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SILICON DEVICE PERFORMANCE MEASUREMENTS TO SUPPORT TEMPERATURE RANGE ENHANCEMENT

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MOS Controlled Thyristor (MCT) Testing

The following section details additional characterization results of a MOS controlled thyristor (MCTA60P60). This device is rated for 60A and for an anode to cathode voltage of -600V. As discussed in the last report, the MCT failed during 500V leakage tests at 200°C. In contrast to the BJT, MOSFET and IGBT devices tested, the breakdown voltage of the MCT decreases significantly with increasing temperature. Figure 1 presents the breakdown voltage of the MCT measured at the knee (onset of breakdown). The device manufacturer has seen similar decreases in breakdown voltage during characterization to 150°C. The leakage current at the knee is also plotted. Hence, in our earlier leakage current measurements at 500V we were exceeding the breakdown voltage of the device at elevated temperatures which resulted in catastrophic failures. Figure 2 presents leakage current information measured at 300V between anode and cathode.

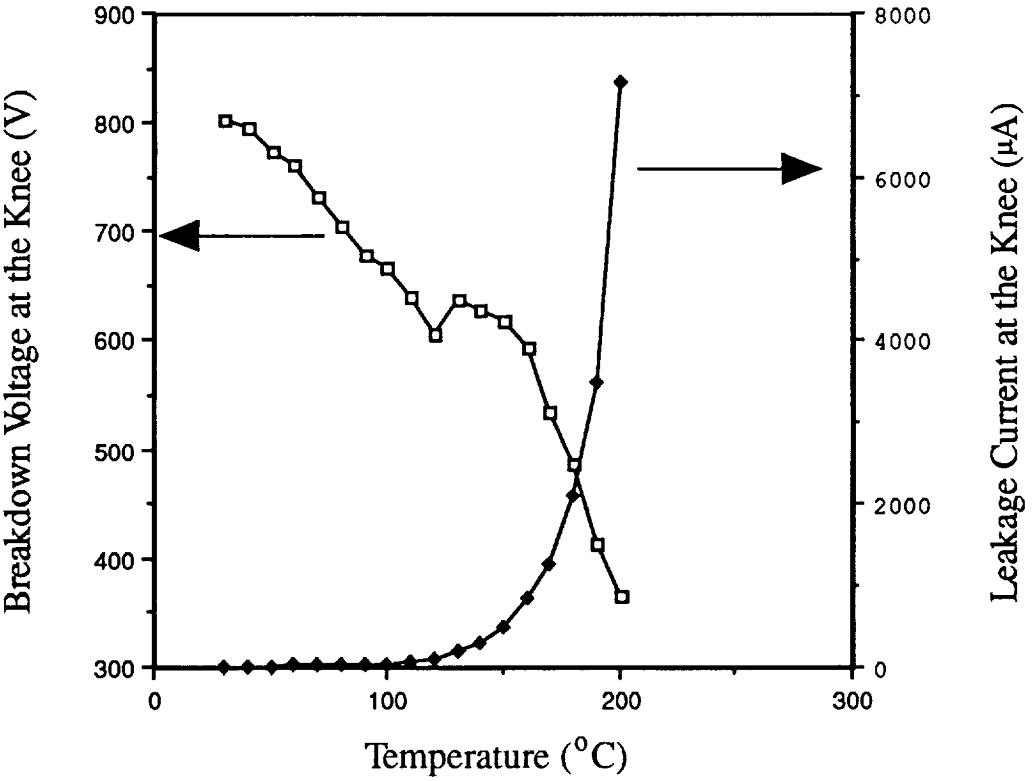

Figure 1. MCT breakdown voltage as a function of temperature.

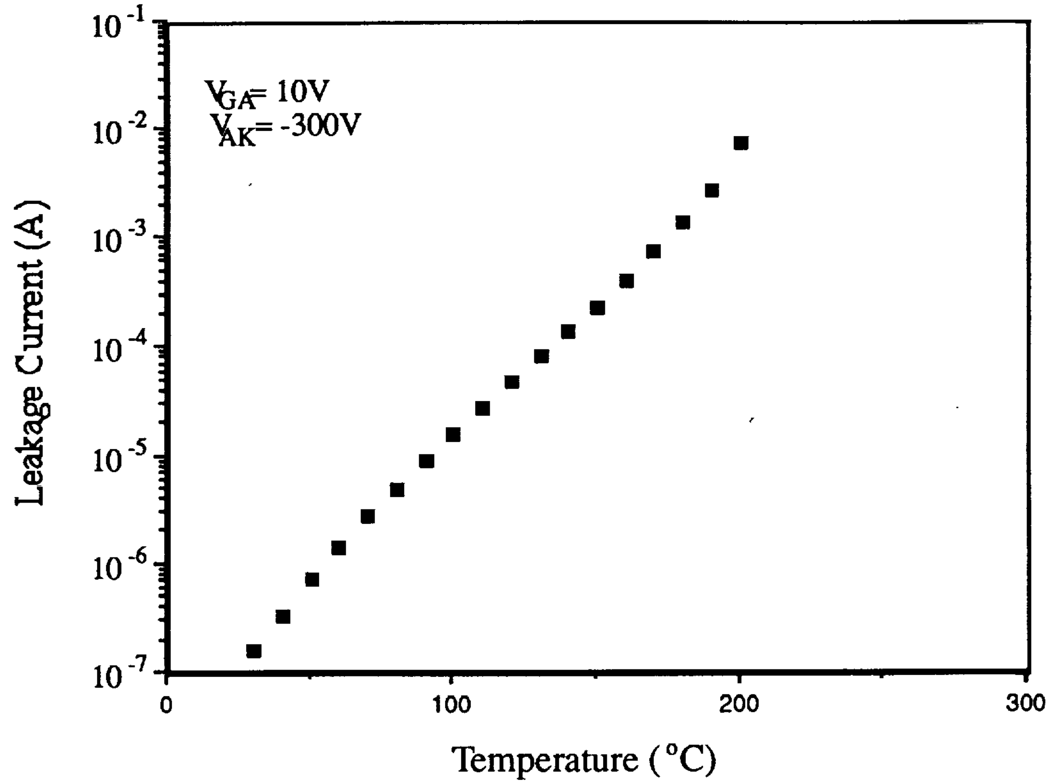

Figure 2. MCT leakage current as a function of temperature.

Switching Times

The switching tests were performed on the original lot of MCT. 10% to 90% rise and fall times of the MCT were measured as a function of temperature. These measurements were made using the HP6030 power supply to a cathode to anode voltage of 200V. Two Lambda LLS7060 power supplies were used to provide +/-13 volt rails for the gate to anode drive. The gate drive between these rails used an IR2110 output buffer. A resistive load (3.39Ω, 1.040μH) was used for this test. The voltages and currents were measured with a Tektronix 2440 Oscilloscope. Results of these measurements are shown in Figure 3 and Figure 4. There is a significant decrease in switching speed with increasing temperature.

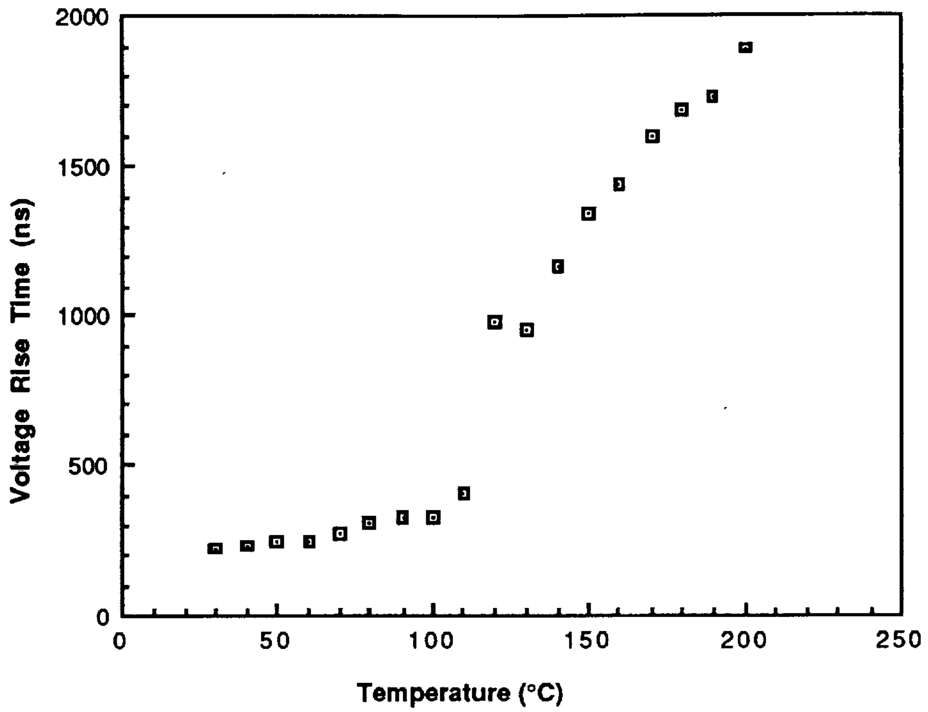

Figure 3. MCT rise time versus temperature.

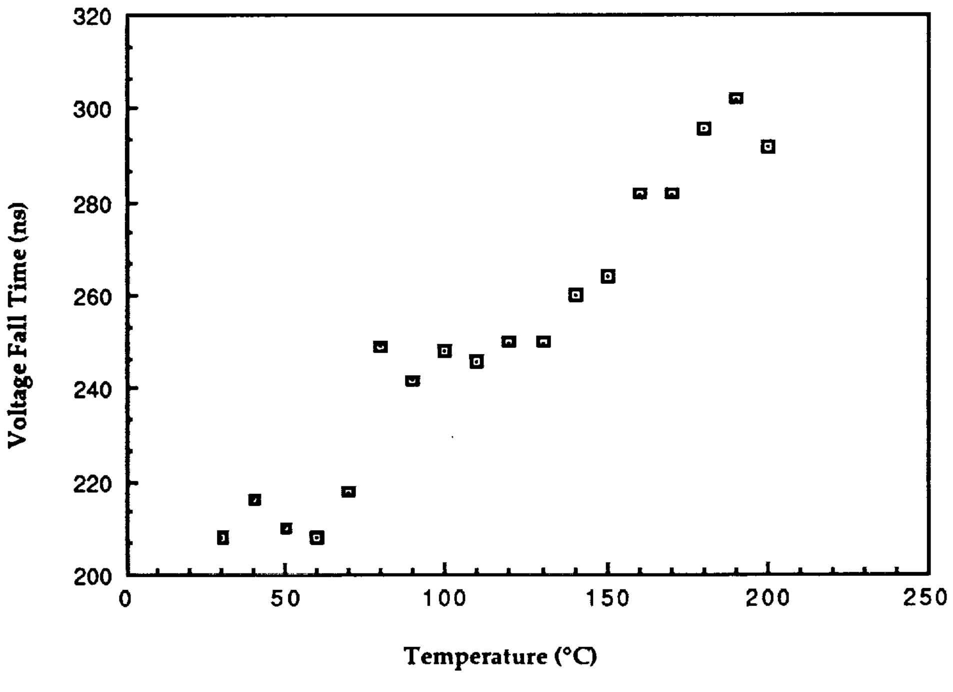

Figure 4. MCT fall time versus temperature.

MCT Summary

The MCT devices used in this study are rated by the manufacturer for use up to 150°C. The test results indicate the devices are good to 150°C. However, due to the increased switching delays, increased leakage current and the significant drop in breakdown voltage, these devices can not be recommended for 200°C applications.

Switch-mode Power Supply Design and Performance

A 28V to 42V zero voltage, 100Watt switch-mode converter was designed to operate from 30°C to 200°C. Figure 5. shows a schematic of this regulated power supply which utilizes an IGBT (TA9876), which has previously been characterized over this temperature range.

A zero-current switching scheme was selected for the power supply to reduce the switching stress on the IGBT/diode pair. Leakage currents in the devices increase with temperature which causes increased losses. The IGBT, with its 600V breakdown voltage is well suited to zero-current switching. Zero-current switching kept losses through the IGBT at a minimum. The power supply was tested extensively at 200°C for periods up to 7 hours without one failure. Long-term tests will be conducted after the final design is completed.

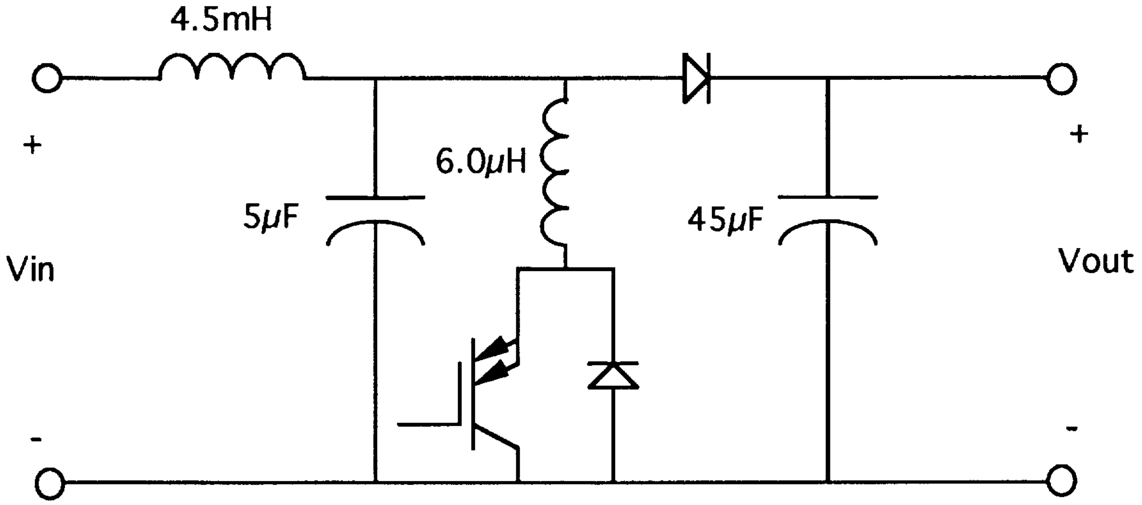

Figure 5. Zero current switching 28V to 42V boost converter.

An effort was made to produce a similar power supply with a RHF75N05E MOSFET in place of the IGBT. The MOSFET has a room temperature breakdown voltage rating of 50V, only 8V above the output voltage of the converter. In this topology, with both the IGBT and MOSFET, the voltage across the switch rang well above the 42V when the switch was turned off. Efforts were made to reduce this ringing but they were unsuccessful. This problem resulted in multiple failures in the MOSFET. Due to this ringing, it was determined that the MOSFET, with its lower breakdown voltage, was not suited to this topology. A zero-voltage switching topology is being developed for the MOSFET.

Losses in the IGBT version of the circuit have been analyzed between 30°C and 200°C. In this testing, all converter components except the two capacitors and the control circuitry were placed in the oven. Input power, output power, power loss in the input inductor and power loss in the IGBT/diode pair were measured while the circuit was delivering approximately 100W. The input power and the output power were measured using a DM5110 multimeter to record the currents and voltages. Losses in individual components were calculated from voltage-current measurements made using a Tektronix 2440 oscilloscope

Figure 6. shows the overall circuit efficiency as a function of temperature. As is shown in Figure 6, the efficiency of the converter is 79.75% at room temperature and drops to 71.38% at 200°C. Figure 7 shows the losses in the input inductor (Magnetics, Inc. Moly Powdered Permalloy Torroid Core Number 55717-A2). The losses through this inductor nearly doubled over the temperature range and represent a major portion of the losses in the circuit. At 200°C, the total circuit losses are 41.45W and the inductor losses account for 19.5W (47%).

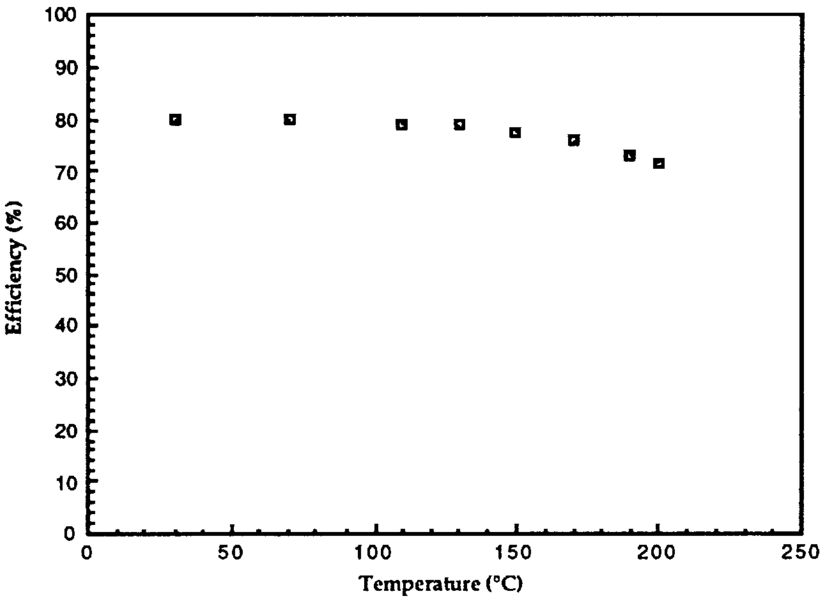

Figure 6. Overall converter efficiency versus temperature.

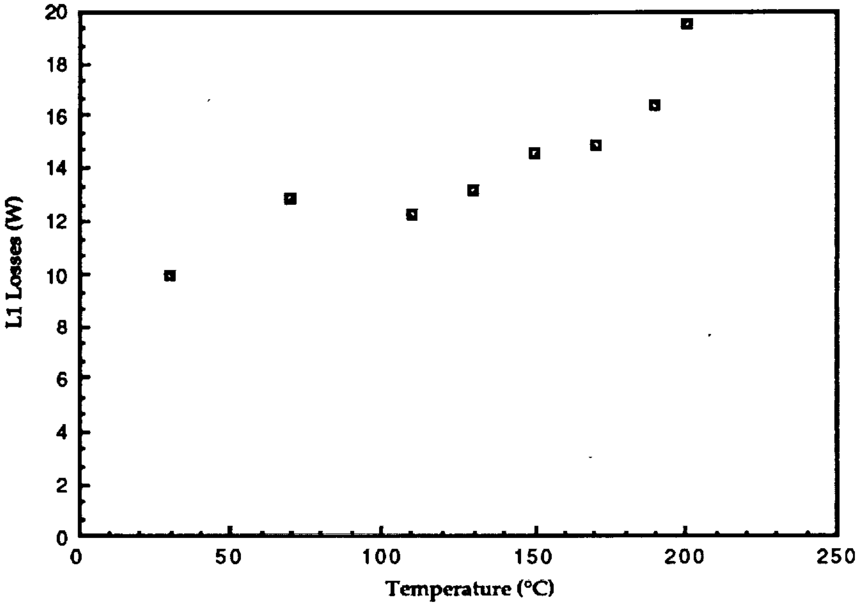

Figure 7. Input inductor losses versus temperature.

The second largest losses were associated with the IGBT/diode pair. These losses are plotted versus temperature in Figure 8. These losses went from 6.588W at room temperature to 14.71W at 200°C. The majority of this power was dissipated in the IGBT.

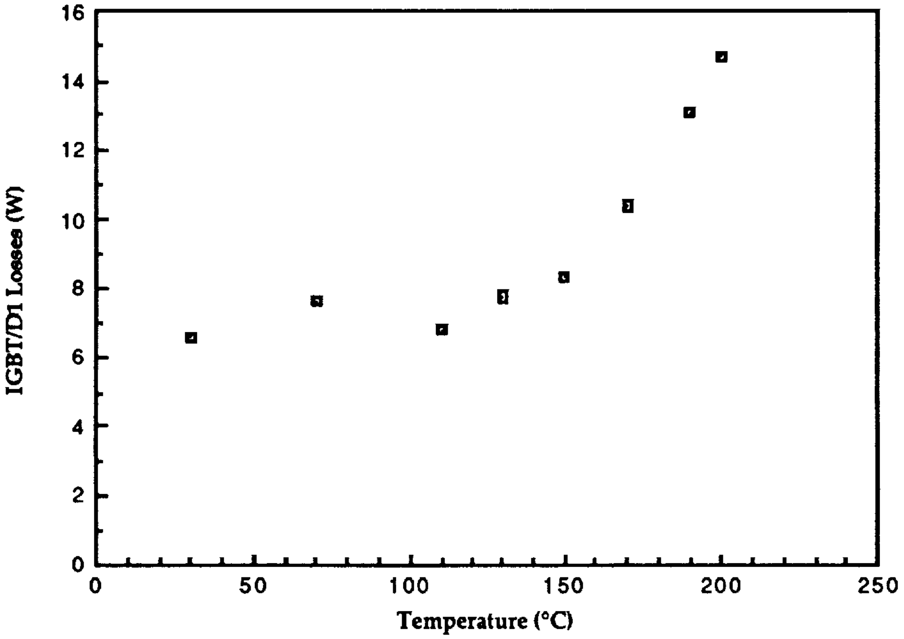

Figure 8. IGBT/diode pair losses versus temperature.

The losses through the two capacitors in the circuit were measured using the Tektronix 2440 Oscilloscope. The 5µF capacitor dissipated 3.39W and the 45µF capacitor dissipated 1.94W. Since the capacitors were not in the oven, the waveforms across them changed very little as the ambient temperature of the IGBT's and the inductors was changed. The capacitor losses were essentially constant. The 39.36W lost between the capacitors, the IGBT/diode pair and the input inductor accounts for most (95%) of the 41.45W lost in the circuit at 200°C. The remaining loss of 2.09W in the circuit include the resonant inductor and the output diode.

The control circuitry was based on a Unitrode 3860 resonant mode control integrated circuit. During testing of the U3860 as a function of temperature, the devices failed at temperatures from 150°C to 190°C and varied from device to device. Thus for these tests the control circuitry remained outside the oven. An alternate control scheme is being developed for use at 200°C.

The current circuit design uses two capacitors, a 5µF and a 45µF. The 5µF capacitor is used to set the resonant frequency of the circuit and its absolute value is critical. In discussions with AVX, a capacitor manufacturer, a 5µF capacitor could be fabricated which would be temperature stable to 200°C by paralleling NPO multilayer ceramic chip capacitors. There was some concern over the mechanical reliability of the structure of the composite capacitor during solder assembly and during thermal cycling. The capacitor would also be very large and 5µF is about the largest value AVX will quote in an NPO dielectric. NASA Lewis has evaluated the electrical performance of multilayer ceramic capacitors and the results have been good.

The 45µF capacitor is for filtering and affects the output voltage ripple. This capacitor could not be made with NPO dielectric and was quoted using an X7R dielectric. The plan was to design the capacitor with a room temperature capacitance of 100µF. This would decrease to approximately 45µF at 200°C. The output ripple voltage would increase as the temperature increased (capacitance decreased), but would still be within design limits at 200°C. The capacitors have not been ordered. We are waiting until the design is finalized and will continue testing of the preliminary designs with the capacitors outside of the oven. We are also investigating converter topologies which do not rely on absolute capacitance values.

As stated previously, the room temperature breakdown voltage of the MOSFET is only 8 volts above the output voltage of the converter. As a result, the MOSFETs failed when utilized in the zero-current switching converter. A new topology was selected in order to keep the same output

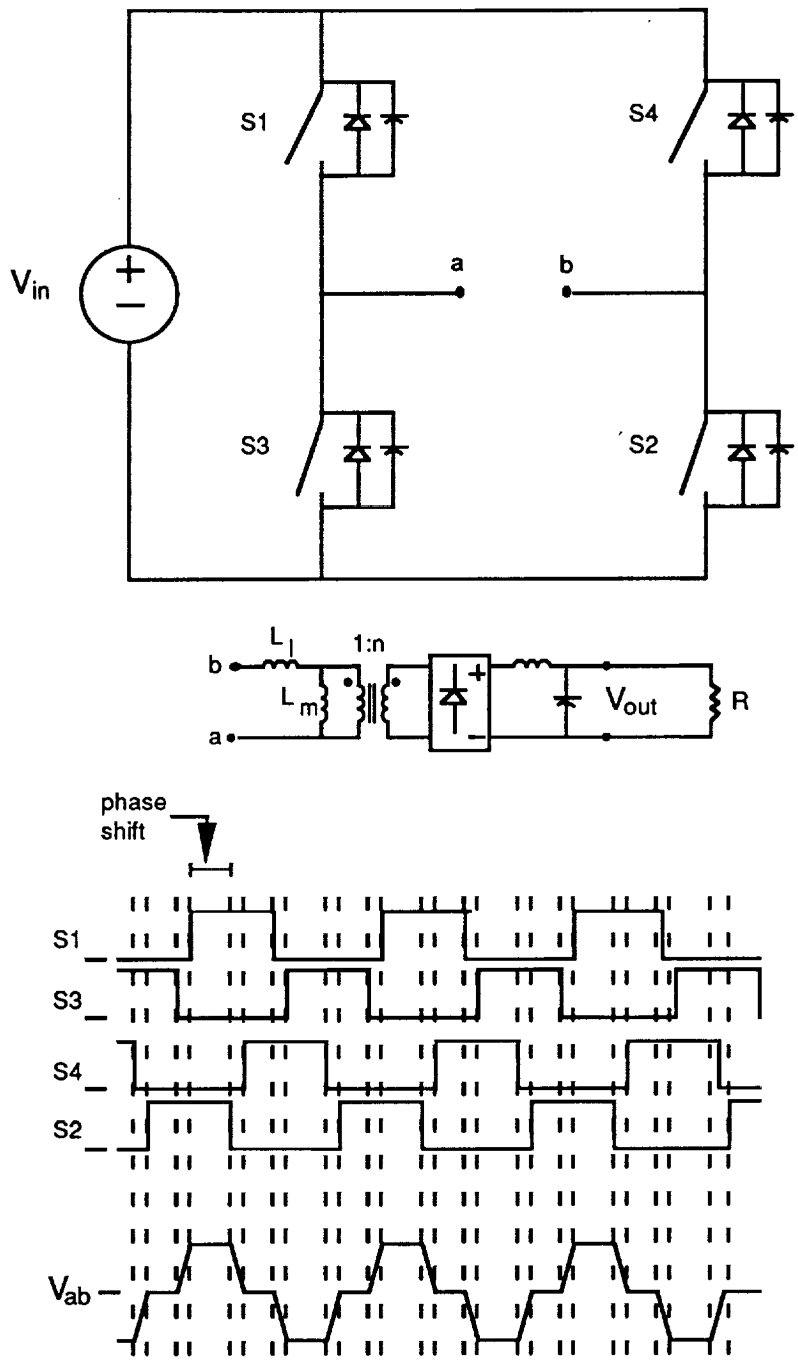

Figure 9. Zero-voltage switching topology for MOSFET

voltage while using the MOSFETs. This full-bridge dc-dc converter topology is shown in Figure 9. The voltage across any of the switches is clamped at the input voltage V_{in}. This allows the 50 V MOSFETs to be utilized since they do not have to block more than 28 V. The energy stored in the leakage and magnetizing inductances of the transformer is used for zero voltage switching of all switches. A phase-shifted PWM scheme is employed for control. The current status of this converter is that the control circuitry has been constructed and tested. The high temperature transformer has been wound and tested. The next step will be operation of the converter at room temperature. When proper operation of the converter is verified, it will be placed in the oven and tested at higher temperatures.

Summary

Device characterization has been completed. The IGBT is the most rugged device at 200°C. The major limitations of the IGBT are slow switching speed (20-100kHz depending on the application) and the high on-state forward voltage drop (3-4V). MOSFETs can also be used at elevated temperatures in zero voltage switching applications. Work will continue during the next six month period to develop higher power 28V-to-42V converters using IGBTs and MOSFETs and to improve converter efficiency.