

# HIGH CURRENT, HIGH DI/DT, SOLID STATE SWITCH RESISTANCE MODEL

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**Abstract -** The efficiency of a solid state switch used in short pulse applications is determined by how rapidly the effective resistance decreases during turn-on. Applied Pulsed Power has examined the resistance fall for our high current, high di/dt, solid state switches and produced a useful model for the resistance versus time under various operating conditions. The model covers voltages up to 48kV, currents up to 8kA, di/dt up to 75kA/ $\mu$ s, and pulse widths up to 1 $\mu$ s. It has been implemented in SPICE circuit simulations, and using the SPICE model, the efficiency of the switch in different applications can be predicted.. This paper will present data examining actual resistance measurements compared to the SPICE circuit simulations and discuss the solid state physics involved in the model.

## I. INTRODUCTION

The design of efficient pulsed power generators incorporating solid state switching requires a suitable resistance model of the switch involved. This is essential for short pulse applications where the switch turn-on time is a substantial fraction of the current pulsewidth. An empirical model that suitably predicts the resistance of the switch allows for examination of the efficiency of different pulsed power configurations without requiring the expense of building and testing the configurations. It was with this goal that we examined the model S38 and model S33A switches to develop an empirical model for the instantaneous resistance for pulsed power applications.

## II. MODEL S38

The model S33A is comprised of a set of model S38 modules in series [1],[2]. Therefore, the turn-on of the model S38 module was initially examined. Precise voltage and current data was taken for different circuit configurations using the model S38 module as the switch. An example of this data can be seen in Figure 1, using an 80nF capacitor charged to 4kV and a 10 $\Omega$  load.

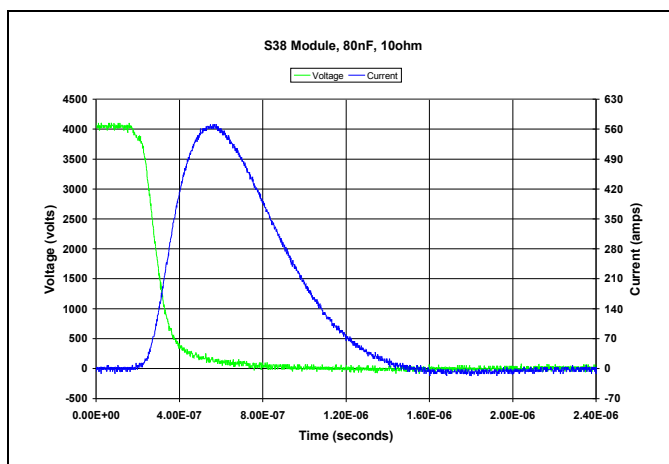


Fig. 1. Model S38 Voltage and Current Data

## III. FITTING THE MODEL S38

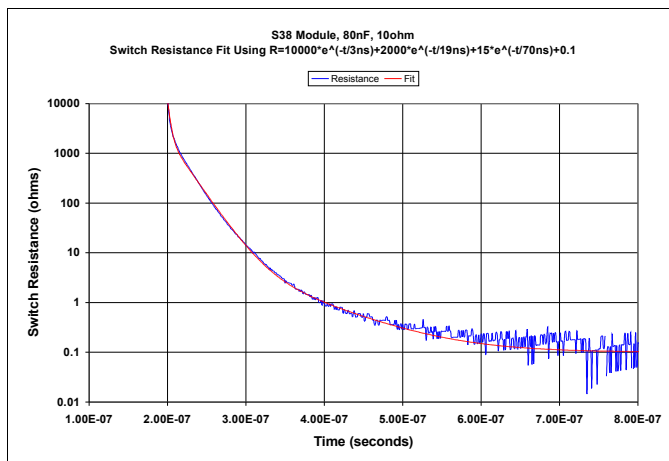


Fig. 2. Fit Versus Data for Model S38 Resistance

An equation for the resistance was developed using the data taken with the S38 module. The best fit was obtained using a sum of three decaying exponentials and a constant. This equation can be summarized by (1).

$$\Omega(t) = a * e^{(-t/b)} + c * e^{(-t/d)} + f * e^{(-t/g)} + h \quad (1)$$

Fig. 2 shows a graph of equation (1) fitting the switch resistance derived from the data shown in fig. 1. Use of different circuits resulted in different values for the terms. Some example circuits can be seen in table 1. For most circuits tested, only the final term varied with any significance.

TABLE 1  
EXAMPLE CIRCUITS AND FIT PARAMETERS

| V    | C     | $\Omega_{load}$ | a     | b   | c    | d    | f  | g    | h    |
|------|-------|-----------------|-------|-----|------|------|----|------|------|
| 4000 | 80nF  | 10              | 10000 | 3ns | 2000 | 19ns | 15 | 70ns | 0.01 |
| 4000 | 80nF  | 5               | 10000 | 3ns | 2000 | 23ns | 3  | 80ns | 0.01 |
| 4000 | 150nF | 0.25            | 10000 | 3ns | 2000 | 17ns | 2  | 60ns | 0.01 |
| 4000 | 500nF | 0.2             | 10000 | 3ns | 2000 | 22ns | 2  | 50ns | 0.01 |

#### IV. RELATING THE MODEL S38 TO THE MODEL S33A

Two versions of the model S33A were used, an S33A-4 and an S33A-12. These have 4 and 12 model S38 modules in series respectively. We found that the addition of modules in series basically changed the resistance fit equation by a multiple equivalent to the number of modules in series. Fig. 3 shows the fit versus data for a model S33A-12. As can be seen, the first two terms and the constant are 12 times the values of a model S38. The last term is only twice the value. The difference is the change in di/dt for the circuit the model S33A-12 was tested in, versus the model S38. The di/dt was much higher for the model S33A-12, resulting in a more rapid fall in resistance.

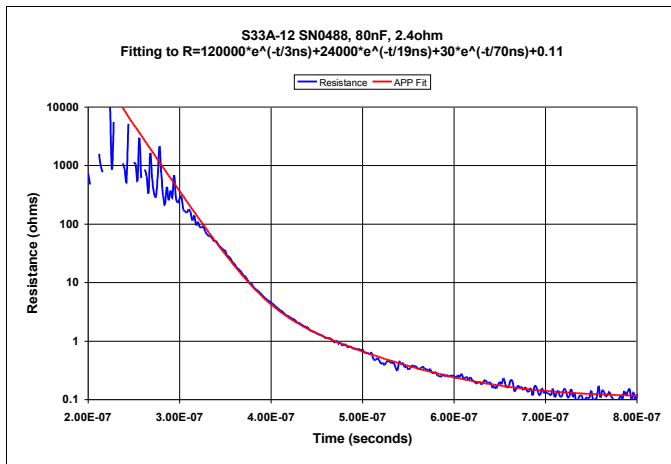


Fig. 3. Thyristor Based Switch Performance

The equation used can be summarized by (1).

$$\Omega(t) = 120000 * e^{(-t/3ns)} + 24000 * e^{(-t/20ns)} + f * e^{(-t/g)} + 0.11 \quad (1)$$

Where the resistance is for a model S33A-12 switch and the terms F and G are dependent on circuit parameters.

#### V. SPICE MODEL VERSUS TEST

Using the resistance equation in SPICE, we examined the performance of the S33A-12 in an inverting Marx configuration. This Marx was then built and tested to determine the accuracy of the SPICE model. Fig. 4 shows the simplified schematic of the system. C1 and C2 are charged via L2 and L3. S1 is triggered and the voltage across C1 inverts, with the inversion time determined by the inductance of L1. When the voltage on the Marx reaches peak, magnetic switch S2 saturates, charging C3. Fig. 5. shows a comparison of the results for the model versus the actual test results. These results demonstrate that the resistance model of the switch is useful in accurately predicting the behavior of the switch in a complicated circuit.

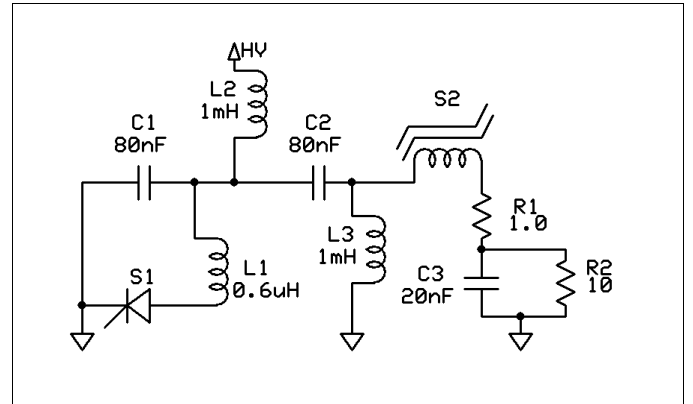


Fig. 4. SPICE LC Marx Circuit Model

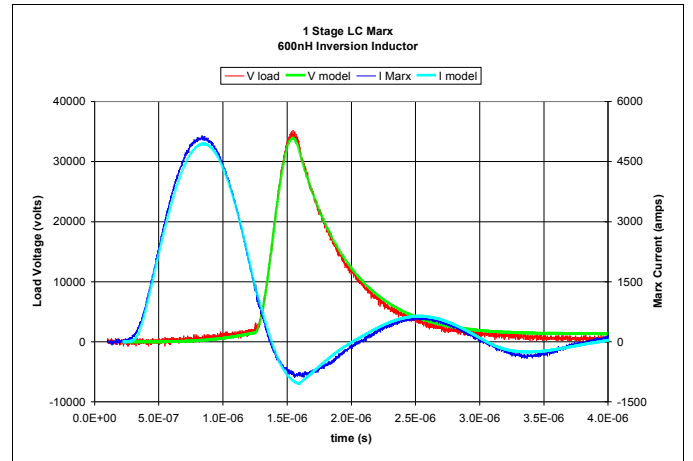


Fig. 5. Spice Model Versus Test Results

#### VI. RELATED PHYSICS

The fall in resistance is related to three factors which correlate to the three decaying exponential terms. The first effect is the creation of charge carrier paths from the anode to the cathode generated by the introduction of charge carriers created in the gate structure. The growth of these paths then depend on the voltage applied across the device and the rate of

change in current, which correlate to the second and third terms respectively. This fit is only suitable for the devices used in the S38 module. Other devices would have different decay rates and constants.

## VII. CONCLUSION

We have demonstrated a valid empirical model useful for determining the efficiency of Applied Pulsed Power's line of thyristor based solid state switches. This will allow the switch to be evaluated for use in applications without requiring expensive testing. This model is being used to develop designs for a solid state upgrade to the Electra [3], [4] main amplifier at the Naval Research Laboratory, Laser Plasma Branch.

## REFERENCES

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