TECHNOLOGY UTILIZATION

CASE FILE
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DC POWER CIRCUITS

A COMPILATION
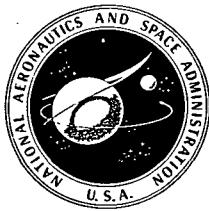
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Foreword

The National Aeronautics and Space Administration and the Atomic Energy Commission have established a Technology Utilization Program for the dissemination of information on technological developments which have potential utility outside the aerospace community. By encouraging multiple application of the results of research and development, NASA and AEC earn for the public an increased return on the investment in aerospace research and development programs.

The items in this first of an updated series of compilations dealing with electronic circuits represents a carefully selected collection of dc power circuits. Many of them are based on well-known solid-state concepts that have been simplified or refined to meet NASA's demanding requirements for reliability, simplicity, failure resistance, and resistance to environmental extremes. The items contained in the sections dealing with power supplies, power conversion and power regulation should be of interest not only to the professional engineer but to the electronics hobbyist as well.

Additional technical information on individual devices and techniques can be requested by circling the appropriate number on the Reader Service Card included in this compilation.

Unless otherwise stated, NASA contemplates no patent action on the technology described.

We appreciate comment by readers and welcome hearing about the relevance and utility of the information in this compilation.

Technology Utilization Office
National Aeronautics and Space Administration

Contents

Section 1. DC Power Supplies

SMALL, EFFICIENT POWER SUPPLY FOR XENON LAMPS

The unusual power demands of xenon lamps—constant voltage of 15 V when "on," supply voltage of 40 V when "off," and ionizing source of 25 kV pulse—can be met with a new power supply, which is smaller and more efficient than previous models.
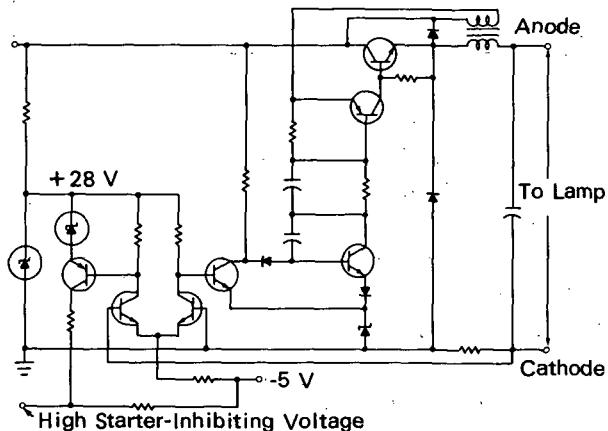
Figure 1. Schematic Diagram of Current Regulator

The supply has four sections: a preregulator, a dc-to-dc converter, a current regulator (see Fig. 1), and a high-voltage starter (see Fig. 2). Although the individual sections are basically conventional, each has specific characteristics that are somewhat unique.

The preregulator requires fewer components than other models and can operate at frequencies between 100 and 300 kHz with an efficiency of 90%. At high frequencies, smaller transformers and filter-capacitors can be used.

In the dc-to-dc converter, voltage feedback and current feedback are both used. The current feedback is applied from a separate transformer in series with the voltage-feedback transformer. The converter is free running with either feedback, but voltage feedback predominates at high loads and current feedback predominates at low loads. The unit provides 40 V for lamp operation and −5 V for control of the current regulator, which is a ripple-type device.

Another lead from the transformer's −5 V winding provides a 10 V square wave to drive the high voltage starter. Adding secondary windings to the transformer can produce different voltages for different purposes.

The high-voltage lamp starter has a balanced voltage-doubling circuit driven by a 10 V peak-to-peak square wave supplied by the converter. The wave is transformed at 160 V peak-to-peak

Figure 2. Schematic Diagram of Starter Circuit
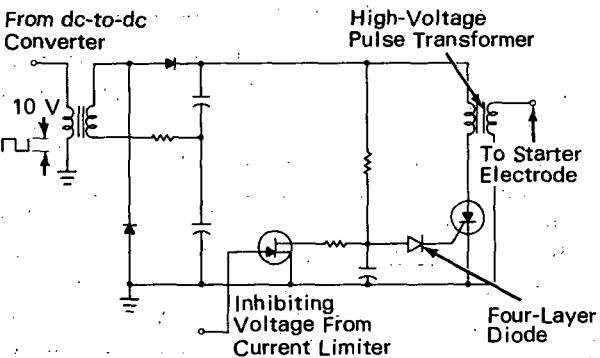
before the voltage is doubled. The resulting 160 V signal is stored across the voltage-doubling capacitors until the relaxation oscillator fires a silicon-controlled rectifier. The rectifier discharges the capacitor's energy through the primary of a high-voltage pulse transformer. The oscillator allows the voltage-doubling capacitors to charge and discharge until the xenon lamp lights. The starter-inhibiting circuit then provides a positive voltage to the gate of an N-channel field effect transistor. The transistor turns on and shorts the timing capacitor in the oscillator so that additional firing of the rectifier is prevented.

Source: J. E. Goodwin of
Martin-Marietta Corp.
under contract to
Manned Spacecraft Center
(MSC-13637)

Circle 1 on Reader Service Card.

DUAL-VOLTAGE POWER SUPPLY WITH INCREASED EFFICIENCY

This circuit can be used in lieu of relatively complex and expensive voltage regulators to supply dual voltages wherever precise voltage regulation is not required.

Power Transformer
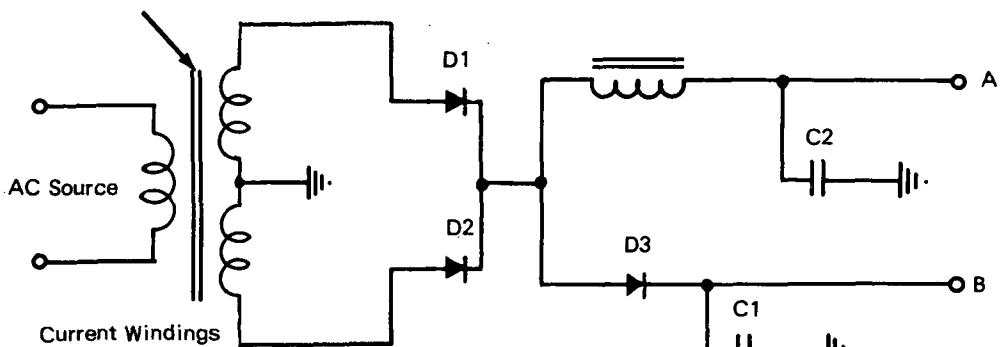
The primary winding of the power transformer (see fig.) is connected to the ac source, and the secondary winding is connected to the full-wave rectifier consisting of diodes D1 and D2. The unfiltered output from the full-wave rectifier is fed, in parallel, to a conventional choke-input filter branch and a diode-capacitor branch. The diode, D3, in this branch conducts on the peaks of the full-wave rectifier current and charges

capacitor C1 to the peak voltage across one-half of the secondary winding of the power transformer. The voltage at terminal A is approximately 40% greater than at terminal B. The required peak inverse-voltage rating of diode D3 is only one-half the peak voltage across the full secondary winding. For maximum voltage output at terminal A, a high-conductance semiconductor diode is used in the branch.

Source: Lewis Research Center
(LEW-90107)

No further documentation is available.

PRECISION FULL-WAVE RECTIFIER

Conventional full-wave rectifier circuits which use operational amplifiers require at least two operational amplifiers and six precision resistors.

This circuit uses only one operational amplifier (acting as a linear amplifier and a switch driver) and two precision resistors. The operational amplifier is operated open loop for switching and closed loop for linear gain, both simultaneously.

Precision resistors R1 and R2 (see fig.) are of equal value, and function as the conventional input-feedback loop for the operational amplifier; the other resistors can be ±20% carbon types. When the input voltage is positive, the voltage at point B will be equal in magnitude but π rad (180°) out of phase with the input. This requires the output of the operational amplifier at point A to be more negative by an amount equal to the sum of the forward and reverse
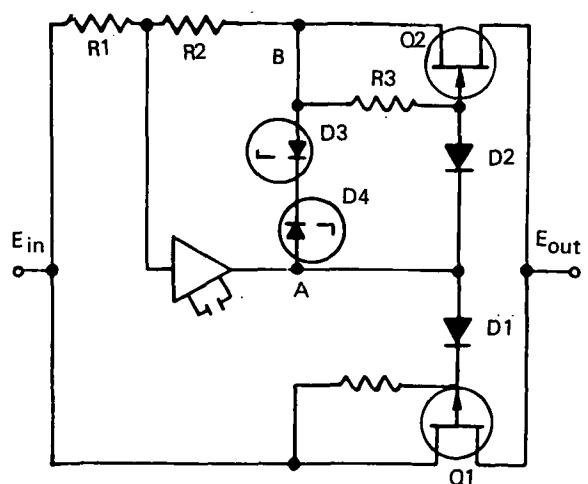
potentials of the zener diodes D3 and D4; this value will be on the order of 6 V for diodes which have zener breakdown potentials of about

5.5 V. Thus, even though the input voltage may be a very small positive value, the amplifier generates at least −5.5 V at point A, and this potential is more than sufficient to turn off Q2 via the forward biased diode D2. D1 prevents transfer of the voltage at point A to the gate of the FET switch Q1, and since the gate and source of Q1 are at the same potential (the condition for minimum source-to-drain channel resistance), Q1 is on and the input is coupled directly to the output.

When the input voltage is negative, Q2 is turned on and Q1 is turned off. Hence, full-wave rectification (positive output voltage) is achieved by coupling the input to the output terminal in one mode of operation via Q1, and by having the amplifier output, which is inverted, appear at the circuit output via Q2 in the other mode.

Since the FET switches in the signal paths have very low values of resistance and no offsets, the circuit provides linear full-wave rectification. Frequencies up to a few kHz can be handled by the components; higher frequency operation is possible by replacing the FET switches with MOSFET devices of superior high-speed switching characteristics and using high-bandwidth operation amplifiers.

If Q1 and Q2 are interchanged and D1 and D2 are each reversed, the polarity of the output terminal will be negative. The FET switches minimize temperature-sensitive offsets.

Source: G. J. Deboo and R. C. Hedlund
Ames Research Center
(ARC-10101)

Circle 2 on Reader Service Card.

VARIABLE VOLTAGE SUPPLY USES ZENER DIODE REFERENCE

This circuit uses a zener diode as a reference element to provide a stable variable reference voltage. The circuit may have application in low voltage power supplies.

Zener diode D1 (see fig.) is used as the reference element. Voltage control is provided by a two-stage amplifier, consisting of transistors Q1 and Q2. The output voltage can be varied by selecting a value for R2, such that $V_{out} = V_z (1 + R1/R2)$, where V_z is the breakdown voltage of zener diode D1.

Zener diode D3 is used to start the circuit. The voltage drop across diode D2 must be larger than the collector-emitter voltage of Q2. A positive feedback loop between the transistors is incorporated in the circuit; therefore, D3 is cut off when the circuit is ON.

Current flow through Q1 and Q2 is controlled by the setting of R1. Increasing the resistance of R1 increases the current flow through the transistors, which in turn causes an increased current flow through D1 and R3. The output voltage appears across the series connection of D1 and R3. Since the characteristics of D1 are fixed, an increased output voltage can be ob-

tained by increasing the voltage (IR drop) across R3. This is accomplished by adjusting R1. The voltage rise at the emitter of Q1 limits the positive feedback and prevents unrestricted increase of the output voltage.
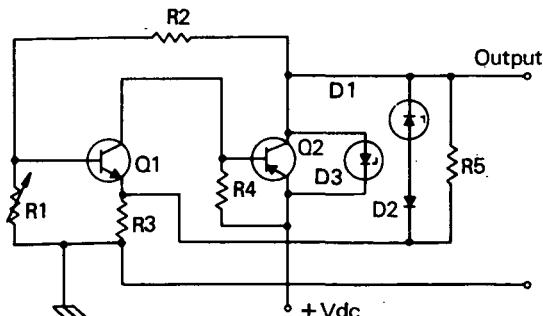
Diode D2 is included in the circuit to eliminate voltage dependence upon the emitter-base voltage of Q1. The output voltage may be applied to an emitter-follower circuit to obtain higher operating currents.

Source: R. C. Lavigne and L. L. Kleinberg
Goddard Space Flight Center
(GSC-262)

Circle 3 on Reader Service Card.

4

REGULATED POWER SUPPLY FOR VARYING LOADS

While tungsten has many favorable properties when used as a heating element, it has a sizeable resistance change in going from low temperature to high temperature operation. If a constant voltage source is used to provide the power, high peak power often requires an additional power source, such as a storage battery. A constant power regulator (shown in the block diagram) delivers constant power to a varying resistance load such as a tungsten filament, thus eliminating the peak-power requirements and the need for a storage battery.

A novel pulse-width scheme uses magnetic pulse-width control to simplify the control circuitry, and a simple but effective regulator-converter combination supplies the amplifier power and reference voltages. An integrated-circuit, differential amplifier is used to simplify the design and packaging, as well as to increase the re-

liability. The constant power regulated supply can maintain an output power within ±2% over a moderate temperature range (278 to 313 K).
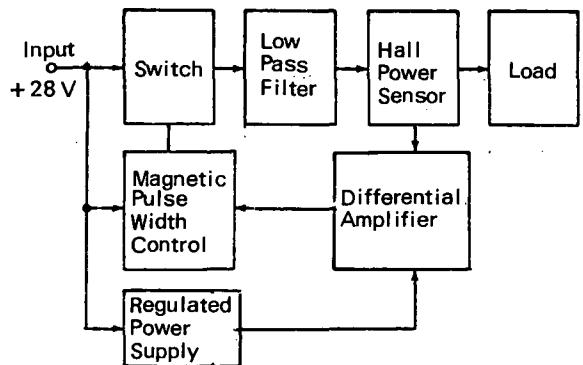
Source: P. L. Weitzel
Goddard Space Flight Center
(XGS-10036)

Circle 4 on Reader Service Card.

POWER SUPPLY WITH OVERLOAD PROTECTION AND LOAD ISOLATION
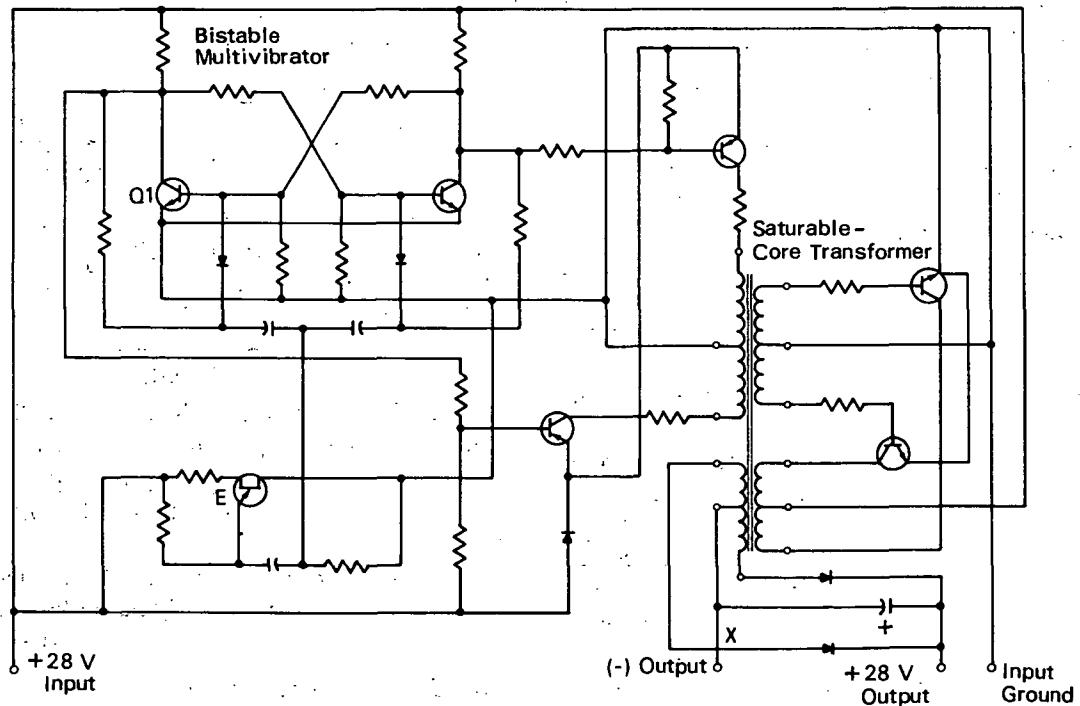
The power supply shown delivers 100 mA at 28 Vdc and provides voltage isolation and overload protection for an extended length of time. It has the unique capability of recovering from a short circuit while operating at normal load conditions. The circuit consists of a bistable multivibrator which drives a saturable-core output transformer that has three secondaries. The transformer supports the load voltage and current, yet maintains the capability to turn on after a short-circuit, with a minimum of power and limited hysteresis.

Source: J. R. Remich of
General Electric Company
under contract to
NASA Headquarters
(HQN-10539)

Circle 5 on Reader Service Card.

STABLE POWER SUPPLY FOR CO$_2$ LASERS

The design criteria for the laser power supply is based on the fact that CO$_2$ lasers are insensitive to amplitude and frequency variations superimposed on a ripple voltage, if the ripple frequency is relatively high. The high voltage power supply generates a dc voltage for the excitation of the gas discharge in the tubes, which show negative resistances. It has high efficiency and permits operation of the laser with high amplitude and frequency stability.

Experimental measurements have shown that the negative resistance is present only for frequencies below 1 kHz. The fluctuations decrease considerably with increasing frequency of the superimposed voltage, probably due to the long lifetime of the transition levels and partly due to the high ac impedance of the discharge tube at frequencies above about 10 kHz.

The conventional design of power supplies for gas discharge tubes takes into account the fact that a stable circuit requires ballast resistors to compensate for the negative differential resistance of the discharge tube.

This power supply has the advantage that no ballast resistor is required to excite a stable discharge. Therefore, the overall efficiency of the laser is higher than that of conventional dc power supplies. Further, only filter capacitors with small values are necessary, thus reducing the weight and cost of the power supply. The supply circuit shown contains a source, a signal generator, and a 50 W amplifier. Since it is difficult to construct transformers at the operating frequencies between 70 kHz and 100 kHz for the full voltage (about 3 kV), a rectifier is used to provide a voltage multiplication factor of four. In place of a conventional ballast resistor, the inductance L is connected in series with the primary winding. The laser operates with 10 mA at 3.15 kV.

Source: G. Schniffer
Goddard Space Flight Center
(GSC-11222)

Circle 6 on Reader Service Card.

DUAL POLARITY POWER SUPPLY

A majority of electronic systems use individual oscillator-transformer-rectifier power supplies, operating from 28 Vdc, to supply a positive and a negative voltage for the subassembly units. The dual polarity power supply provides a +14
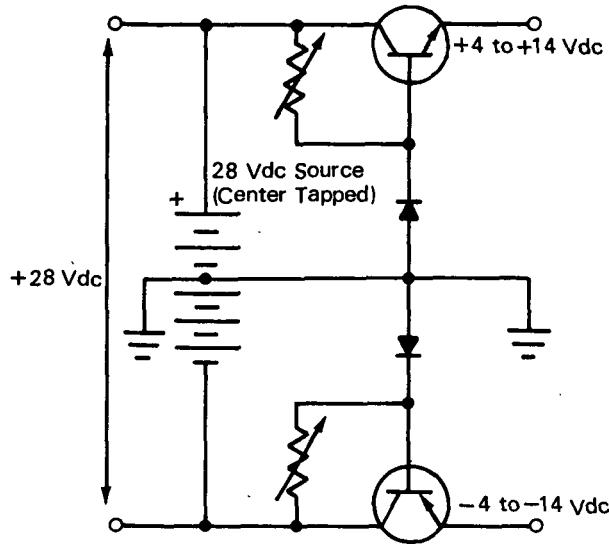
and −14 V to operate the various subassembly electronic modules directly, instead of using a 28 Vdc supply with the negative terminal grounded. Other 28 V accessories, i.e., motors, relays and solenoid valves, can be operated on a 28 V input, with the return to −14 V. Using separate supplies provides a measure of redundancy and minimizes electronic interference from closing relays and switches.

The circuit performs the function of a power distribution network for the other modules, without the need of a transformer. Important advantages of the unit include significant reductions in weight, size and costs, and internal power dissipation.

Source: G. O. Bohot, P. E. Fincik, and
A. L. Varneau of
North American Rockwell Corp.
under contract to
Manned Spacecraft Center
(MSC-17072)

Circle 7 on Reader Service Card.

ZENER DIODE STARTER FOR TRANSISTOR-REGULATED POWER SUPPLY

A starter circuit uses a zener diode in parallel with a silicon transistor to supply the starting current for a power supply which features high quality silicon transistors as variable impedance regulators. Zener diodes, D1 and D2 (see fig.), of suitable voltage rating are connected in parallel with the silicon transistors, Q1 and Q2, which are used as the variable impedance in each leg of the regulation portion of the circuit. The voltages developed across the diodes provide an initial current through the transistors which is sufficient to turn them on. The silicon transistors, Q1 and Q2, require an initial starting current because they have exceedingly small leakage current.

The diodes are selected with zener voltage ratings large enough to provide sufficient starting current but small enough to be effectively open-circuited when the transistor is conducting.
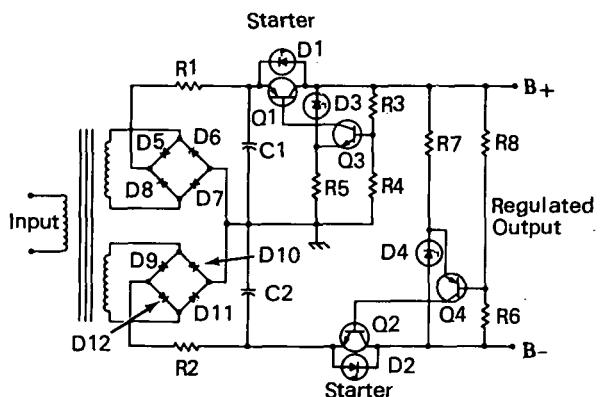
Source: G. A. Gilmour of
Westinghouse Astronuclear Laboratory
under contract to
Space Nuclear Systems Office
(NUC-0015)

Circle 8 on Reader Service Card.

Section 2. Power Converters

HIGH EFFICIENCY DC-TO-DC CONVERTER

A new power supply is designed to provide high efficiency for low output power levels and to provide good regulation with a minimum of circuitry.

Inherently, power supplies with low output power levels (less than 1 W) are highly inefficient. For a typical conventional design of 0.5 W output, the expected efficiency would be about 40%. An efficiency of 70% can be obtained with the new supply, without the use of precision resistors or capacitors. The design is applicable to any output power requirement, and at higher output power levels, the efficiency is greatly increased. As the output power increases, the internal power loss increases, but at a much slower rate, making the efficiency increase. A maximum regulation of 0.2% is possible without additional regulation circuitry.

In the simplified diagram, the input control circuitry consists of a voltage-controlled, free-running multivibrator which gates the transistor switch in the primary. The multivibrator compares a portion of the output voltage to a fixed reference voltage and generates pulses whose time duration is dependent upon the difference in compared voltages. These pulses are applied to the switching transistor which controls the current through the primary windings of the transformer. Through control of the pulse duration, regulation of the output is obtained.

The input control circuitry and the transistor switch also serve as the input dc-to-ac converter by chopping the input voltage. The transistor switch is either turned completely "off" or "on" in hard saturation. Hence, the switch consumes very little power.

The transformer uses a core which has a linear hysteresis curve. The primary and secondary windings are phased so that, when primary current flows, the secondary appears as an open circuit because the rectifier diodes are reverse biased. Only a small primary magnetizing current flows and power is stored in the core. When the transistor switch is opened, primary current

flow stops and the stored energy is transferred to the secondary windings. Secondary current then flows until all the stored energy is drained from the core. The process is repeated when the transistor switch is again turned on. If energy transfer takes place during primary current flow, a much larger primary current is required, and the power losses in the core are greatly increased.
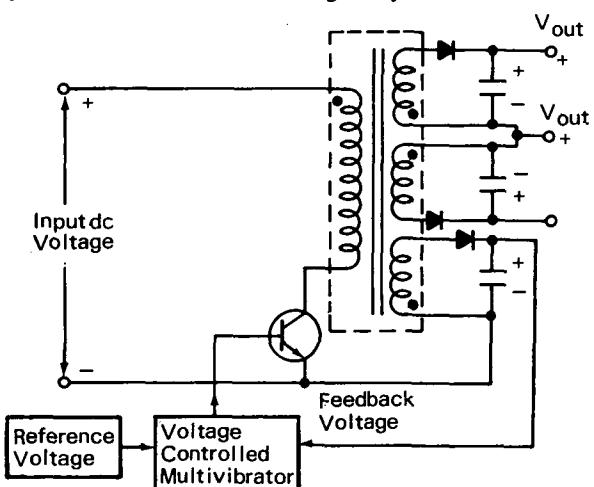
The voltage controlled multivibrator can have a constant frequency with variable duty cycle, or a constant pulse width with variable frequency. For equivalent circuit complexity, the constant frequency multivibrator offers better output regulation. However, the load output variation should be kept to a factor of about three to one from a nominal load value. This means that, for a nominal load resistance of 300 Ω, the load variation should be kept to within 100 to 900 Ω. The constant pulse width multivibrator with controlled frequency should be used for larger load variations. Any degree of load variation can be handled by this circuit.

Source: S. Gussow and H. Brey of
Sperry Rand Corp.
under contract to
Marshall Space Flight Center
(MFS-14392)

Circle 9 on Reader Service Card.

EFFICIENT, TRANSFORMERLESS, POSITIVE DC-TO-DC CONVERTER

The converter provides a source of lower positive voltage derived from a source of higher positive voltage without the use of transformers. Both voltages are referenced to a common ground. The lower voltage can be 1/2, 1/3, 1/4, etc., of the higher voltage.
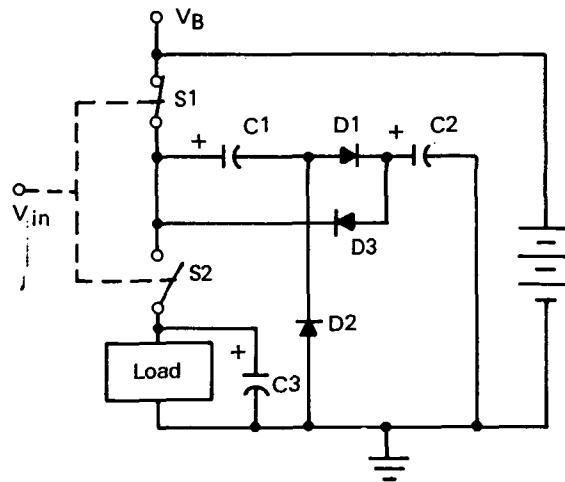
Switches S1 and S2 (transistors represented as switches) (see fig.) are turned either full on or full off at a frequency above 5 kHz. The switches are synchronized so that S1 is open when S2 is closed, and vice versa. The complete operation is as follows: With S1 closed, C1 and C2 charge to the positive battery voltage through the path provided by S1 and D1. If C2 and C1 have approximately the same value, the battery voltage divides equally across each capacitor. One-half cycle later, S1 opens and S2 closes. Both capacitors then apply their stored voltage across the load. C1 discharges through S2, the load, and D2. C2 discharges through D3, S2, and the load. Assuming ideal diodes and transistors, the voltage applied to the load is 1/2 of the battery voltage. Since the charge time-constant of the filter capacitor C2 is much less than the discharge time constant, the load voltage remains during the 1/2 cycle when C1 and C2 are charging. If less than 1/2 of the battery voltage is desired, more stages of capacitors and diodes may be added.

Source: F. J. Nola and E. H. Berry
Marshall Space Flight Center
(MFS-14301)

Circle 10 on Reader Service Card.

TRANSIENT SUPPRESSION IN DC INVERTERS

To keep the current transients from occurring in a dc inverter, a saturating magnetic core, L1, is connected to the bases of the power transistors Q1 and Q2 (see fig.). Transformers T1 and L1 are so designed that L1 saturates before T1, turning off the conducting transistor and turning on the nonconducting one. If T1 were to saturate in the inverter, current transients would appear in the collector of Q1 and Q2 and additional circuit losses would occur.

To design T1 for this dc inverter, the following equation is applied:

$$N = \frac{V_{in} \times 10^8}{4 \, F \, B_{max} \, A} \qquad (1)$$

where N is the number of turns, V_{in} is the voltage applied across the turns, F is the desired frequency of operation, B_{max} is the
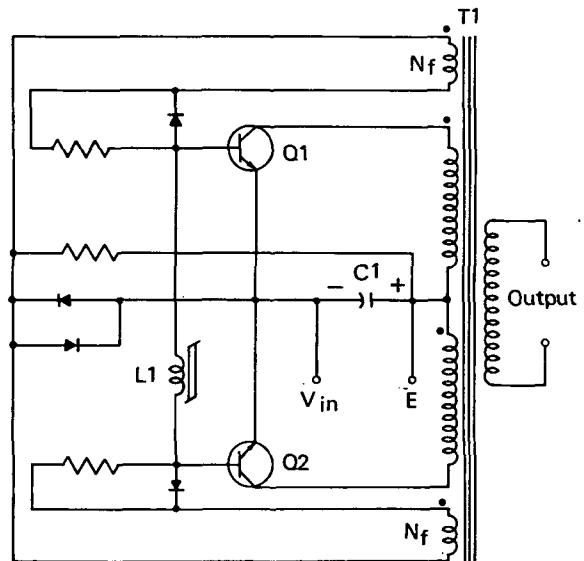
saturated flux density in gauss, and A is the *effective cross sectional area in square centime-*ters. To keep T1 from saturating, ·equation (1) ·is modified as follows:

$$N = \frac{V_{in} \times 10^8}{2/3\,(4\,F\,B_{max}\,A)} \qquad (2)$$

Once the turns N are determined, the remaining windings of T1 can be calculated from the voltage ratio requirements. A desirable voltage · range for the feedback windings is 2.5 to 3.5 V, allowing sufficient biasing of Q1 and Q2 without excess power losses.

The advantages of this design are simplicity and increased reliability. The connection of L1 to the bases of Q1 and Q2 provides the necessary control for eliminating the undesirable current transients. If a precise inverter frequency is desired, the windings of L1 can be modified to compensate for inaccuracies of core material and design approximations.

Source: W. D. Steele of
Sperry Rand Corp.
under contract to
Marshall Space Flight Center
(MFS-21194)

Circle 11 on Reader Service Card.

EFFICIENT DC-TO-DC CONVERTER ELIMINATES LARGE, STRAY MAGNETIC FIELDS

A converter avoids the excessive waste of power and the generation of stray magnetic fields by using two concentric cores with the same number

Primary and Secondary Windings

Outer Core

Inner Core   Secondary Winding

of magnetizing turns (see fig.). The inner core saturates before the outer core and provides the positive feedback for switching. To assure that

the magnetizing current is the same for both cores, the current in the feedback winding is minimized. A high input impedance amplifier is used to amplify the feedback signal. If Q1 is "on," a positive voltage is applied from B to A and a voltage is induced at C, keeping Q1 on. Since the inner core saturates before the outer core, the voltage at C collapses and Q1 turns "off". The flux in the inner core begins to change in the other direction, turning Q2 "on." Q2 remains "on" until the inner core saturates in the opposite direction.

After the inner core saturates, the rate of change of magnetizing current does not increase greatly because the flux in the outer unsaturated core can still increase substantially before the latter core saturates. Since the rate of change of magnetizing current is not increased greatly, the transistor turns off immediately after saturation of the inner core, and switching occurs.

Source: E. O. Tums of
Enrico Fermi Institute for Nuclear Studies,
The University of Chicago
under contract to
Goddard Space Flight Center
(GSC-463)

Circle 12 on Reader Service Card.

EFFICIENT, RELIABLE DC-TO-DC INVERTER

Certain types of primary electrical power sources have output voltages as low as one or two volts. A conventional practice is to step up the output voltage with a dc-to-dc inverter that employs large-area, high-current transistors.

mining loop-function interval. Other advantages include: (1) Total circuit switching time approaches the intrinsic transistor component rise and fall time; (2) overlap and switching inverter crossover ripple is minimized for a wide range of
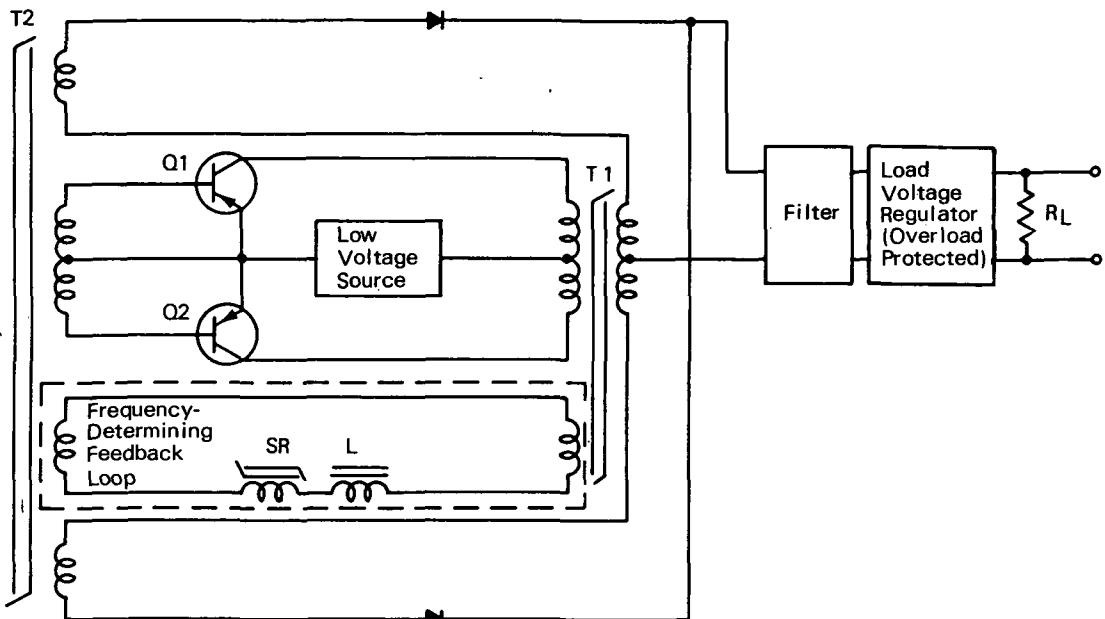
The long rise, decay, and storage times inherent in this type of transistor produce switching and circuit overlap losses which degrade inverter efficiency and reduce its operational lifetime. This problem has been eliminated by a novel frequency-determining feedback loop added to a standard inverter circuit, as shown in the schematic. The feedback loop contains an inductor, L, in series with a saturable reactor, SR; the proper value of inductance in this loop permits the inverter power transistors Q1 and Q2 to be switched in a controlled and efficient manner. It is important to note that this inverter design is protected against T1 core saturation effects as well as storage time overlap.

The dc-to-dc inverter can be used with a transformer current feedback inverter or with a voltage feedback-driven inverter, since the switchover is controlled only by the frequency-deter-

load demands and input voltages; and (3) proper base-drive current-shaping for optimum inverter performance is provided during the entire cycle.

The new crossover technique can be used with both high and low impedance sources. The base current control and shaping, used with push-pull oscillator inverters, improve total inverter crossover performance and eliminate most of the transient voltage and current spiking conditions normally present at the source output. Output ripple conditions at the load are also reduced without the need for additional filters. Thus, minimal input/output ripple can be obtained without incurring a size and weight penalty.

Source: E. R. Pasciutti
Goddard Space Flight Center
(XGS-06226)

Circle 13 on Reader Service Card.

CONVERTER PROVIDES CONSTANT ELECTRICAL POWER
AT VARIOUS OUTPUT VOLTAGES

The power converter transfers electrical energy at a constant rate from a dc source to a number of individual batteries which are to be charged one at a time. For some applications, the power converter can invert the polarity of the source

and provide the correct charging voltage, which may range from 3 to 25 V. The circuit uses an inverted flyback switching circuit as a means of transferring energy to the battery to be charged. Energy is stored in an inductor during the first part of the cycle and is released to the battery during the remainder of the cycle. The power (product of the input voltage and current) corresponding to the peak power point of the voltage vs. current characteristic of the dc source is transferred to the battery, and does not change as a function of battery voltage.

The saturable core transformer (consisting of three windings on one core) and transistor Q3 comprise the flyback switching circuit (see fig.). The transformer determines the energy-storage period of the inductor L. Q2 supplies

the initial turn-on pulse to Q3. At the end of the time required to energize the inductor (L), the transformer saturates. Under this condition, Q3 is turned off and the stored energy in L is passed to the output circuit which has pre-

viously been switched to the desired battery. During this charging period, the transformer core is reset through the transformer winding associated with resistor R2.

The operating level of the input voltage is determined by the input sensing circuit comprised of D1, R1, Q1, and D2. These components are selected for operation at the peak-power point on the voltage vs. current curve of the dc source. Resistor R1 limits the maximum current of Q1. A potentiometer may be substituted for R1 for setting the circuit to compensate for any variation in the peak power point of the source.

Source: J. Paulkovich
Goddard Space Flight Center
(GSC-519)

Circle 14 on Reader Service Card.

LOWER INPUT VOLTAGE DC-TO-AC CONVERTER

The dc-to-ac converter circuit shown is particularly suited for operation with a very low input voltage. Reliability is improved by eliminat-

ing current surges through the transistors. Efficiency is maintained with variations in input voltage and load current.

The operation of this circuit as a self-oscillating current-feedback converter depends on the combined effects of three nonlinear characteristics: (1) the current-voltage characteristic of the rectifying emitter-base junction of the transistors; (2) the current-voltage characteristics between the collector and emitter terminals of the transistors; and (3) the hysteresis loop of transformer T2. Transformer T1 serves merely as the output

+ Vdc Input
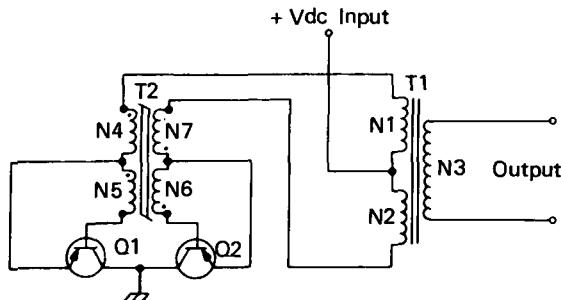
transformer for the inverter. The two transistors in this circuit, Q1 and Q2, are alternately turned on and off to apply the input voltage across turns N1 and then across turns N2 of the output transformer T1, inducing a square wave of alternating voltage in the output turns of N3. Switching of the transistors is caused by the cyclic saturation of the square-loop core of transformer T2.

Transformer T2, with its windings, is a saturable current transformer. With one transistor conducting and T2 unsaturated, the load impedance limits the transistor collector current, and the base current is dictated by the turns ratio, N4/N5 = N7/N6, of the current transformer. This ratio is chosen in accordance with the base-drive requirements of the transistors.

When transistor Q1 is conducting with given values of collector and base currents, its emitter-to-base voltage drop appears across N5 and establishes the rate-of-change flux in the core of transformer T2. Transformer T2 becomes saturated and N4 and N5 are decoupled. The base current to transistor Q1 then decreases and Q1 turns off. Some energy is stored in the core of transformer T2 after saturation. This energy is returned to the circuit and transistor Q2 is turned on. The circuit is self-oscillating and is symmetrical, with events in alternate half cycles being complementary.

It is important to use closely matched transistors to avoid a loss in efficiency. Transformers T1 and T2 are hand wound on saturable toroid cores. The oscillating frequency is given by the relation:

$$f = \frac{V_{be}}{4NAB_m} \times 10^8$$

where V_{be} is the base-to-emitter voltage, which is a function of the load current, and where $N = N5 = N6$, $A = $ the cross sectional area of core T2 in square centimeters, and $B_m = $ saturation flux density of core T2 in gauss.

Source: E. T. Moore and T. G. Wilson
Goddard Space Flight Center
(GSC-130)

Circle 15 on Reader Service Card.

Section 3. Current-Voltage Power Supply Regulators

CIRCUIT REGULATES VIDICON BEAM CURRENT

The circuit shown regulates the beam current of a vidicon camera in a television system and maintains the vidicon cathode at a constant potential.

The vidicon cathode potential is held constant by the reference diode D1, in the base circuit of Q1. D2 in series with D1 compensates for the base-to-emitter voltage variations of Q1.

The voltage drop across the emitter resistors, R2 and R3, is proportional to the sum of the vidicon cathode current and the emitter current of Q1. Since the beta of this transistor is

greater then 100, the base current may be neglected in computing this voltage drop. In operation, the circuit maintains V_{be} of Q1 constant. Any increase in the vidicon cathode current results n a decrease in the voltage drop across R2 and R3, tending to turn Q1 "on." This lowers the collector voltage and provides less base drive to Q2. When this occurs, the Q2 collector voltage increases to the value of the supply. The negative output is applied to the grid G1, and tends to cut off the vidicon to compensate for the increased cathode current. D3 protects the base-to-emitter junction of Q2 from reverse voltages, while D4 and D5 limit the maximum and minimum excursions of G1. C1 reduces ripple and noise on the sensitive G1 line.

The technique described may be used wherever the cathode current of a thermionic emissive device must be regulated and maintained at a constant voltage.
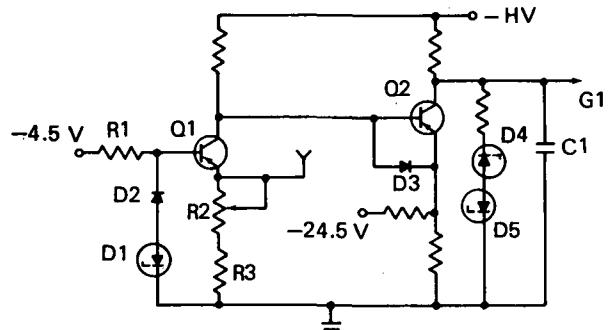
Source: Radio Corp. of America
under contract to
Goddard Space Flight Center
(XGS-10023)

Circle 16 on Reader Service Card.

CURRENT-LIMITED DC SERIES REGULATOR

The current-limited dc series regulator shuts off a series regulated power supply when a steady state overload is present. The circuit (see fig.) also senses the removal of the overload condition, back on automatically when the current has been restored to a safe value.

If an overload condition is present for the length of time required to charge C (through R2
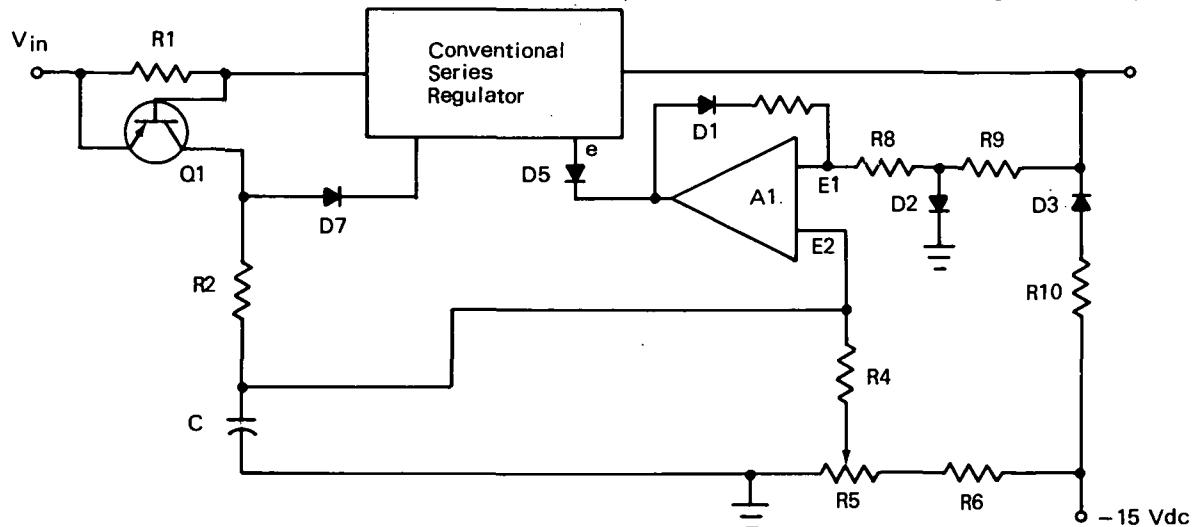
and automatically resumes normal operation. The unique feature of this circuit is that it shuts off the regulator circuit to avoid excessive power dissipation in the regulator, and senses the load on the output to allow the regulator to turn and Q1) to a voltage level higher than E1, the output of amplifier A1 is driven negative. D1 becomes reverse biased and the loss of the feedback signal causes E1 to decrease, depending on the nature of the overload. The negative output

of A1 is coupled into the series regulator to reverse bias the transistors and cut off the regulator. Since no output current flows with the regulator cut off, Q1 also turns off. A1 is held in the negative output state long enough for the output voltage of the regulator to drop to zero after it cuts off. When the output goes to zero, E1 is reduced to a very low value, the biasing amplifier output goes negative and the regulator turns off.

Once the regulator is turned off, due to overload, a small amount of bleeder current is provided to the load through R10 and D2. D3 is used to keep the output voltage from feeding back into the +15 V supply during normal operation of the regulator. When the overload condition is removed, the current through R10 and D3 develops a small voltage cross the load. If the load is restored to a safe value, the voltage developed across the load makes E1 more positive than E2, providing positive feedback which turns on the regulator.

Source: D. J. Dixon and R. T. Mattle of General Electric Company under contract to NASA Headquarters (HQN-10342)

Circle 17 on Reader Service Card.

REGULATOR CIRCUIT PROVIDES INPUT-OUTPUT ISOLATION FOR HIGH VOLTAGE

Complete isolation is provided between the input voltage and the control circuits of the regulator shown. This is particularly important in applications where a common connection between the output and input of a system is not permissable. The circuit has proven useful in a regulated high voltage power supply where the voltage to be measured was 2500 Vdc and isolation between this voltage and the control system voltage was necessary.

The operation of the circuit is as follows: The output voltage V between points A and B, or the current through R between points B and C, develops a voltage across C1. This voltage is impressed across R1 and C2, causing C2 to charge to the value of the voltage on C1. When

the breakdown voltage of the four-layer device D1 is reached, D1 conducts and allows C2 to discharge into the primary of the pulse transformer T1. The pulse appearing on the secondary of T1 is rectified by D3 and filtered by C3 and R2 to an average value. When the charge on C3 exceeds the voltage of the reference diode D4 a current flows through R3 into the base of Q1, causing Q1 to conduct. The state of conduction of Q1 is used as the error signal between ·points D and E that is fed back to other circuits to provide accurate control of the voltage from A to B (or the current from B to C). A change in the error signal changes the pulse frequency of D1, which in turn increases the conduction of Q1.

MOSFET IMPROVES PERFORMANCE OF POWER SUPPLY REGULATOR

The circuit shown provides a higher degree of power supply voltage regulation and temperature compensation than a conventional circuit using
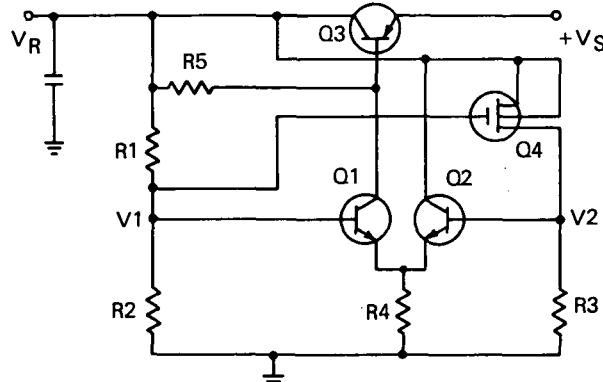
a zener diode as a voltage reference. The improvement is made possible by using a MOSFET, Q4, as the voltage reference in place of the zener diode. As in the case of the conventional regulator, the improved regulator utilizes a bridge circuit R1, R2, Q4 (in place of a zener diode) and R3, and a difference amplifier consisting of Q1, Q2, and R4, with R5 allowing initial operation at power turn-on. The regulator performance is determined by the voltage difference between V1 and V2 produced by a change in regulator supply V_R. The difference amplifier gain and the current gain of transistor Q3 amplify this voltage difference to determine the closed loop performance. Cross coupling of the gate of Q4 to the base of Q1 allows Q4 to serve also as an additional amplifier.

HIGH-EFFICIENCY STEP-UP REGULATOR

An improved step-up regulator, developed for a power supply which operates from an input of 28 ± 4.2 V, provides a constant output of 35 V from the variable input. The single-ended, step-up regulator-chopper power supply combines the advantages of chopper and switching regulator circuits to achieve a conversion efficiency of 97%.

The step-up regulator, which converts the input to a 35 V output, consists of Q1, Q2, R4 and C2. The 35 V can be held within ±0.25 V without the use of filtering. The output from the step-up regulator is applied to the chopper section (Q3, Q4, R4 and R5) where the inductance of the transformer in the chopper tends to eliminate the spikes from the regulator. Since
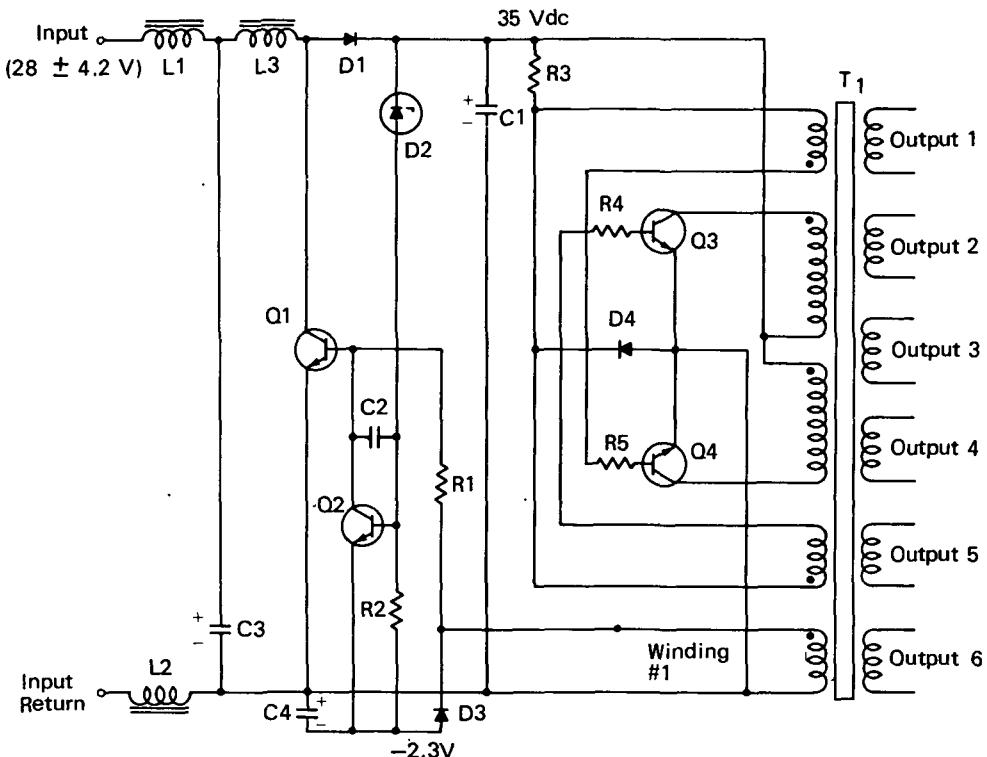
the chopper operates at 35 V, instead of the customary 18 V, the current in the primary of T1 is reduced to one-half, resulting in less heat dissipation and greater efficiency.

The voltage drop across the series regulators in the output circuits can be maintained at 1.0 ±0.003 V. Six isolated outputs are available at the secondary of T1.

Circle 19 on Reader Service Card.

CURRENT-LIMITING VOLTAGE REGULATOR

A voltage regulator operates within preset current limits and acts as a circuit breaker to prevent overload failure. Automatic reset occurs when the overload is removed.

Normal voltage control is accomplished by the voltage sampling circuit consisting of Q4, R4, R6, C2, R7, R5, and zener diode D1. An increase in the output voltage V_o causes an increase in the current through Q2, resulting in an output voltage drop to the level set by R4.

Transistor Q3 is the current-limiting control device. Current sampling resistor R12 controls the current available through D4 to the base of Q3.

Zener diode D4 is forward biased as a conventional diode except under very light load conditions. Under normal operating conditions, Q3 performs as an output-voltage regulating element to supplement the action of Q4. The current limiting level is controlled by the choice of R9, and the combination of R9 and R3 sets the operating level at the emitter of Q3 below current-limiting levels. Above the current-limiting level, the combination of R9, R10, and R3 sets the voltage at the emitter of Q3 such that, when Q1 is shut off, excess power is dissipated in the parallel circuits of R1, R3 and Q2, and R10,
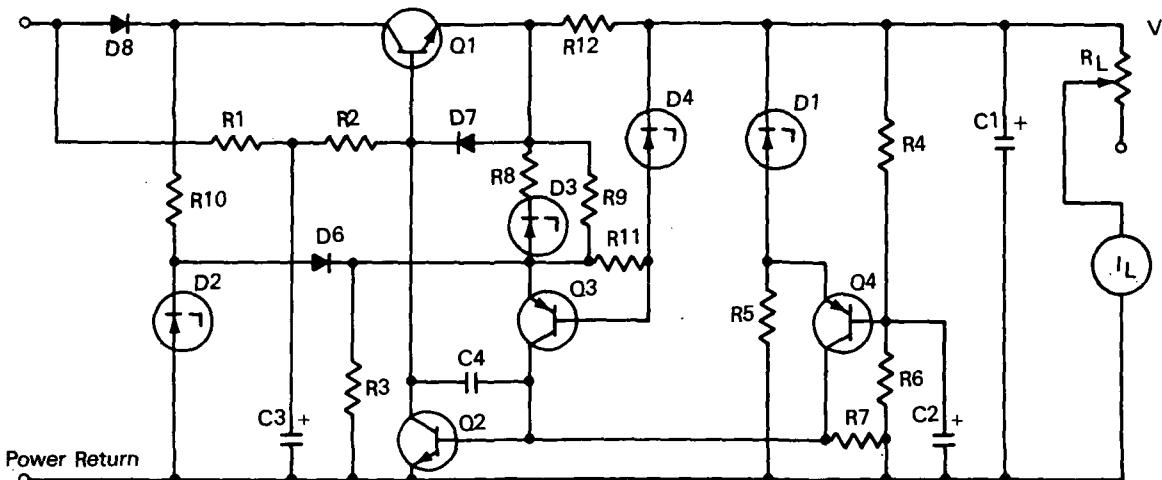
D6 and R3. The combination of R8 and D3 and the elements D7, R11, and D4 serve to provide temperature compensation.

An important feature of this circuit is the approximately constant power dissipation in the series transistor Q1, from normal load to short-circuit condition. In the conventional current-limiting approach, the power dissipation of Q1 increases from normal load to short-circuit condition.

Source: E. F. Cleveland of Lockheed Electronics Co. under contract to Manned Spacecraft Center (MSC-11824)

Circle 20 on Reader Service Card.

Section 4. Overload Protection Circuits

ELECTRONIC WARNING SYSTEM FOR MECHANICAL STRUCTURES TEST OVERLOADS
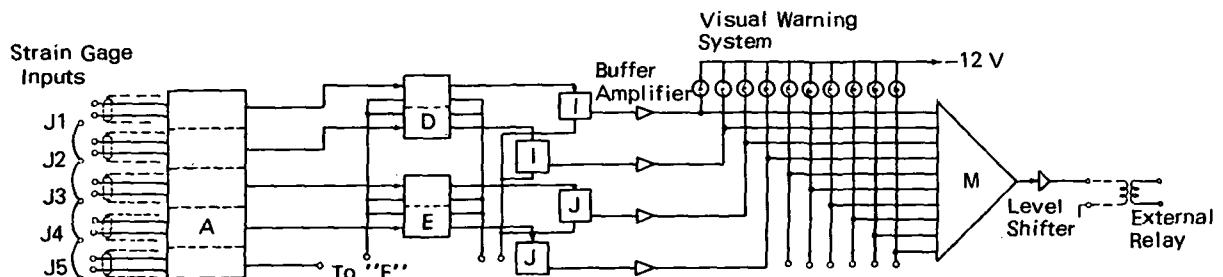
Mechanical components undergoing structural integrity tests can be damaged if overloaded by a driving force (hydraulic power supply). With the use of strain gages applied to critical load-carrying links and electrically connected to the visual warning system shown in the schematic, the forcing operation can be removed before damage occurs.

The mechanical members are selected for critical load-path transmission and are monitored with

strain gages connected to a recorder. The gage outputs are individually buffered, amplified, and then applied to Schmitt triggers for transmission into a lamp-driver circuit. When an overload condition occurs in one of the members, the appropriate lamp lights up indicating a pre-selected danger level. The lamp-lighting circuits are controlled by relays which also apply

control signals to shut off the hydraulic power source of the forcing function.

Source: P. G. Smith of
North American Rockwell Corp.
under contract to
Manned Spacecraft Center
(MSC-11441)

Circle 21 on Reader Service Card.

TWO-LEVEL VOLTAGE-LIMITER PROTECTS BATTERIES FROM OVERCHARGING

The two-level voltage-limiter operates in conjunction with a constant-current charge source and a battery. Initially, all of the current from

level, additional circuitry within the limiter is activated to produce a new (and lower) voltage limit. This new voltage limit is chosen so that
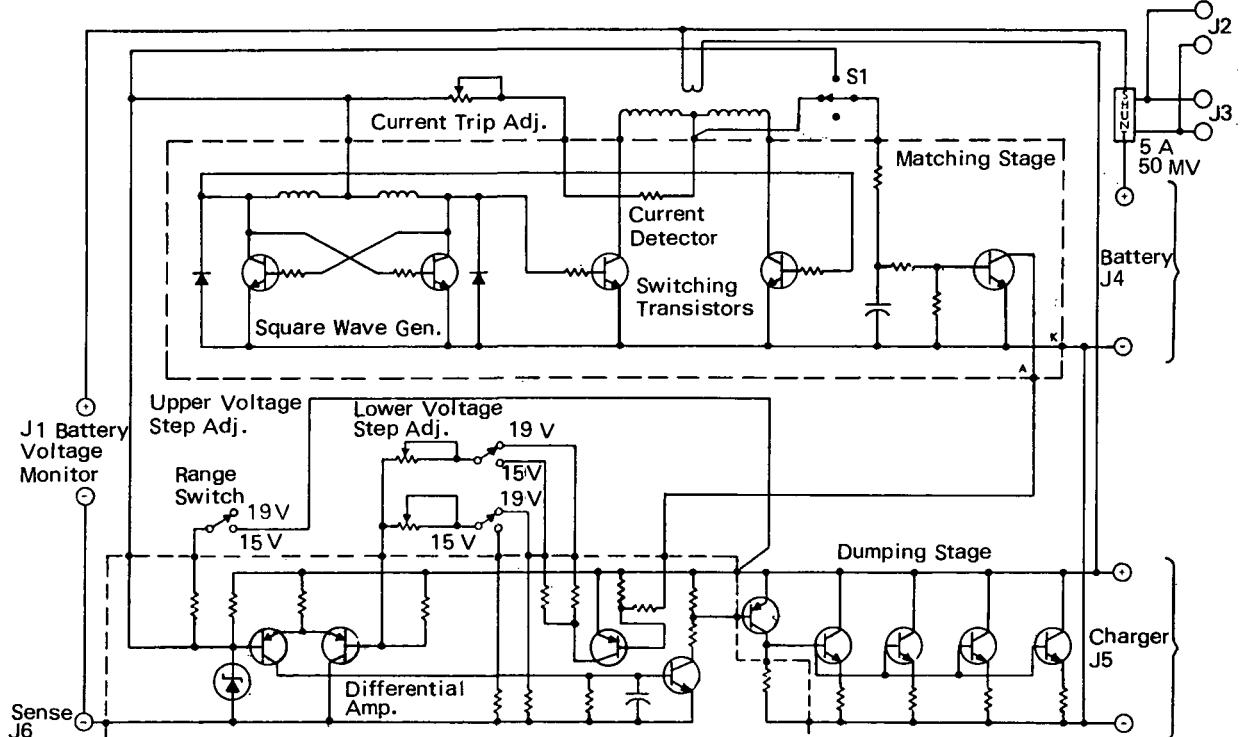
the source flows into the battery. As the battery charges and the voltage rises to a predetermined level of 19.6 V, the voltage limiter starts to divert a portion of the charging current from the battery. At this point, a further rise in battery voltage results in the diversion of more current, which results in less current to the battery. When the battery current is reduced to low

all of the current from the source now flows through the voltage-limiter and the battery current is reduced to zero.

Source: N. H. Potter and R. L. Morrison
Goddard Space Flight Center
(GSC-10696)

Circle 22 on Reader Service Card.

OVERVOLTAGE TRIP-OUT FOR VARIABLE DC POWER SUPPLY

The overvoltage, trip-out delay for a variable dc power supply prevents the removal of input power during sudden decreases of the dc output voltage.
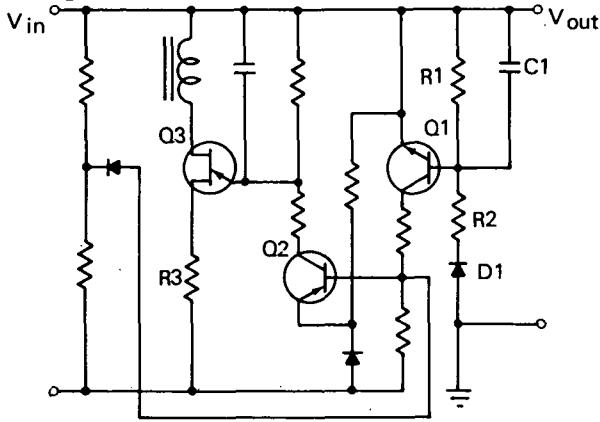
The voltage divider, R1, R2, and D1 (see fig.), provides the proper biasing to transistor Q1. Should the output voltage suddenly be lowered by an external operation, the capacitor C1 will prevent instant turn on of Q1. Approximately 10 msec elapse before C1 is fully charged, allowing Q1 to turn on and actuate the over-voltage device. By this time, the output voltage has decreased sufficiently to prevent the over-voltage sensor from being actuated.

Source: North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-16948)

Circle 23 on Reader Service Card.

UNDER-VOLTAGE CIRCUIT

An under-voltage, cut-off circuit acts quickly to shutdown a power supply when a sudden voltage drop occurs. The power supply is so designed that removal of a frequency reference reduces the output to zero. The under-voltage cut-off is essentially a complementary flip-flop in which both Q2 and Q3 (see fig.) are in the conducting state. Q2 is normally saturated and, in this state, provides the ground return for buffer amplifier Q1. The circuit is supply-voltage sensitive so that, when the minus 12 Vdc output is reduced to a preset level, Q2 becomes unsaturated. The flip-flop then drives itself into a non-conducting condition whereby both Q2 and Q3 are turned off. The action occurs in a few microseconds once the cut-off level is reached. The ground return for Q1 is thus opened, and the frequency reference input to the power supply is removed, thereby shutting off all outputs and removing the dc supply from the under-voltage cut-off circuit.

To restore operation, the return path for Q1 is reestablished through a control relay. Capacitor C1 makes the circuit immune to bus voltage transients or momentary losses of the frequency reference by providing a sufficient time constant

to sustain Q2 in the saturated state for approximately 0.1 sec.
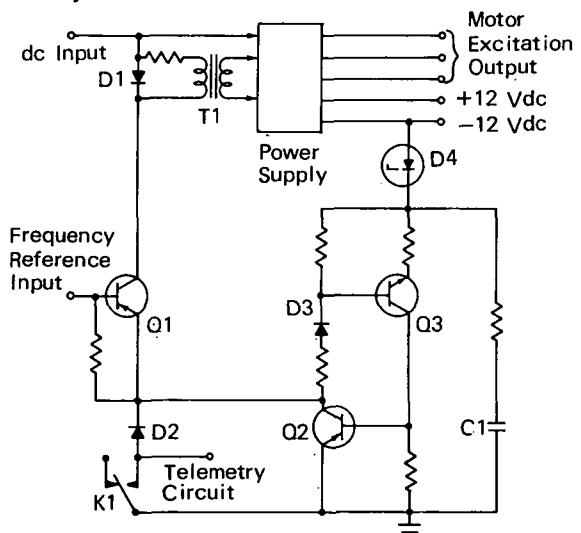
Source: T. Wood of
Sperry Rand Corp.
under contract to
Goddard Space Flight Center
(GSC-10139)

Circle 24 on Reader Service Card.

CIRCUIT PROTECTS REGULATED POWER SUPPLY
AGAINST OVERLOAD CURRENT

A tunnel diode controls a series-regulator to protect a low-voltage transistorized dc supply from damage by excessive load currents. R4, Q3 and D3 (see fig.) form the series-regulator
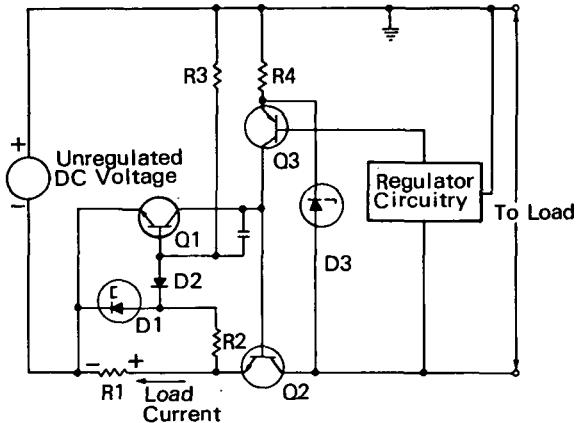
driver stage, and Q2 is the regulator series element. In case of overload, the overload circuit, composed of R1, R2, R3, D1, D2, and Q1, shunts the base current of Q2 through Q1,

thereby shutting off Q2 and limiting the fault current. The volt-ampere characteristics of D1 are used to provide the voltage threshold detection and the voltage across R1 is used to detect the magnitude of the load current.

Typical changes of the threshold-detection current are ±10% over a range from 273 to 343 K (0° to +70° C). Any change with temperature in the base-emitter voltage threshold of Q1 is compensated for by a similar change in the threshold voltage of D2. This circuit provides sharp detection of overload currents at very low voltage levels and limits the short circuit current to less than 10% above the detector threshold current.

Source: H. B. Airth of
Westinghouse Electric Corp.
under contract to
Goddard Space Flight Center
(GSC-453)

Circle 25 on Reader Service Card.

IMPROVED LIMITER FOR TURN-ON CURRENT TRANSIENT

This circuit limits the turn-on current transient to a specified amplitude and provides a low-impedance path between supply voltage and load

The new circuit (see fig.) automatically controls the initial peak current that can flow into a high-capacity load when voltage is applied.
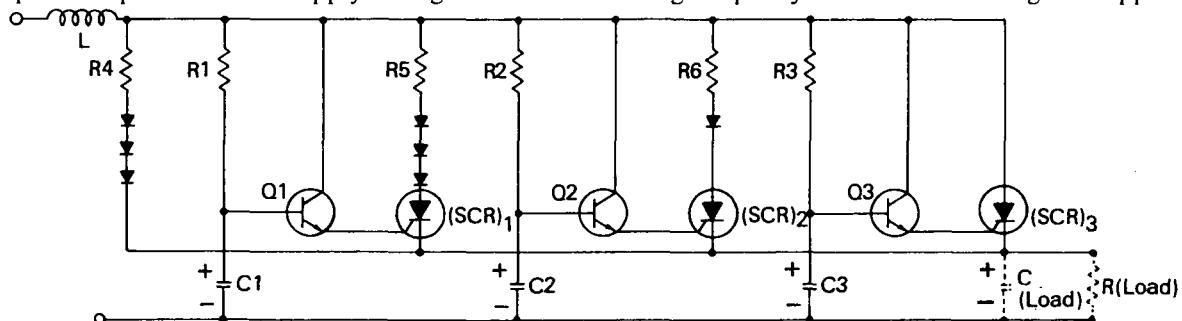
after a prescribed time interval. The circuit offers a wide range of flexibility in adjusting the peak current and the time to complete the connection to the load. It is more compact and lighter than a comparable limiter circuit which uses a large choke.

Peak-current limiting is controlled by the values of resistors R4, R5, and R6, and the time for completion of the cycle is determined by the time constants R1C1, R2C2, and R3C3. The small choke, L, offers a high impedance to small stray-capacity charging currents and short-

duration voltage changes. When power is removed, the sequence of steps is automatically ready for the next power turn-on.

In one modification of the basic circuit, a relay (switched on by SCR3) is used to eliminate the unnecessary gate current.

Circle 26 on Reader Service Card.

Section 5. DC Constant-Current Power Supplies

TEMPERATURE-COMPENSATED, CONSTANT CURRENT SUPPLY

The current supply is designed to maintain a constant output current for temperature changes as great as 413 K (140° C). Unlike conventional power sources, which have a nonlinear change in current as a function of temperature, this circuit has a current which increases (or decreases) linearly as the temperature changes.

The temperature coefficient of the current source can be determined by analyzing the equivalent circuit schematic shown in the figure. A constant current is maintained through resistor R1 if the voltage across it is constant. This voltage is determined by amplifier A and the resistor ratio R2/R3. The relative gain-error of amplifiers A and B is fed back to the input of amplifier A. To ensure a constant voltage across R1, it is only necessary to set the ratio R2/R3 to provide the correct gain error associated with amplifiers A and B. Amplifier B has a high input impedance and maintains a small but constant current drain through R.

The supply output current increases linearly with increases in temperature if the ratio of resistor R2/R3 is made less than one; con-
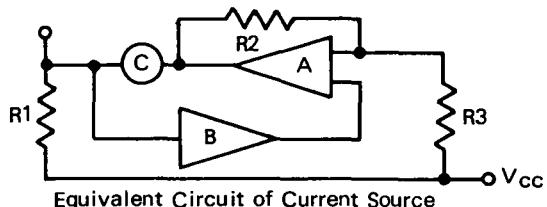
Equivalent Circuit of Current Source

versely, the supply output current decreases linearly with increases in temperature if the resistor ratio is greater than one. The amount of current increase or decrease for changes in temperature is dependent on the relative ratio.

Circle 27 on Reader Service Card.

MAGNETICALLY COUPLED EMISSION REGULATOR

A new type of high performance emission regulator provides a constant current for ion sources. A magnetic amplifier provides dc isolation between input and output circuitry, with a significant reduction in circuit complexity. This innovation has particular application in the design of electronic power supplies for use in mass spectrom-

eters, vacuum ionization gages and similar instrumentation.

High voltage isolation is achieved through the use of magnetic coupling between the input and the power handling circuits (see fig.). A feedback regulator, consisting of an error sensing amplifier and zener reference, samples the ion

source bias current and provides deviation signals to a magnetic amplifier pulse modulator. The pulse modulator controls the dc to ac power inverter, which in turn controls the emission current.

Drive voltages (20 V peak-to-peak at 5 kHz) are applied to the primary of the magnetic amplifier T2, through blocking diodes D1 and D2. The secondaries bias the transistor power switches Q1 and Q2 "on" for equal periods, determined by the pulse source. The length of the periods is determined by the amount of current flowing from the error amplifier, Q3 and Q4, through the magnetic amplifier control winding. The input to the isolated error amplifier is derived from the voltage difference between the zener diode D3 and the voltage across R3 caused by the electron collector current. As a function of this control current, the magnetic amplifier goes into saturation at some point during either half-cycle period. The inrush of current through the primary increases the voltage drop across R2, reducing the primary voltage. The secondary voltage is thus reduced until the appropriate power switch is turned off.

The phasing of the error correction loop is such that an increase in current (appearing as a negative going voltage at the junction of Q3–R3) tends to cause a decrease of the "on" periods of the power switches.

Power transfer efficiency has been measured at 93% with a 2.5 A filament load. The regulator, as designed, can handle filament currents up to

3 A. The emission current can be regulated from 10 μA to 100 μA with a total regulation error of 0.1%.
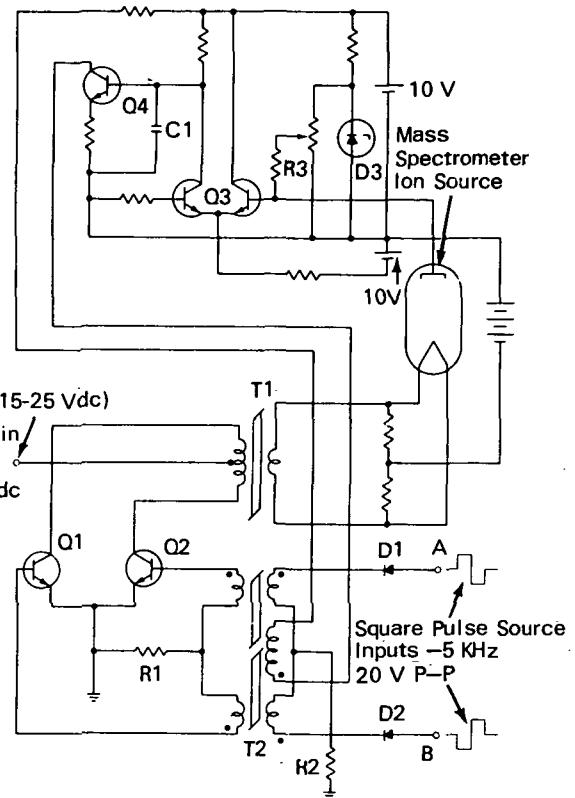
Source: Consultants and Designers
under contract to
Goddard Space Flight Center
(GSC-10056)

Circle 28 on Reader Service Card.

OPERATIONAL CURRENT SOURCE
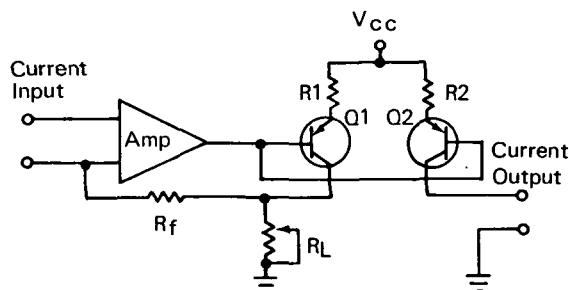
Through the use of a matched, dual bipolar transistor, the output of an operational amplifier is converted to a current source suitable for

driving a low impedance such as a voltage-to-frequency converter.

The circuit (see fig.) provides an output current proportional to the input current. R_L and the feedback resistor are selected for a given input current range, and R1 and R2 are selected for a given output-current range. The current flowing through R1 is equal to the current through R2 since Q1 and Q2 and R1 and R2 are matched components. Therefore, the collector current of Q1 is equal to the collector current of Q2. Adjusting R_L provides control over the current sen-

sitivity of the amplifier. The amplifier could be an electrometer or a similar amplifying device. The active input is not at ground potential in applications using an input current source. Typical output currents range from 1 to 1000 μA, although lower input currents may be used if the amplifier is stable.

CONSTANT-CURRENT SOURCE CONVERTS TEMPERATURE TO ANALOG VOLTAGE

Temperature sensor devices such as thermistors, diodes, and carbon resistors require an extremely accurate current supply in order to generate an analog output voltage. Normally, a large power supply is required as the energy source. A novel current source has been designed which is economical, stable and accurate. The circuit (see fig.) contains a matched differential amplifier, Q1, a temperature-compensated zener diode, D1, and a field-effect transistor, Q2.

Excellent voltage regulation is maintained across D1 by the use of Q2 as a constant current source. Resistor R1 is selected so that I_c compensates for the desired temperature range.

For a resistance variation between 50 and 1500 Ω, the accuracy obtained is 0.43%. Temperature changes over a range of 248 to 363 K ($-25°$ to $+90°$ C) create an error of less than 0.08%.

Constant Current Source
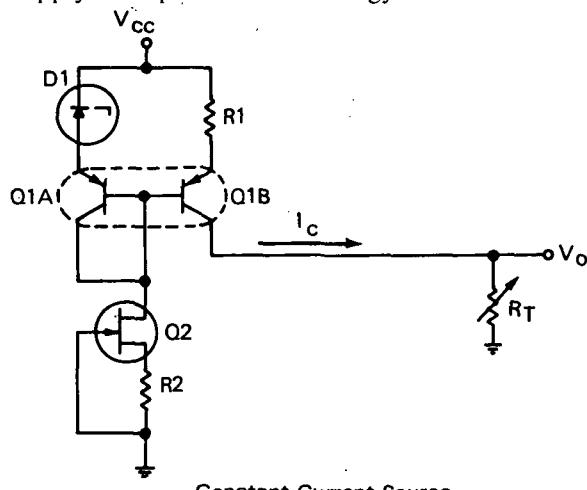
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conducted so as to contribute . . . to the expansion of human knowl-
edge of phenomena in the atmosphere and space. The Administration
shall provide for the widest practicable and appropriate dissemination
of information concerning its activities and the results thereof.*"

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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