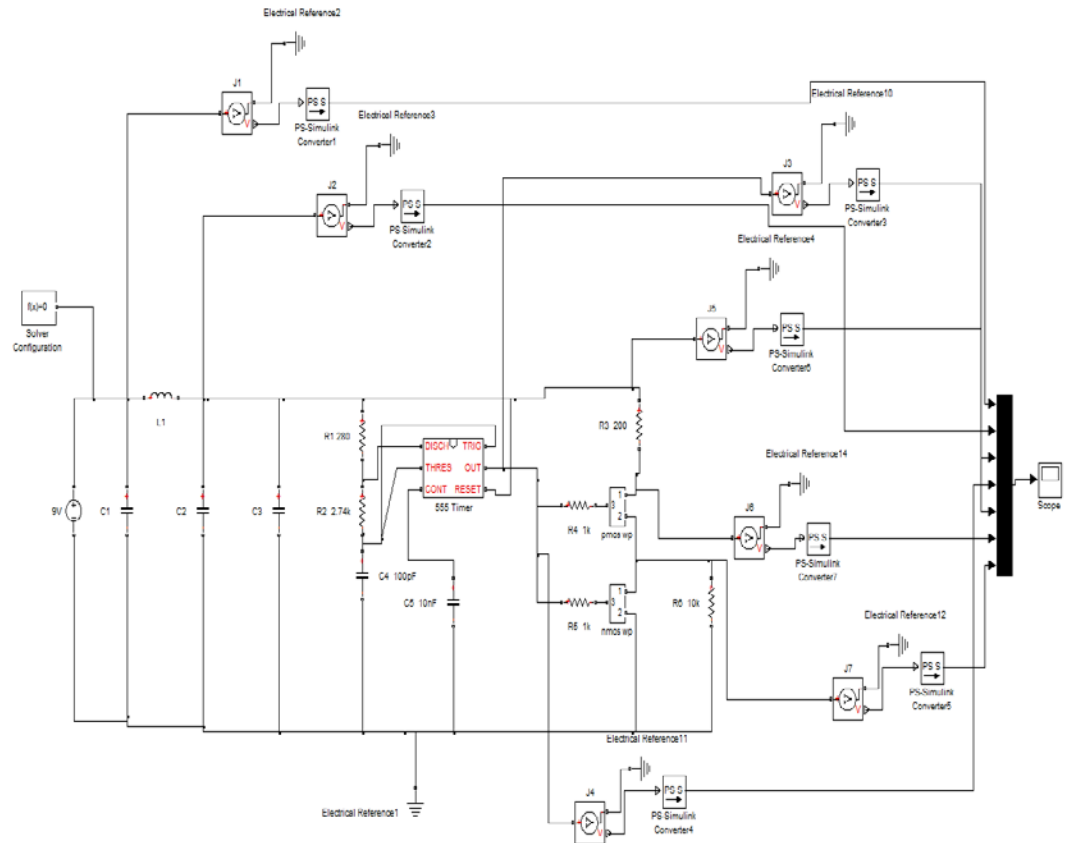
- Perform additional field testing of the sample circuit to verify simulated data
  - More data needs to be collected on the circuit with and without exposure to the UWB pulse system.
- Investigate different circuit schematics that are digital and analog.
- Importance to ARDEC Mission:
  - If successful, this modeling method will be useful in the analysis of weapons systems vulnerabilities to Directed Energy threats
  - This method could decrease time and cost of systems development by reducing the need for costly and time consuming field testing to determine armament circuit responses to DE