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DESENSITIZATION OF DC POWER SUPPLIES TO MOMENTARY AC POWER FLUCTUATIONS

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Naval Civil Engineering Laboratory
Port Hueneme, California

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DESENSITIZATION OF DC POWER SUPPLIES TO MOMENTARY AC POWER FLUCTUATIONS

Technical Report R-657

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by

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ABSTRACT

Lightning storms and faults cause momentary voltage dips and momentary power interruptions in the AC power. These brief disturbances reach electronic equipment through fluctuations in the output voltages of DC power supplies. This report describes methods to desensitize DC power supplies to momentary AC power source perturbations. DC output voltage sustaining characteristics for basic transistors and silicon-controlled rectifier power supply circuits are discussed and performance data presented. By the use of an auxiliary energy reservoir circuit, the DC output of a power supply was maintained at its nominally rated value when an AC power interruption of 167 msec occurred.

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INTRODUCTION

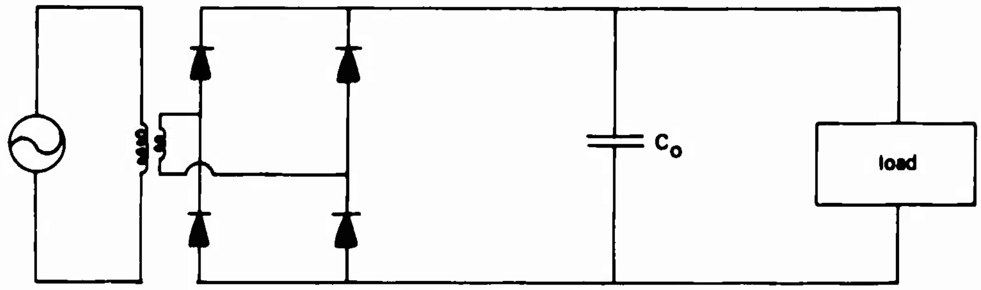
Lightning storms and faults introduce electrical disturbances into utility power transmission lines and power distribution networks. These events cause momentary degradation in the quality of electric power provided to military facilities. This degradation includes momentary voltage dips and momentary power loss. These electrical disturbances reach the circuits in electronic equipment through the DC power supply. Perturbations in the DC output voltages can adversely affect operation of individual circuits and collectively disturb the normal function of the equipment. This report details the feasibility of desensitizing DC power supplies to momentary AC power interruptions.

BACKGROUND

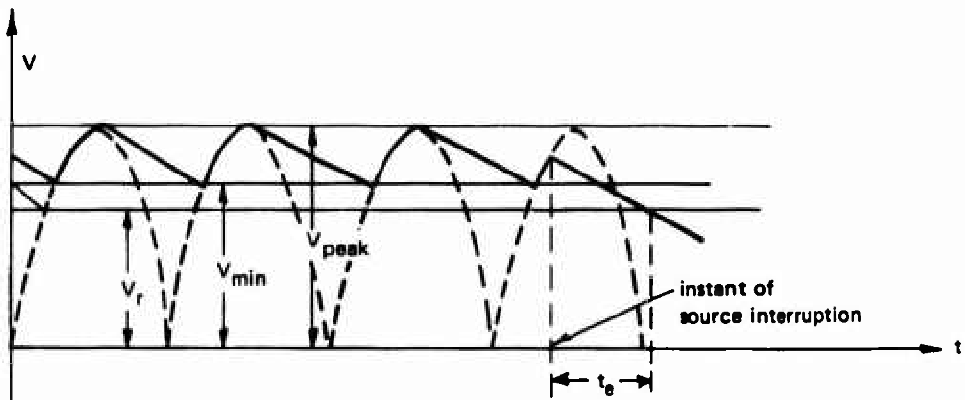
DC power supply designs neglect requirements for maintaining DC output voltage during momentary AC power source interruption. Therefore, the DC output voltage has a tendency to drop partially or completely to zero when there are source voltage dips or momentary power losses. A DC power supply receives energy from an AC source, stores it, and then releases it as required by the load. If the AC source fails, the DC output voltage drops exponentially with time as the quantity of stored energy diminishes. The time duration for depletion of energy depends upon the amount of energy stored, the amount consumed by the load, and the minimum voltage required by the load.

BASIC DC POWER SUPPLY CIRCUIT

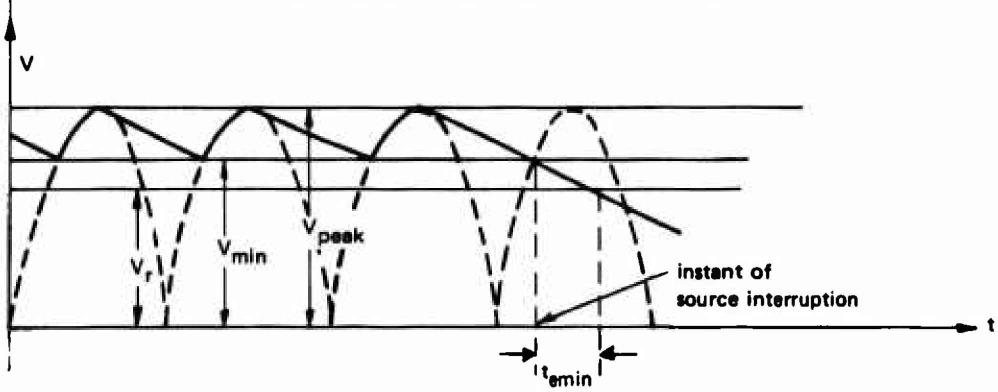
A basic configuration for the conversion of AC voltage to DC voltage is a bridge rectifier and a capacitor connected as shown in Figure 1a. The output voltage waveform with source interruption is shown in Figure 1b. The energy storing capacitor, C_0, stores and supplies energy to the load. If the AC source is interrupted, the DC output voltage decays exponentially to zero. To illustrate, a voltage, V_r, is arbitrarily chosen as the minimum value required



(a) Circuit diagram.



(b) Output waveform with source interruption.



(c) Output waveform with source interruption occuring at V_{min}.

Figure 1. Basic DC power supply circuit diagram and associated output voltage waveforms.

to maintain load operation. The time, t_e, (Figure 1b) is the duration between the instant AC power is lost and the DC output voltage reaches V_r. The useful charge, Q_u, on capacitor C_o that extends t_e is given by Equation 1.

$$Q_u = C_o (V_{inst} - V_r) \tag{1}$$

where V_{inst} is the instantaneous voltage across capacitor C_o at the time the AC source is interrupted. The time duration, t_e, is given by Equation 2.

$$t_e = \frac{Q_u}{I_{dc}} = \frac{C_o (V_{inst} - V_r)}{I_{dc}} \tag{2}$$

where I_{dc} is the DC load current. The shortest t_e results when the AC source is interrupted at the time when the instantaneous voltage across capacitor C_o is V_{min} (Figure 1c); then Equation 2 becomes

$$t_{emin} = \frac{C_o (V_{min} - V_r)}{I_{dc}} \tag{3}$$

Equation 3 shows that for a fixed I_{dc}, t_{emin} is extended by increasing C_o. Increasing C_o also raises V_{min}. Therefore, the quantity $V_{min} - V_r$ increases concurrently with C_o. However, the increase in C_o contributes predominantly in increasing Q_u, hence, t_{emin}.

Figure 2 shows the increase in t_e obtained by using a larger C_o. Curve 1 is for the large-valued capacitor C_o. Figure 3 compares the lengthening of t_e in a series-regulated transistor DC power supply circuit with C_o of 450 and 4,450 μf. Therefore, a simple method of extending t_e is to increase C_o. Factors which limit the selection of the largest value energy storing capacitance are discussed next.

With increasing capacitance, the ratio of initial turn-on current to rated load current increases. This necessitates operation of rectifiers at increasingly derated condition, which is economically inefficient. With the selection of a larger valued capacitance, it becomes necessary to examine the rise in rectifier cost against the extension of t_e obtained. Also, larger valued capacitance increases the response time of the DC power supply, thereby lengthening the flow duration of the turn-on current. Longer flow duration contributes to rectifier failure from heating.

In cases where a limiting-valued capacitor provides insufficient Q_u to obtain the required t_e, then the energy reservoir circuit, described later, may be used to advantage.

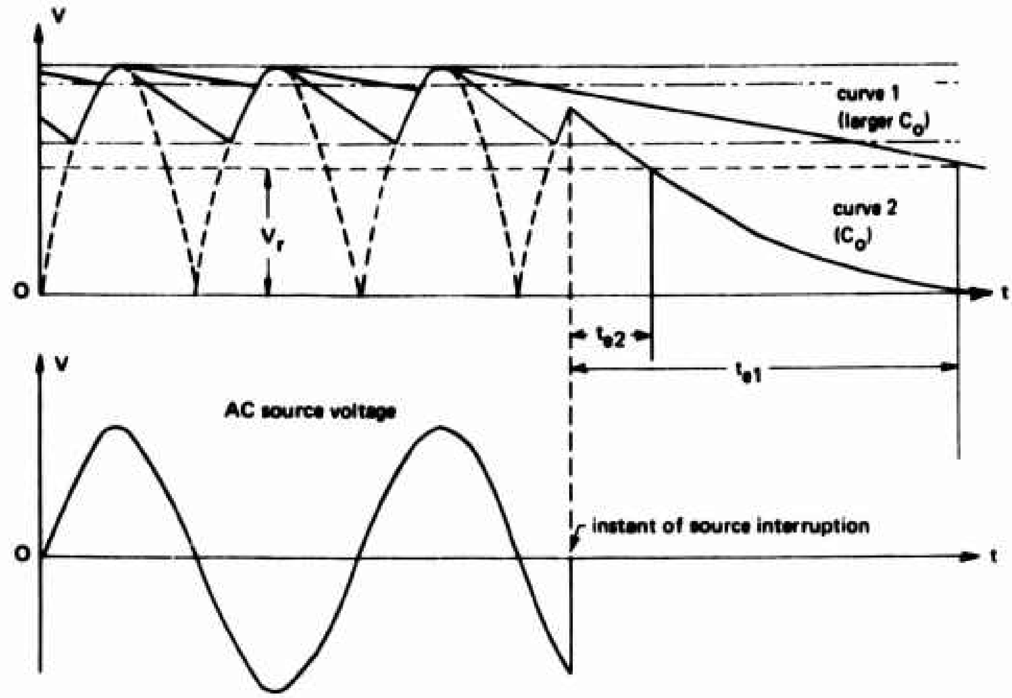


Figure 2. Comparison of output voltage decay with different values for the energy storing capacitor, C_o.

Figure 4a shows a circuit diagram of a basic silicon-controlled rectifier (SCR) DC power supply. The DC output voltage level is controlled by the "variable phase angle firing" technique which provides a partial full-wave rectified waveform and requires a very large capacitance to obtain a "smoothed-out," limited-ripple waveform; therefore, unlike the transistor-regulated DC supply circuit, the SCR circuit is not amenable to significant increase in t_e by the mere increase of capacitance. Figure 4b illustrates the limited-ripple voltage obtained by using a large capacitor, C_o. It also shows the extended duration t_{e1} obtained with the loss of the AC power source. Increasing the capacitance reduces the ripple further, as shown in Figure 4c, but V_{min} - V_r is essentially unchanged and duration t_{e2} is increased only slightly.

ENERGY RESERVOIR CIRCUIT

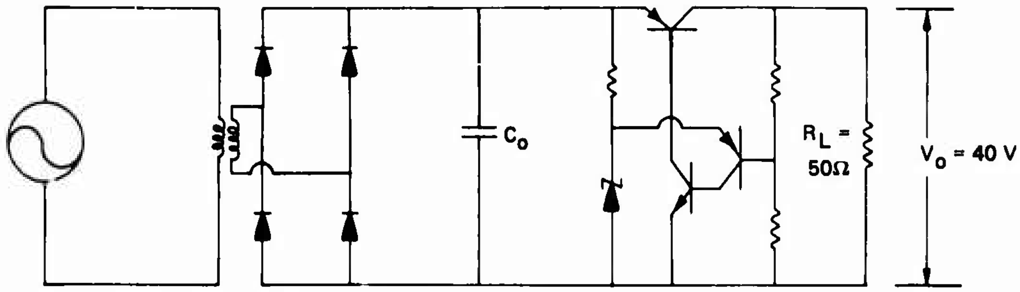
The previous section presented the limitations of extending t_e in a basic DC power-supply circuit. The limitation is more severe in a power-supply circuit using SCRs instead of transistors. To supplement the Q_u available in the basic power-supply circuit for achieving extended t_e, an energy reservoir circuit is described; the circuit diagram is shown in Figure 5a. The basic principle of this circuit is to charge an energy-storing capacitor at a high voltage and release this energy to the load during momentary AC power loss. The energy storing C_{aux} is charged rapidly to its peak capacity during normal operations of the AC power source. The reservoir circuit remains on standby status and consumes very little power. At the instant of AC power loss, the reservoir circuit supplies Q_{aux} to supplement Q_u and maintains V_o throughout the outage. The current limiter is used to prevent damage to the rectifiers, D, by the initial of charging current C_{aux}. This limiter also permits the use of a low-current-rating rectifier. The function of the comparison circuit (Figure 5a) is to sense the voltage drop and to furnish the actuating signal to operate the control circuit. The control circuit adjusts the flow rate of Q_{aux} as required by the load to maintain the output voltage.

The energy reservoir circuit is connected to the basic power supply as shown in Figure 5b. The reservoir circuit offers considerable latitude in the selection of the value for the energy-storing capacitance and the operating voltage. This flexibility is not offered in the basic DC power supply circuit because the required output voltage fixes the voltage across the energy storing capacitor, C_o. The method of obtaining the larger Q_u is limited to increasing C_o, and a larger C_o is accompanied by undesirable effects, such as excessive in-rushing of turn-on current.

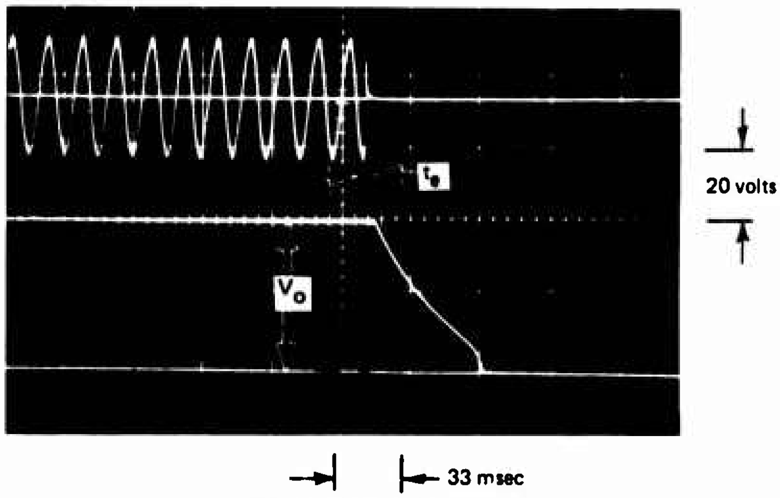
The power ratings of the components in the reservoir circuit can be modest because the average power is low, although the peak energy delivered momentarily may be appreciable. The auxiliary reservoir circuit, even by the use of large energy-storing capacitors, C_{aux}, does not reduce the response time of the basic power supply because the reservoir circuit is independent of the basic supply circuit. Figure 6 compares the time-extending characteristics obtained in a transistorized shunt-regulated power supply circuit either by adding a capacitor or by using the auxiliary energy reservoir circuit. By the addition of a capacitor, the time is extended by 12 msec. With the auxiliary circuit using the same valued capacitor, the time is extended by 38 msec.

DC POWER SUPPLY DESCRIPTION

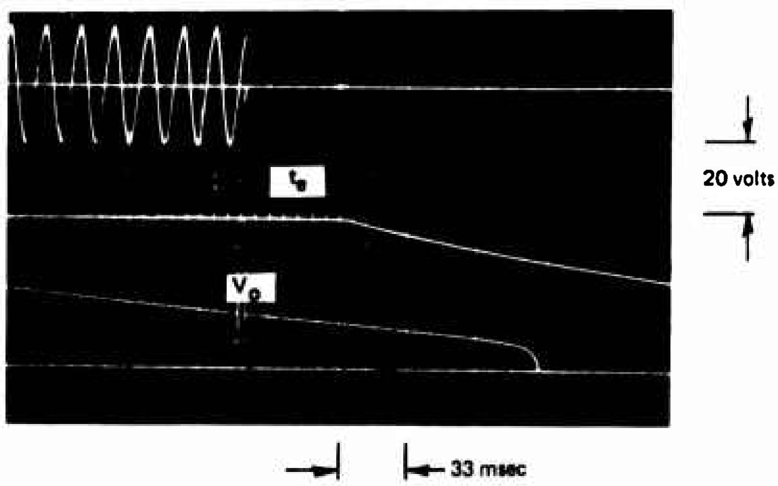
The KGP-5(T-1)/TSEC DC power supply is shown in Figure 7. The schematic diagram of the power supply, including the energy reservoir circuits bordered by a broken line, is shown in Figure 8. The output voltages are one +6 volts, two - 18 volts, and one - 7.5 volts. The +6-volt output consists of an L-C filter and a transistorized shunt regulator; the - 18(b)-volt output consists of an R-C filter and a zener shunt regulator; the - 18(a) volt output consist of a two-section L-C filter and SCR unregulated supply; and the - 7.5-volt output uses an R-C filter and a transistorized shunt regulator and is connected to the - 18(a)-volt output.



(a) Circuit diagram.

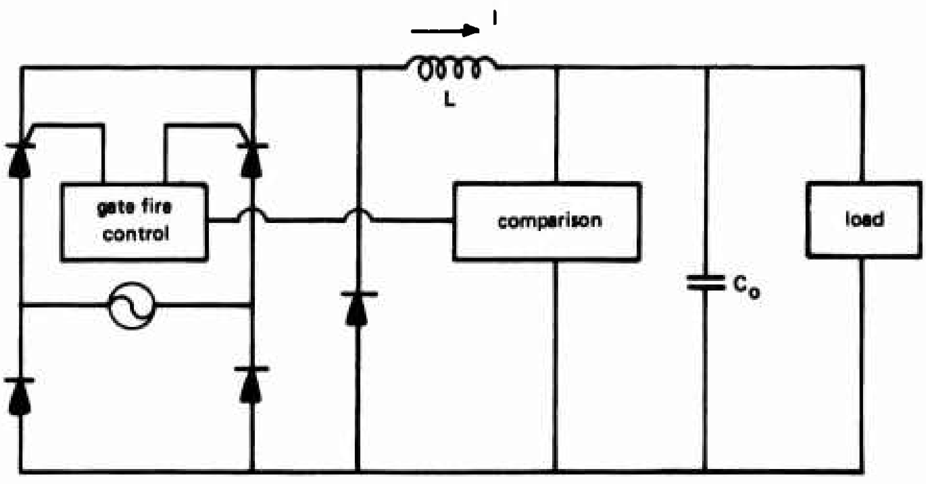


(b) C_o = 450 μf.

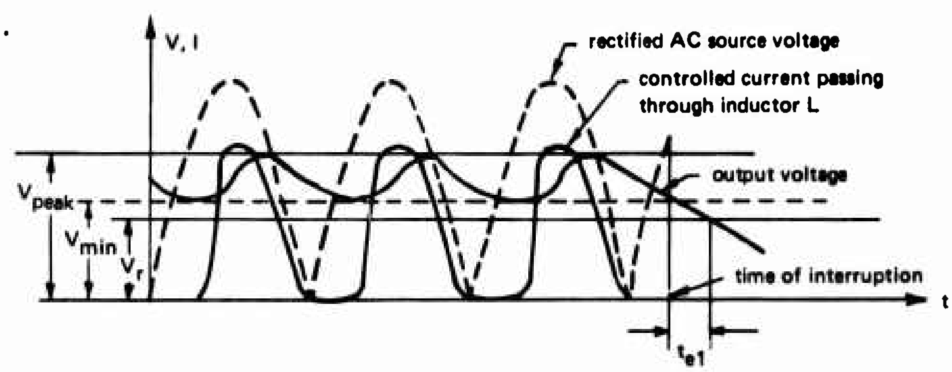


(c) C_o = 4,450 μf.

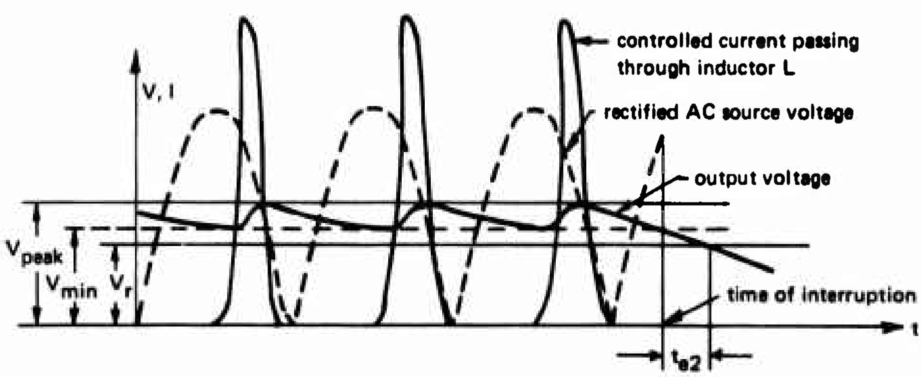
Figure 3. Lengthening of t_e in a series regulated transistor DC power supply using different C_o values.



(a) Circuit diagram.

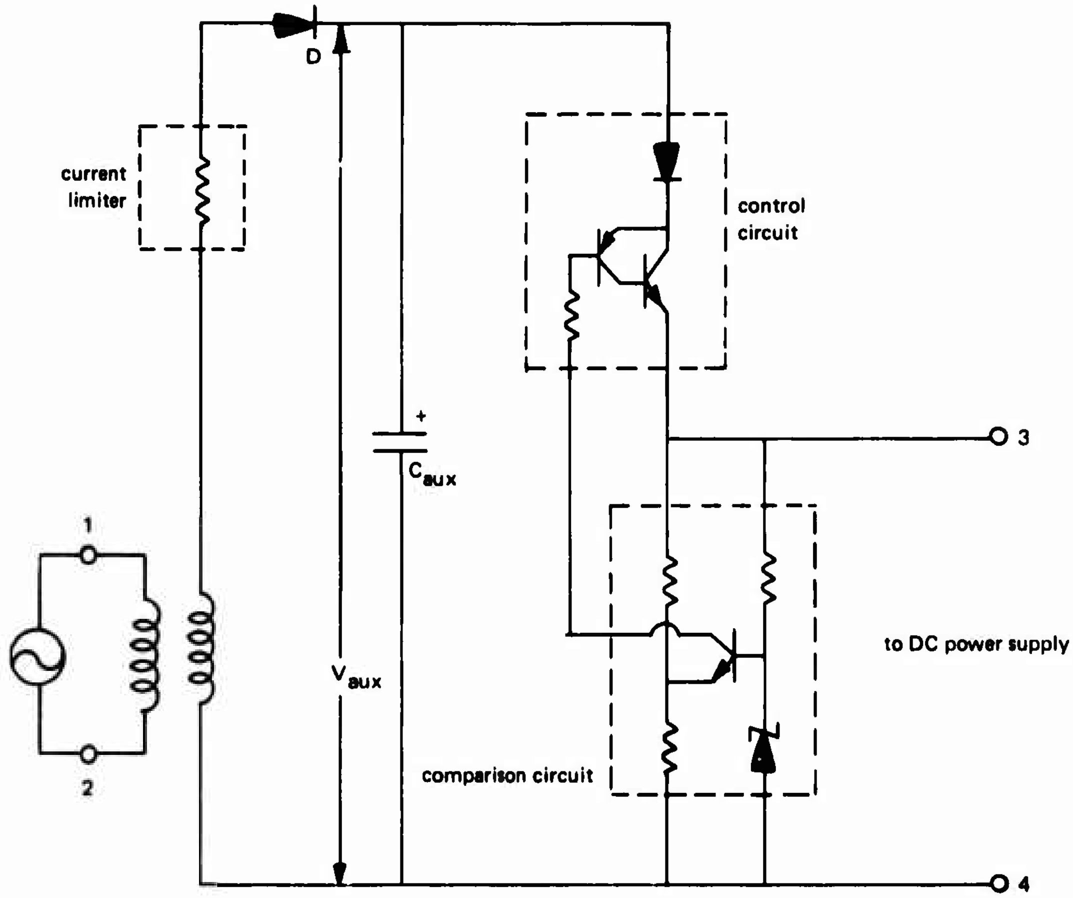


(b) Output waveform with C_o.

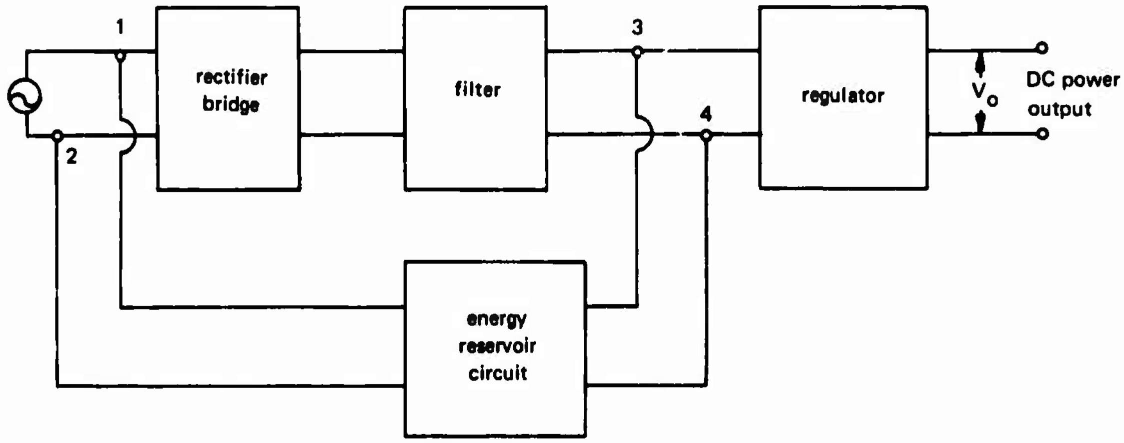


(c) Output waveform with a larger C_o.

Figure 4. Circuit diagram and associated waveforms of an SCR power supply using two different energy storing capacitors, C_o.

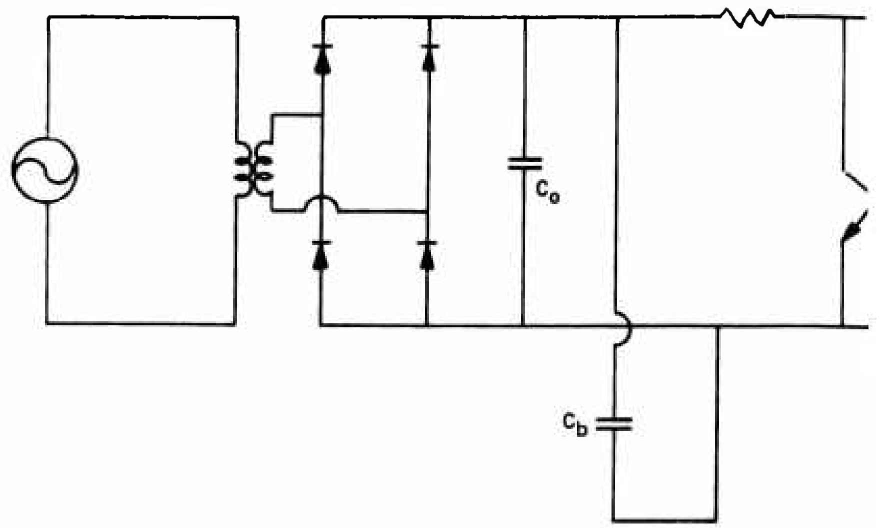


(a) Circuit diagram.



(b) Connection diagram.

Figure 5. Energy reservoir circuit and connection diagram for a DC power supply.



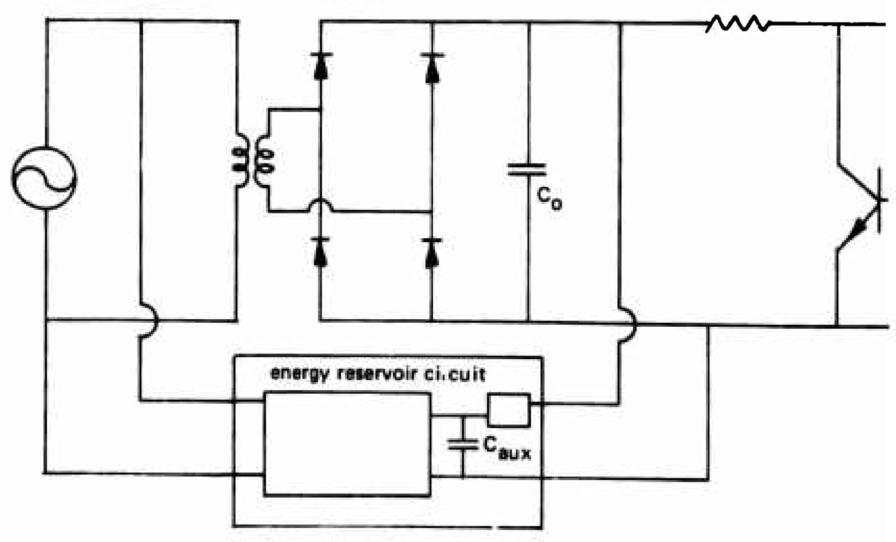
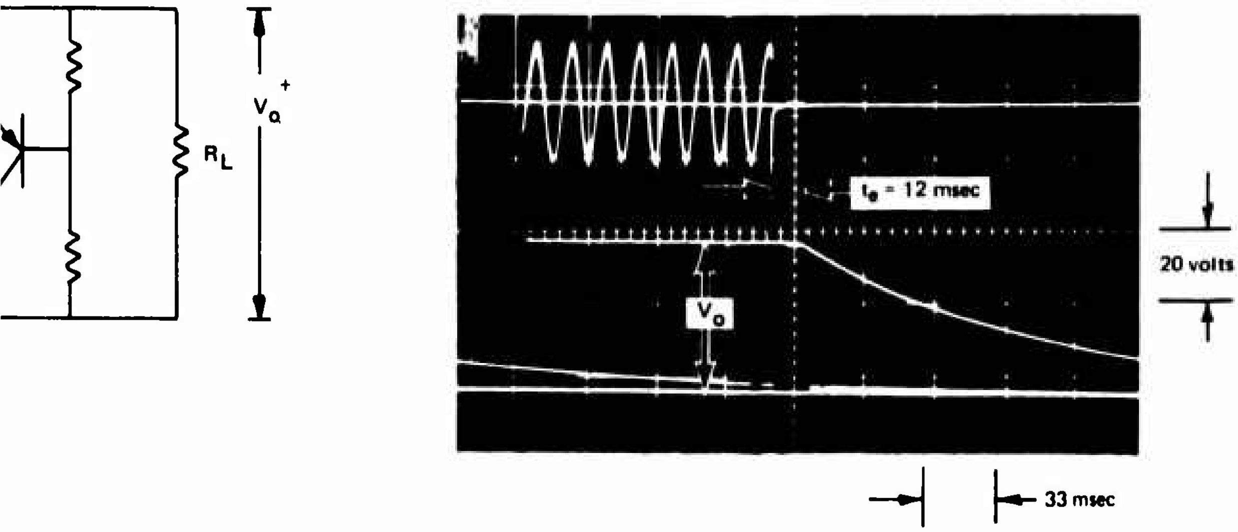
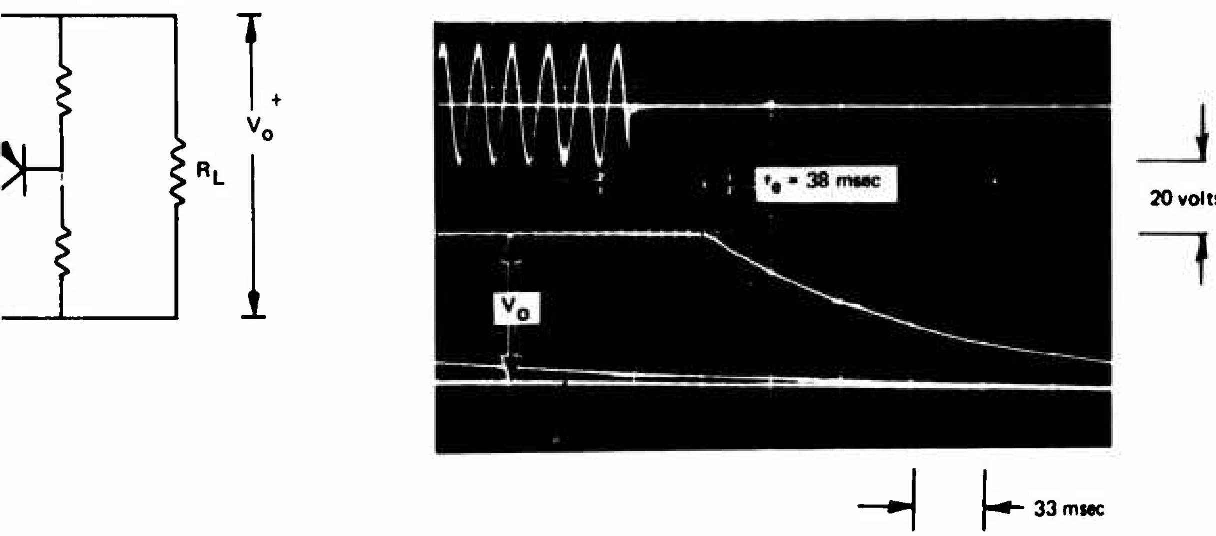


Figure 6. Comp



a) Supplementing C_o with C_b = 1,000 μf.



ing energy reservoir circuit, C_{aux} = 1,000 μf.

of two methods for extending t_e for a DC power supply.

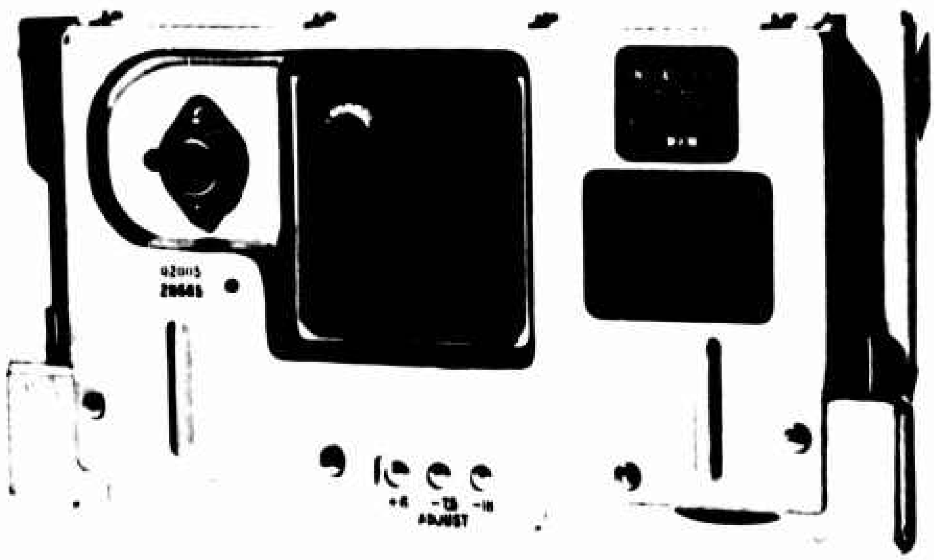


Figure 7. KGP-5(T-1)/TSEC power supply.

TEST RESULTS

Figure 9 shows the performance of the KGP-5(T-1)/TSEC power supply as manufactured. Note that even a 4.2-msec interruption affects the -7.5-volt and -18(a)-volt output. With an 83-msec momentary interruption, all three outputs fall to zero volts except the -18(b)-volt output, which falls to approximately 14% of its rated value. Upon recovery of the AC voltage, note that the -18(a)-volt output exhibits a voltage with overshoot and oscillations.

Figure 10 shows the performance of the KGP-5(T-1)/TSEC using the energy reservoir circuit. With a 75-msec interruption, all the output voltages are essentially maintained; the overshoot of the -18(a)-volt output has been suppressed. Figure 11a shows that with a 167-msec interruption all the outputs are essentially maintained with the -18(a)-volt output falling to 80% of its rated value; Figure 11b shows a complete outage.

CONCLUSION

The auxiliary energy reservoir circuit is an effective method for maintaining DC power supply output voltages during momentary loss of AC power.

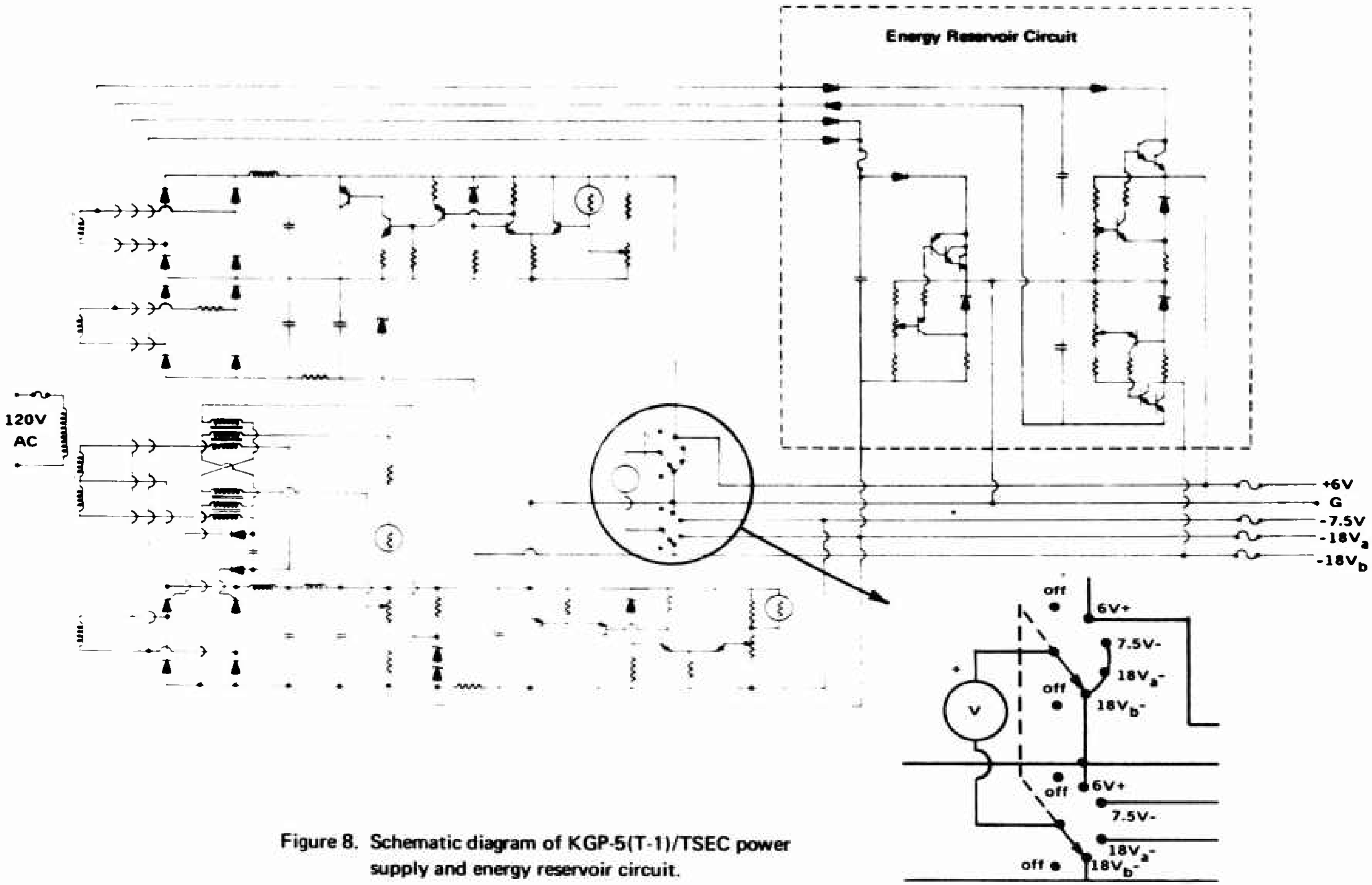


Figure 8. Schematic diagram of KGP-5(T-1)/TSEC power supply and energy reservoir circuit.

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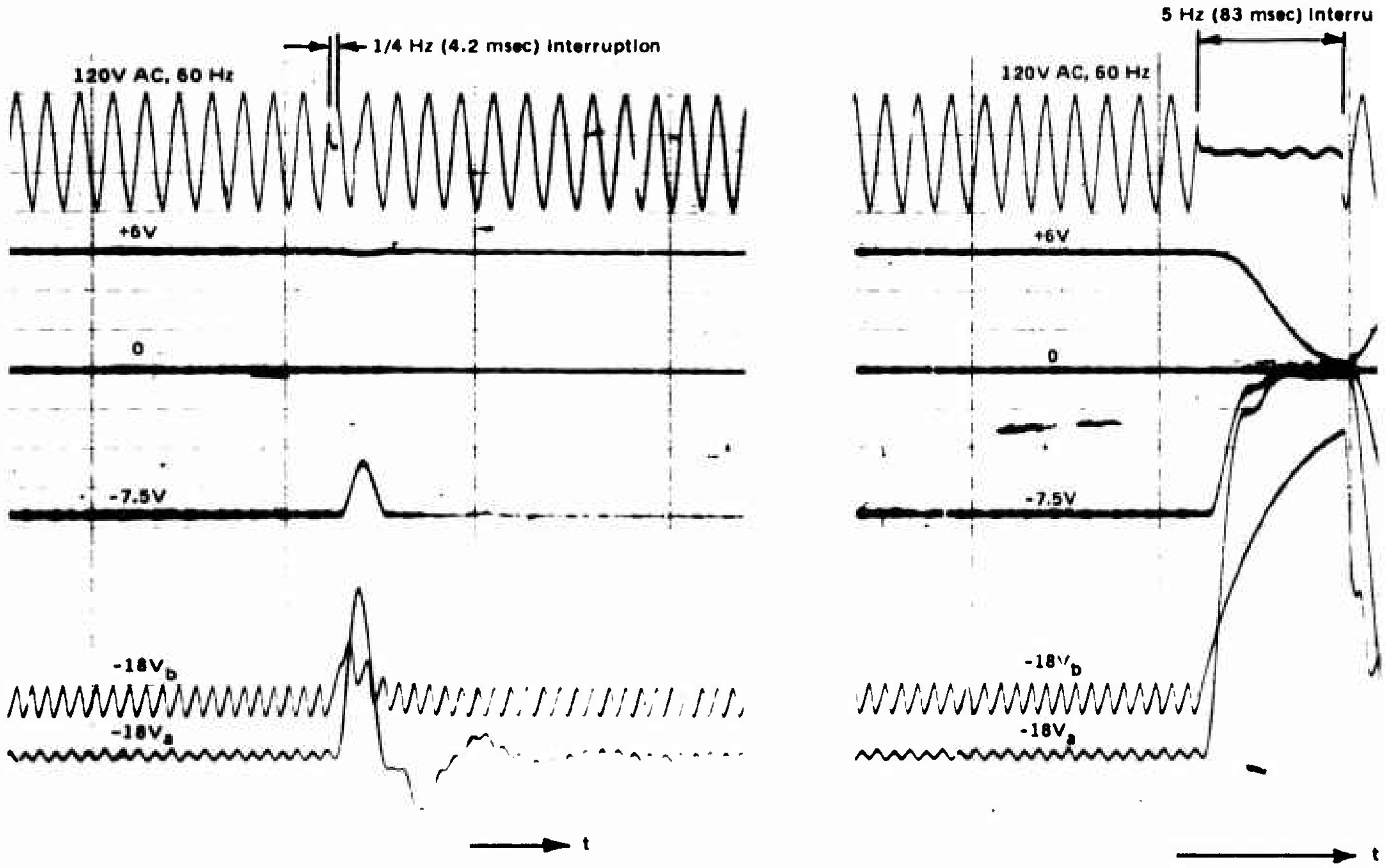
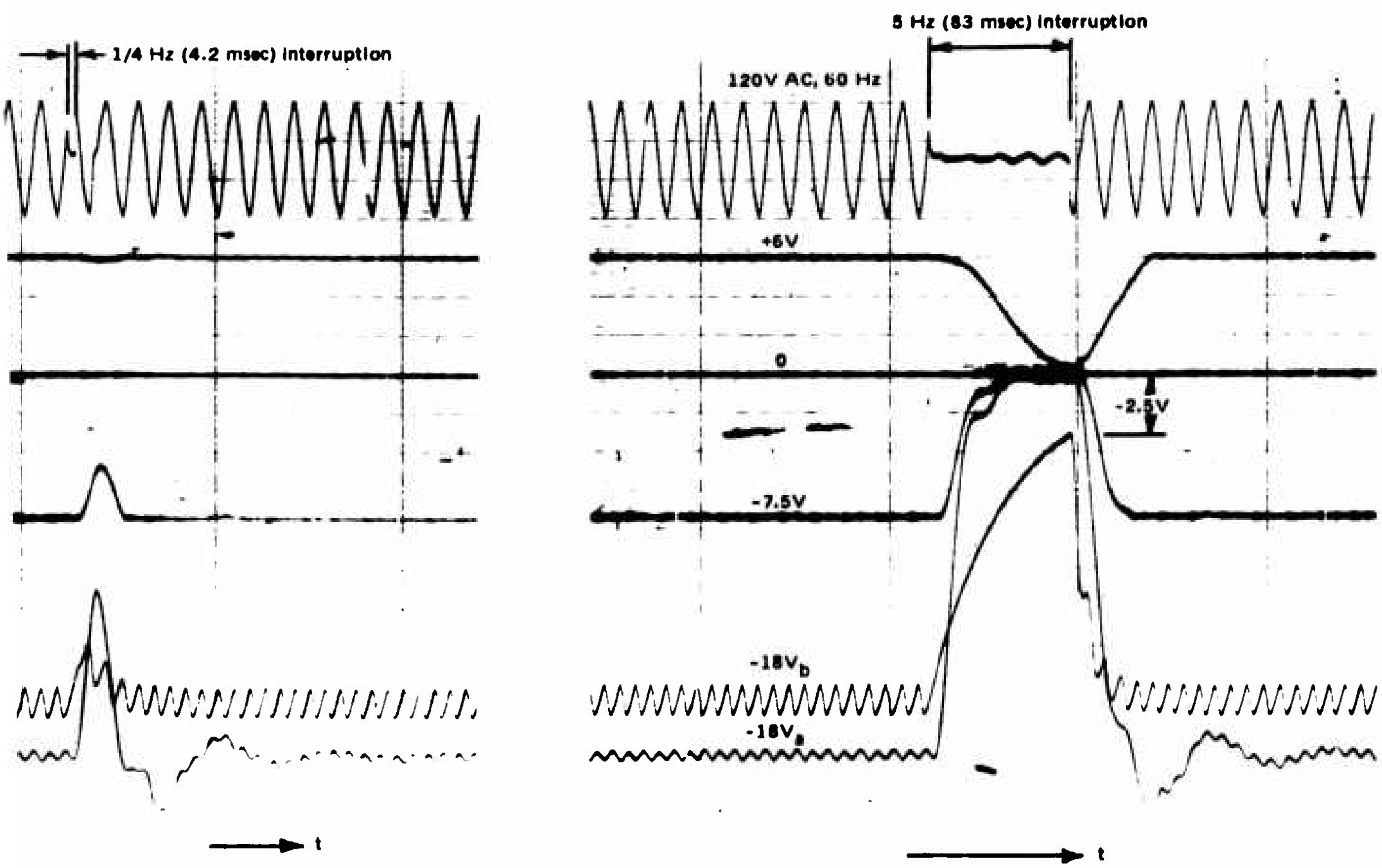


(a) 4.2-msec interruption.

(b) 8.3-msec interruptic

Figure 9. Oscillograph recordings of KGP-5(T-1)/TSEC output voltages with varying momentary interruptions of AC power source.



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(b) 8.3-msec interruption.

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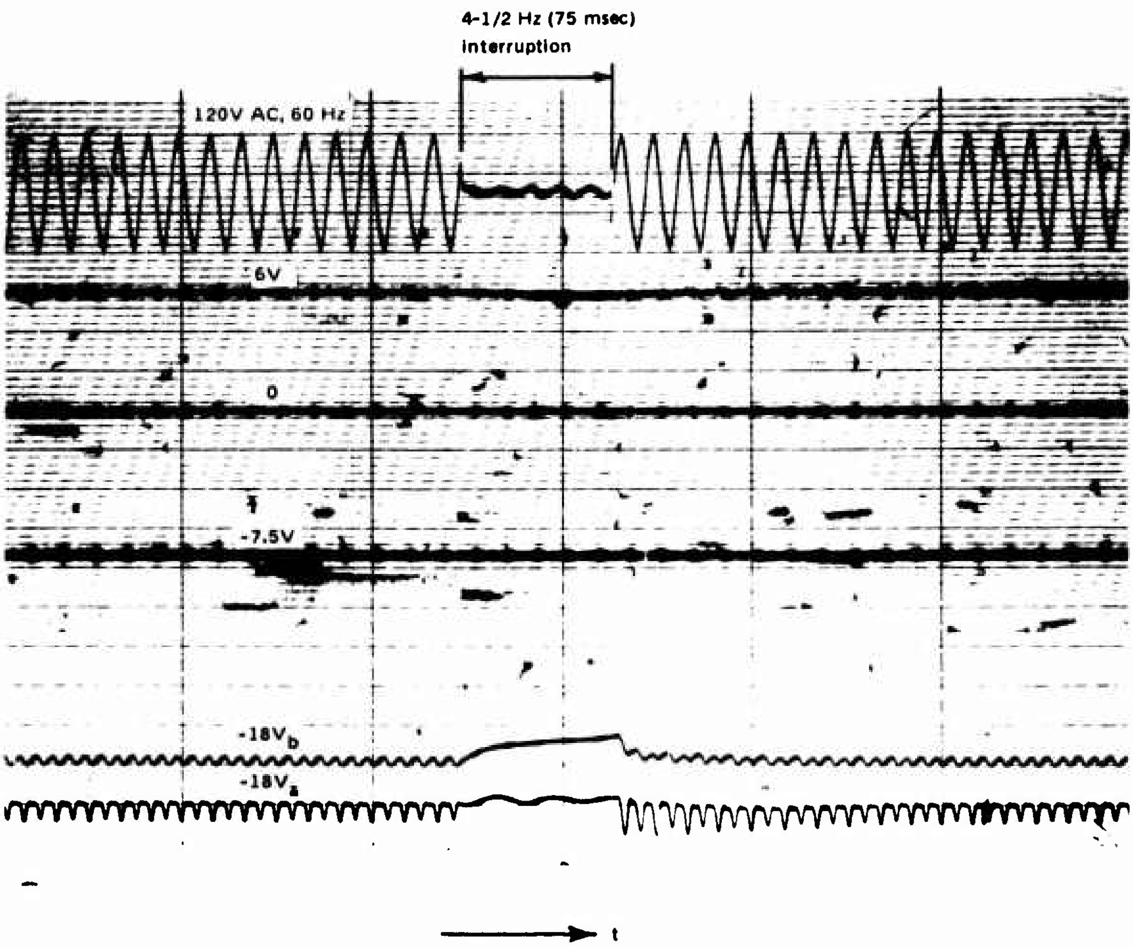
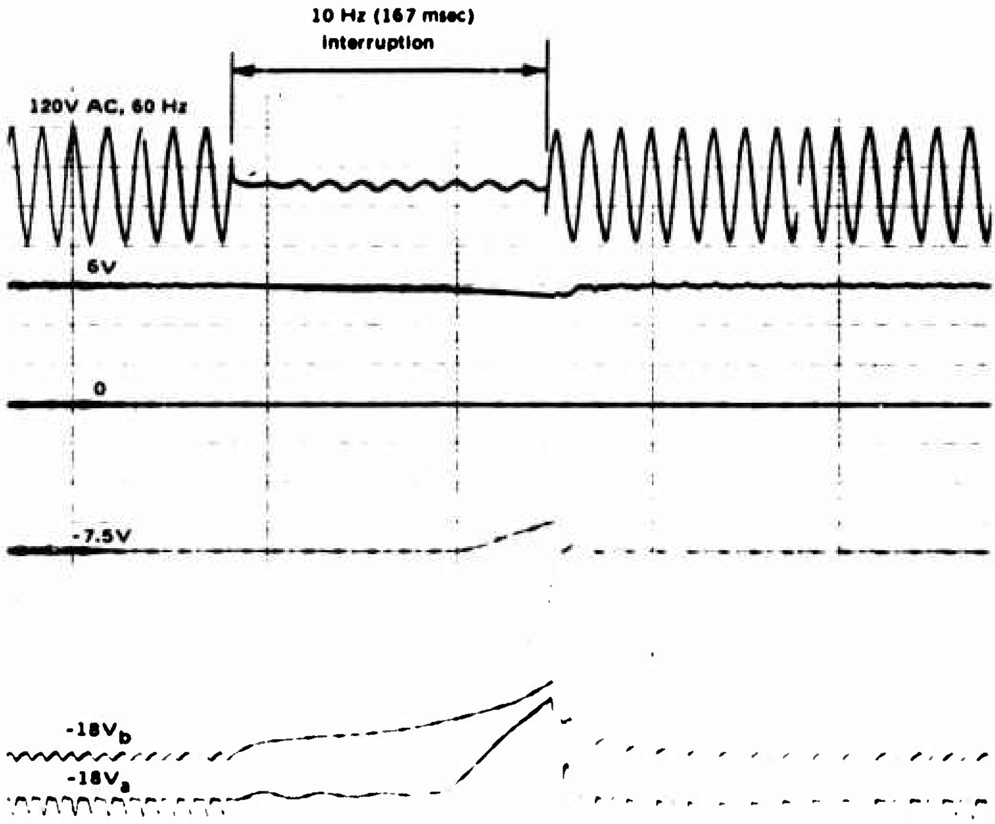
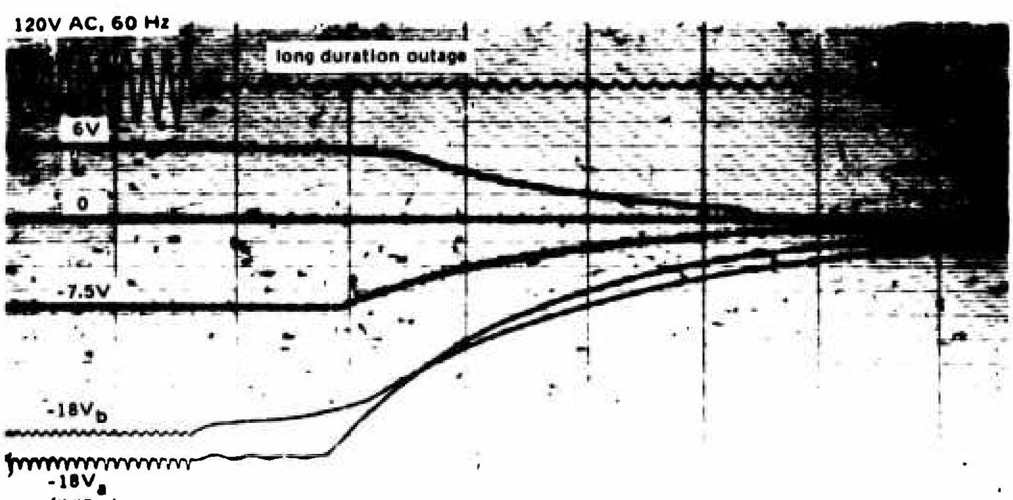


Figure 10. Oscillograph recording of KGP-5(T-1)/TSEC output voltage subjected to a 75-msec momentary power interruption; energy reservoir circuit connected.



(a) 167-msec interruption.



(b) Complete power outage.

Figure 11. Oscillograph recordings of KGP-5(T-1)/TSEC output voltages; energy reservoir circuit connected.

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13. ABSTRACT

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Voltage drops						
Power interruptions						
Desensitization						
Energy storing capacitors						
Energy reservoir circuit						