BME 398 Design History File

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Joint Department of Biomedical Engineering, UNC-CH and NC State

BME 398 - Biomedical Engineering Design and Manufacturing II

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Traceability Matrix
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Work Breakdown - contribution from each team member

All team members selected and evaluated two user needs and their associated inputs, outputs, verification, and validation. The team also came together to discuss key standards and how they applied to some of our user needs. With 10 total user needs, each group member contributed 20% to the total work.

User Needs	Design Inputs	Design Outputs	Design Verification	Design Validation	
Temperature Safe Ablation Tip	Temperature of the ablation tip shall not exceed 44 degrees Celsius	Temperature sensor	Temperature Calibration Test	Feedback about temperature monitoring from surgeons, Beta Testing	
		Circuit Diagram [2]	Multisim Simulation [1]		
Sterility	Sterility Assurance Level of at least 10^6	Ethylene Oxide Sterilization	Chemical Indicator Sterilization Test	User feedback on temperature needed to store, Ethylene Oxide Fluid Dynamic Modeling	**ANSI/AAMI ST67:2003. Sterilization of health care products – Requirements for products labeled "STERILE."** This standard requires an SAL value of 10^6 (design input) for products that are intended to come into contact with breached skin or compromised tissue or invasive products that enter normally sterile tissue.
		Sterile Packaging	Seal Testing		
		Packaging Temperature	Tempertaure Indicator on Package		
Efficiency	Must operate between 915 MHz and 2450 MHz	Circuit Design [2]	Multisim Simulation [1]	Ablation time of less than 10 minutes, average of 5 minutes in an ex-vivo study, or in an in-vitro clinical trial.	
			Electromagnetic Simulation		
Variability in Power	Must be able to deliver 1-100 Watts, dependent on user input, Must have a method for User input (dial, touchscreen, etc.)	Power Supply Datasheet	Benchtop Testing	Test effective ablation on various tumor sizes in-vitro or ex-vivo	
		Circuit Design [2]	Multisim Simulation [1]		
		Solidworks part for user control [3]	Assembly Verification		
Biocompatability	Contact between cells and probe shall have >95% cell viability	Materials data sheet for chosen biocompatible metal/polymers [4]	Chemical Testing	In vivo testing proves no adverse immune responses	
			MTT assay		
Usability	Probe shall weigh less than 2 lbs	Materials data sheet [4]	Weight Testing	Test that the probe can be lifted and maneuvered easily by physicians; ask for user feedback from physicians	
		Solidworks Schematic of Probe [3]	Statistical testing with weights of probes of different materials		
Shelf Stable	Probes shall have a shelf life of 4 years from the date of sterilization	Dupont Tyvek Lid Specifications	Seal Testing	Accelerated aging testing (shelf life testing), package strength testing, and package integrity testing according to ISO 11607	**ISO 11607-1:2009. Packaging for terminally sterilized medical devices - Part 1: Requirements for materials, sterile barrier systems and packaging systems**. This standard outlines material testing methods, packaging systems, and specific requirements to maintain sterility of the device as it is stored until it is ready to be used. These methods and requirements will be used to ensure a shelf life of 4 years (design input) which appears to be the standard shelf life for most thermal ablation probes.
		Materials data sheet [4]	Material Compatability Testing		
Temperature Safe Ablation Shaft	Temperature of shaft should not exceed 41 degrees Celsius.	Temperature sensor	Thermal FEA (Transient)	Ex vivo tests that monitor the temperature of the shaft during ablation for the longest possible ablation duration.	[1] Multisim Simulation [2] Schematic of PCB Design [3] Solidworks Parts and Assembly [4] Data Sheet in Design Outputs
		Saline Cooling System	Temperature Calibration Test		
		Insulation			
Rigidity	The probe tip should withstand 50N of force with no deformation	Materials data sheet [4]	Finite Element Analysis	Feedback from physicians who insert probe into patient's tissue with no deformation.	
		Mechanical Reinforcements	Three Point Bending Test		
			Compression Test		
Comfortable	Probe diameter must not exceed 2mm	Solidworks Schematic of Probe [3]	Assembly Verification	Feedback from patients on any discomfort during and after the procedure due to the diameter	

Risk Register
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Work Breakdown - contribution from each team member

Each team member chose two hazards associated with our device and completed their associated harms, probabilities, impacts, risks, and mitigation. With 10 total hazards, each group member contributed 20% to the total work.

ID	Hazards	Harm	Probability of Occurence	Impact/Severity	Risk	Acceptable?	Mitigation	Residual Risk
1	Leakage Current out of Handle	User macro/microshock	Likely	High	High Risk (3)	No	**Engineering Control**: extend insulator to close gap in the handle. **PPE**: Latex gloves offer high electrical insulation between the leakage current and the user	Leakage current escapes extended insulator and PPE to shock user
2	Sharp point at end of probe	Tears tissue during insertion/extraction	Unlikely	High	Medium Risk (2)	Yes	**Administrative Control**: provide training and verification checklist with product	Improper usage results in tissue lacerations
3	Electric Field produced too large	Destroy surrounding tissue	Unlikely	High	Medium Risk (2)	No	**Engineering Control:** Include a voltage sensor to detect power output and produced electric field.	Sensor also malfunctions
4	Probe Diameter too Thick	Uncomfortable for Patient	Unlikely	Moderate	Low Risk (1)	Yes	**Engineering Control:** Include tolerances on engineering drawings; Alter design based on patient feeback	Probe design not efficient for producing required electric field
5	Misinterpretation of touch screen interface to set ablation power	Destroy surrounding tissue	Unlikely	High	Medium Risk (2)	No	**Administrative Control:** provide training and verification checklist with product **Engineering Control:** Create Intuitive UI and power limits	User does not read manual and misuses device
6	Overheating of Handle	User Burn	Unlikely	Moderate	Low Risk (1)	Yes	**Engineering Control:** Insulation of probe	Insulation not incorporated on probe properly
7	Corrosion of metal probe	Inflammation due to metal particles	Unlikely	Moderate	Low Risk (1)	Yes	**Engineering Control:** add anti corrosive biocompatible coating **Administrative Control**: train users to store probe properly to evode exposure to environment that could induce corrosion	Coating could decrease efficiency of ablation
8	Deformation of Shaft after Insertion	Tissue Damage during Probe Removal	Unlikely	Moderate	Low Risk (1)	Yes	**Engineering Control:** Selectivity of 316L Stainless Steel (High Stiffness)	Defomation caused by imperfections in the material
9	Contamination of stainless steel probe	Infection	Likely	Moderate	Medium Risk (2)	No	**Elimination:** Sterilization techniques after manufacturing process and sterile packaging	Contamination after probe is removed from packaging.
10	Detached Moving Thumb Tab	Unable to retract the probe, causing electroporation in unwanted areas	Unlikely	High	Medium Risk (2)	No	**Engineering Control:** Include sensor to track probe extension compared to thumb tab location.	Sensor also malfunctions

Design Outputs
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Work Breakdown - contribution from each team member

Alex and Drew completed the Bill of Materials, Data Sheet, and PCB, providing 20% of work each.
Mattie and Bevin completed the Engineering Drawings and the Manufacturing Summary, providing 20% of work each.
Jefferson completed the CNC Milling of the probe tip, providing 20% of work.

Manufacturing Summary

In order to fulfill the user need of “Variability in Power,” the nanosecond pulse electric field ablation system must be able to deliver 1-100 Watts of power which can be varied depending on the size of the specific osteoid osteoma that is being removed. The parts of the design that need to be manufactured to verify this need are the subnanosecond pulse generator and the probe. The subnanosecond pulse generator will be built using a circuit outlined in a paper by Krishnaswamy et al. which will make it reasonably easy to assemble [1]. Since this circuit design may need to be modified to meet the needs of our device, it was decided that the generator should be built rather than bought to ensure that we have a solid understanding of the circuit design. This way, we can exchange the circuit elements with confidence that the circuit will still work. The probe will also be built rather than bought since the probe is essentially a long piece of conductive material that can be easily manufactured using CNC milling which can be accomplished in the Fab Lab. This will be financially advantageous since we will only have to buy the raw materials instead of buying the entire part from an outside supplier.

The connectors to the PCB will utilize the poka yoke DFM principle so that they will not be confused. Additionally, all the components are on one side, allowing for easier scaling in manufacturing. The components are orientated in the same direction, allowing for the PCB to be produced using wave soldering. The probe design incorporates many DFM principles including the use of available manufacturing techniques, compatible materials, and optimal geometry. As aforementioned, the probe will be manufactured using CNC milling which can be accomplished using the machine in the Fab Lab or other instrument shops on campus. It will also be composed of 316 Stainless Steel which is low cost and can be CNC milled. The probe will also be quite easy to manufacture since it has a very simple and symmetrical geometry that is essentially a long cylinder with a point.

A printed circuit board (PCB) design will be chosen for the manufacturing technique for the subnanosecond generator because it is a compact solution that can be created in a short amount of time at a low cost. Since the circuit for the generator contains numerous circuit elements, the PCB will allow us to avoid “wire spaghetti” and ensure the circuit is connected properly in a neat and organized manner. CNC milling will be chosen as the manufacturing method for the probe. As previously mentioned, the probe is composed of stainless steel which is compatible with CNC milling. The probe also has a simple geometry that can easily be produced by grinding the ends of a stainless steel cylinder into a point. We also have access to a CNC milling machine through the Fab Lab and other facilities on campus which makes it an ideal manufacturing method.

Bill of Materials

Part Name	Unique Identifying Number	Description	Quantity	Material	Vendor	Unit Cost	Total Cost
Avalanche Transistor	TR1	Avalanche Transistor	8	n/a	Mouser	$9.73	$77.84
DC-DC Converter	CONV1	DC-DC Converter	1	n/a	PicoElectronics	$136.24	$136.24
Resistors (1K)	R1	Resistors (1K)	8	n/a	Mouser	$1.25	$10.00
Resistors (8)	R2	Resistors (8)	4	n/a	Mouser	$0.46	$1.84
Resistors (181K)	R3	Resistors (181K)	1	n/a	Mouser	$0.10	$0.10
Resistors (50)	R4	Resistors (50)	1	n/a	Mouser	$1.62	$1.62
Resistors (8.5k)	R5	Resistors (8.5k)	1	n/a	Mouser	$0.10	$0.10
Resistors (255)	R6	Resistors (255)	1	n/a	Mouser	$0.10	$0.10
Resistors (105)	R7	Resistors (105)	1	n/a	Mouser	$0.10	$0.10
Capacitor (120p)	C1	Capacitor (120p)	1	n/a	Digikey	$21.32	$21.32
Capacitor (18p)	C2	Capacitor (18p)	1	n/a	Digikey	$14.34	$14.34
Capacitor (6.8p)	C3	Capacitor (6.8p)	2	n/a	Digikey	$14.34	$28.68
Capacitor (3.3p)	C4	Capacitor (3.3p)	1	n/a	Digikey	$15.50	$15.50
Capacitor (2.2p)	C5	Capacitor (2.2p)	1	n/a	Digikey	$1.50	$1.50
Capacitor (1.5p)	C6	Capacitor (1.5p)	1	n/a	Digikey	$1.50	$1.50
Capacitor (1.0p)	C7	Capacitor (1.0p)	1	n/a	Digikey	$1.50	$1.50
Capacitor (0.8p)	C8	Capacitor (0.8p)	1	n/a	Digikey	$0.80	$0.80
Capacitor (12p)	C9	Capacitor (12p)	1	n/a	Digikey	$14.34	$14.34

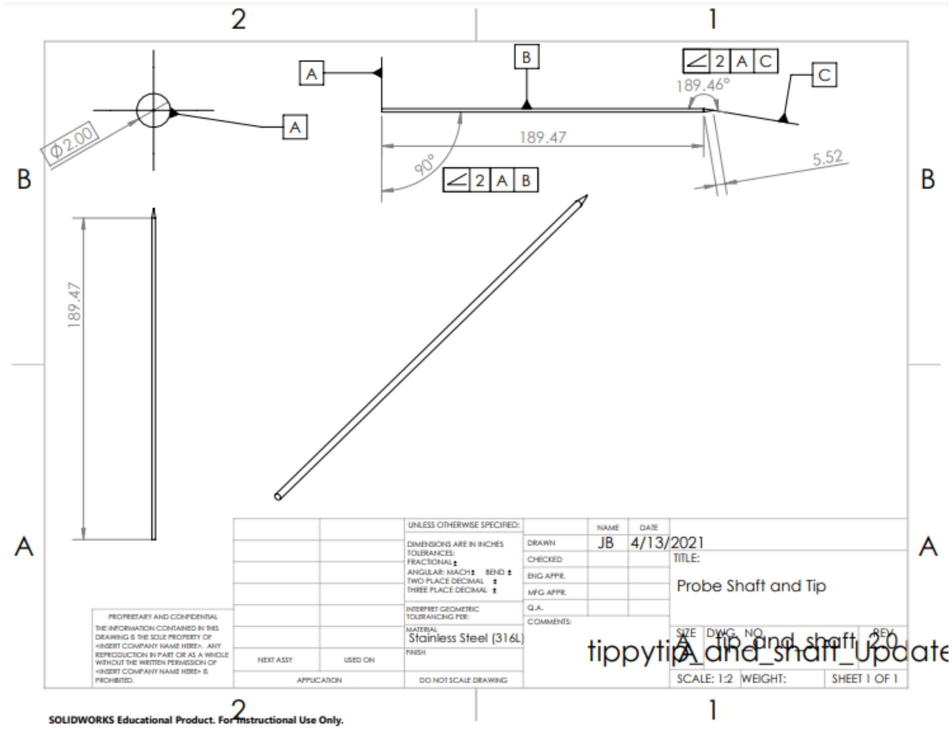
Capacitor (0.1u)	C10	Capacitor (0.1u)	1	n/a	Sparkfun	$0.95	$0.95
Capacitor (10n/0.01u)	C11	Capacitor (10n/0.01u)	1	n/a	Sparkfun	$0.95	$0.95
Zener Diode (300 V)	D1	Zener Diode (300 V)	6	n/a	Mouser	$12.67	$76.02
Zener Diode (270 V)	D2	Zener Diode (270 V)	2	n/a	Mouser	$0.30	$0.60
SMA Connector	J1	SMA Connector	1	n/a	Mouser	$3.07	$3.07
Transformer	T1	Transformer	1	n/a	Digikey	$3.92	$3.92
PCB	PCB1	Printed Circuit Board	1	n/a	JLCPCB	$7.40	$7.40
Metal Probe	PRB1	316L Stainless Steel Rods Wire Diameter 2mm, length 0.5m	1	316L Stainless Steel	Ethionec	$6.99	$6.99

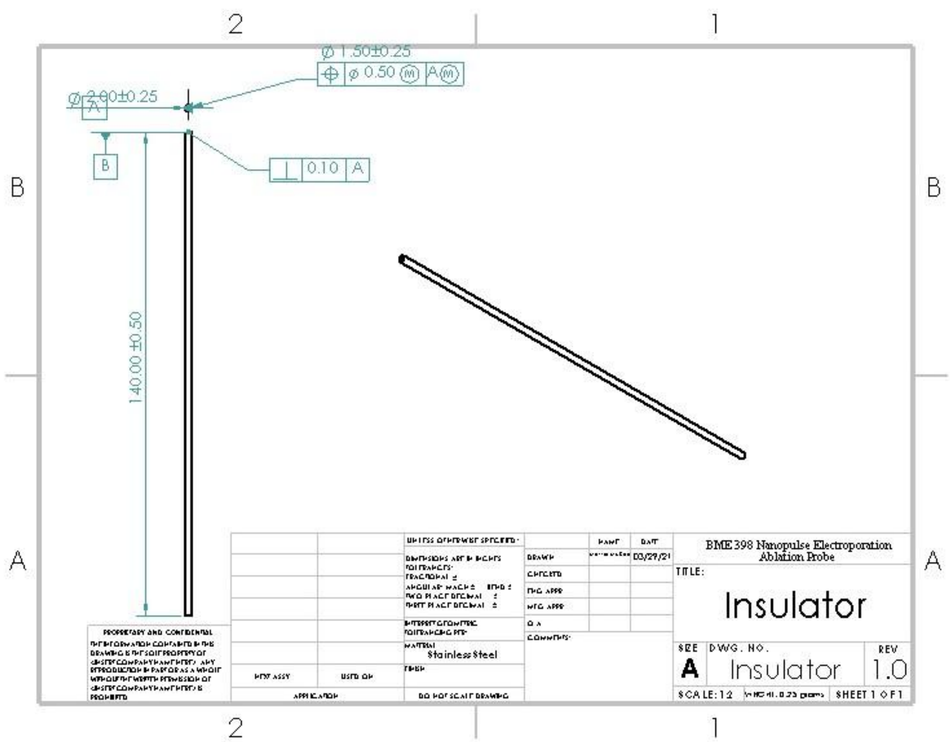
Total Prototyping Cost (Probe and Generator): $427.32

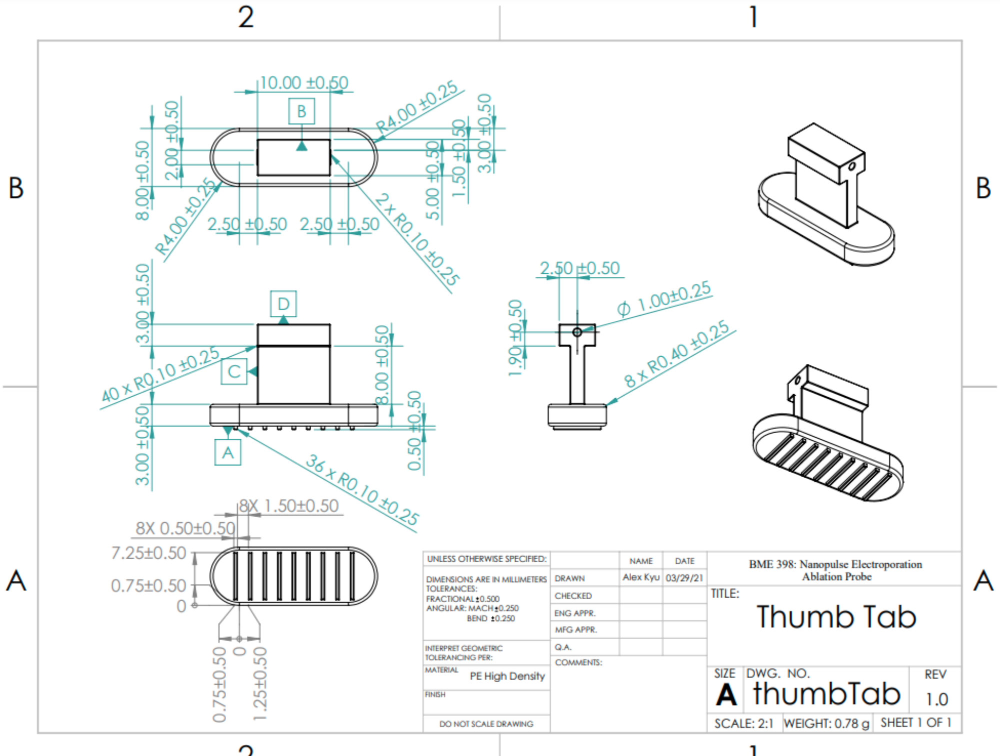
Data Sheet or MDS

Part Name	**Unique Identifying Number**	**Datasheet**
Avalanche Transistor	TR1	https://www.mouser.com/datasheet/2/115/FMMT415-46058.pdf
DC-DC Converter	CONV1	https://www.picoelectronics.com/node/13287
Zener Diode (300 V)	D1	https://www.mouser.com/datasheet/2/268/SA5_37-1592261.pdf
Zener Diode (270 V)	D2	https://www.mouser.com/datasheet/2/308/MM5Z4678T1_D-1811647.pdf
Transformer	T1	https://media.digikey.com/pdf/Data%20Sheets/Pulse%20PDFs/LAN%20Isolation%20Transformer%20Catalog.pdf
Metal Probe	PRB1	https://www.metalshims.com/t-316-Stainless-Steel-technical-data-sheet.aspx

Engineering Drawings



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R4.00 ±0.25
8.00 ±0.50
2.00 ±0.50
R4.00 ±0.25
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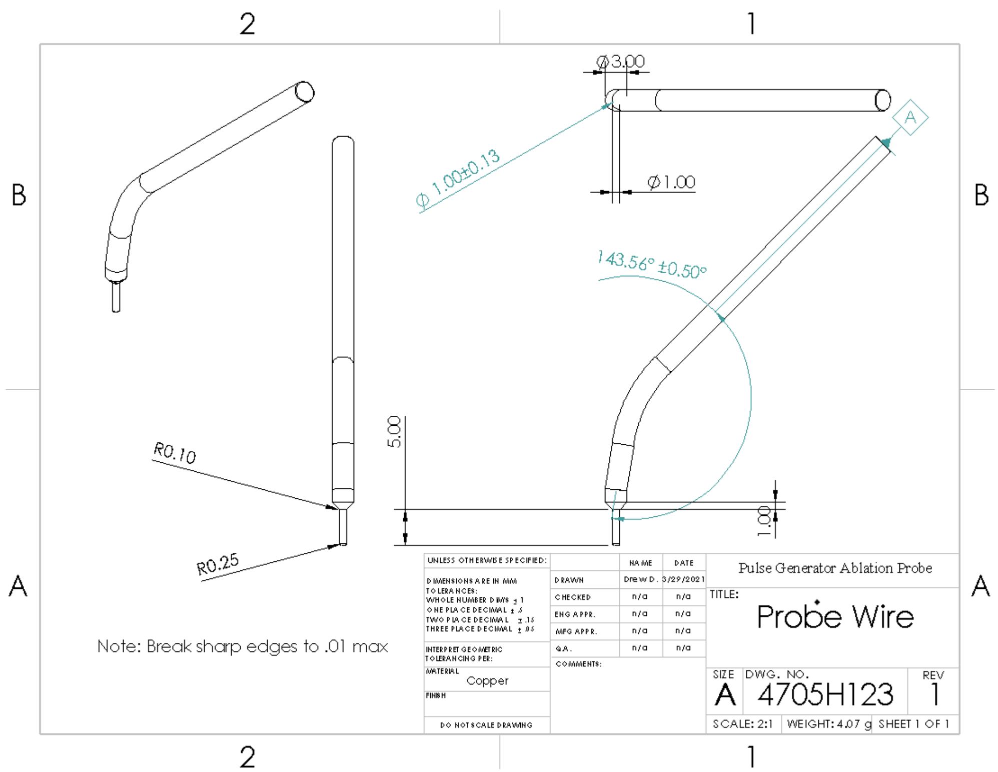
5.00 ±0.50
1.50 ±0.50
3.00 ±0.50
2 x R0.10 ±0.25
3.00 ±0.50
40 x R0.10 ±0.25
8.00 ±0.50
3.00 ±0.50
0.50 ±0.50
36 x R0.10 ±0.25
2.50 ±0.50
Ø 1.00±0.25
1.90 ±0.50
8 x R0.40 ±0.25
8X 1.50±0.50
8X 0.50±0.50
7.25±0.50
0.75±0.50
0.75±0.50
1.25±0.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
FRACTIONAL ±0.500
ANGULAR: MACH ±0.250
BEND ±0.250
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL PE High Density
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN Alex Kyu 03/29/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
BME 398: Nanopulse Electroporation Ablation Probe
TITLE:
Thumb Tab
SIZE A
DWG. NO. thumbTab
REV 1.0
SCALE: 2:1
WEIGHT: 0.78 g
SHEET 1 OF 1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Ø 1.00±0.13
Ø1.00
143.56° ±0.50°
5.00
1.00
R0.10
R0.25
Note: Break sharp edges to .01 max
UNLESS OTHERWISE SPECIFIED:
MATERIAL Copper
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN Drew D. 3/29/2021
CHECKED n/a n/a
ENG APPR. n/a n/a
MFG APPR. n/a n/a
Q.A. n/a n/a
COMMENTS:
Pulse Generator Ablation Probe
TITLE:
Probe Wire
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DWG. NO. 4705H123
REV 1
SCALE: 2:1
WEIGHT: 4.07 g
SHEET 1 OF 1

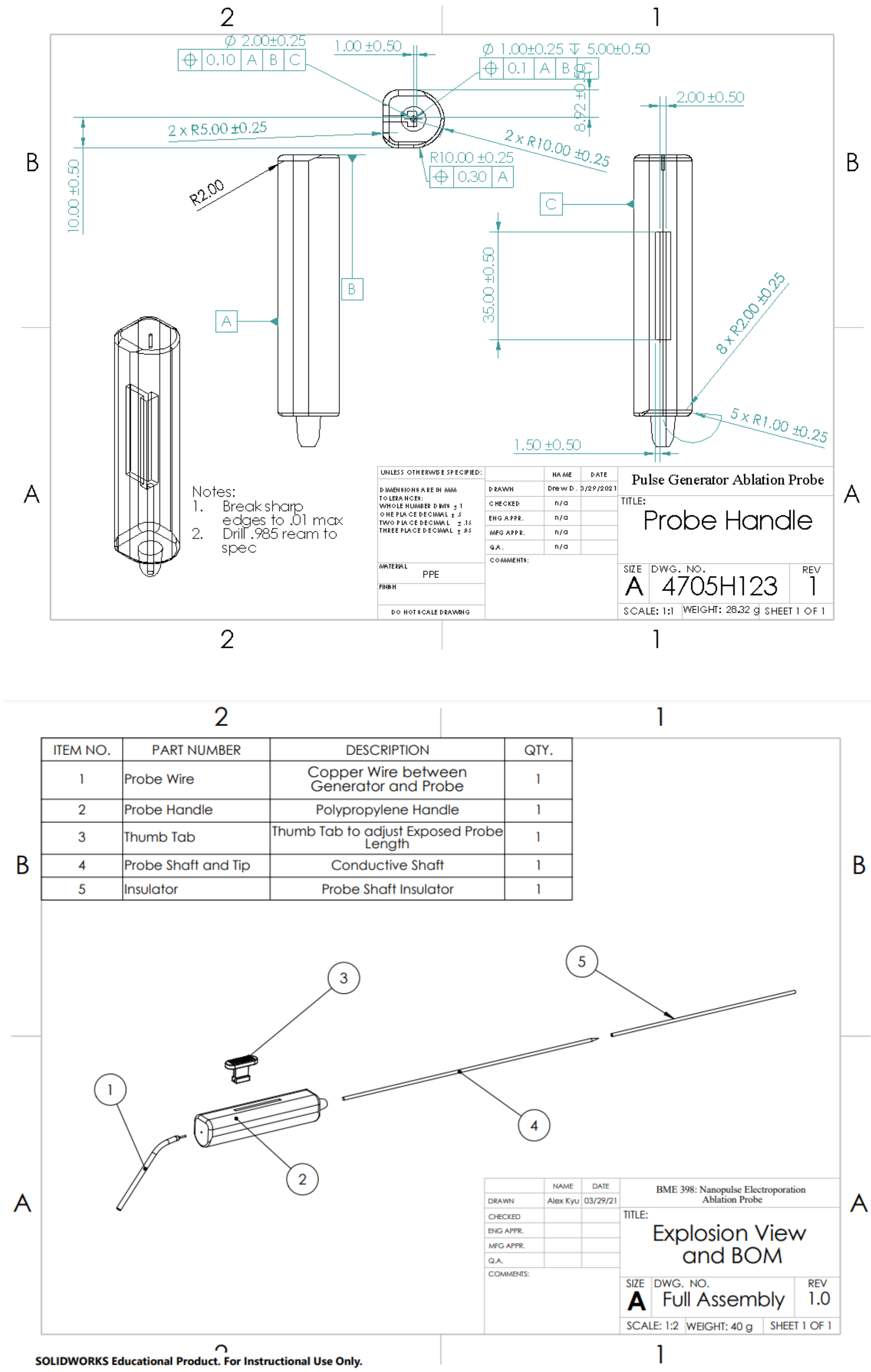

Figure 1: Engineering drawings for each part of the ablation probe created in Solidworks

CNC Milling: Probe Tip

Tool Crib:

Main Removal of Material	T01 - 6mm Flat End
Shaping Probe Tip	T07 - 4mm Ball Nose

Results:

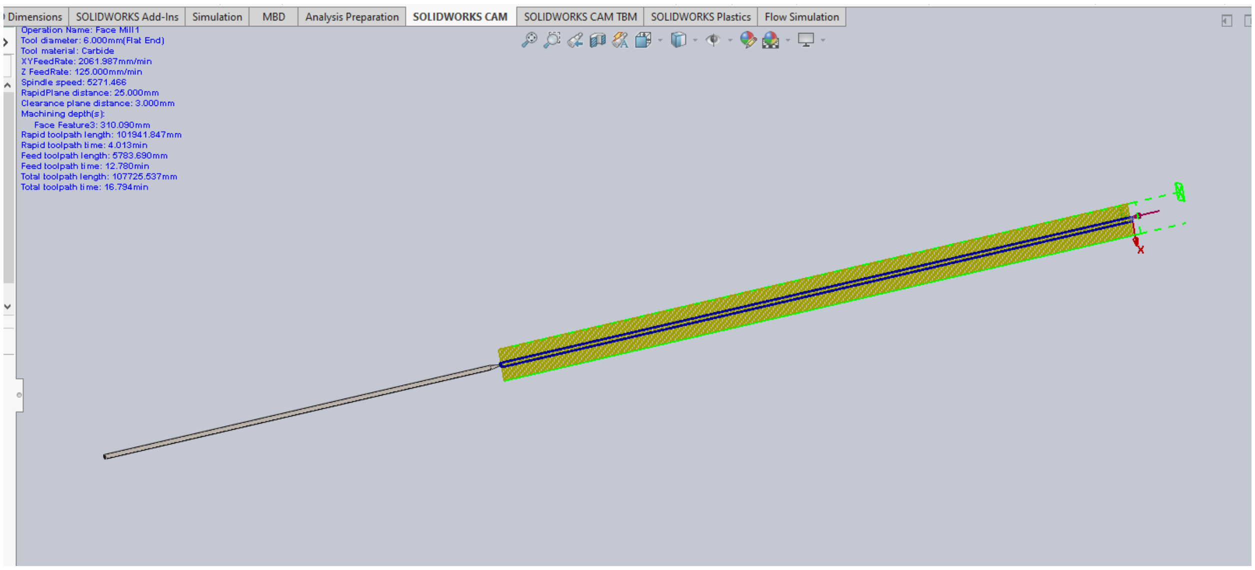

Figure 2: the CNC milled tip of the ablation probe

G-code: see attached

Pulse Generator PCB

See attached schematic, board and gerber files.

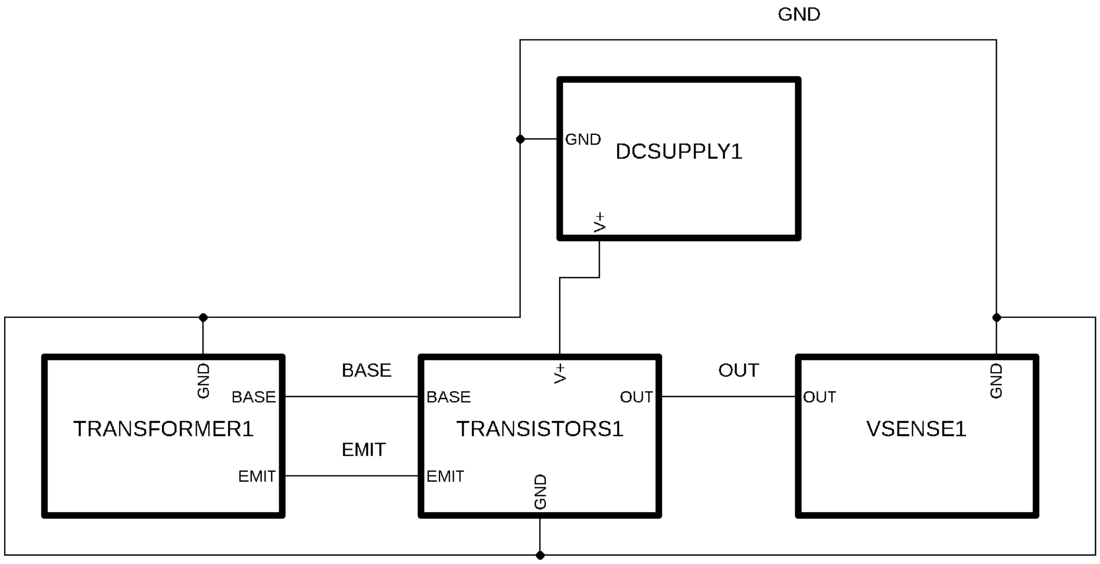

Figure 3: the outline schematic of the PCB

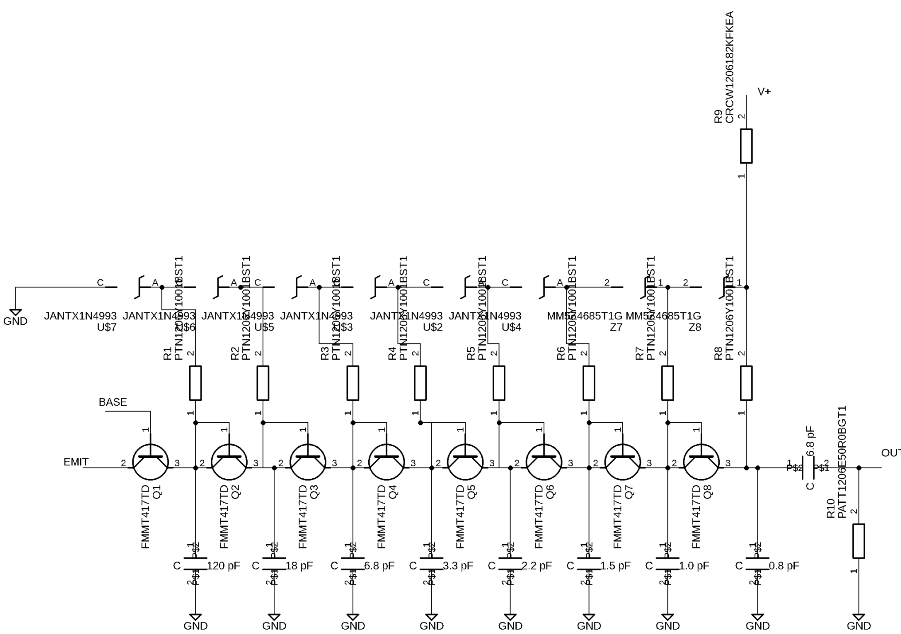

Figure 4: the transistors schematic block

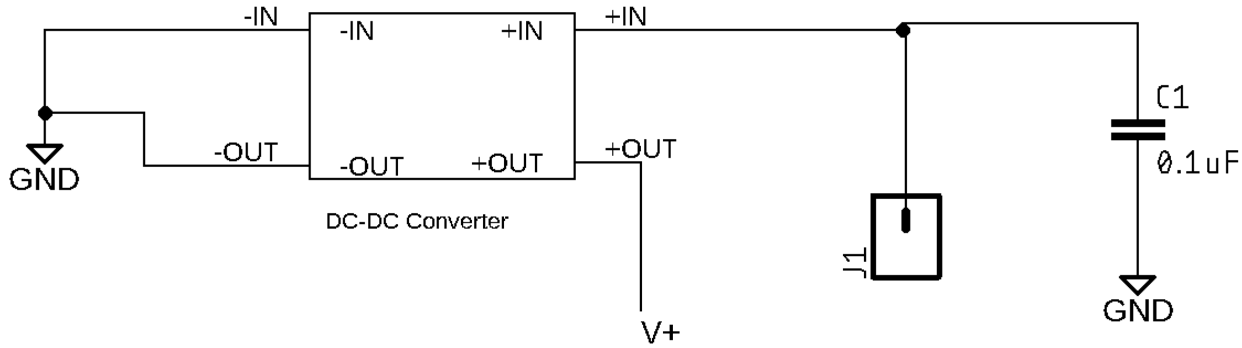

Figure 5: the DC supply schematic block is shown including the DC-DC converter

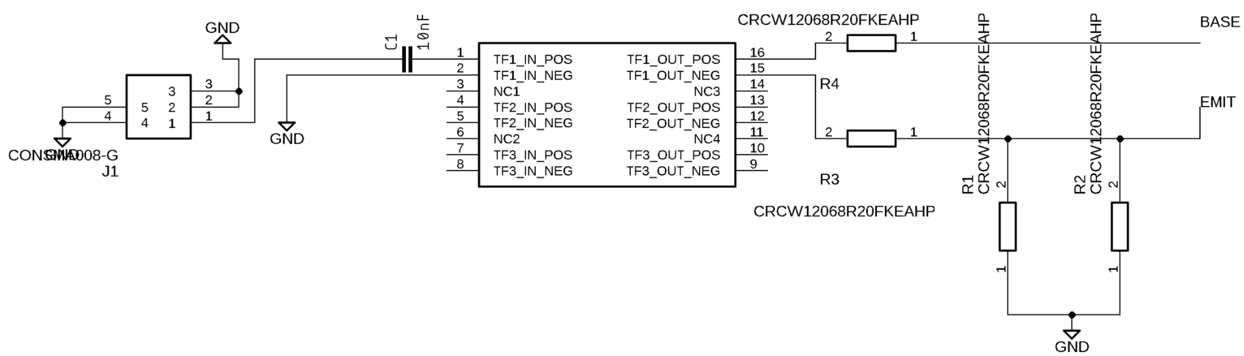

Figure 6: the transformer schematic block is shown including a connector for the trigger source and the transformer used

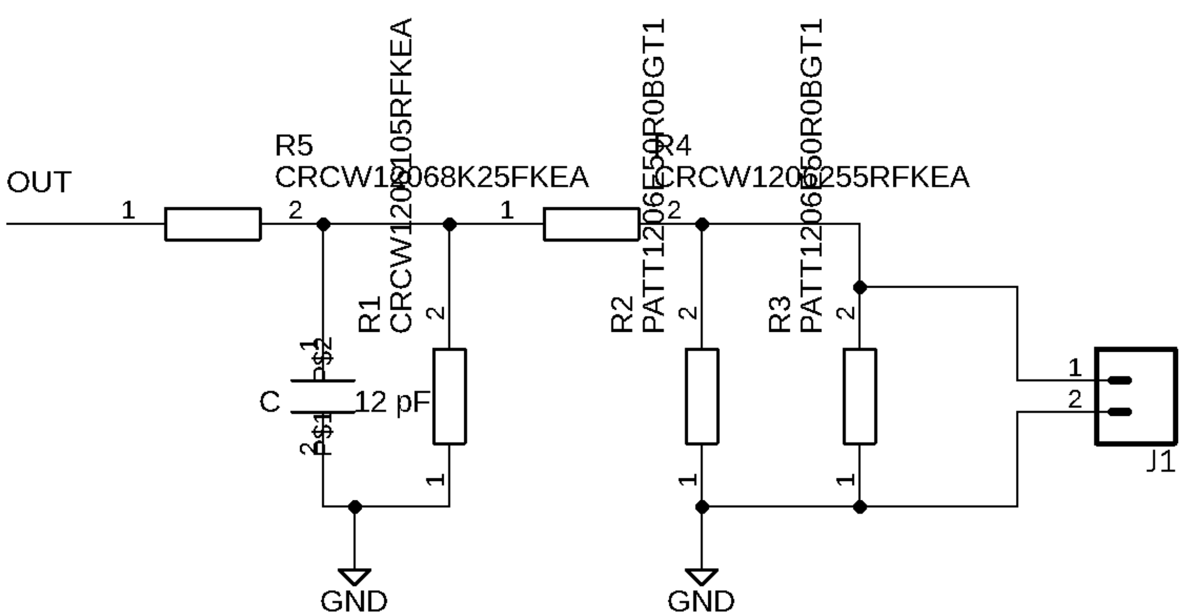

Figure 7: the voltage sensor schematic block

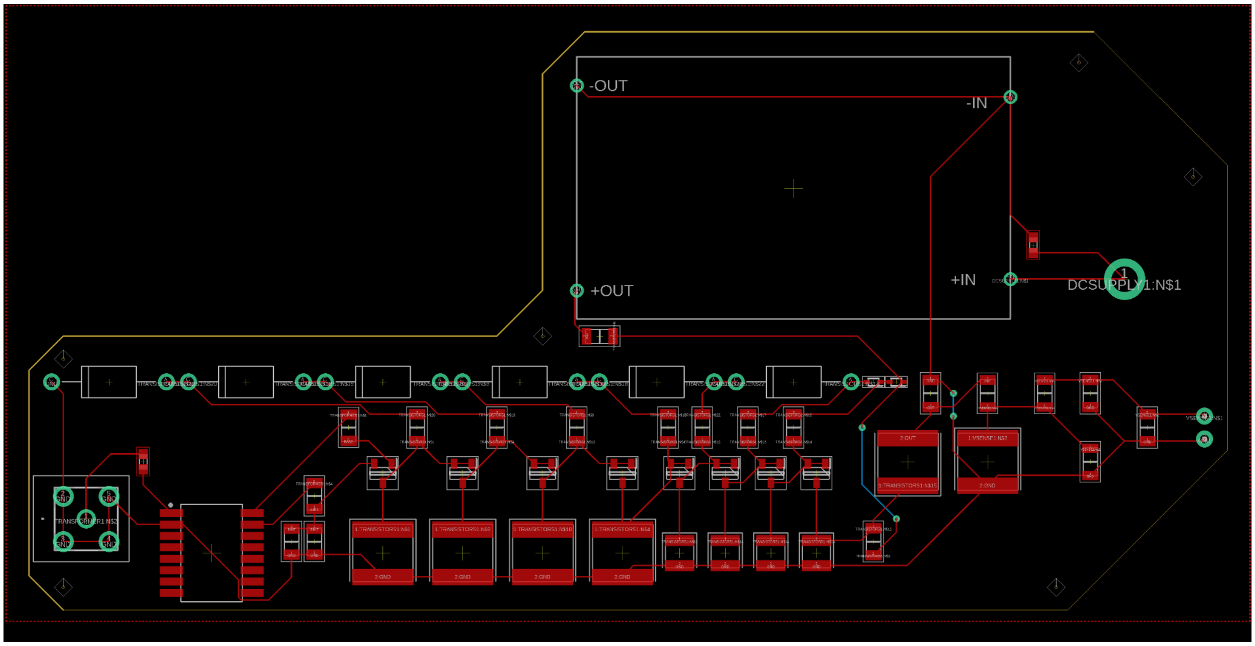

Figure 8: the PCB board file highlighting the placement of each part

Verification/Validation
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Work Breakdown - contribution from each team member

Alex and Drew designed the circuit in Multisim and calculated results from the simulation, providing 50% of work each.
Bevin, Jeff and Mattie worked on the final paper deliverable while Alex and Drew completed the verification/validation document.

Verification/Validation

Using Multisim software, the nanosecond pulse generator circuit was modeled as shown in figure 1 and simulated with a transient response of time step 0.1 ns. The waveform produced was analyzed and the peak voltage and rise time of the output waves were recorded. This analysis was performed for varying voltage peaks of the trigger source input to the circuit while keeping a constant rise time of 0.5 ns. While spice code for avalanche transistors was downloaded, use of the code for the transistor component did not yield a pulse wave. Accordingly, the bipolar junction transistor (BJT) NPN transistor was used to model the avalanche transistor. This transistor provided a conservative estimate of the circuit as the transistor lacked the quick response of the avalanche transistors. The DC power supply block, which consisted of a 8-14.5 VDC power supply followed by a DC-DC converter, was simplified as a 2.5 kV voltage source in the simulation. The transformer was modeled with no leakage inductance or resistance; the core was modeled as non-ideal with a flux of 250uWb * tanh(.2*i) where "i" was the magnetizing inductance current.

While the results of the simulation didn't meet the desired specifications, it did confirm that the project is plausible. With the use of Avalanche Transistors and the right components, this circuit should be able to produce the desired waveforms. Unfortunately, with the limitations of Multisim and inability to fully model the components, these waveforms could not be reproduced at the magnitude required for our device, despite simplifying the circuit to only two transistor stages. The results shown below are from the circuit schematic with all eight transistor stages (Figure 1).

However, a desired waveform was generated using switches instead of transistors, demonstrating that given a working model of the desired Avalanche Transistor, this simulation should produce the correct output voltage. Furthermore, other components may have an influence in the results too. Results for varying trigger source voltages are shown below, demonstrating that higher trigger source voltages, decreased rise time and increased peak pulse voltages (Figure 2, 3). The simulation for the pulse with a 5V trigger source is also shown below. A relatively low rise time of 5.5352 nanoseconds is shown, which could be further improved by the use of Avalanche transistors which have subnanosecond rise times (Figure 4).

Table 1: Multisim Parameters

Parameters	**Value**
Trigger Source Initial Value	0 V
Trigger Source Pulse Value	5 V
Trigger Source Rise Time	0.5 ns
Trigger Source Fall Time	1 ns
Trigger Source Pulse Width	5 us
Period	1 ms
Transformer Non-ideal Core	Flux = 250u*tanh(0.2*i)
Transformer Leakage Inductance	0 H
Transformer Coil Resistances	0 Ω
Transformer Coil Turns	4:4
Simulation Type	Transient Analysis
Initial Conditions	Set to Zero
Maximum Time Step Size	0.1 ns
Initial Time Step Size	0.1 ns

<u>Simulation Results:</u>

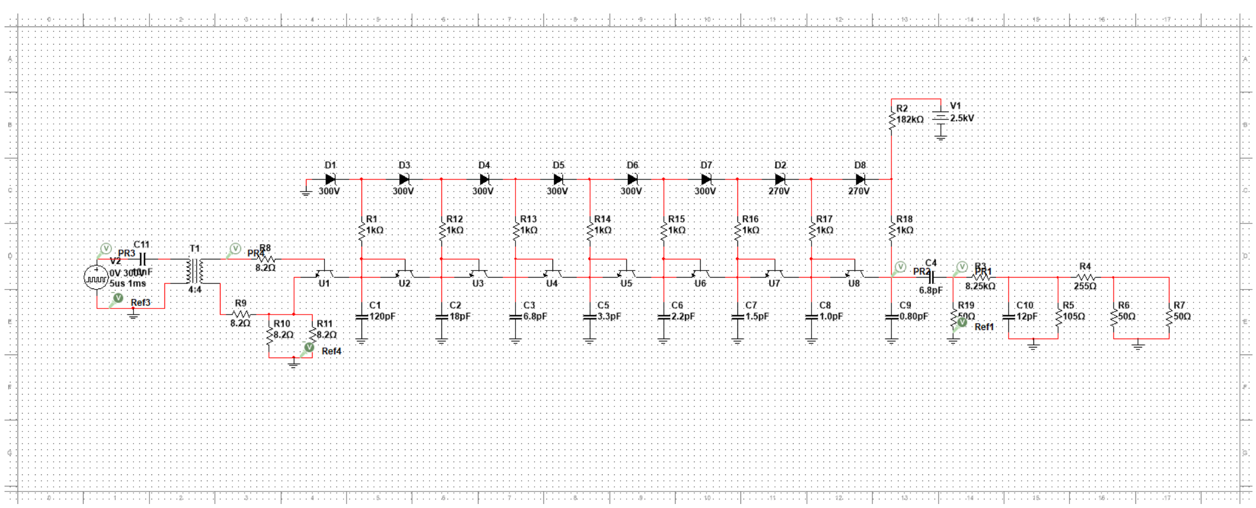

Figure 1: Multisim Circuit Schematic

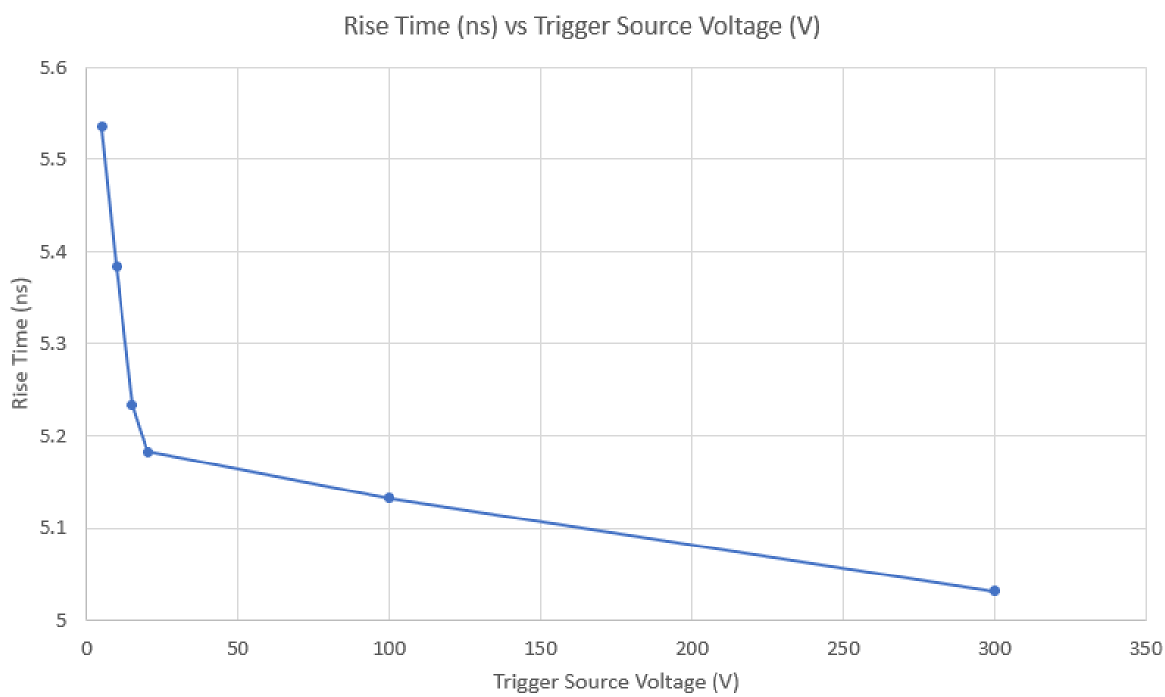

Figure 2: Simulation Results comparing Rise Time of the Pulse with changing Trigger Source Voltages.

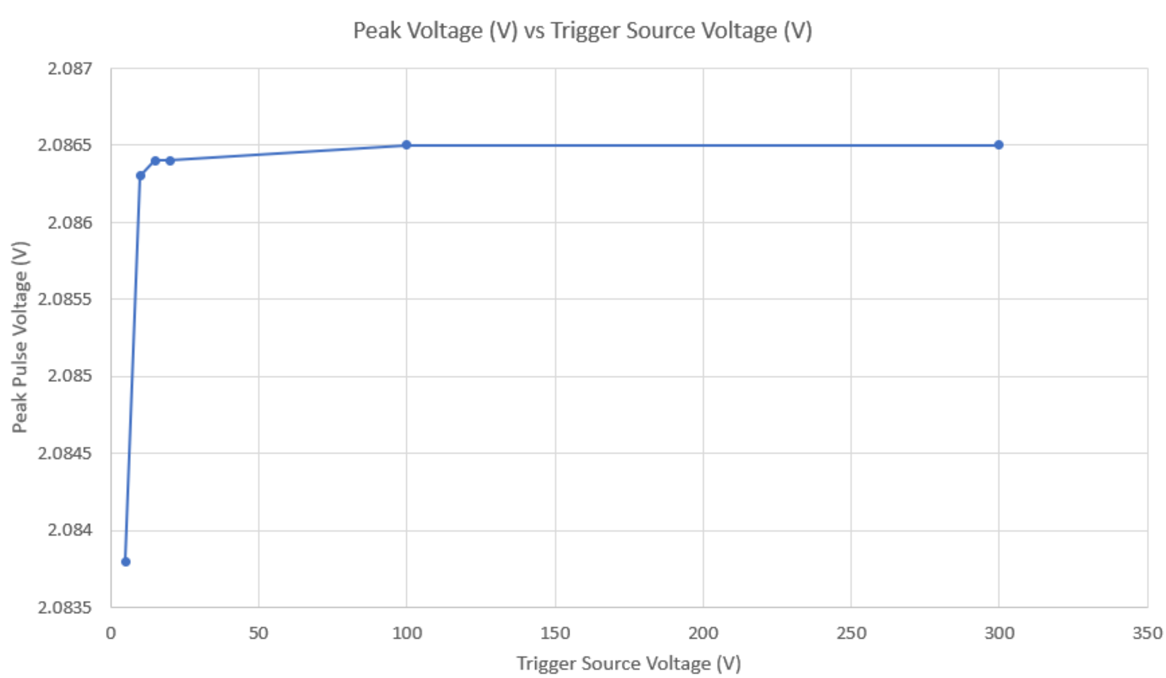

Figure 3: Simulation Results comparing Peak Pulse Voltage with changing Trigger Source Voltages.

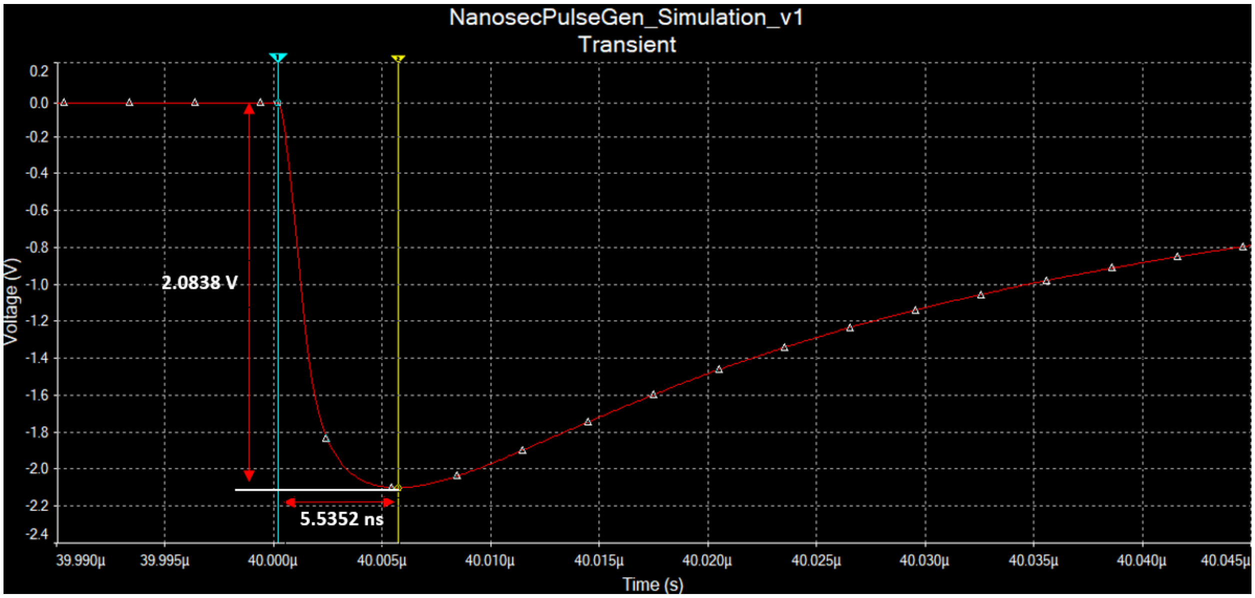

Figure 4: Simulation Results with a 5V Trigger Source. The Rise time was 5.5352 nanoseconds and the Peak Pulse Voltage was 2.0838 V.