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D2 Channel Bank:

Power Conversion

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The D2 Channel Bank requires a variety of voltage sources to operate. Some have lenient regulation requirements, while a few have extremely tight tolerance requirements. To derive these voltage sources from a 48-volt central office supply with a minimum of complexity and good conversion efficiency, a tailored design is chosen where, for the less critical voltages, a single switching regulator is used to supply a dc-to-dc converter with several dc voltage outputs and, for the critical voltage sources, series-type regulators are used.

I. INTRODUCTION

The D2 Channel Bank depends on a variety of power supply voltages for its operation. The Power Systems Converter Circuit (PSCC), driven by the minus-48-volt central office battery source provides the seven regulated dc voltages required by the D2 Channel Bank.

By using a high-powered switching-type regulator for primary regulation followed by a dc-to-dc converter for voltage transformation, high efficiency and compactness are achieved. Series-type regulators with high-gain feedback circuits are used to stabilize the voltages for three of the outputs where very stringent voltage requirements exist.

Overvoltage turn down, interlocking of critical voltages, voltage tracking and overcurrent protection are also provided. The switching regulator and dc-to-dc converter are designed to operate at commutating frequencies above 20 kHz to eliminate acoustical noise.

The power supply is packaged to facilitate manufacturing, testing, and maintenance. The unit is arranged to be mounted in the same type rack as the rest of the D2 Channel Bank.

1.1 *Requirements*

The power supply requirements are shown in Table I. It is seen that

TABLE I—D2 BANK ELECTRICAL REQUIREMENTS

Output Voltage (Volts dc)	Current Range (Amperes dc)	Output Voltage Tolerance (%)	Trouble Voltage (Volts dc)	Maximum Ripple	
				<20 kHz	>20 kHz
+24	2.1– 4.4	±5	+27.6	5 mV p-p	24 mV p-p
−24	0.9– 2.2	±5	−27.6	5 mV p-p	25 mV p-p
−12	1.8– 3.8	±5	−15.0	36 dBrnC	100 mV p-p
−5	2.2– 5.0	±10	*	*	*
+5	3.5– 10.0	±4	+ 5.30	50 mV p-p	50 mV p-p
+32	0.055–0.150	±0.75	+38.0	5 mV p-p	40 mV p-p
−32	0.035–0.100	†	−38.0	5 mV p-p	40 mV p-p

NOTE: The output voltage tolerance, trouble voltage and maximum ripple apply for an input voltage range of 42 to 53 volts dc and an ambient temperature range of 10 to 50 degrees Centigrade.

* No requirement specified.

† The minus-32-volt output must track the plus-32-volt output to within ±0.375 percent.

the first four of the voltages in Table I have relatively lenient requirements, whereas the last two, because they are used to generate reference currents in the coder, have extremely tight requirements. The plus-5-volt supply is also considered more critical than the first four because, although the allowed percentage variation is comparable, the absolute allowable voltage variation is quite small. Furthermore, because that voltage is used to power integrated circuits that are sensitive to overvoltages, greater protection is required.

The plus-24- and minus-24-volt supplies are used primarily for the channel counters, which are realized in blocking-oscillator form. The −5 and −12 are utility biasing voltages used for most DPD transistor circuits.

1.2 *Powering Plan*

The PSCC is divided into five sections, shown in Fig. 1. Four of these are plug-in units. The four plug-in units connect physically to the converter frame, the fifth section, which is hardwired into the D2 bay. The converter frame contains most of the filtering for the input, and for all of the outputs. It has no active elements. The switching regulator is the primary regulator in this circuit. It converts the unregulated minus-48-volt dc input into a regulated minus-24-volt dc voltage. The regulated minus-24-volt dc is one of the outputs, and is also used as the input for the converter. The converter inverts (converts to ac) the dc input and, by means of step-up and step-down transformers and rectifiers, furnishes six different dc voltages. Three of these voltages, minus 12 volts, minus 5 volts, and plus 24 volts, are

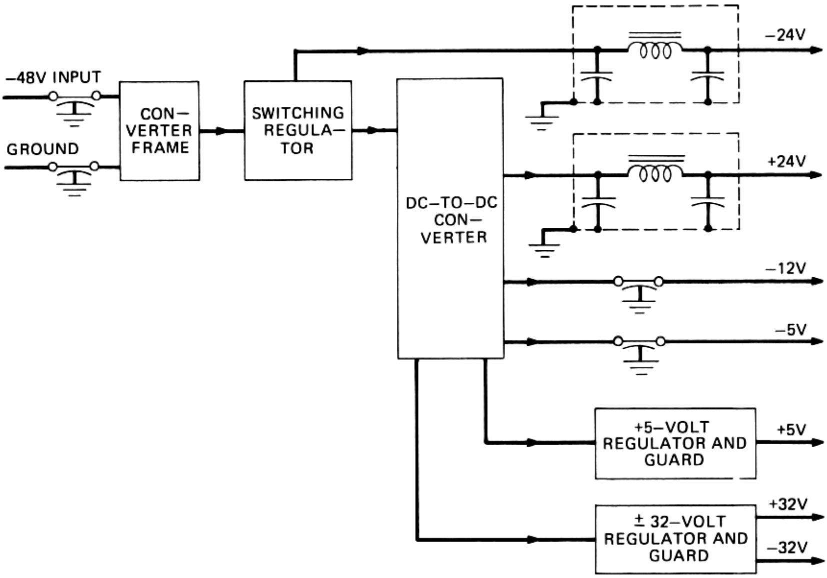

Fig. 1—Block diagram of PSCC.

delivered to the load through the necessary filtering in the converter frame. Thus a single switching regulator is shared by four output voltages. The other three voltages are fed to the inputs of three precision-series-type regulators. The precision regulators deliver plus 5 volts, plus and minus 32 volts to the load. Figure 1 illustrates the relationships of the circuitry among the various units. The filters shown for the input and output leads are physically in the converter frame.

II. REGULATORS AND CONVERTERS

2.1 *Switching Regulator*

The PSCC was designed to use a primary regulator in order to eliminate the need for separate regulators for each of the seven outputs. Only the three outputs with very tight tolerances have separate series regulators, and the power dissipation in these is held to a minimum because of the preregulation provided by the primary regulator. A switching-type regulator is used as the primary regulator in the PSCC because of the high efficiency that can be achieved with this type of circuit.[1,2]

The switching regulator is illustrated in Fig. 2. The operation of the switching regulator can be described briefly as follows. A simplified schematic is shown in Fig. 3. The unregulated minus-48-volt central office battery is connected to the regulated minus-24-volt load through a switch and filter inductor. By sensing the output voltage, comparing it against the voltage developed across a reference diode, and amplifying the resultant error signal, the off-time of three switching transistors connected in parallel are controlled to produce the regulated output. The on-time of the switching transistors is controlled primarily by the current in the secondary winding of the current transformer. This secondary current decreases exponentially with time due to the exponentially increasing exciting current in the transformer primary which subtracts from the constant primary current. This secondary current is used to keep the switching transistors in saturation and when the current falls below the level required to keep the switching transistors in saturation, switching occurs and the switching transistors turn off. The dc output voltage is derived by integration of the train of pulses from the switching transistors through the use of a large inductor with a fly-back diode and an output filter capacitor.

To increase the reliability of the switching regulator, the three high-power switching transistors are driven by another power transistor. These are arranged in a Darlington configuration to reduce the switching time and to provide current sharing among the paralleled units. The amplifier section of the switching regulator is located in

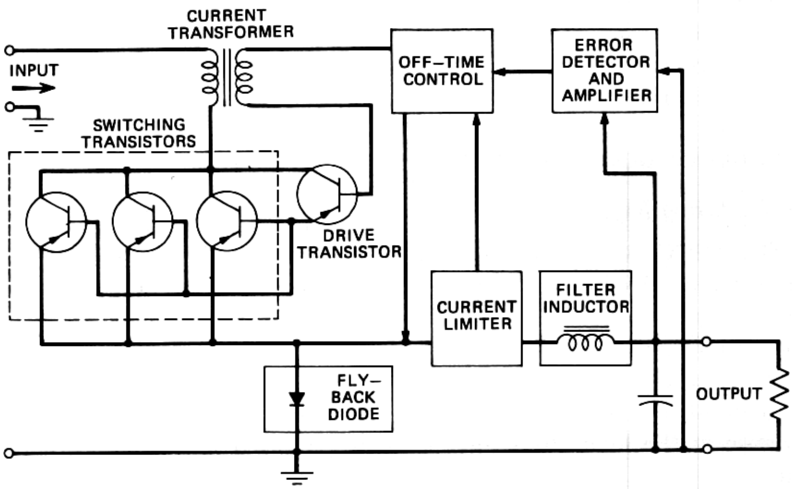

Fig. 2—Switching regulator.

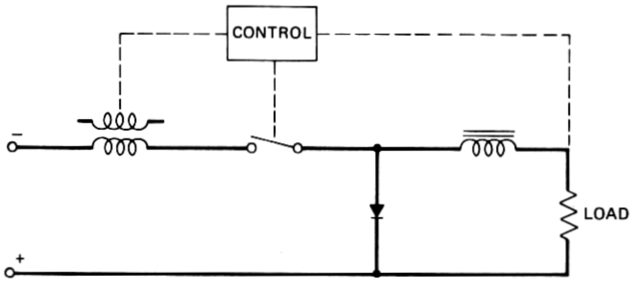

Fig. 3—Simplified schematic of the switching regulator.

an enclosed container within the switching regulator plug-in unit. This feature is used to protect the amplifier from the electromagnetic interference generated in the switching regulator and the dc-to-dc converter. A current limiter is used to protect the regulator against excessive current during turn-on and in the event of an output short.

2.2 *DC-to-DC Converter*

The dc-to-dc converter is shown schematically in Fig. 4. The converter, which operates from the regulated minus 24 volts dc supplied by the switching regulator, operates at approximately 24 kHz, which is beyond the audible range and so prevents objectionable disturbance to operating personnel. The converter consists of two main sections; the drive oscillator and the power converter.

The switching frequency of the drive oscillator is determined by the volt-seconds required to saturate the base drive transformer used in conjunction with the oscillator switching transistors. The base drive transformer alternately drives the two switching transistors into saturation and cut-off, thereby producing a square wave output across the primary of the oscillator transformer.

The power converter is driven by the square-wave base drive signal supplied by the output winding of the oscillator transformer. The high-power switching transistors in the power converter, therefore, also operate in a class "D" mode and generate a square wave. The switching duration is kept very short, thereby limiting power dissipation in the converter. The square wave generated by the high-power switching transistors is applied across the primary of four output transformers, the five secondary windings of which supply the voltages to the rectifiers and filters for the six outputs.

2.3 *Plus and Minus 32-Volt Regulators*

The plus and minus 32-volt regulators are high-gain series regulators

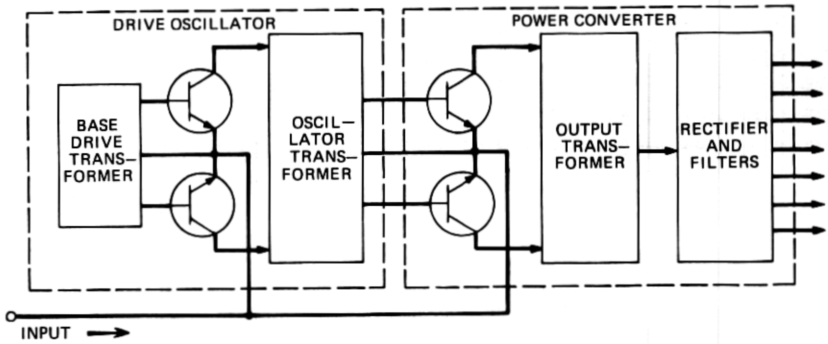

Fig. 4—DC-to-DC converter.

which derive their input from the plus and minus 45-volt outputs of the converter.

Both the plus and minus 32-volt regulators consist of a series-regulating transistor, a current amplifier, a differential error detector and a voltage reference. The series-regulating transistor acts as a variable series resistance and absorbs the difference between the partially regulated dc input voltage, and the highly regulated dc output voltage.

Since the minus-32-volt regulator must track the plus-32-volt output to within ±0.375 percent, the error detector section of the minus-32-volt series regulator is connected across the plus and minus 32-volt outputs. Therefore, when the plus-32-volt output changes, the voltage change is also sensed by the minus-32-volt error detector. This arrangement causes the minus-32-volt regulator to track any change in the plus-32-volt output.

To protect the regulators in the event of an output short circuit, a zener diode is connected across the series transistor. It protects the transistor by limiting the maximum collector-to-emitter voltage of the transistor to the breakdown potential of the zener, until the 32-volt circuit breakers operate and shut down the regulators.

2.4 *Plus-5-Volt Regulator*

The plus-5-volt regulator is a high-gain series-type regulator which derives its input from the plus-7-volt output of the dc-to-dc converter through special filtering located in the converter frame. To reduce the power dissipation in the transistors used in the series element, the circuit uses a unique arrangement of paralleled transistors and resistors as shown in Fig. 5.

The operation of the series element can be described briefly as follows:

a portion of the input current flows through transistor Q2 and its series resistor R2, and the rest of the current flows through a parallel branch made up of transistor Q1 and series resistor R1. The voltage drop developed across resistor R1 increases the effective base-to-emitter voltage of transistor Q1 and forces more base current into transistor Q2.

Under normal conditions, most of the input current flows through Q2 and resistor R2. Resistor R2 dissipates most of the power developed across the series element, because Q2 operates near saturation. When the input voltage decreases due to changes in line or load, transistor Q2 saturates, and a greater portion of the input current flows through Q1. However, the voltage across Q1 also decreases so that the power dissipation in Q1 is maintained at a safe level.

A separate bias voltage is required by the plus-5-volt regulator to provide sufficient voltage to operate the differential error detector and voltage reference circuits.

III. PHYSICAL DESIGN

The PSCC is packaged as shown in Fig. 6. The overall width of 21 inches and depth of 12 inches was fixed by the bay requirements. The height of 16 inches was determined by the component density as illustrated later in this article.

Construction in the form of plug-in units was chosen for ease of manufacturing and field maintenance. The plug-in unit concept also contributed to lower cost, which was a design consideration. This type of unit also conforms to the D2 System philosophy of shipping separately all units that are not bay wired. The four plug-in units, i.e., dc-to-dc Converter (CONVERTER), Switching Regulator (REG-

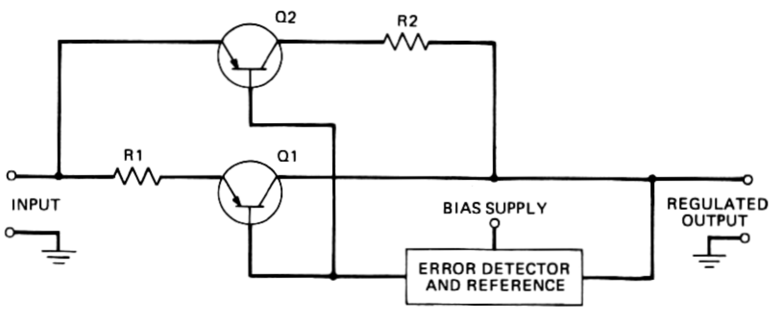

Fig. 5—Paralleled transistors and resistors used in the circuit of the plus-5-volt regulator.

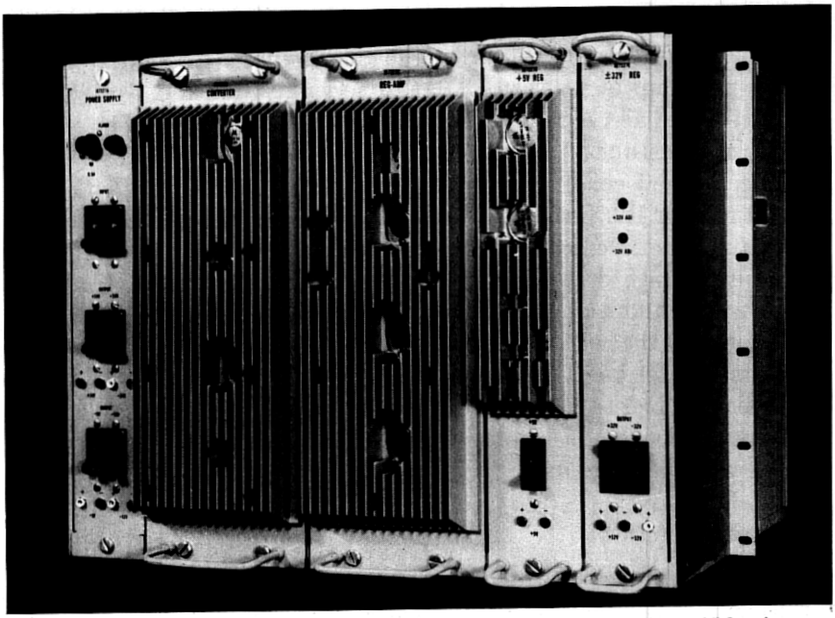

Fig. 6—D2 Channel Bank–J87327A power supply prototype, front/side view.

AMP), plus-5-volt Regulator (+5V REG) and the plus and minus 32-volt Regulator (±32V REG), are of different widths due to the amount of circuitry contained in each one. The largest unit weighs 20 pounds and the smallest unit weighs 4 pounds. Figure 7 shows the front/left/top view of the dc-to-dc converter illustrating the typical compactness of all the plug-in units. The plug-in units are held in place by $\frac{1}{4}$-turn quick-release fasteners, and handles are provided for easy removal of the units for maintenance. The panel located on the left side of the converter frame contains the main control apparatus and may be released from the converter frame by means of two $\frac{1}{4}$-turn quick release fasteners for ease of maintenance.

An electromagnetic interference shield is located between the switching regulator and the series regulators to prevent the radiated noise from affecting the circuits in the series regulators.

3.1 *Shielding*

The stringent noise requirements dictated by the D2 system required the shielding of the noise radiating components. Figure 8 displays the shielded compartment located at the rear of the converter frame with its cover removed. The compartment contains the interconnecting

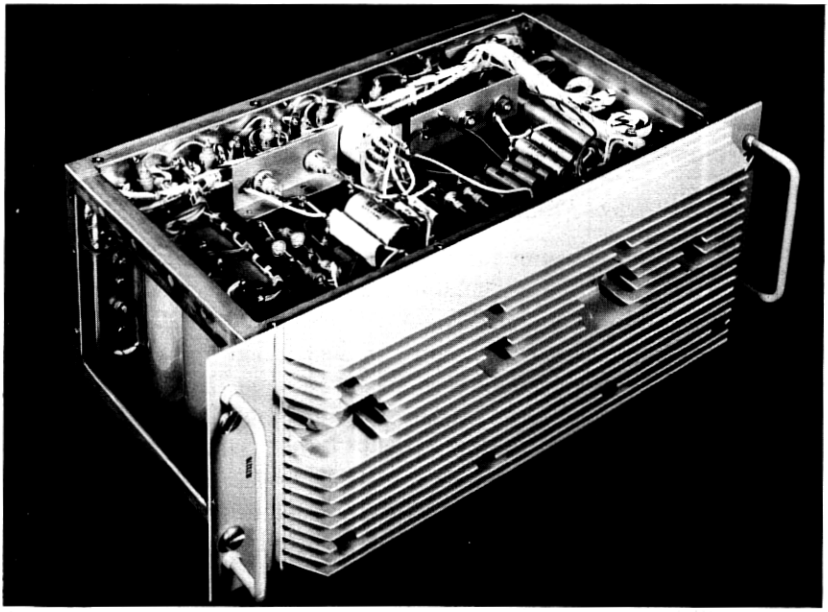

Fig. 7—D2 Channel Bank–J87327B power supply prototype (converter), front/left/top view.

wiring for the plug-in units and the input and output filtering. All leads that enter or leave this compartment are filtered by feed-through capacitors or feed-through filters. These capacitors and filters restrain the longitudinal conducted noise on the input and output leads. The cover when fastened in place will confine any EMI noise radiating from within the compartment.

3.2 *Plug-in Construction*

Figure 9 shows an exploded view of the dc-to-dc converter illustrating the method used to achieve low junction temperatures in the power semiconductors. The transistors are mounted on a massive extruded aluminum heat sink which projects 1-1/4 inches beyond the front panel to insure adequate air flow for convection cooling, thereby minimizing the temperature at the semiconductor junctions and within the unit. The angle framework construction is used to provide easy access to any of the five sides for assembly and maintenance. The open type of construction also provides for good air flow through the unit, thus contributing to the low equipment temperature. This method of construction, coupled with the use of heat sinks, eliminates the need of a fan or blower for forced convection thus assuring additional reliability of the Power Supply.

IV. FEATURES AND ALARMS

4.1 *Special Electrical Features*

The D2 Bank transmission equipment requires special electrical features from the PSCC. The minus-32-volt output must track the plus-32-volt output very closely. A difference in the absolute value of these two voltages causes a shift in the voltage reference used for the coder and the decoder modules, and even a small reference voltage change can produce an error in the pcm code. Interlocking is required for the plus- and minus-24-volt outputs to provide simultaneous turn-on of the two outputs, and to remove the plus 24 volts when the minus-24-volt output falls below minus 18 volts in order to prevent destructive overheating of circuits biased by the plus and minus 24 volts.

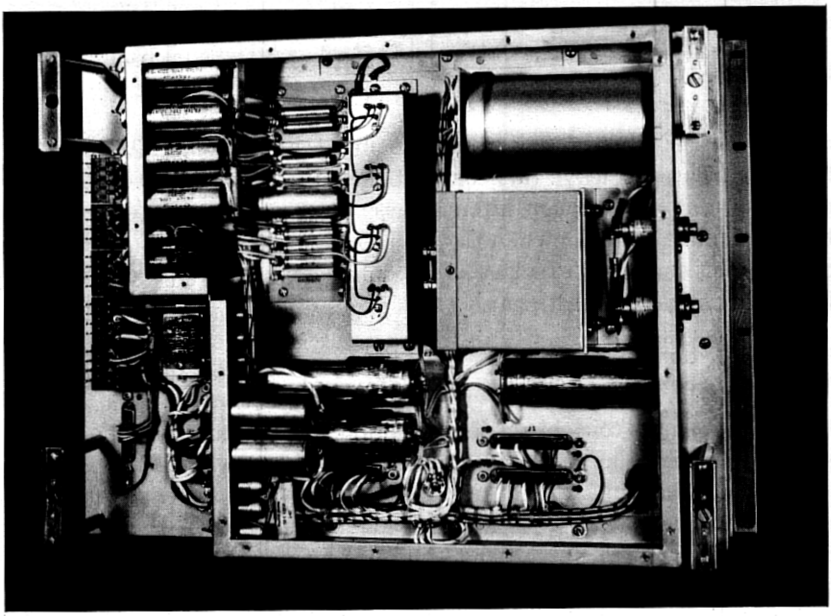

Fig. 8—D2 Channel Bank–J87327A power supply prototype (chassis), rear view, shield cover removed.

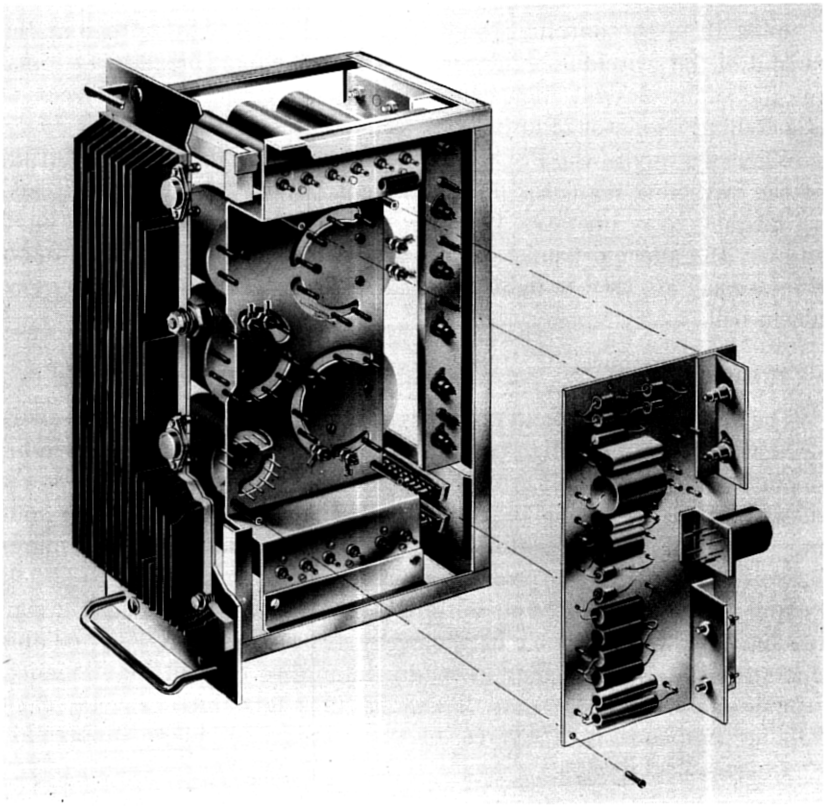

Fig. 9—Exploded view of dc-to-dc converter.

4.2 *Alarm System*

The D2 Bank bay must have all seven of the PSCC output voltages available in order to operate. Therefore, an extensive alarm system was designed so that, in the event of a PSCC failure, the affected system would be removed from service, the operating personnel alerted, and the location of the failure flagged to minimize down time.

To provide the alarm features, there is a circuit breaker in series with each of the outputs, and also one in series with the input. The circuit breakers will self-trip on input or output overloads. The circuit breakers associated with the three highly-regulated outputs (+5V, +32V, −32V) will also be tripped by their respective high-voltage shutdown circuits. The 24V circuit breaker may also be tripped by the low-voltage shutdown circuit on the minus-24-volt output.

Since all of the outputs would be affected by a high voltage at the output of the switching regulator, the INPUT circuit breaker is tripped by the minus-24-volt high-voltage shutdown circuit in the event of a switching regulator failure.

Whenever any of the PSCC circuit breakers trip, or when the output of the switching regulator is lost, a front panel alarm light is lit and an internal relay operates. One pair of contacts on the relay are used to busy the affected trunks out of service and another pair of contacts on the relay are used to light a bay alarm light and to activate an office alarm bell.

V. SUMMARY

The power-systems converter circuit described here features many design innovations. High-power switching regulator and converter operation above 20 kHz, resulting in silent operation with low power dissipation. A switching regulator used as the sole regulator for four outputs and as a preregulator for three other outputs. A plus and minus 32-volt regulator which provides precision tracking of the plus-32-volt output by the minus-32-volt output. A five-volt series regulator design producing low dissipation in the series transistors, and very reliable operation. The use of plug-in modules for ease of field maintenance, trouble shooting and repair. These features introduced several challenging problems in the area of electromagnetic noise suppression and mechanical design.

VI. ACKNOWLEDGMENTS

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The circuit design was done under the supervision of G. W. Meszaros, the mechanical design was done under the supervision of S. Mottel and the magnet apparatus design was done under the supervision of T. G. Blanchard.

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