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CONSTANT CURRENT CHARGING CIRCUITS FOR HIGH ENERGY MODULATORS.(U)
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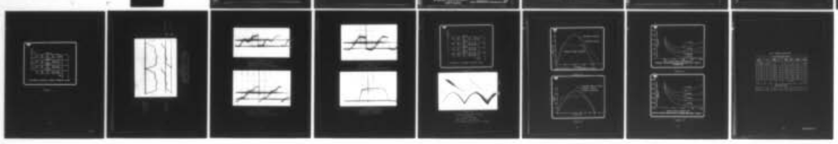

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CONSTANT CURRENT CHARGING CIRCUITS FOR HIGH ENERGY MODULATORS

John L. Carter

Electronics Technology & Devices Laboratory

February 1977

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A technique to achieve square wave charging of the pulse forming networks in line type pulser has been investigated. The proposed circuit uses parallel PFNs with charging inductors connected between PFNs. The charging network pulse width equals the interpulse time for the pulser. Experimental and computer data is presented for the circuit.

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CONSTANT CURRENT CHARGING CIRCUITS FOR HIGH ENERGY MODULATORS

John L. Carter
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Fort Monmouth, NJ 07703

ABSTRACT. In the design of power conditioning systems for high energy systems for short term operation, the interface between the prime power and the pulser requires careful consideration. In the majority of cases the prime power source considered is a battery or conventional alternator with rectified output. The considerations of transient operation of the prime power source and allowable peak values of voltage and current supplied by the prime power source has profound effects on the design of the prime power source. For the case of an alternator feeding into a rectifier and resonant charging of a PFN the fact that the current on the dc side of the rectifier is time variable adds not only additional transients and heat loading to the alternator but also generates mechanical stress problems because the torque loading of the generator varies with the output power. In the case of a battery prime power source, resonant charging leads to the requirement for a battery bank with larger peak values of voltage and current than would normally be required to supply the same average power into a constant load.

A technique has been investigated to achieve square wave charging of the pulse forming networks in line type pulsers. The proposed circuit uses parallel PFNs with charging inductors connected between the PFNs. The value of the charging inductors is chosen so that when combined with the total capacitance of the PFNs, the charging network pulse width equals the interpulse period.

Experimental and computer data will be presented for the constant current charging circuit and compared with resonant charging circuits.

INTRODUCTION

The conventional resonant charging circuit for high energy pulsers is shown in Figure 1. The pulser consists of multiple PFNs and switches. Multiple PFNs are used in order to achieve the low PFN impedance required to match the load through the pulse transformer. There is a lower limit to the PFN impedance determined by capacitor inductance. Therefore, the most practical approach is to parallel a number of PFNs to achieve the low impedance value. Multiple switches are used in order to maintain the current ratings of the switch within realistic values. Thyratrons are used as the switch element in the circuit shown in Figure 1. The capacitors are charged from the dc power supply through a charging inductor. The charging inductor is designed to resonate the total capacitance of the networks at the specified pulser repetition rate. The charging inductance of the network is given by the equation:

$$L = \frac{T^2}{\pi^2 \, 4C} \qquad (1)$$

Where L = charging inductance
T = charging period
C = total PFN capacitance

The charging current for this type of circuit is given by:

$$I = \left(\frac{E}{Zo}\right) \sin \omega t \qquad (2)$$

$$\text{Where } Zo = \left(\frac{L}{C}\right)^{1/2}$$

$$\omega = (LC)^{-1/2}$$

E = dc power supply voltage

The charging current wave form for this circuit is a half sine wave with a maximum value of E/Zo, with a period equal to 1/PRF.

The proposed constant current charging circuit is shown in Figure 2. Charging inductors are connected to each of the pulse forming network terminals. The inductance of each section is chosen so that charging inductors and the total capacity of the networks comprise a pulse forming network which will allow constant current and voltage charging. The inductance of the individual networks is small enough to be ignored in comparison with the charging inductance. Each PFN section requires its own discharge switch. A single discharge switch cannot be used since the PFNs would then have to be connected to a common point which would short out all but the first charging inductor section. A single discharge switch can be used if diodes are inserted to prevent charging from the switch end of the PFNs.

Experimental Test Circuit

A low voltage test circuit was used to verify the concept. The low voltage circuit makes it possible to make accurate measurements at various points in the circuit without encountering high voltage measurement problems. Fabrication cost and time are also greatly reduced.

The test circuit is shown in Figure 3. Four PFNs and four switches are connected in parallel. The switches are 1258 thyratrons. The individual 25 ohm PFNs have a pulse width of 5 μs. The capacitance of each network is 0.1 μf and the inductance is 62.5 μH. These values were used in the design of a charging network for a pulser operating at a pulse discharge repetition frequency of 250 Hz, or a charging period of 4×10^{-3} seconds. The charging period and the total capacitance of the discharge pulse forming network is used to calculate the inductance required for the charging pulse forming network using the following equation:

$$L = \frac{T^2}{4C} = \frac{(4 \times 10^{-3})}{16 \times 10^{-7}} = 10 \text{ henrys} \quad (3)$$

The inductance value for each of the adjustable inductors is therefore 2.5 henrys. The calculated discharge load impedance is 6.25 Ω since four 25 ohm networks are connected in parallel through the thyratron switches. Since operation was at low dc voltage (100 volts) the thyratron impedance had to be considered. It was determined experimentally that a load impedance of 1.3 ohms gave the best impedance match. The charging voltage and current for the circuit is shown in Figure 4. The charging voltage is 100 volts, the top horizontal line of the lower voltage curve represents the 100 volt calibration line. The charging sequence for the PFNs is shown in the voltage curves in Figure 4 to Figure 7. The last PFN #4 charges directly to twice the power supply voltage after a delay of about 1 millisecond, the third and second charge in steps after a time delay. The charging current pulse width in Figure 4 is very close to the design value of 4 milliseconds at the half amplitude point. The rise time is 0.5 millisecond and the fall time approximately 0.8 millisecond. The amplitude of the pulse is 22 milliamps compared to the calculated value of 20 milliamps. The discharge current through the 1.3 ohm load is shown in Figure 8. Measurement of the current through the switches indicates that the current is shared equally by the switches.

The experimental circuit was modified for resonant charging in order to obtain comparison data. The resonant charging circuit is shown in Figure 9. The charging current waveform and the PFN voltages for resonant charging are shown in Figure 10 for a charging potential of 100 volts and 250 Hz discharge rate. The charging current is a half sine wave with a measured amplitude of 36 milliamps. The value calculated using equation (2) is 32 milliamps.

The circuit was also analyzed by computer using the ECAP circuit analysis program. The current wave form for the experiment circuits shown in Figure 3 and Figure 9 obtained using computer analysis is shown in Figure 11. Good agreement was obtained between the two techniques.

Preliminary Design of a Multi-Megawatt Average Power Pulser

The circuit for a proposed pulser for multi-megawatt applications is similar to that shown in Figure 2, except that thyratron switches are used, and each thyratron switches a group of PFNs connected in parallel. The charging network consists of charging inductors connected between the groups of PFNs. The design procedure described above for the experimental circuit was used to calculate the inductance values. In order to achieve a better pulse shape the value of the first and last inductor was increased by 20% and 15% respectively. The current wave form for the six section charging network obtained by computer analysis is plotted in Figure 12. The wave form obtained using resonant charging is also plotted. The constant current charging circuit draws 35% less current than the resonant charging circuit.

The trade-off between resonance charging and constant current charging is peak current vs. weight. In order to gain some insight on the weight of the two circuits, a weight analysis of both circuits was made for the case of charging 60 μf to a peak voltage of 40 kv at a repetition rate of 125 Hz.

The results of this analysis is given in Table I. A current density of 14,000 amps per in^2 was used in calculating wire size. The best available information indicates that this is the maximum current density that can be used for aluminum wire and still satisfy thermal operating requirements. The RMS current for each section of the charging inductor was calculated and the wire size selected to maintain a constant current density. The power dissipated is calculated in the same manner.

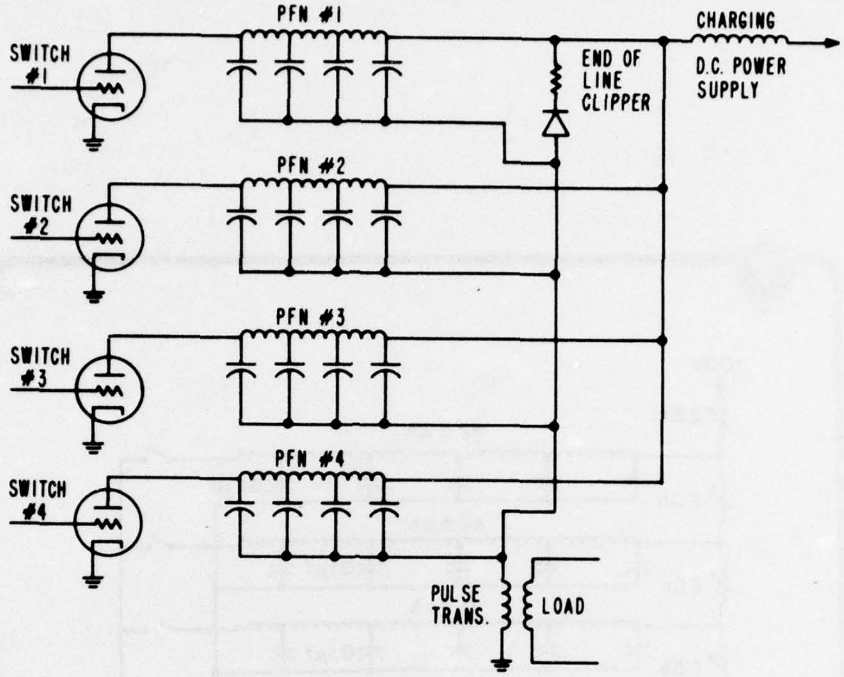
The weight of the constant current inductor is 127 pounds while the weight of the resonant charging inductor is 64 pounds. This is wire weight only, and does not include insulation, form, and bushing weight.

Another factor that must be considered is the amount of power dissipated in the charging inductor. The power dissipated in the inductor must be supplied by the prime power supply, therefore, adding additional weight to the supply and the overall system. In order to obtain a realistic comparison of the two different types of charging circuits, a power supply weight penalty must be added to the actual charging circuit weight. The power supply weight penalty will vary for different types of supplies, and the dissipation is a function of the type of conductor material and the current density in the material. The total weight of the charging inductor for the 6 MW modulator described above has been calculated as a function of wire current density assuming power supply penalties ranging from 0.4 pounds - 1.8 pounds per kW of inductor dissipation. The results for resonant charging is plotted in Figure 13 and constant current charging in Figure 14. Preliminary prime power studies indicate that the prime power penalty will be in the range of 0.8 pound to 1.2 pounds per kW of power dissipated. If we consider this penalty range the minimum weight for both the resonant charging and the constant current charging circuits falls in a current density range of 10,000 to 14,000 amps per square inch for aluminum wire. The current density selected using thermal considerations was 14,000 amps per in^2.

It should be noted that the weight of the constant current circuit is about twice the weight of the resonant charging circuit at the same current density and prime power penalty.

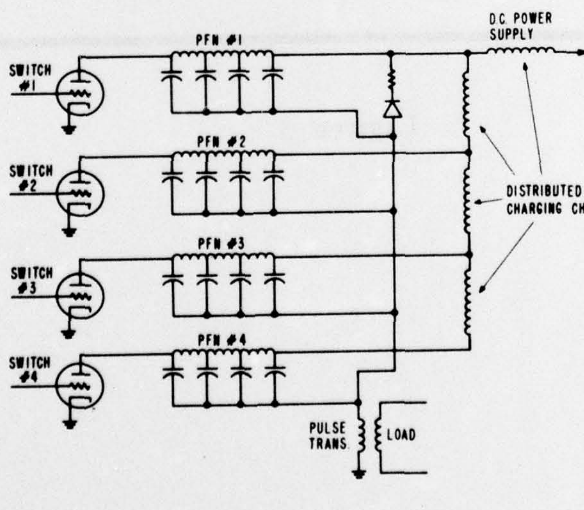
CONCLUSIONS

The results of the investigation described above show that a circuit to achieve constant current charging is feasible. The major disadvantage is the increased weight and dissipation of the components. The constant current charging circuit is desirable only if the lower peak current demands, and reduced mechanical requirements result in a weight savings in the prime power supply that exceeds the increased weight of the constant current charging inductor.



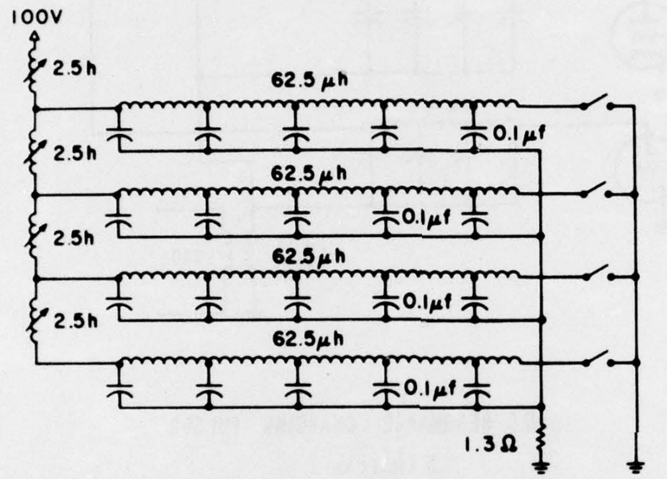
D.C. RESONANCE CHARGING PULSER

Figure 1



CONSTANT CURRENT D.C. CHARGING PULSER

Figure 2



EXPERIMENTAL CONSTANT CURRENT CHARGING CIRCUIT

Figure 3

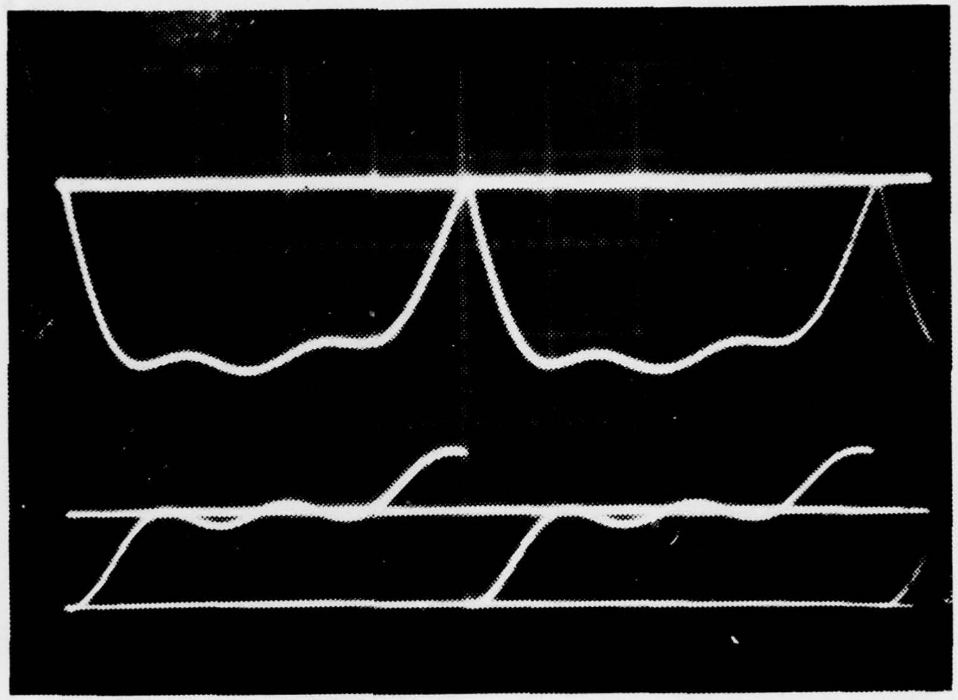


Figure 4
Constant Current Charging
Upper Trace Vertical 10 MA/div
Lower Trace Vertical 100 V/div
Horizontal 1 Millisecond/div

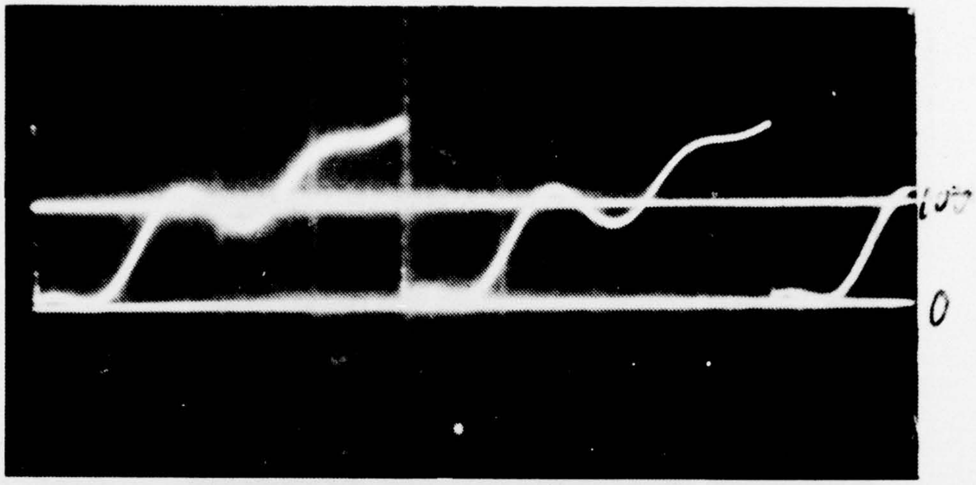


Figure 5
Charging Voltage PFN #2
Vertical 200 volts/div
Horizontal 1 millisecond/div

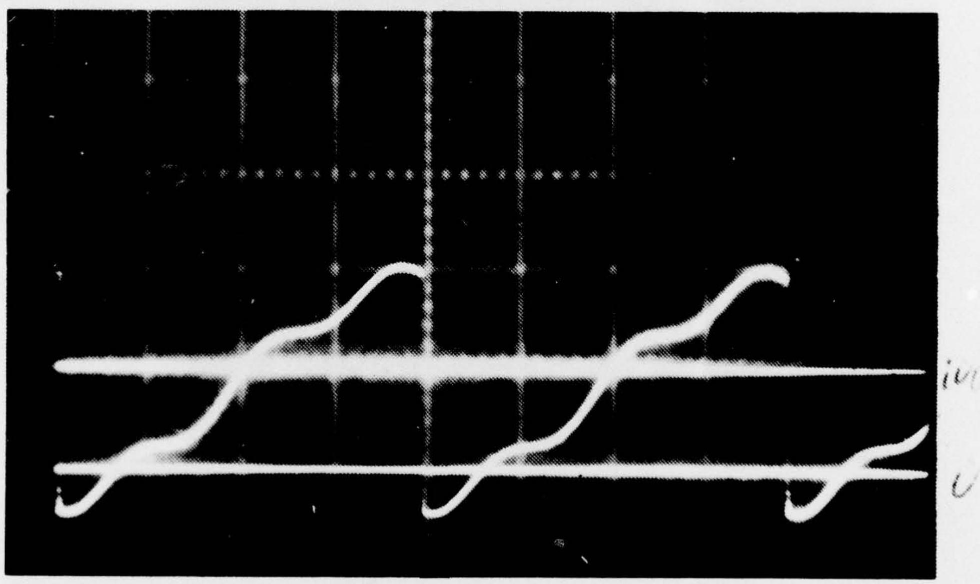


Figure 6
Charging Voltage PFN #3
Vertical 100 V/div
Horizontal 1 millisecond/div

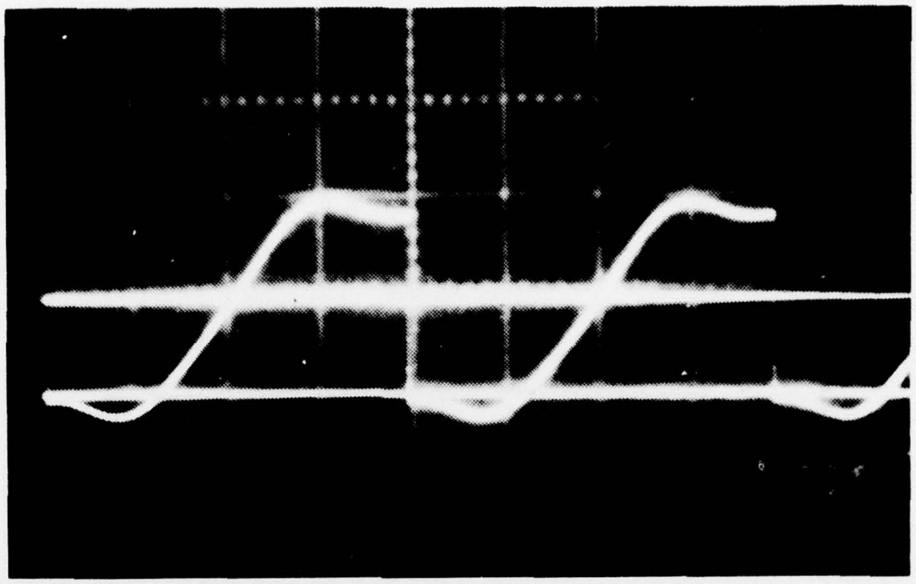


Figure 7
Charging Voltage PFN #4
Vertical 100 V/div
Horizontal 1 millisecond/div

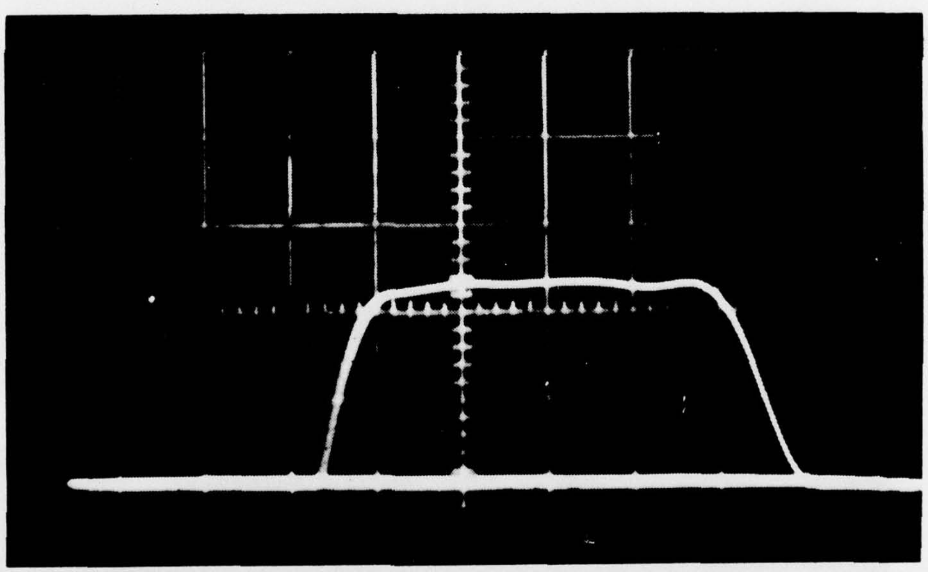


Figure 8
Discharge Load Current
Vertical 2.5 Amp/div
Horizontal 1 usec/div

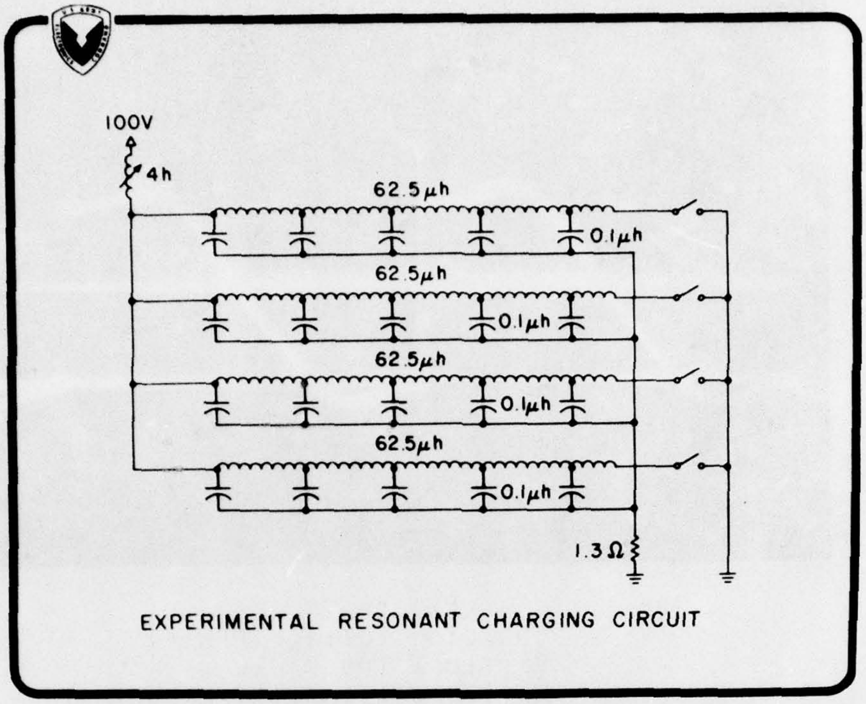


Figure 9

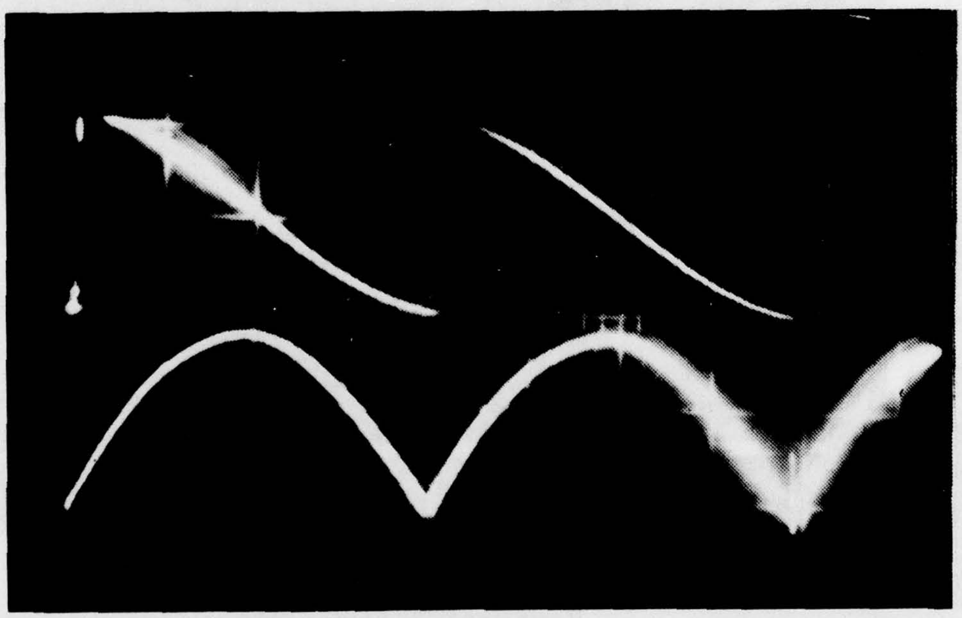


Figure 10

Resonant Charging Voltage
and Current
Upper Trace 100 V/div
Lower Trace 20 MA/div
Horizontal Sweep Speed 1 MS/div

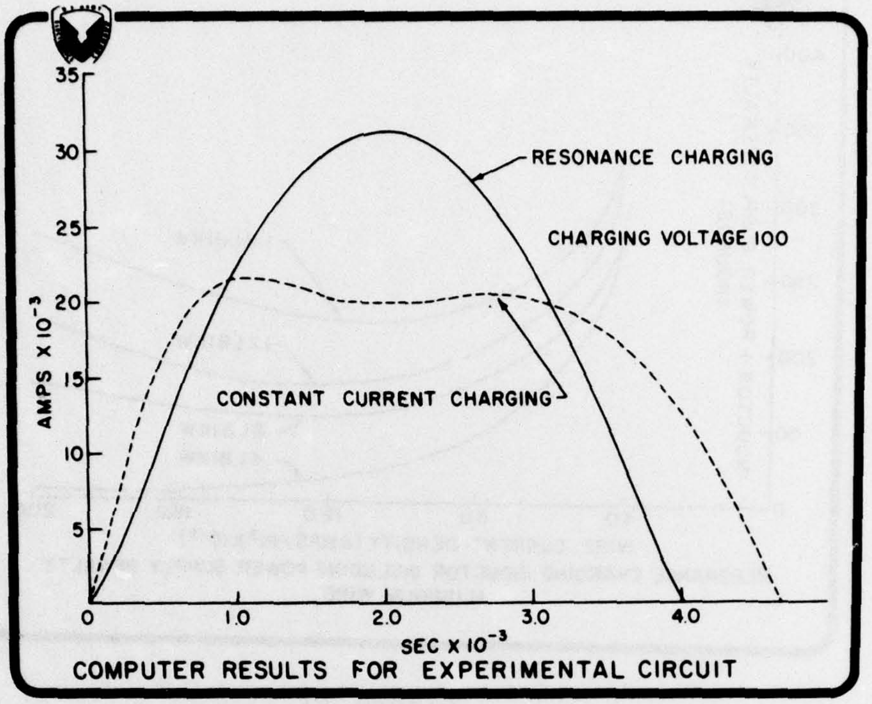


Figure 11

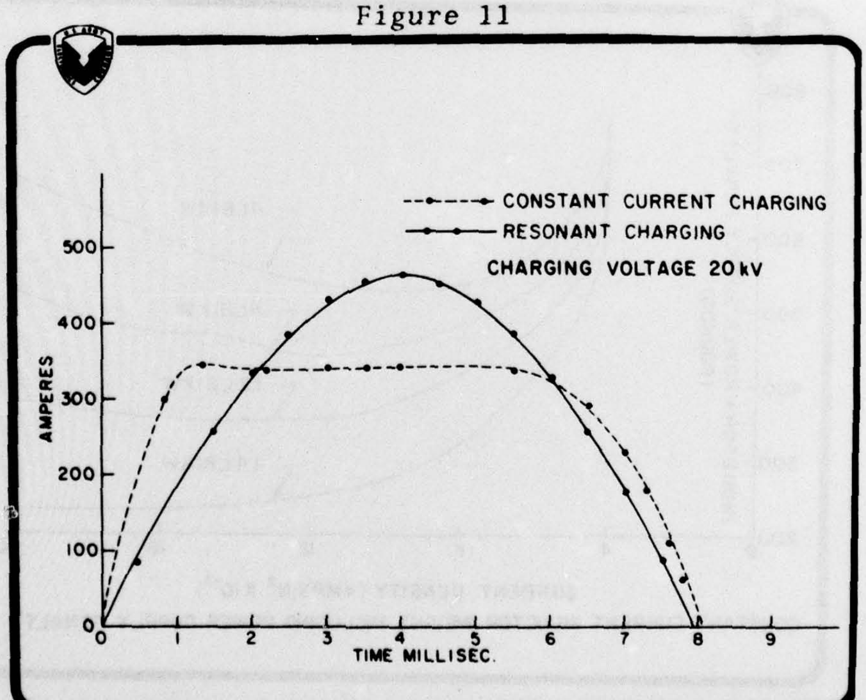


Figure 12

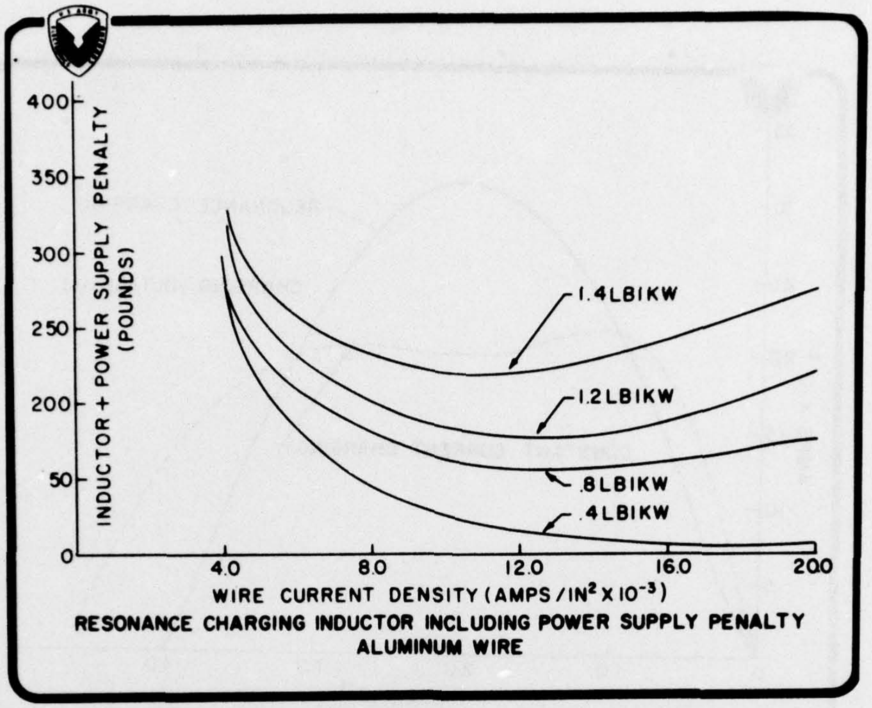


Figure 13

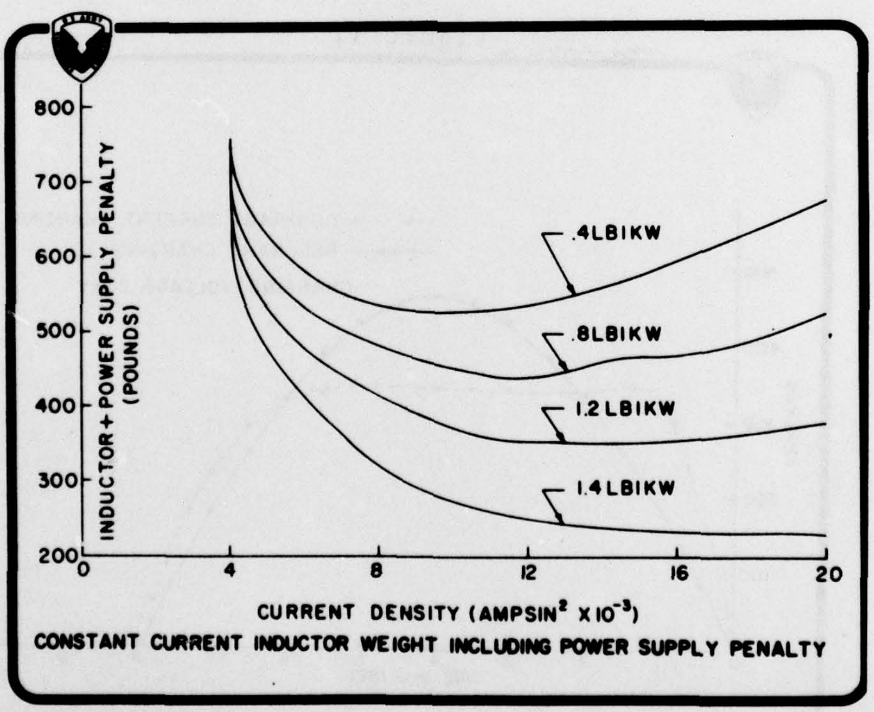


Figure 14

TABLE I. PARAMETERS FOR CHARGING INDUCTORS

CONSTANT CURRENT CHARGING INDUCTOR								
COIL INDUCTANCE		CURRENT	WIRE DIAMETER	WIRE NO.	WIRE LENGTH	COIL WEIGHT	COIL RESISTANCE	COIL DISSIPATION
Units	Milli Henrys	Amps RMS	Inches		Feet	Pounds	Ohms	Kilowatts
#1	40.8	327	0.182	#5	1,172	35.71	0.594	63.5
#2	34.2	302	0.162	#6	1,024	24.73	0.655	59.7
#3	34.2	277	0.162	#6	1,024	24.73	0.655	59.7
#4	34.2	243	0.144	#7	979	18.76	0.800	46.6
#5	34.2	181	0.129	#8	934	14.20	0.952	31.1
#6	39.1	114	0.102	#10	923	8.83	1.490	19.4
TOTAL						126.96		280.0
RESONANT CHARGING INDUCTOR								
TOTAL	108	328	0.182	#5	2,103	64.1	1.067	115