DRSSTC
BUILDING THE MODERN DAY TESLA COIL

miniBrute Reference Design

FIRST EDITION

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DRSSTC : Building the Modern Day Tesla Coil
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PREFACE

This text documents the complete electrical and mechanical design of the miniBrute DRSSTC system which was previously designated as the DRSSTC III system in the publication, *DRSSTC: Building the Modern Day Tesla Coil.* The miniBrute DRSSTC system was designed from the bottom up with three distinct requirements in mind: reliability, portability, and power. Firstly, the miniBrute DRSSTC was designed as a demonstration coil, which meant it had to withstand the stress of continuous operation and excessive run times. This high reliability is achieved through the use of synchronized drive and shutdown circuitry as well as through the use of both thermal and current sensors to ensure the system operates within safe operating limits. Also, the use of second generation DRSSTC primary current feedback allows the system to soft-switch reducing both the switching losses of the IGBTs and the high di/dt conditions which can lead to large voltage spikes across the IGBTs. The enclosure was also designed to provide maximum cooling for the power switching devices and primary MMC capacitors which can dissipate considerable heat during operation. Secondly as a demonstration coil, the miniBrute had to be designed in the smallest and lightest weight package possible. Standing at two feet tall and weighing less than 30 pounds, the miniBrute is highly portable and can easily be transported by a single person. Finally, the miniBrute's operation had to look impressive, therefore it was designed to pack the biggest punch possible. Standing at only two feet tall, the coil can easily produce arcs in excess of 36 inches and under optimum tuning, can produce output arcs exceeding 48 inches in length. With the use of the Advanced Modulator, the miniBrute DRSSTC can produce an infinite variety of output effects. The miniBrute DRSSTC, being a solid state system, also does not require the use of heavy high voltage transformers or mechanically complex spark gaps. The miniBrute DRSSTC runs directly off of 120VAC (or 220VAC for those in other parts of the world) and requires only a small variac to vary the input power of the system.

The design for the miniBrute DRSSTC has been presented in this text in such a way that anyone with basic electrical and mechanical skills can follow the design and reproduce it exactly from the inside out. Highly detailed electrical schematics, and mechanical drawings are shown for every part of the system including complete parts and distributor listings as well. And for the first time ever, Eastern Voltage Research is providing complete bareboard printed circuit board kits for all electrical assemblies inside this unit including the Advanced Modulator. No longer will one have to design, fabricate, and procure their own printed circuit boards. Customizable miniBrute and Advanced Modulator panels are also available for that added professional touch.

Finally, in addition to the detailed electrical and mechanical designs included in this text, highly detailed, step-by-step test procedures are included, as well as a complete section on advanced tuning techniques.

Daniel McCauley

DISCLAIMER

The author of this document is an amateur, not a professional. The information, both technical and safety related, provided in this document should be interpreted with this distinction clearly in mind. The author hereby disclaims any liability for injury to persons or property that may result due to the construction of solid state Tesla coils and other high voltage apparatus. This publication is for informational purposes only, and makes no claims to its completeness or accuracy. Solid state Tesla coils are inherently very dangerous devices and should only be constructed and operated by individuals familiar enough with these dangers.

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miniBrute DRSSTC Operation (Second Generation)

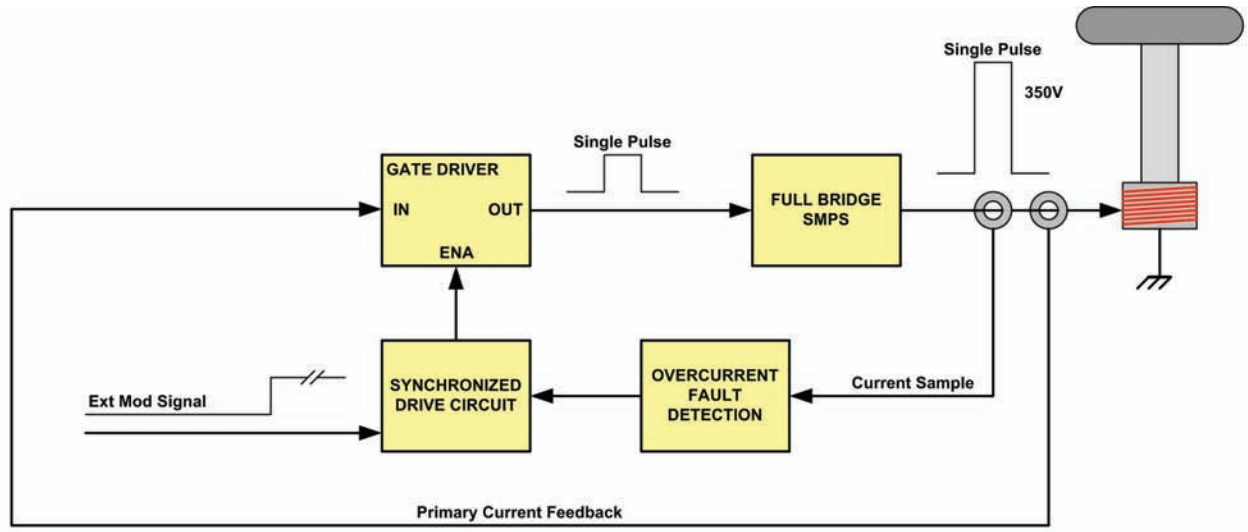


Figure 1-2 *miniBrute DRSSTC Operation - Self Starting*

The next few paragraphs briefly discuss the operation of the miniBrute DRSSTC system. Note that this is only a brief summary into how the miniBrute DRSSTC system operates, and does not go into the great detail of the complex operational theory behind the DRSSTC concept. For this description, I have broken down the operation of the miniBrute DRSSTC into four simple steps: self-starting, primary current feedback, continuous oscillation, and overcurrent fault detection and synchronized shutdown.

Self-Starting

Because the oscillator on the DRSSTC system is feedback driven, it requires an external source to start oscillation. This external source is the modulation pulse from the external modulator or "interrupter." When the external modulator outputs an ON pulse, this ON pulse is fed into the ENABLE input on the gate driver IC. Due to the properties of the Texas Instruments UCC3732x gate driver ICs, a low-to-high transition on the ENABLE input causes the gate driver IC to output a single-shot pulse. As shown in Figure 1-2 above, this single-shot output pulse activates the half-bridge switching circuit for a single cycle and a single-shot output pulse from the half-bridge switching circuit is sent to the primary coil.

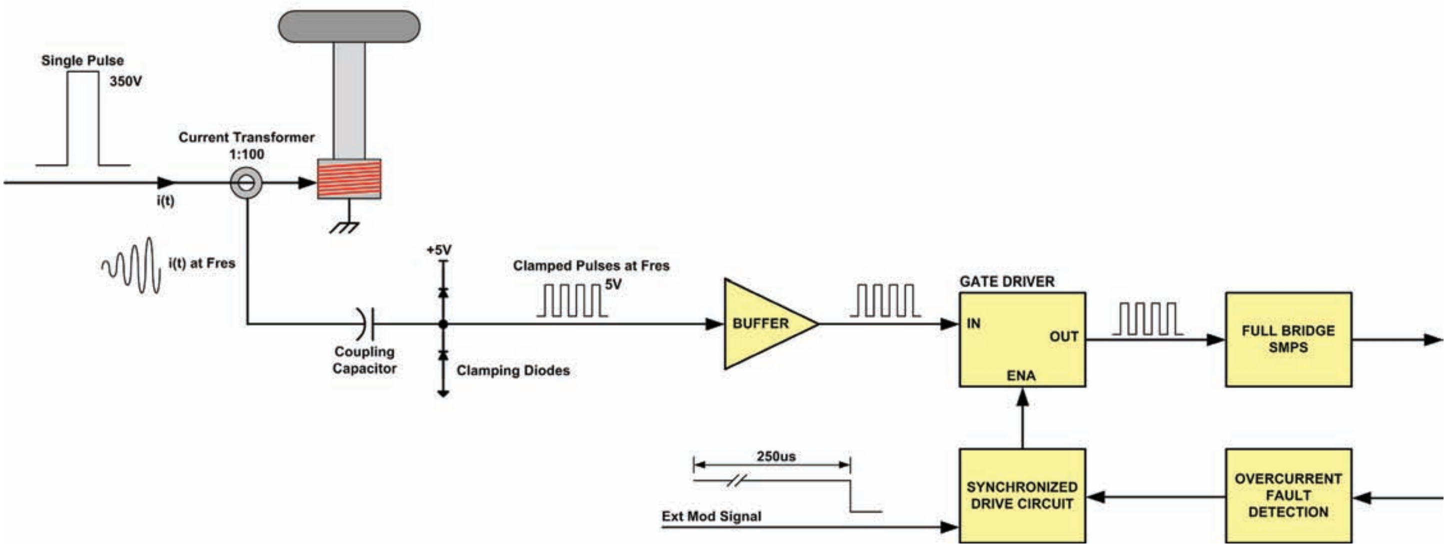
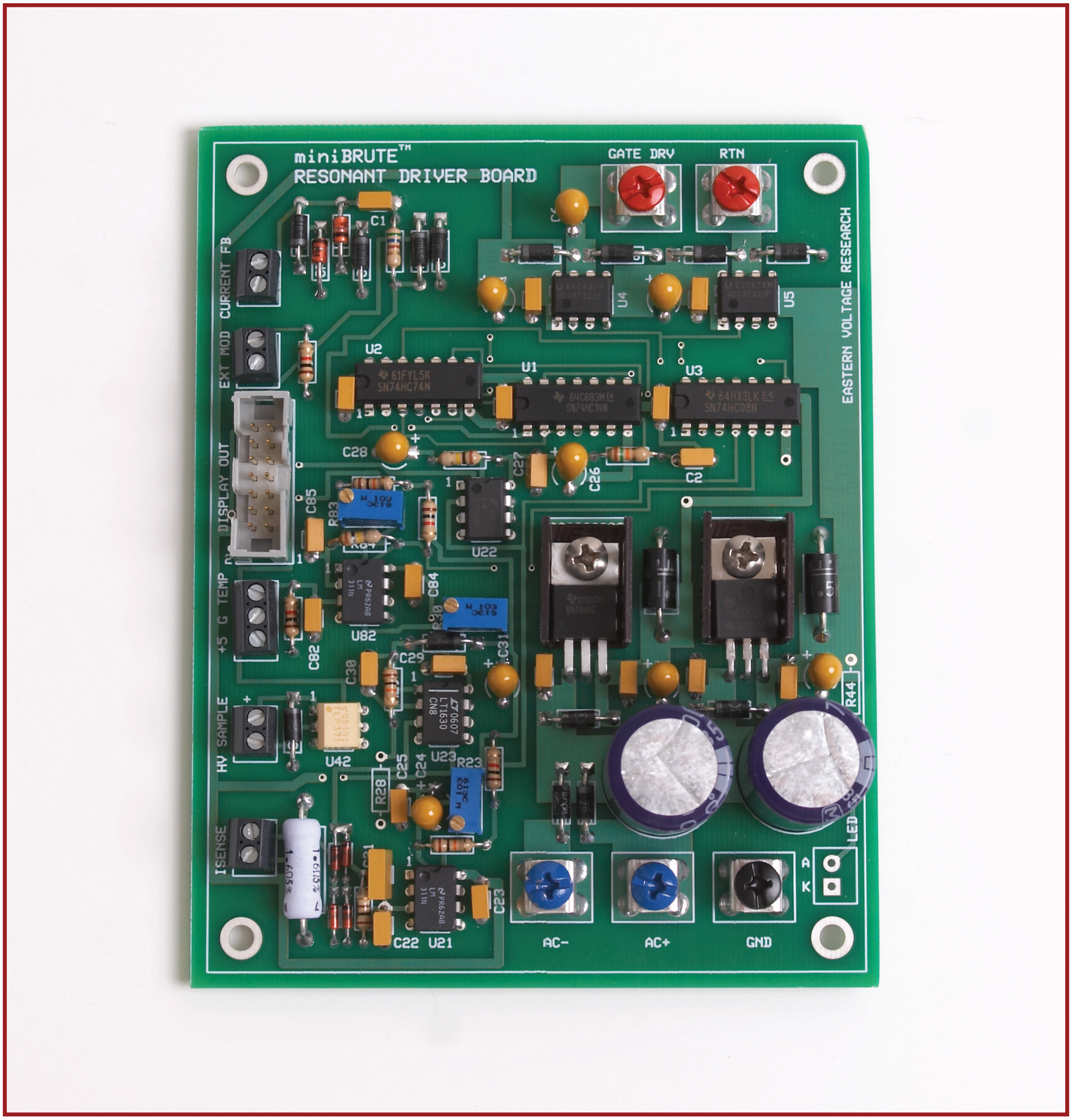


Figure 1-3 *miniBrute DRSSTC Operation - Primary Current Feedback*



miniBrute DRSSTC - Self-Resonant Control Board

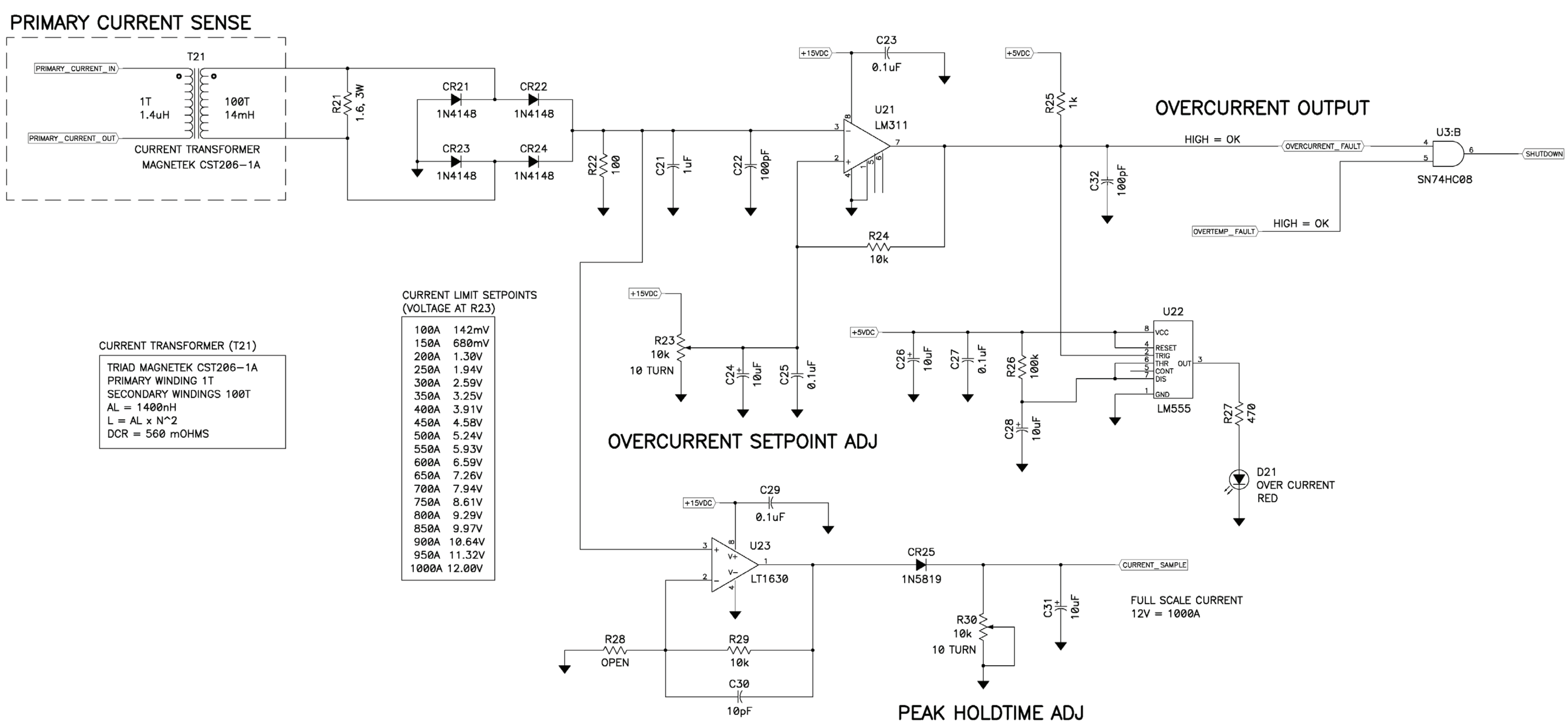


Figure 2-2 *miniBrute DRSSTC Schematic (Section 2/7)*

Notes:

1. If operational duty cycles are greater than 10%, the power rating of R21 will need to be re-evaluated.

2. R25 and C28 are used to set the duration that the overcurrent LED, D21, will illuminate when an overcurrent condition is detected. The duration in seconds is approximately equal to 1.1 * R25 * C28. In this schematic, the duration is set to approximately 1 sec.

3. The overcurrent setpoint, set by potentiometer, R23, will need to be fine tuned in the circuit for proper operation.

4. R27 is used to provide hysteresis for the comparator, U21. This value may need to be fine tuned if overcurrent setpoints are particularly low.

5. Due to the forward voltage drops of the bridge rectifier circuit, the minimum overcurrent setpoint for this circuit is approximately 200A. If a lower setpoint is required, R21 should be changed accordingly to reduce the scaling factor.

Item	Ref Des	Part No.	Description	Distributor	Qty
1	R1	560QBK-ND	Resistor, 560 ohm, 1/4W, 5%	Digikey	1
2	R2	15KQBK-ND	Resistor, 15k, 1/4W, 5%	Digikey	1
3	R3,R25,R81,R85,R125	1.0KQBK-ND	Resistor, 1k, 1/4W, 5%	Digikey	5
4	R21	P1.6W-3BK-ND	Resistor, 1.6 ohm, 3W	Digikey	1
5	R22	100QBK-ND	Resistor, 100 ohm, 1/4W, 5%	Digikey	1
6	R23,R30	3296W-103LF-ND	Potentiometer, 10k, 10 Turn	Digikey	2
7	R24,R29	10KQBK-ND	Resistor, 10k, 1/4W, 5%	Digikey	2
8	R26,R84	100KQBK-ND	Resistor, 100k, 1/4W, 5%	Digikey	2
9	R27,R43,R61,R86	470QBK-ND	Resistor, 470 ohm, 1/4W, 5%	Digikey	4
10	R29	2.49KXBK-ND	Resistor, 2.49k, 1/4W, 1%	Digikey	1
11	R41	634XBK-ND	Resistor, 634 ohm, 1/4W, 1%	Digikey	1
12	R44,R62	1.5KQBK-ND	Resistor, 1.5k, 1/4W, 5%	Digikey	2
13	R82	13KXBK-ND	Resistor, 13k, 1/4W, 1%	Digikey	1
14	R42,R83	3296W-502LF-ND	Potentiometer, 5k, 10 Turn	Digikey	1
15	R62	1.5KQBK-ND	Resistor, 1.5k, 1/4W, 5%	Digikey	1
16	R101,R102	5.1W-2-ND	Resistor, 5.1 ohms, 2W	Digikey	2
17	R103-R106	10MH-ND	Resistor, 10Meg, 1/2W, 5%	Digikey	4
18	R121,122	20J6K0E-ND	Resistor, 6k, 10W, Vitreous Enamel Wirewound	Digikey	2
19	R123	20J500E-ND	Resistor, 500 ohm, 10W, Vitreous Enamel Wirewound	Digikey	1
20	R124,R125	25J25KE-ND	Resistor, 25k, 5W, Vitreous Enamel Wirewound	Digikey	2
21	C1,C3,C7,C8,C9,C10,C23,C25 C27,C29,C41,C62,C64,C66 C68,C81,C83,C84,C86	BC1101CT-ND	Capacitor, 0.1uF, 50V, Ceramic	Digikey	19
22	C2	BC1089CT-ND	Capacitor, 1000pF, 50V, Ceramic	Digikey	1
23	C4,C5,C6,C24,C26,C28,C31 C42,C63,C67	399-3654-ND	Capacitor, 10uF, 35V, Tantalum	Digikey	10
24	C21,C82,C85	445-2647-ND	Capacitor, 1uF, 50V, Ceramic	Digikey	3
25	C22,C32	BC1013CT-ND	Capacitor, 100pF, 50V, Ceramic	Digikey	1
26	C30	BC1001CT-ND	Capacitor, 10pF, 50V, Ceramic	Digikey	1
27	C61,C65	P5172-ND	Capacitor, 4700uF, 35V, Electrolytic	Digikey	2
28	C102-C105	42L3332	Capacitor, 0.33uF, 2000V, Polypropylene	Allied Electric	4
29	C121,C122	507-0018	Capacitor, Powerlytic, 36DX282F200BC2A, 2800uF, 200V	Allied Electric	2
30	C101	41L4471	Capacitor, 4.7uF, 600V, Polypropylene	Allied Electric	1

Table 2-1 *miniBrute DRSSTC Parts List*

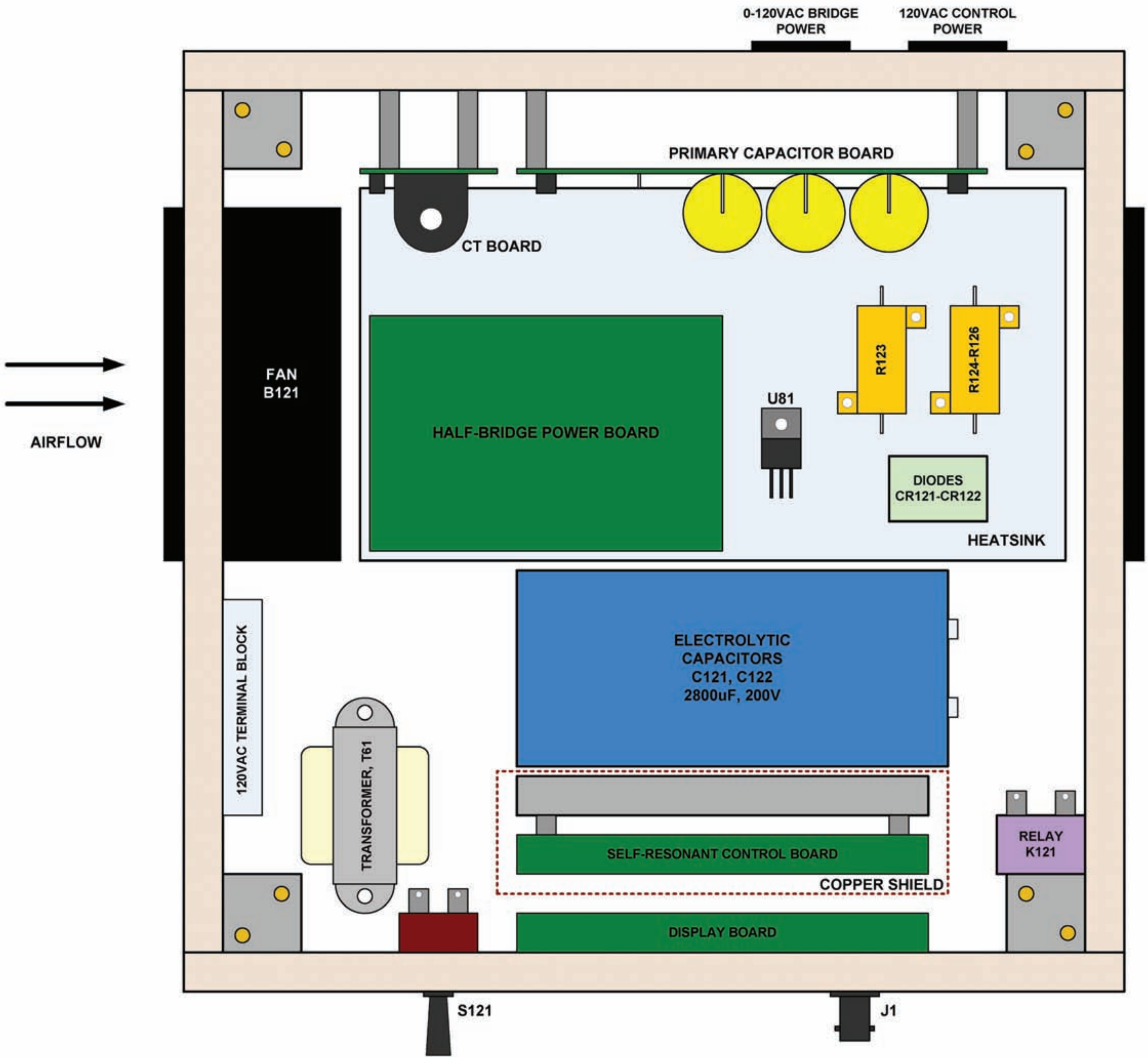


Figure 2-11 *miniBrute DRSSTC Enclosure Layout*

Enclosure Layout

Figure 2-11 above shows the internal enclosure layout for the miniBrute DRSSTC. Note that the heatsink size shown in this view was of a heatsink I had available when first building this design. That being said, the large size of the heatsink is quite overkill and a much smaller heatsink can be used without problems.

Although wiring isn't shown in this particular diagram, proper routing is important. All wires should be routed as close to the bottom of the enclosure as possible. Due to the high electrical and magnetic fields produced by the Tesla Resonator, the wiring should be placed as far as possible to reduce any potential interference. Also, all control wires should be shielded if at all possible and twisted together. Also, pay special attention to the mounting of the Primary (MMC) Capacitor Board. This should be mounted using nylon (non-conductive) stand-offs and placed so that there is adequate clearance between adjacent assemblies (including the heatsink) because high voltages are present on this board.

Inner Support Detail

The following is the detail drawing of the inner support. The inner supports are used four (4) places within the internal support assembly.

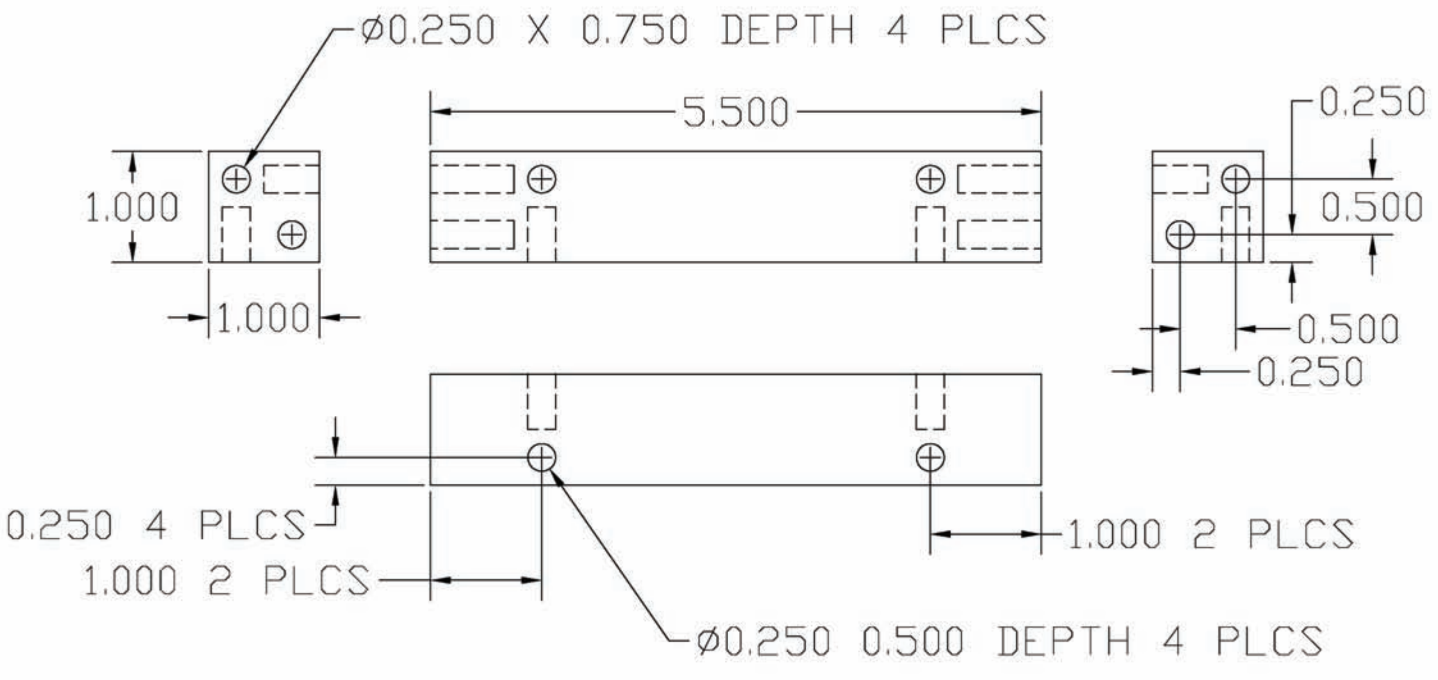
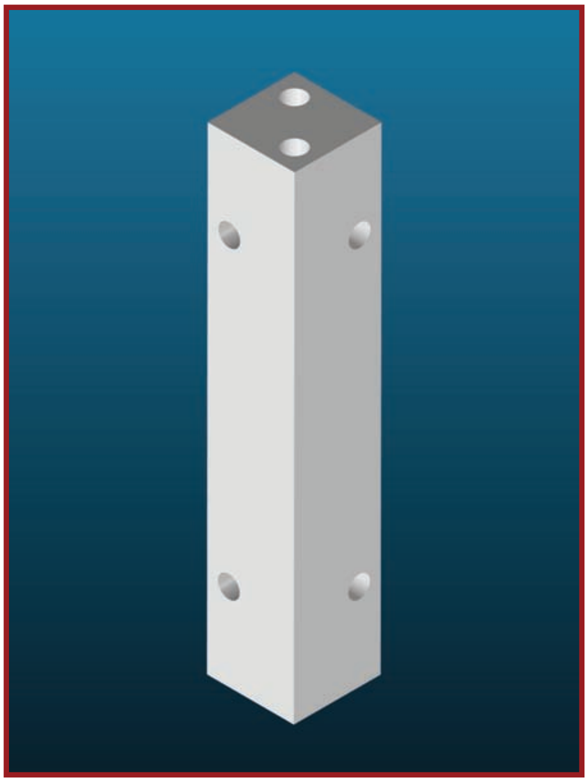
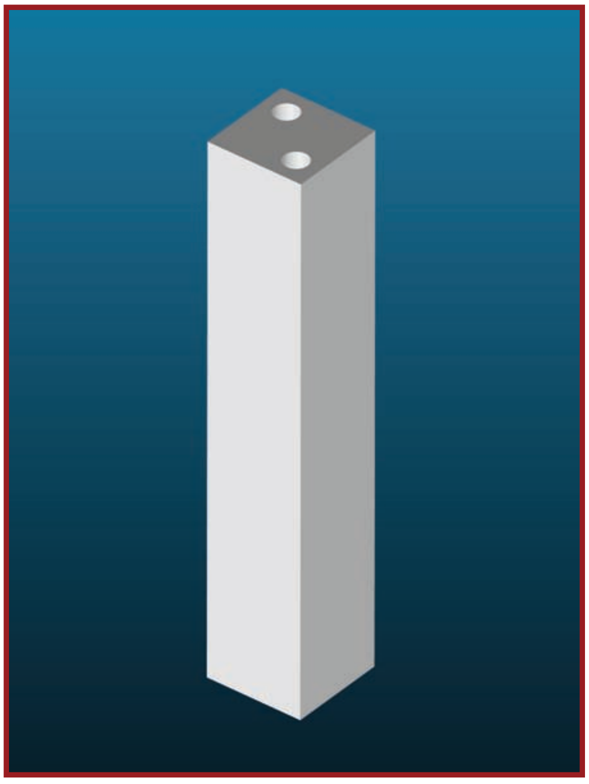


Figure 3-3 *Inner Support Detail*



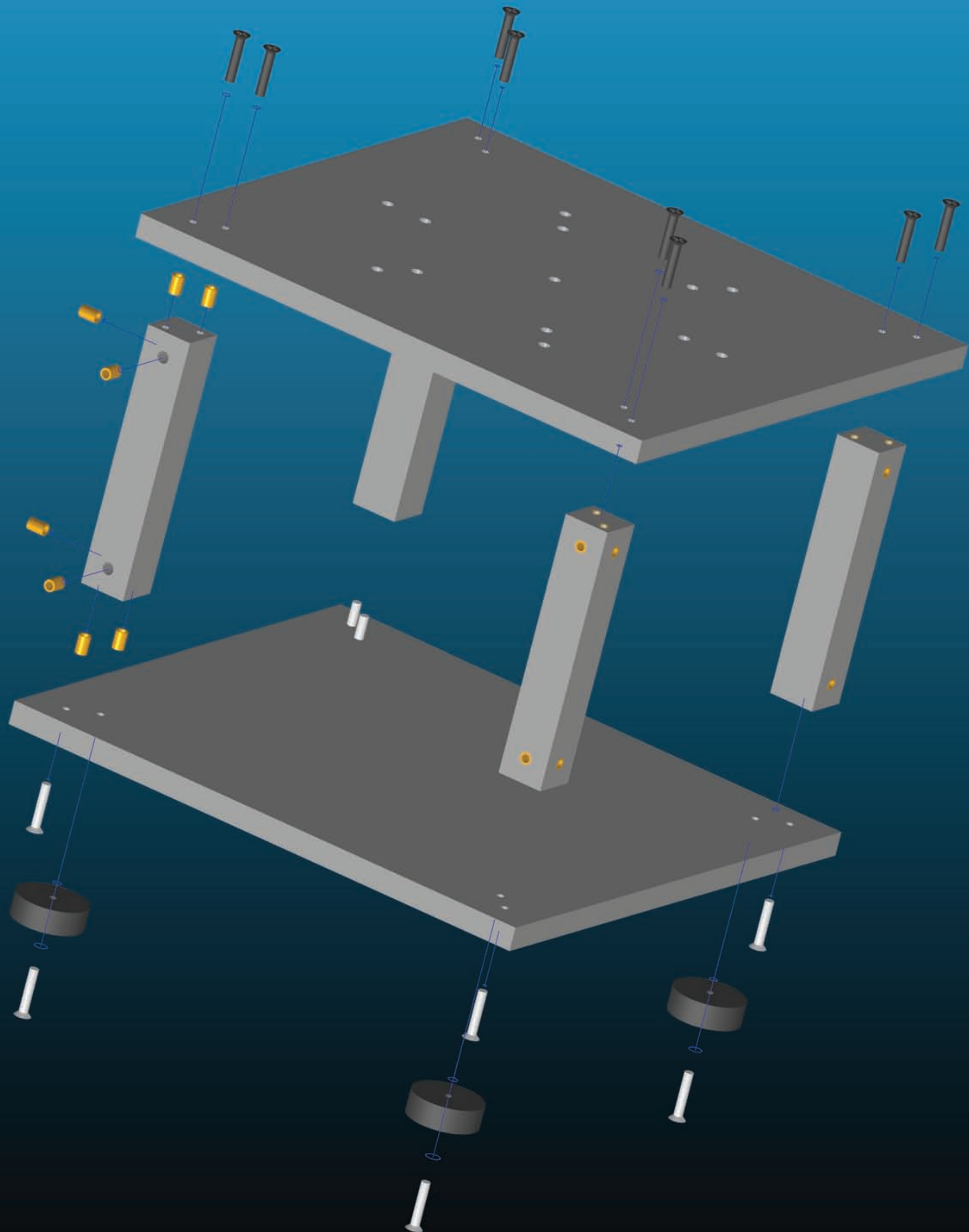
Inner Support (Outside View)



Inner Support (Inside View)

Material Specification

1” x 1” x 5.5” Type I PVC (or similar)



Self-Resonant Control Board Mounting and Shielding Provisions

The following is the detail drawing of the self-resonant control board mounting block which attaches to the base of the bottom mounting plate.

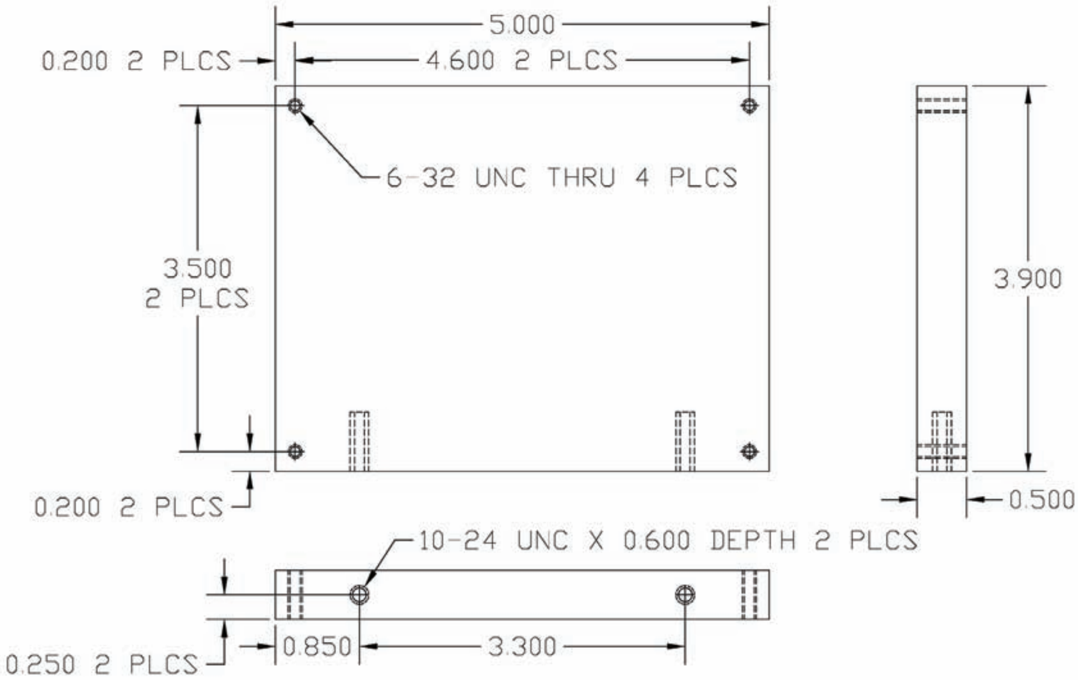
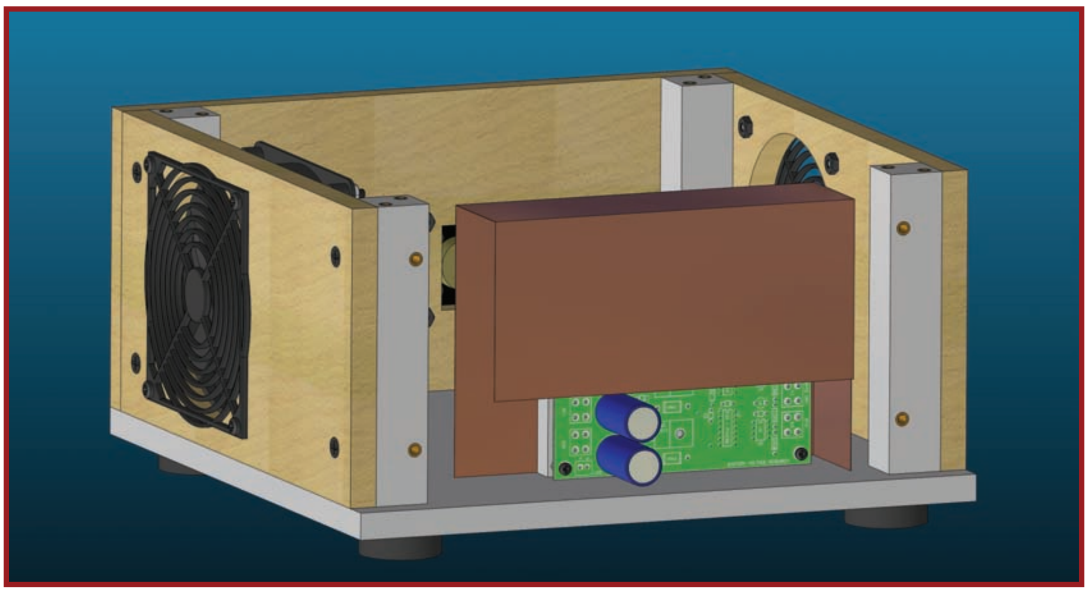


Figure 3-8 *Self-Resonant Control Board Mounting Block*

Item	Part No.	Description	Distributor	Qty
1	8747K635	Type I PVC, 6” x 6” x 0.5”	McMaster-Carr	1
2	8963K31	12” x 12” x 0.016” Copper sheet	McMaster-Carr	1
3	93505A440	Stand-off, Male-Female, 6-32, 1/4” head length, aluminum	McMaster-Carr	4
4	91400A143	6-32 Pan head phillips machine screw, 3/16” length, stainless steel	McMaster-Carr	4
5	91771A247	10-24 Flat head phillips machine screw, 1” length, stainless steel	McMaster-Carr	2

Table 3-3 *Self-Resonant Control Board Mounting Block and Shield Parts List*



Self-Resonant Control Board Shield

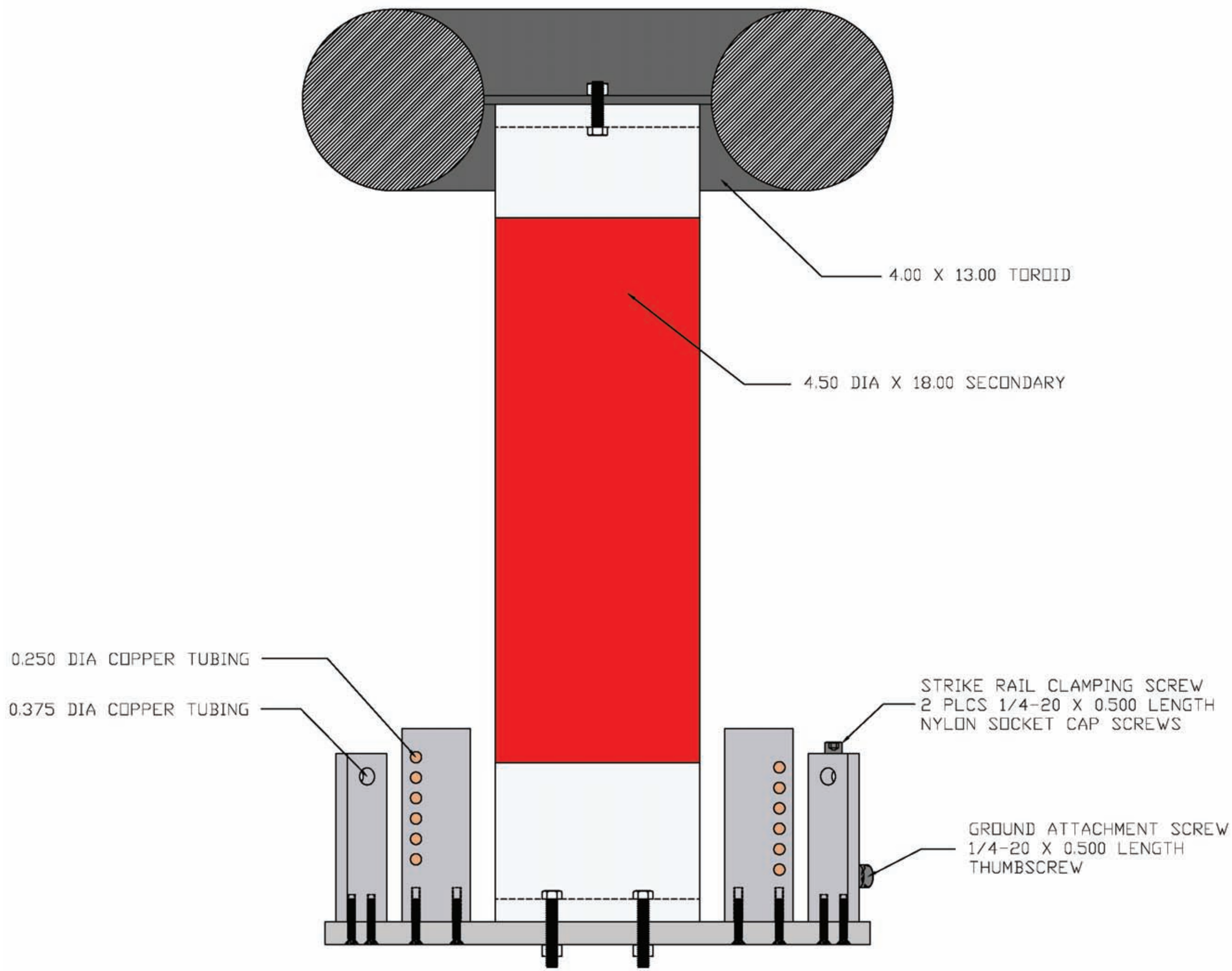


Figure 3-13 *Assembly Dimensional Detail (Side View)*

Figure 4-6 *Advanced Modulator*

Advanced Modulator Operational Specifications

Normal Mode	
Pulsewidth Adjust	20us to 430us (continuous)
PRF Adjust	22Hz to 318Hz (continuous)
Burst Mode	
Pulsewidth Adjust	20us to 430us (continuous)
PRF Adjust	22Hz to 318Hz (continuous)
Burst Length Adjust	20us to 100ms (continuous)
Lock-out Adjust	100ms to 10s (continuous)
Long Pulse Mode	
Pulsewidth Adjust	20us to 100ms (continuous)
Lock-out Adjust	100ms to 10s (continuous)
Aux. Mode (Alternate Frequency Mode)	
ON time Adjust	0 to 10ms (continuous)
OFF time Adjust	9ms to 768ms (continuous)

Table 4-1 *Advanced Modulator Operational Specifications*

7. Remove all power from the system. Make sure the DC Power supply capacitors, C121 and C122, are completely discharged before handling the DC power supply and moving on. This test is now complete.

Half-Bridge Power Board

The following test procedure references the electrical schematics shown in Figures 2-1 through 2-8.

1. Complete the half-bridge power assembly, including heatsink, and ensure that each IGBT is properly orientated and attached to the half-bridge power board.

2. Connect the self-resonant control board's gate drive outputs (E1 and E2) to the gate drive inputs of the half-bridge power board as shown in Figure 2-8. Optimally, twisted shielded pair cable should be used to connect the gate output of the self-resonant control board to the gate input of the half-bridge power board. If twisted shielded cable is not available, then the gate connection wires should be twisted tightly together to increase coupling between the wires and to minimize inductance. **Do NOT connect the DC power supply to the half-bridge power board at this time.**

3. Connect a signal generator to the "CURRENT FB" terminals of the self-resonant control board. Set the output of the signal generator to a 5V peak-to-peak, 100kHz square wave. An HP 200CD oscillator may work as well for this application, however the amplitude must be limited to avoid damage to the self-resonant control board. If you do not have a signal generator, the simple 555 based timer circuit shown in Figure 5-2 can be used.

4. Connect the Advanced Modulator to the "EXT MOD" terminal of the self-resonant control board. Pulsewidth should be set to approximately 250us and pulse repetition frequency (PRF) set to approximately 100Hz.

5. Turn ON the Advanced Modulator, apply power to the self-resonant control board, and enable the signal generator. Once this is done, make sure the Advanced Modulator is working correctly. Check each of the gate driver ICs (U4-U5) on the self-resonant control board to ensure they are not overheating. If the gate driver ICs are hot, there may be a problem with the Advanced Modulator.

6. Using a dual channel oscilloscope with two probes, take a differential measurement of the gate-to-emitter, V_{GE}, voltage at each of the two (2) IGBTs on the half-bridge power board. Verify that the waveforms measured at the IGBT gates approximately match that of the waveforms shown below in Figure 5-4. Risetime (0 to 20V) of the waveform should be less than 250ns and falltime (20V to 0) should be less than 250ns.

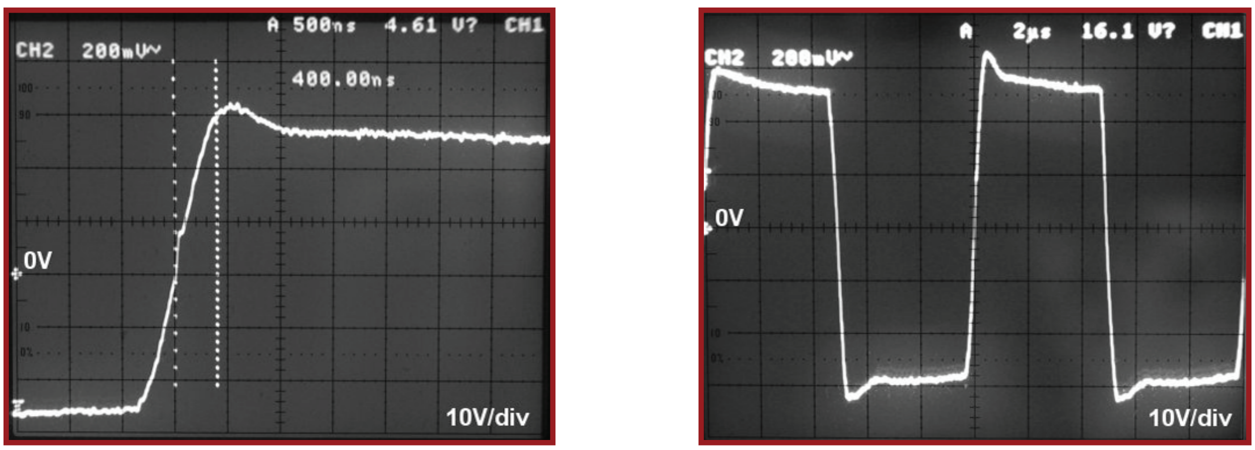


Figure 5-4 *Gate Drive Waveforms, V_{GE} as measured at IGBT*

7. Once the measured gate waveforms have been verified, the next step is to check the phasing of the gate drive waveforms. This will check to see if the polarity of the gate drive transformer is correct and whether or not the half-bridge will operate properly. Using a dual channel oscilloscope with two probes, verify the phasing of the gate drive waveforms as shown

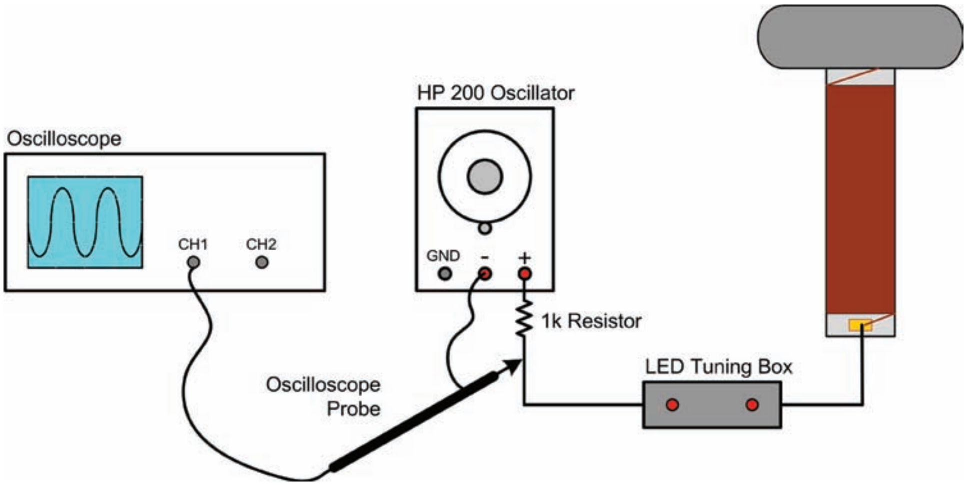


Figure 5-8 *Secondary Coil Resonant Frequency Measurement Set-up*

4. Once the resonant frequency of the secondary coil assembly is determined, the next step is to determine the initial tuning point of the primary coil. Connect the test circuit as shown below in Figure 5-9. Set the signal generator for maximum output amplitude, and set the output frequency of the signal generator to the measured secondary coil resonant frequency which was determined in step 3 on the previous page. Verify the output frequency of the signal generator using the oscilloscope to ensure accuracy.

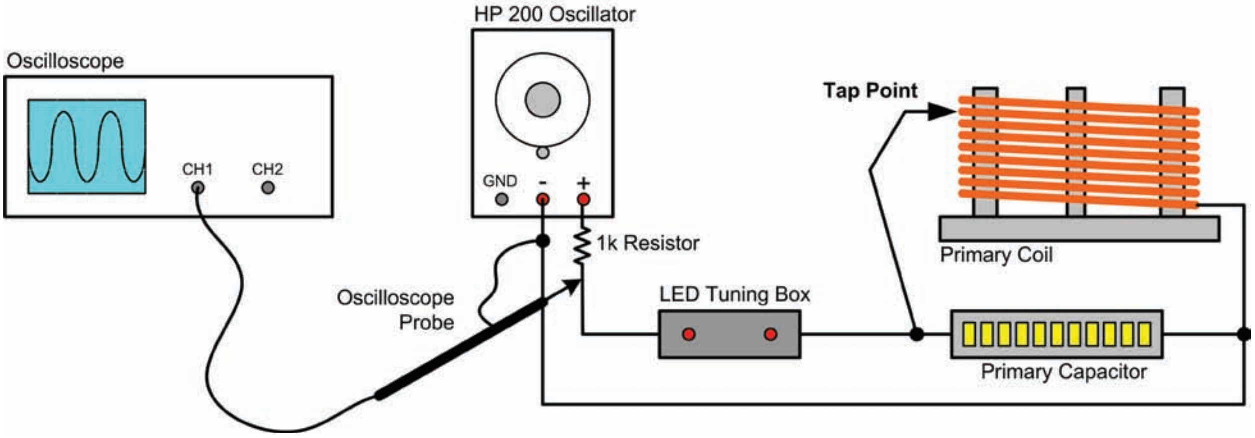


Figure 5-9 *Primary Coil Initial Tuning Set-up*

5. In this step, you will begin moving the upper tap of the primary coil until the point of resonance is found. Parallel resonance is defined as the point where the parallel LC circuit is at maximum impedance, therefore, the point of resonance will be where the LED indicator is at its dimmest, and the amplitude shown on the oscilloscope is at its maximum.

6. Secure the upper tap point to the primary coil. This will be the starting tuning point of the primary coil and completes the initial tuning of the miniBrute DRSSTC system. It is important to note that this tuning point will only be used to test and troubleshoot the system for the first time. Fine tuning will be necessary to maximize performance of the miniBrute DRSSTC system.

Initial Operation

Now that you have completed all subassembly testing and have determined the resonant frequency of the secondary coil assembly and set the primary coil tap point, you are ready to power up the miniBrute DRSSTC for the first time. Assemble and make all connections of the top level DRSSTC system as shown in Figure 2-8. Double check all connections before

Peak Primary Current vs. Arc Length

The plot shown in Figure 6-6 below shows the effect primary tuning has on both maximum arc length and shows how much primary current is required for the system to strike a target set at a specified distance.

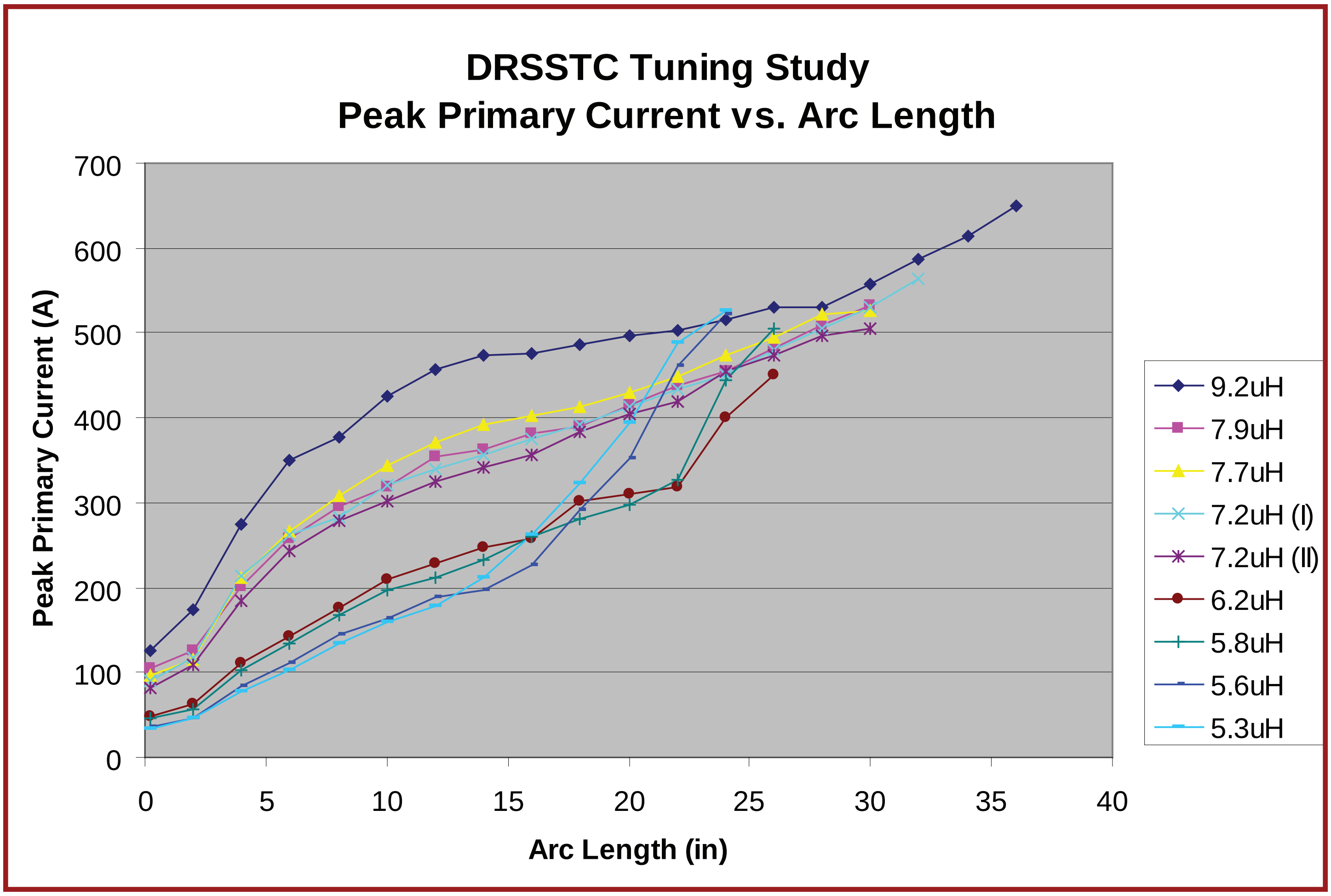


Figure 6-6 *Peak Primary Current vs. Arc Length (PRF = 100Hz, Pulsewidth = 300us)*

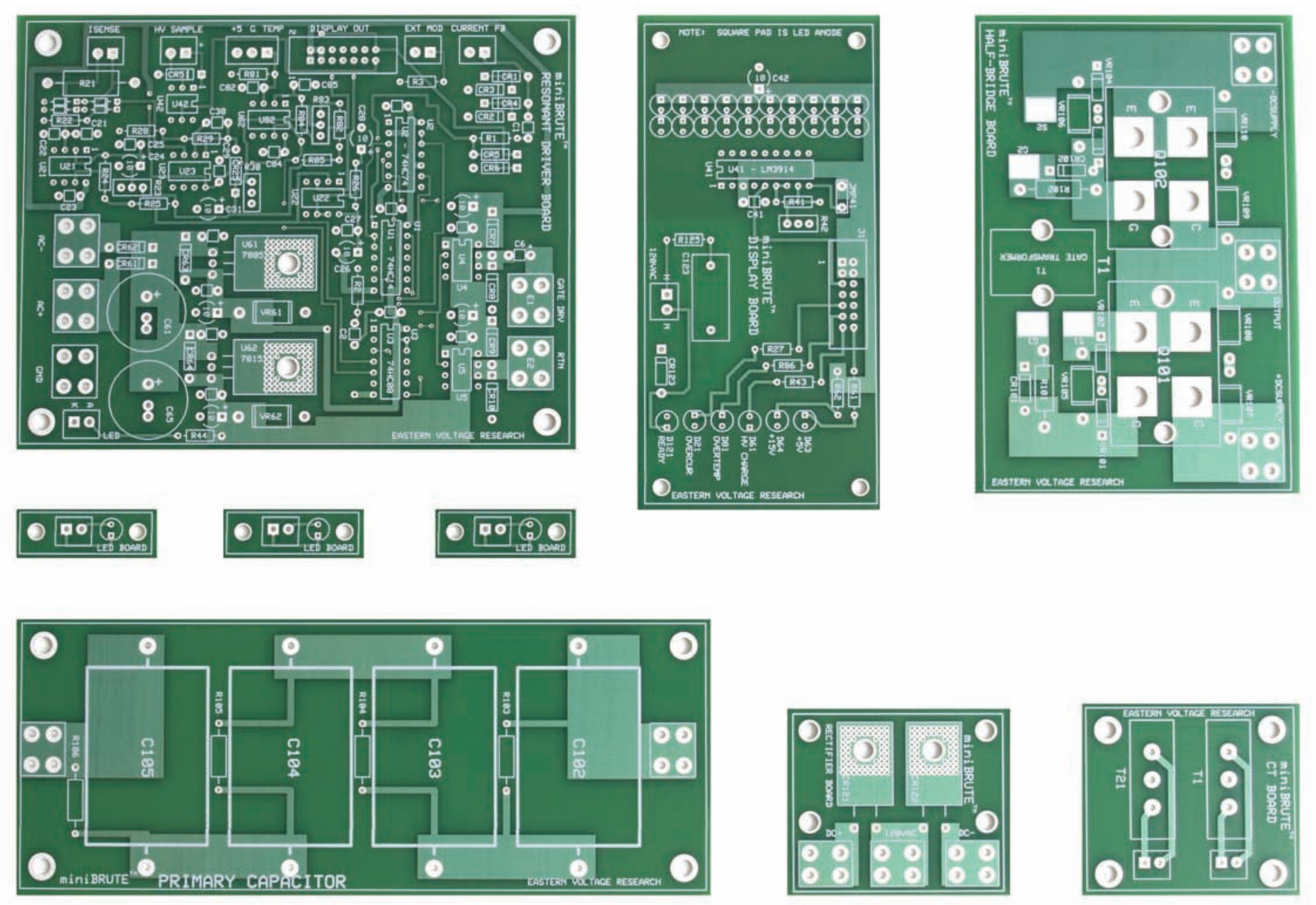
DC Bus Voltage vs. Arc Length

The plot shown in Figure 6-7 on the next page shows the effect primary tuning has on both maximum arc length and shows how much DC bus voltage is required for the system to strike a target set at a specified distance.

Primary Tuning Point > Secondary F_{RES}

Interestingly enough, if the primary tuning point is set to a value so that the primary circuit's natural resonant frequency is greater than the resonant frequency of the secondary coil (198kHz) and the DRSSTC operates in the upper frequency mode of the coupled system, loading of the output arc begins to have a detrimental effect on performance. This can be seen by the drastic increase in the slope for the 5.3uH, 5.6uH, 5.8uH, and 6.2uH waveforms in both Figures 6-6 and Figure 6-7 as arc length increases. Figure 6-8 on the next page illustrates this further. In otherwords, increasingly more DC bus voltage and peak primary current are required to obtain longer output arcs for these primary tuning points. Also, because of this, the maximum arc length obtainable by the DRSSTC becomes less and less as primary inductance is decreased.

miniBrute Printed Circuit Boards



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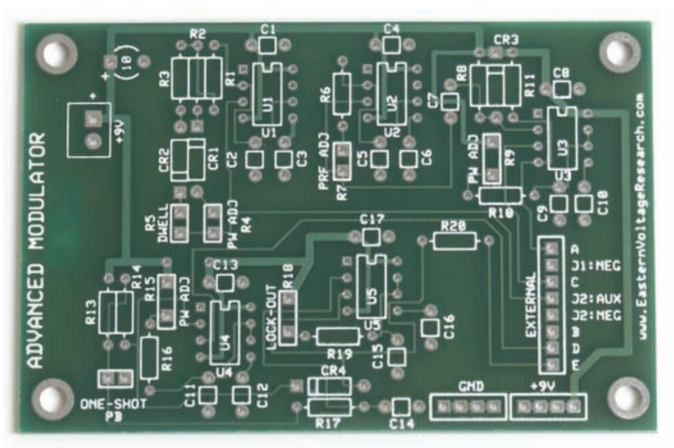

Advanced Modulator Printed Circuit Board

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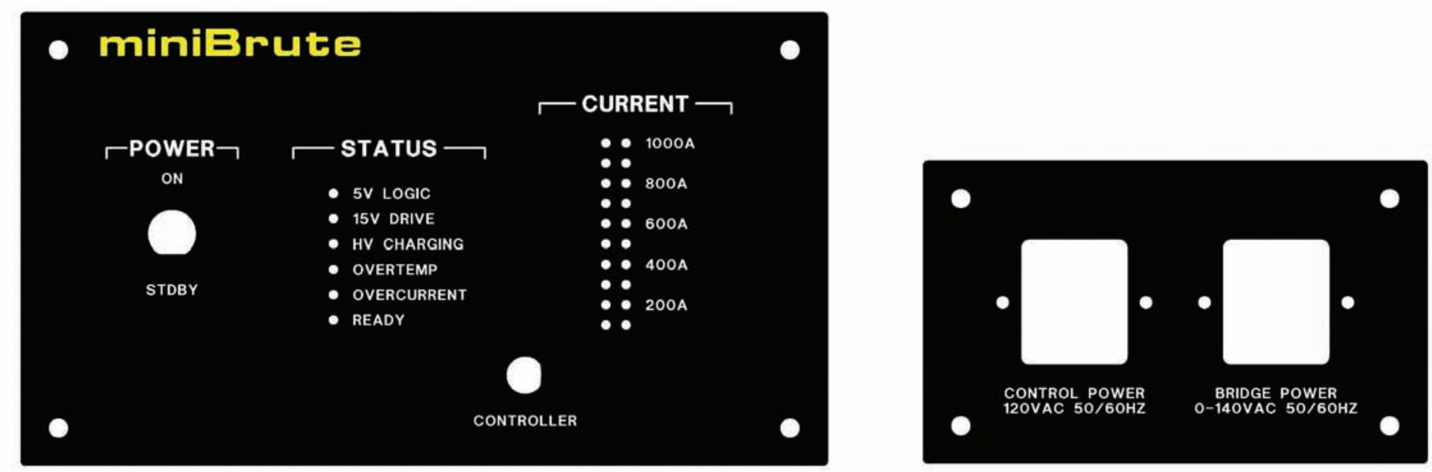
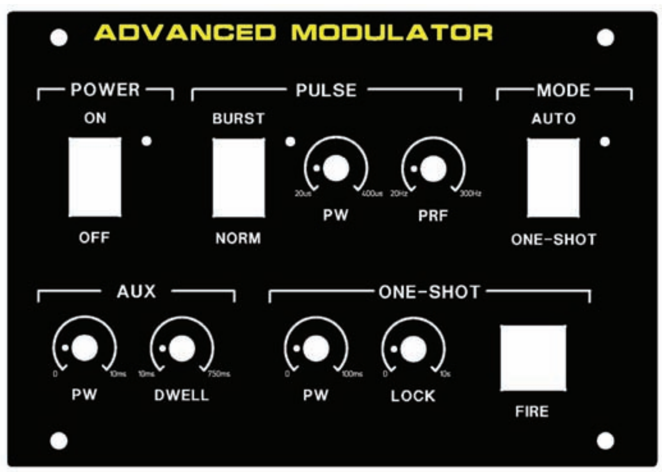
Custom Control Panels



miniBrute Front / Rear Panel Package



Advanced Modulator Control Panel

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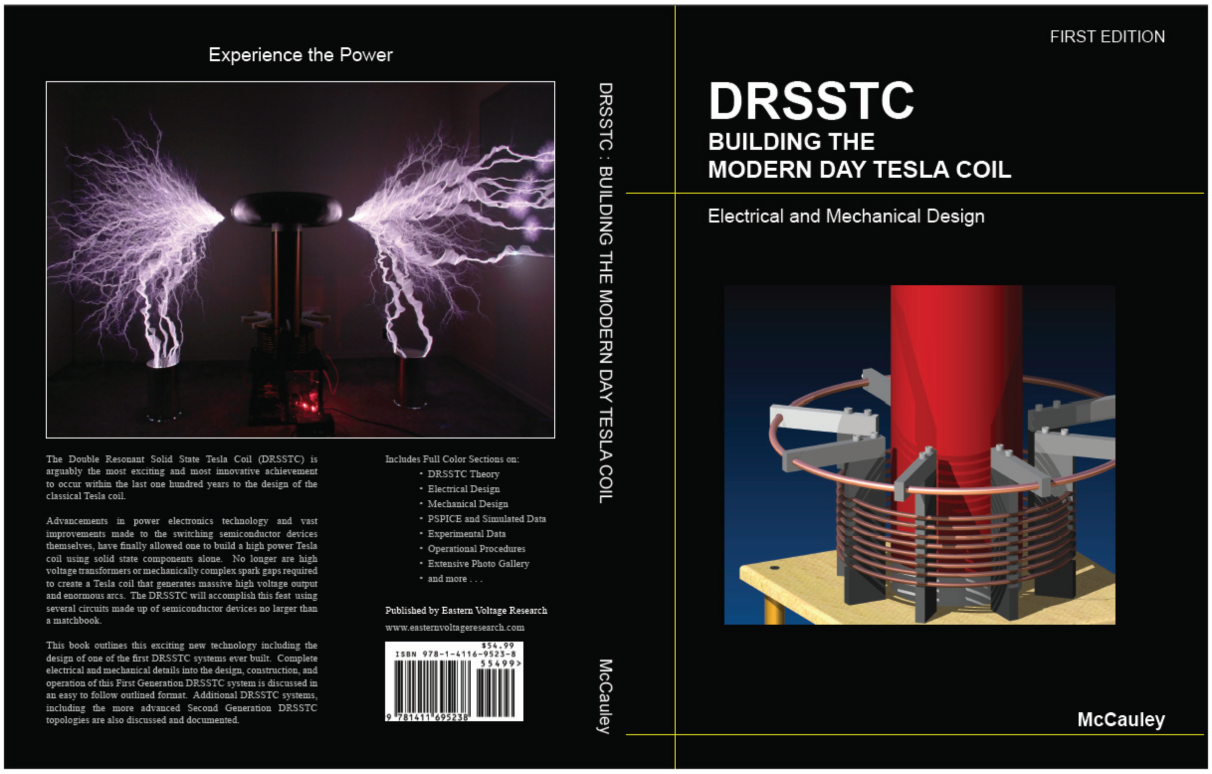

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