SUGGESTED POWER SUPPLY CIRCUITS

for the

TM 500 BLANK PLUG-IN KIT

1 WIDE (040-0652-01)
2 WIDE (040-0754-00)

Section A—General Instructions

Section B—Selector Guide

Section C—Circuit Descriptions

Each circuit description includes schematic construction notes and other pertinent information. For accomodation to various current/power levels and other common factors, refer to Section D.

Section D—General Construction Notes

A set of notes describing subcircuits generally applicable to many of the circuits in Section C; plus other general information applicable to most of the circuits in Section C.

The selector guide is a matrix table which shows various voltage levels and polarities of supply, all attainable with a variety of circuit devices.

IMPORTANT

Observe all CAUTION notes and use all applicable safety procedures in designing and constructing your power supply.

DISCLAIMER OF RESPONSIBILITY

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SECTION A

(1) General Instructions

Users of TM 500 blank plug-in kits will find that most power supply requirements can be met by using one or more of the circuits described here. They are chosen for simplicity, reliability, component availability, and moderate cost.

Supply Use:	Desired Voltage	3-Terminal IC's	µA 723C MC1723 C	Op Amp	Discrete	TYPE
Bipolar Logic	5 V	01-1	10-1	20-1	30-1	P
Linear MOS	5 to 20 V	02-1 04-3	11-1 11-2	21-1 21-2	31-1	O
	20 to 50 V	02-2	14-1	22-1 22-2	32-1	S
Bipolar Logic	5 V	03-1	12-1	23-1	33-1	N
Linear MOS	5 to 20 V	04-1 02-3	13-1 13-2	24-1 24-2	34-1	E
	20 to 50 V	04-2 02-4	14-1	25-1 25-2	35-1	G
			RM 4194			
Linear MOS	5 to 20 V		15-1	26-1	36-1	D
	20 to 50 V			27-1	37-1	U A L

Circuit Selector Guide

Special supply requirements may dictate other circuits, and an almost unlimited number of designs is possible. Users should feel free to use other designs, being sure to take into account mainframe ratings as given in the kit instructions.

(2) Major/Minor Power Requirements

An important step in supply design is to determine the number of regulated voltages required and the amount of current each must deliver. Each compartment in a mainframe gives access to two series-pass transistors (one npn and one pnp) capable of major-supply current and wattage. If more than two supplies are needed, the major supplies should be designed to use the mainframe transistors; the minor supplies will need their own pass devices in the plug-in.

(3) Selector Guide

The next section of this application note will aid in the selection of circuits. There are tables for positive, negative, and dual supplies. Each table refers you to an appropriate circuit based on (1) voltage level, and (2) type of devices preferred or available. Most of the circuits are capable of a wide range of current/wattage levels depending on the type of pass device and the method of heat sinking. To reduce the total number of circuits described, variations based on current/wattage levels are described in Section D.

SECTION B

NOTE
Each vertical column in the selector guide constitutes a group of circuits using related techniques. When evaluating an individual circuit, it is a good idea to read the introduction to that subsection. Also examine any other circuits in the subsection which may be referenced.

3-Terminal IC Regulators

General

A number of semiconductor manufacturers offer families of 3-terminal ic devices that require only raw or preregulated dc input voltage to form a complete regulated supply. Typically, these ciruits include a reference voltage and amplifier, an error amplifier, an output power (pass) transistor, and current-limit and overtemperature circuits. Each device has its own fixed output voltage and current limit. However, since maximum current varies with package size and heat sinking, added external components make it possible to vary output voltage, increase current capacity, or form a current source rather than a voltage source.

This application note makes reference only to simple applications with few external components. Also, it lists only a few of the more recent medium current families. By referring to manufacturer's data sheets and this note, applications of other types should be straightforward. Your main concerns with these devices will be that:

(1) The minimum value of the raw supply voltage must by high enough to maintain regulation. (A typical requirement is a 2-V minimum input to output differential.)

(2) The maximum value of the raw supply voltage should not exceed the device's rating (which can be a problem; this note shows how to connect external protective components).

(3) The current rating of the raw supply should be compatible with that of the ic. 3-terminal ic regulators represent the easiest way to achieve regulated voltage in TM 500 applications, particularly for 5-V bipolar logic supplies.

Performance Summary

The performance of the 3-terminal ic regulators varies somewhat with voltage and family. Refer to the manufacturer's data for specific details. The following specs do not exactly describe any one device, but typify the performance level to be expected:

78XX

1	Input
3	GRD
2	Output

79XX

1	GRD
3	Input
2	Output
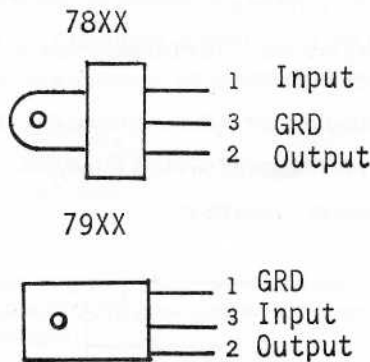
1. Voltage accuracy — 4% of nominal

2. Line regulation — 1% max; 0.25% typical[1]

3. Load regulation — 0.5% max; 0.3% typical

4. Ripple rejection — 60 dB[1]

5. Output current — 1 A cont; 2 A peak[2]

6. Tc of output V — -1.0 mV/°C

7. Maximum input voltage — 35 V[3]

8. Minimum input-output differential (ripple trough to actual output) — 2 V[4]

9. Built-in current limiting

10. Built-in thermal shutdown

NOTES

[1]The effect of line voltage and ripple voltage is greatly reduced if the input voltage is taken from a preregulated supply.
[2]Device rating only; refer to TM 500 Mainframe ratings to determine overall capability.
[3]Except for 5 V logic supplies, raw dc from a TM 500 Mainframe may exceed this value. Use a preregulated supply or a series dropping device to protect the ic; refer to the schematics.

[4]This requirement should normally be met in the applications shown in the following schematics.

WARNING

Be sure to observe proper polarity of all capacitors and make sure you do not physically block the vent of any capacitor you use.
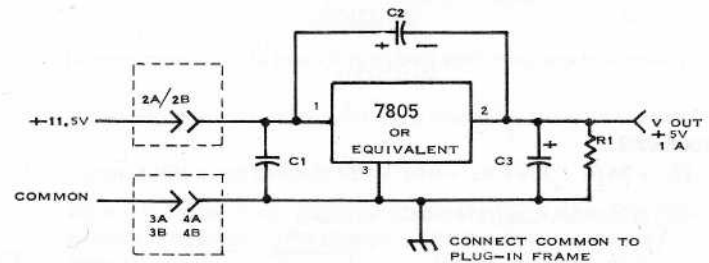
SECTION C-1

Circuit 01-1

(1) + 5V logic supply using a 3-terminal ic.

(2) Typical devices:

Fairchild Semiconductor: µA 7805 C
Motorola Semiconductor Products, Inc.: MC7805 C

National Semiconductor: LM 340-05 or 7805 C equivalent

C1: Decouples transients to and from mainframe. 0.1 µF typical, 15V min

C2: Suppresses oscillation. 4.7 µF typical, 15V min

C3: Output bypass, reduces transients. 10-10 µF typical, 10V min

R1: Improves regulation in case of low load currents 200Ω, 1/8W, 10% typical

Heat sink ic to plug-in rail if maximum current capacity is required (TO-220 package), or use large, fingered radiator (TO-3 package). Refer also to text.

Circuit 02-1

(1) + 6 to + 18 for linear circuits, MOS.

(2) Typical devices:
Fairchild Semiconductor: µA 78XX C

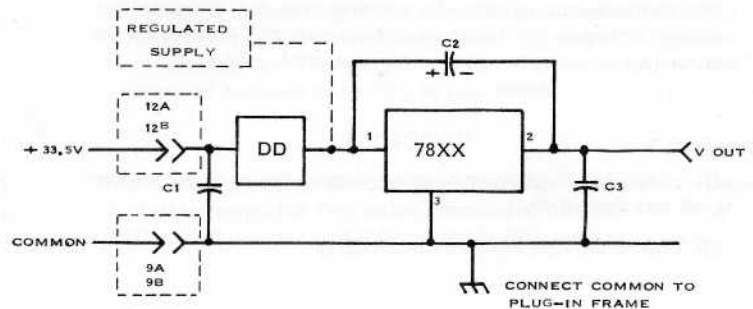Motorola Semiconductor Products, Inc.: MC78XX C

National Semiconductor: LM 340-XX

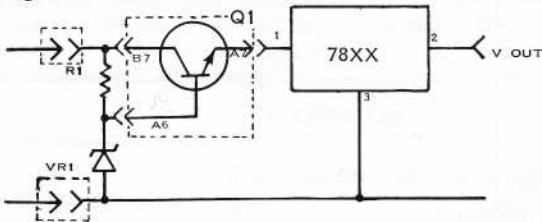| 7806 — 6V |
| 7808 — 8V |
| 7812 — 12V |
| 7815 — 15V |
| 7818 — 18V |

C1, C2, C3: See Circuit 01-1.

DD: Dropping device for overvoltage protection

(a) Use fixed resistor if load is steady. Calculate resistance for 5V drop and wattage as > 25/R.

(b) Zener may be used if current varies widely. Use 5-V zener of adequate wattage rating at I_{max}

(c) For best results, use preregulated supply or simple pre-regulator.

Select VR_1 to be 3 to 6V greater than V_{out}.

For maximum current: Heat sink TO-220 package to rail or use large, fingered radiator with TO-3 package.

CAUTION

Lower voltage units may overheat if used at maximum current.

Circuit 02-2

(1) +24 to +36V (i.e., +6 to +18V stacked on +18V supply)

(2) Typical devices (refer to Circuit 02-1)
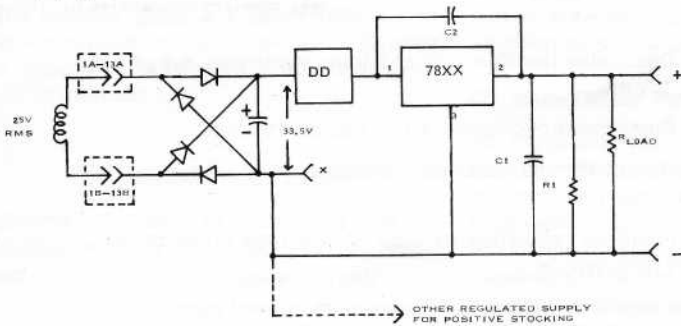
(a) Refer to circuit 02-4 (the same circuit, but with the positive side referenced to a negative supply).

(b) Since these circuits are powered from a floating secondary winding of the mainframe transformer, they may be elevated by connecting either the positive or negative output terminal to an elevating voltage. Both floating windings may be used to construct higher voltage, floating or ground-referenced supplies, according to your needs.
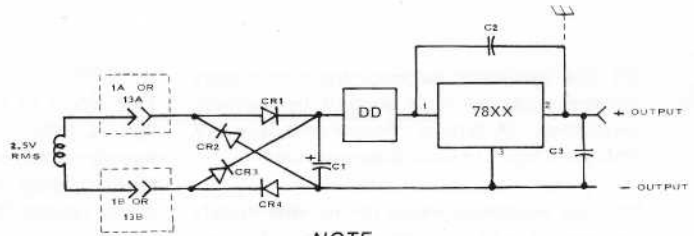
CAUTION

The current-limiting circuits are effective for currents conducted between the two output terminals but may not be effective for currents conducted through other paths.

Circuit 02-3

(1) −6 to −18V floating or negative supply (for positive counterpart, see Circuit 02-1).

(2) Typical devices (refer to Circuit 02-1):

NOTE

Use of the 25V rms ac windings (which are not grounded) permits floating operation of such a supply like this, but with the positive side of this supply ground, it becomes a negative supply.

C1: 50V minimum, capacitance according to load current (at least 500μF per 100 mA)

C2, C3: Refer to Circuit 01-1

DD: Refer to Circuit 02-1

CR1, 2, 3, and 4: Bridge rectifier, 100V minimum, 750 mA minimum, or 4 silicone diodes with similar ratings, eg., 1N3194. Current Rating: 500 mA maximum. (Mainframe limited.)

NOTE

For maximum current, be sure to HEAT SINK TO-220 package to rail, or use large, fingered radiator with TO-3 package.
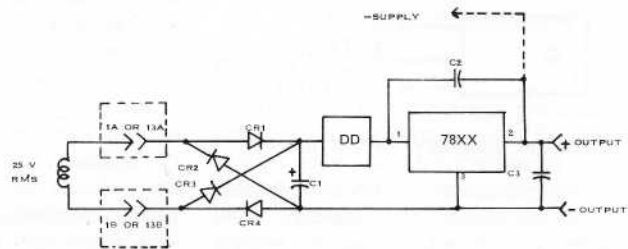
CAUTION

Lower voltage units may overheat if used at maximum current more readily than the higher voltage units.

Circuit 02-4

(1) −24 to −36 V (i.e., −6 to −18 stacked on −18 V supply)

(2) Typical devices: (Refer to Circuit 02-1)

(a) Refer to Circuit 02-2, (i.e., same circuit, but with negative side referenced to a positive supply)

(b) Since these circuits are powered from a floating secondary winding of the Power Module transformer, they may be elevated by connecting either the positive or negative output terminal to an elevating voltage. Both floating windings may be used to construct higher voltage, floating voltages or ground referenced supplies according to your needs.

CAUTION

The current limiting circuits are effective for currents conducted between the two output terminals, but may not be effective for currents conducted through other paths.

Circuit 03-1

(1) –5 or –5.2 V logic supply

(2) Typical devices: Fairchild Semiconductor:
μA 7905 C
μA 7905.2 C

Motorola Semiconductor Products Inc.
MC 7905 C
MC 7905.2 C

COMMON

CONNECT COMMON TO
PLUG-IN FRAME
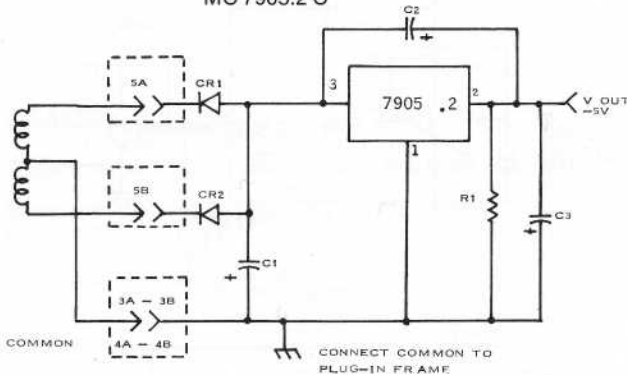
(2) Typical devices: National Semiconductor
(cont) LM 320-05
LM 320-05.2

CR1/CR2: 30 V minimum, 1 A minimum.

C1: 15 V minimum, at least 500 μF per 100 mA

C2: 15 V minimum, 4.7 μF typical: suppresses oscillations

C3: 10 V minimum, 100 μF typical, output filter

R1: 200 Ω, 1/8 W, 10% typical. Improves regulation in case of low load currents.

NOTE

Heat sink to plug-in rail if maximum current capacity is required (TO-220 package), or use large, fingered radiator (TO-3 package).

Refer also to text.

Circuit 04-1

(1) –6 to –18 V for linear circuits, MOS

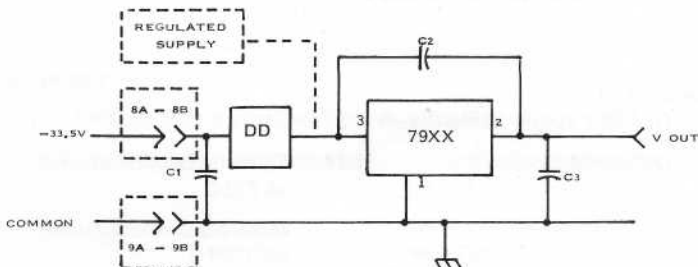(2) Typical devices: Fairchild Semiconductor:
μA 79XX C

|	
7906: –6 V	
7908: –8 V	Motorola Semiconductor Products Inc.
7912: –12 V	MC 79XX C
7915: –15 V	
7918: –18 V	National Semiconductor
	LM 320-XX

C1, C2, C3: See Circuit 01-1

DD: Dropping device for overvoltage protection.

(a) Use fixed resistor if load is steady. Calculate resistance for 5 V drop and wattage as > 25/R.

(b) Zener may be used if current varies widely. Use 5 V zener of adequate wattage rating at $I_{Maximum}$.

(c) For best results, use pre-regulated supply, or simple pre-regulator:
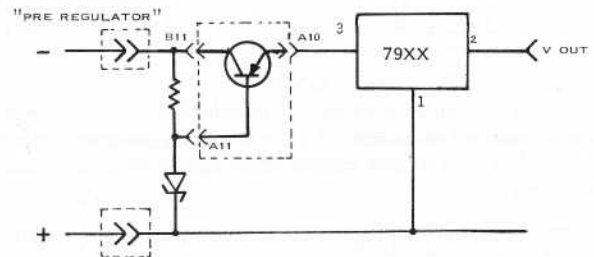
For maximum current: Heat sink TO-220 package to rail, or use large, fingered radiator with TO-3 package.

CAUTION

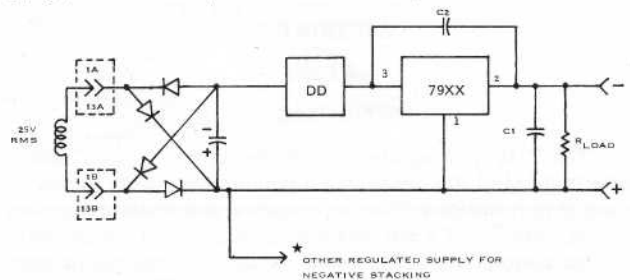*Lower voltage units may overheat if used at maximum current.*

CAUTION

Do not confuse these 79XX IC's with the 78XX IC's. The 78XX series are basically NPN design, while the 79XX series are PNP design.

Circuit 04-2

(1) –24 to –36 V (i.e., –6 to –18 stacked on –18 V supply)

(2) Typical devices: (Refer to Circuit 04-1)

OTHER REGULATED SUPPLY FOR
NEGATIVE STACKING

(a) Refer to Circuit 04-3, (i.e., same circuit, but with opposite side referenced to stable voltage point.)

(b) Since these circuits are powered from a floating secondary winding of the mainframe transformer, they may be elevated by connecting either the positive or negative output terminal to an elevating voltage. Both floating windings may be used to construct higher voltage, floating or ground referenced supplies according to your needs.

CAUTION

The current limiting circuits are effective for currents conducted between the two output terminals, but may not be effective for currents conducted through other paths.

Circuit 04-3

(1) + 6 to + 18 V floating or positive supply (for negative counterpart, see Circuit 04-1)

(2) Typical devices: (Refer to Circuit 04-1)
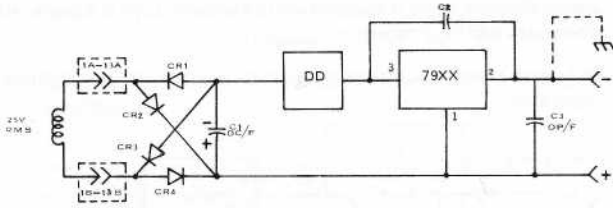
NOTE

Use of the 25 volt rms ac windings (which are not grounded) permits floating operation of such a supply as this, but with the negative side of this supply grounded, it becomes a positive supply.

C1: 50 V minimum, capacitance according to load current (at least 500 μF per 100 mA).

C2, C3: Refer to Circuit 01-1.

DD: Refer to Circuit 04-1.

CR1, 2, 3 & 4: See Circuit 02-3.

Current Rating: 500 mA Maximum (Power Module limited)

NOTE

For maximum current, be sure to heat sink TO-220 package to rail, or use large, fingered radiator with TO-3 package.

CAUTION

Lower voltage units may overheat if used at maximum current more readily than the higher voltage units.

## SECTION C-2

μA 723C

MC1723C

The "723 C" is an integrated circuit containing "blocks" which perform most of the necessary functions for a wide variety of power supply designs. Positive, negative, and floating supplies ranging from 0 to 37 V are feasible. Some external components plus the appropriate unregulated voltage are required to complete any given circuit. Although the 723 contains a series pass transistor, it has limited power capability, and the circuits in this note all show use of an external pass transistor. Both NPN and PNP devices may be used for either polarity of supply, but some combinations require more external components than others. All circuits shown include current limiting, and the current limiting transistor in the 723 is used wherever possible. The use of both types of pass device is shown to give the user maximum flexibility in the use of the TM 500 Power Module pass transistors.

(723 C EQUIVALENT CIRCUIT)

Pin assignments shown for this equivalent circuit are for the 14-lead DIP. For other case styles, please refer to the appropriate manufacturers' data sheets.

Circuit 10-1

(1) + 5 V supply using the μA 723 C/MC1723 C

(2) Typical devices manufactured by: Fairchild Semiconductor
μA 723 C

Motorola Semiconductor
MC1723 C
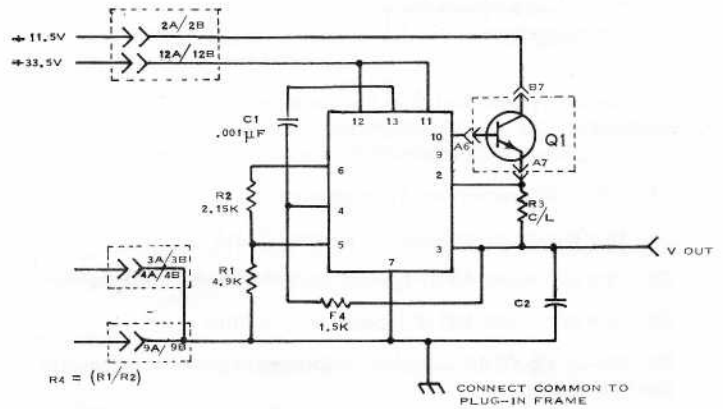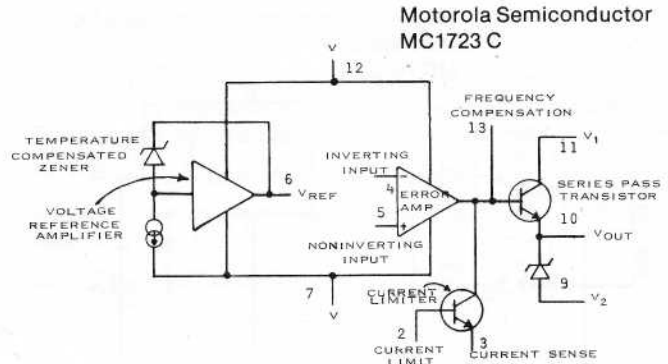
+ 5V USING EXTERNAL NPN PASS TRANSISTOR

R1, R2: Set reference voltage on pin 5 at (5/7) $\times$ 7.15 $\approx$ 5V. This determines V out.

R4 feedback to inverting input. Should equal R1 & R2 in parallel.

Current sense R (C/L): In this circuit this is R3 = $.6/I_{Max}$.

Basic Formula for V_{out}, where V_{ref} is chip oriented at + 7.15 V $\pm$ 0.2 V.

$$V_{out} = \frac{R1}{R1 + R2} \times V_{ref}$$

NOTE

If exact voltage is desired, R1 or R2 should include a variable component so the supply can be calibrated.
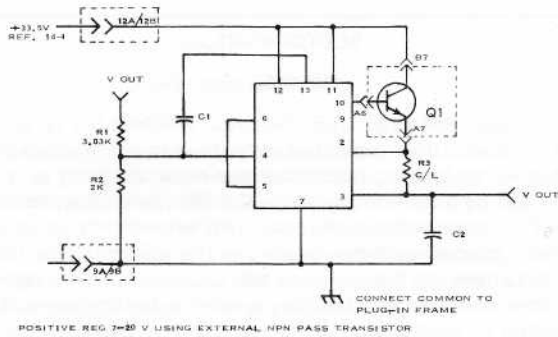
C1 nominal value .001 μF. Breakdown voltage not critical.

C2 10 –100μF typical. VB > 10 V.

Circuit 11-1

(1) 7-20 V supply using the μA 723 C/MC1723 C

(2) Typical devices manufactured by: Fairchild Semiconductor
μA 723 C

Motorola Semiconductor
MC1723 C

POSITIVE REG 7-20 V USING EXTERNAL NPN PASS TRANSISTOR

R1, R2: Values shown will give $(5/2) \times 7.15 \approx 18$ V supply.

Current sense R (C/L): In this circuit, this is R3, see 10-1.

Basic formula for V_{out}, where V_{ref} is chip oriented at $+7.15$ V $\pm$ 0.2 V.

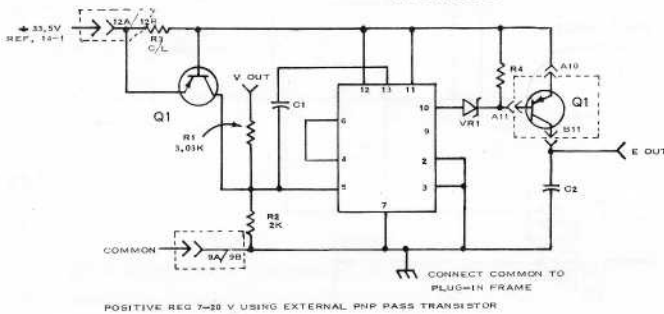$$V_{out} = \frac{R1 + R2}{R2} \times V_{ref}$$

C1 refer to 10-1.

C2 refer to 10-1.

Circuit 11-2

(1) 7-20 V supply using the µA 723 C/MC1723 C

(2) Typical devices manufactured by: Fairchild Semiconductor
µA 723 C

Motorola Semiconductor
MC1723 C

POSITIVE REG 7-20 V USING EXTERNAL PNP PASS TRANSISTOR

R1, R2: Refer to 11-1.

R3, current sense R(C/L): $\approx 0.6/I_{max}$.

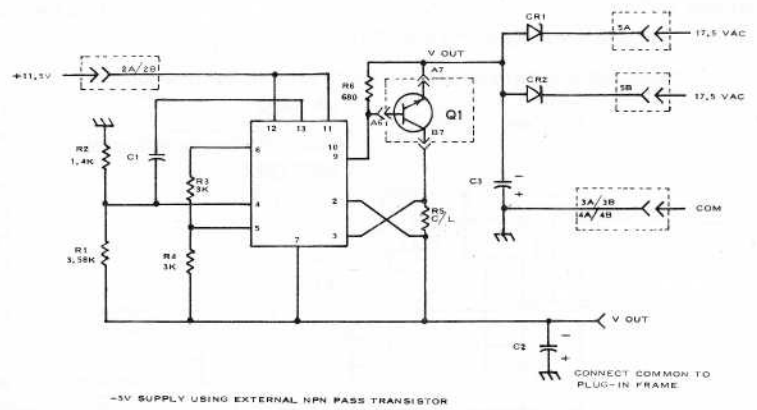Basic formula for V_{out}, where V_{ref} is chip oriented at $+7.15$ V $\pm$ 0.2 V. See 11-1.

C1 & C2 see 10-1.

VR1 Levelshift diode –6.2V Zener.

Circuit 12-1

(1) –5 V supply using the µA 723 C/MC1723 C

(2) Typical devices manufactured by: Fairchild Semiconductor
µA 723 C

Motorola Semiconductor
MC1723 C

-5V SUPPLY USING EXTERNAL NPN PASS TRANSISTOR

R1, R2: Chosen such that pins 4 & 5 will be at the same voltage when the output voltage is at –5 volts.

R3, R4: Chosen to set pin 5 halfway between pin 6 & 7.

Current sense (R(C/L): Refer to circuit 10-1.

Basic formula for V_{out}, where V_{ref} is chip oriented at $+7.15$ V $\pm$ 0.2 V.

$$V_{out} = \left(\frac{R3}{R3 + R4} \times V_{ref} \right) \times \left(\frac{R1 + R2}{R1} \right)$$
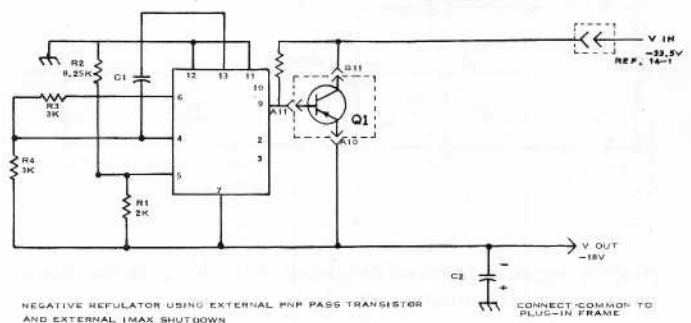
In this circuit for values given:

$$V_{out} = \left(\frac{1}{2} \times 7.15 \right) \times \frac{5}{3.6} \approx 5$$

Circuit 13-1

(1) –18 V supply using the µA 723 C/MC1723 C

(2) Typical devices manufactured by: Fairchild Semiconductor
µA 723 C

Motorola Semiconductor
MC1723 C

NEGATIVE REGULATOR USING EXTERNAL PNP PASS TRANSISTOR AND EXTERNAL IMAX SHUTDOWN

R1, R2: 2k = R1   8.25k = R2

R3, R4: (Both = 3K each)

R6: 2k nominal

Current sense R(C/L): R5

Basic formula for V_{out}, where V_{ref} is chip oriented at $+7.15$ V $\pm$ 0.2 V.

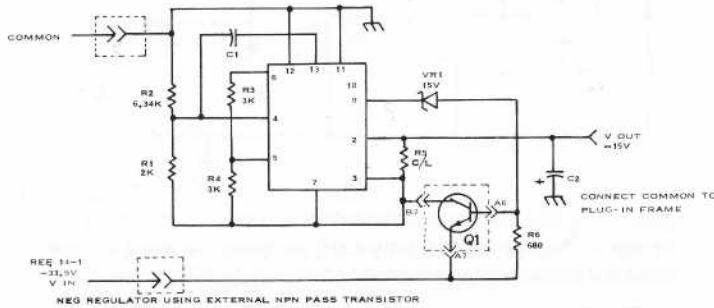Refer 12-1

$$V_{out} = \left(\frac{R3}{R3 + R4} \times V_{ref} \right) \times \left(\frac{R1 + R2}{R1} \right) = 3.5 \times 5.125 = -18$$

NOTE   *This circuit uses external PNP pass transistor.*

Circuit 13-2

(1) –5 to –20 V supply using the μA 723C/MC1723 C

(2) Typical devices manufactured by: Fairchild Semiconductor
μA 723C

Motorola Semiconductor
MC1723 C

R1, R2: Refer to circuit 12-1

R3, R4: Refer to circuit 12-1

Current sense R(C/L): Refer to circuit 10-1 (R5)

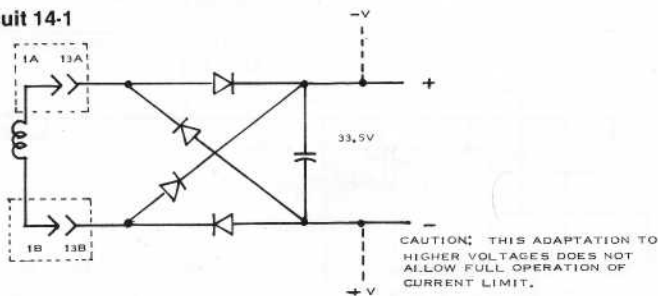Basic formula for V_{out} where V_{ref} is chip oriented at + 7.15 V ± 0.2 V.

Refer to circuit 12-1

$$V_{out} = 3.5 \times \frac{8.4}{2} = -15 \text{ volts (for values shown)}$$

NOTE

This circuit uses external NPN pass transistor.

Circuit 14-1

(1) With negative terminal grounded, this circuit is the basic power source for circuits 11-1 & 11-2.

(2) Connect negative terminal to regulated positive supply for outputs up to 40 volts.

(3) With positive terminal grounded, this circuit is the basic power source for circuits 13-1 & 13-2.

(4) Connect positive terminal to regulated negative supply for outputs up to –40 volts.

(5) Leave plus and minus terminals free of ground or reference voltage for floating operation.

CAUTION

This adaptation to higher voltages does not allow full operation of current limiting.

SECTION C-2

RM 4194

The Raytheon RM 4194 (Tek. Part No. 156-0496-00) is an IC which produces dual regulated outputs with current limiting and thermal shutdown. Since the Maximum V_{in} rating is + & –45 V, it can be used directly on the TM 500 raw dc supplies. To produce balanced output voltages, two external resistors are required. Unbalanced outputs require the addition of a third resistor. Otherwise, the circuit is self contained. (There is provision for external compensation capacitors, but these may not be required.)

Current rating is 200 mA and current limiting occurs at 300 mA; wattage dissipated by this IC is the product of the input-output voltage differential and load current. Since this device is available in both a DIP and TO-66 package, there are two power dissipation ratings. The DIP unit (suffix "D") is rated at 900 mW and the TO-66 (suffix "TK") is rated at 3 W when ambient is 20°C. Be sure to take into account heat sinking and plug-in temperature rise in actual application.

For wiring detail, please see circuit 15-1.

Circuit 15-1

(1) + & – voltage supply using Raytheon RM 4194
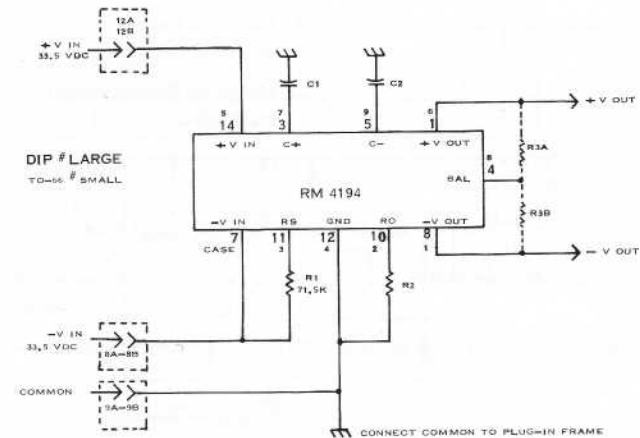
R1: 71.5 kΩ stipulated by manufacturer

R2: Sets (–) V output. Figure at 2.5 kΩ per volt.

Since the internal resistance of this device from balance to + V_{out} and balance to –V_{out} is effectively 20 kΩ, the use of R3A/B results in the following:

R3A: Selected for reduced + V_{out}.

R3B: Selected for increased + V_{out}.

NOTE

Maximum + V_{out} as shown is ≈ + 30 volts, minimum 50 mV.

C1, C2: Compensation capacitors .001 μF nominal.

SECTION C-3

Operational Amplifiers

General

Within a limited range of voltage and current, an IC operational amplifier by itself can form a very tightly regulated power supply. Raw dc voltage, a reference voltage, and gain-setting resistors are all that are needed to complete a basic supply. With external pass transistors and current-limiting circuits, high-current general purpose low voltage supplies are easily fashioned. Due to the high open loop gain of the operational amplifier excellent regulation is obtained, and variations in output voltage are determined primarily by the stability of the reference. Careful ground layout and low resistance current paths to the load are necessary to fully utilize the inherent regulation of this type of circuitry.

Circuit 20-1

+ 5 V Logic Supplies

The operational amplifier is connected as a follower; V_{out} is almost exactly equal to V_{ref}. Q1 is the pass transistor and Q2 serves to limit current when overload occurs.
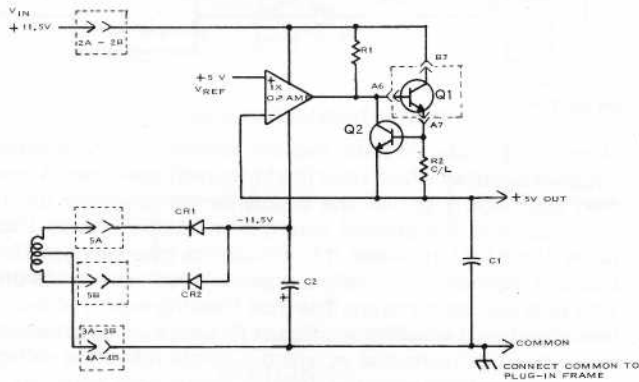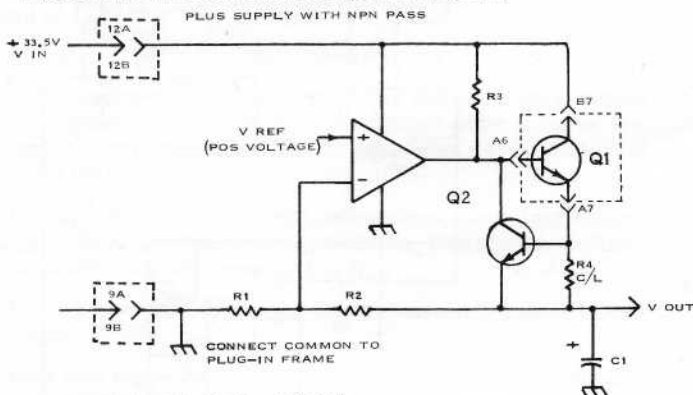

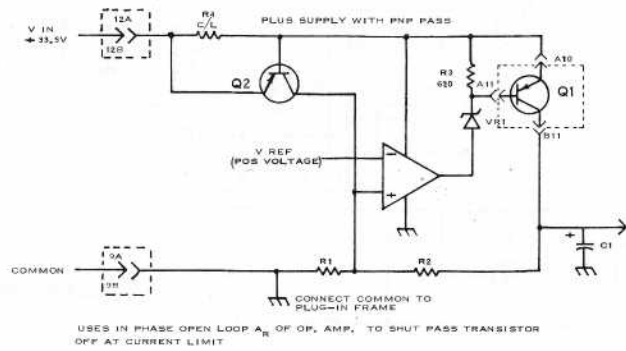#### Circuit 21-1

Circuit 21-2

+ 5 to 20 V Supplies

The operation amplifier is connected as a non-inverting amplifier. V_{out} equals V_{ref} times the closed loop gain $(R1 + R2)/R1$. External transistors are again used for current boost and current limiting. Configurations are shown which allow both NPN and PNP pass transistors to be used for either polarity of supply. Note that a PNP in the positive supply and an NPN in the negative supply act as inverters, so that the operational amplifier input connections are reversed. (See 24-1 & 24-2)

R_3 SET BY IMAX AND V_{CC} @ (+33.5V)

I.E., $\frac{33.5}{.5} = 67\Omega$

Circuit 22-1

USES IN PHASE OPEN LOOP A_R OF OP. AMP. TO SHUT PASS TRANSISTOR OFF AT CURRENT LIMIT
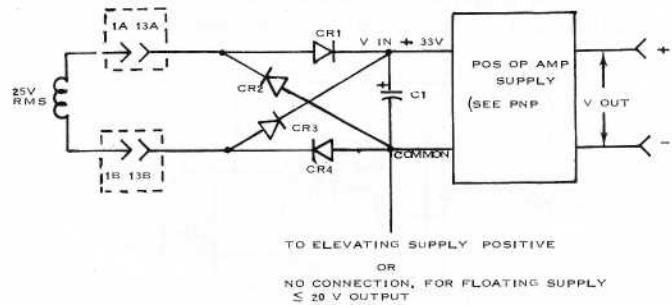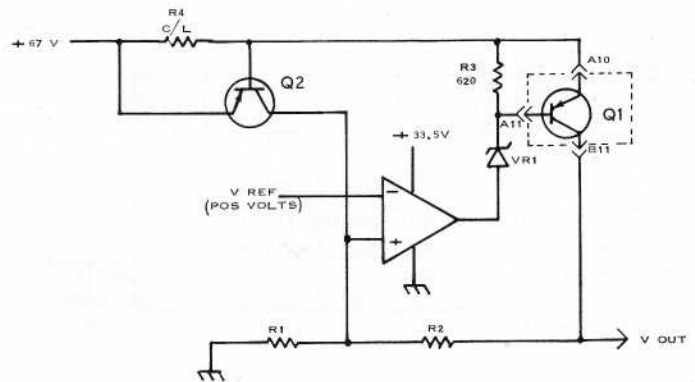
Circuit 22-2

+ 20 to 50 V Supplies

The voltage rating of the operational amplifier is inadequate for direct operation up to 50 volts. This problem may be solved by either:

(1) Stacking one supply on top of another (limited to about 40 V maximum output) or,

(2) Operating the operational amplifier nearer ground or common potential, with a Zener diode used as a level-shifter.

TO ELEVATING SUPPLY POSITIVE

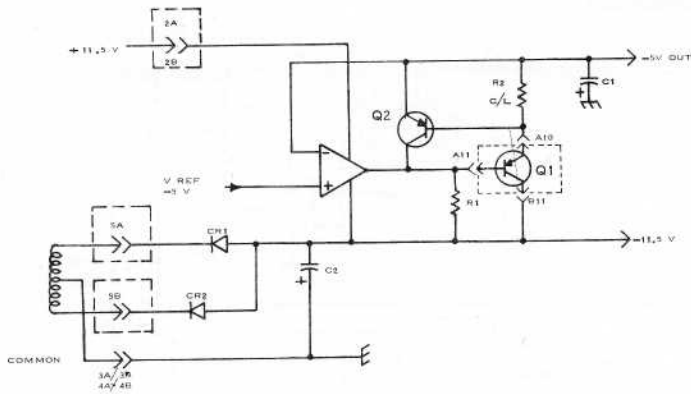OR

NO CONNECTION, FOR FLOATING SUPPLY ≤ 20 V OUTPUT

> 20V POS} WITH PNP, NOT STACKED.

NOTE: ZENER VOLTAGE ≅ 67V−V OUT + V ACROSS R_2

$V\ OUT = \frac{R_1 + R_2}{R_1} \times V\ REF$

Circuit 23-1

−5 V Logic Supplies

The operational amplifier is connected as a follower; V_{out} is almost exactly to V_{ref}. Q1 is the pass transistor and Q2 serves to limit current when overload occurs.
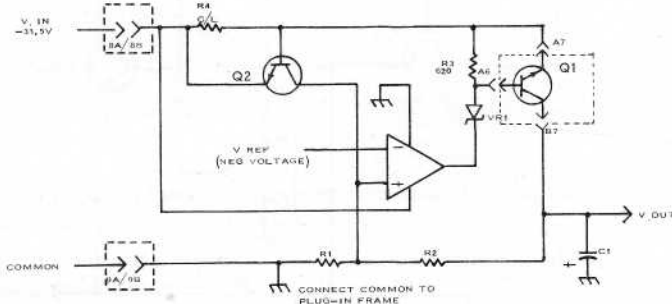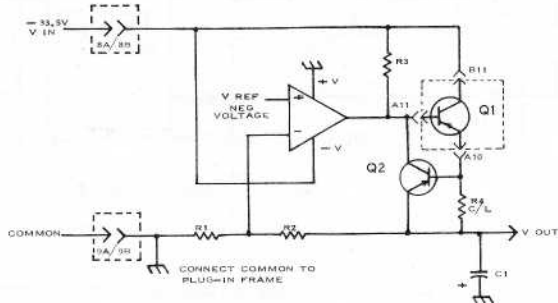
Circuit 24-1

Circuit 24-2   **−5 to −20 V Supplies**

The operational amplifier is connected as a non-inverting amplifier. V_{out} equals V_{ref} times the closed loop gain (R1 + R2)/R1. External transistors are again used for current boost and current limiting. Configurations are shown which allow both NPN and PNP pass transistors to be used for either polarity of supply. Note that a PNP in the positive supply and an NPN in the negative supply act as inverters, so that the operational amplifier input connections are reversed. (See 21-1 & 21-2)
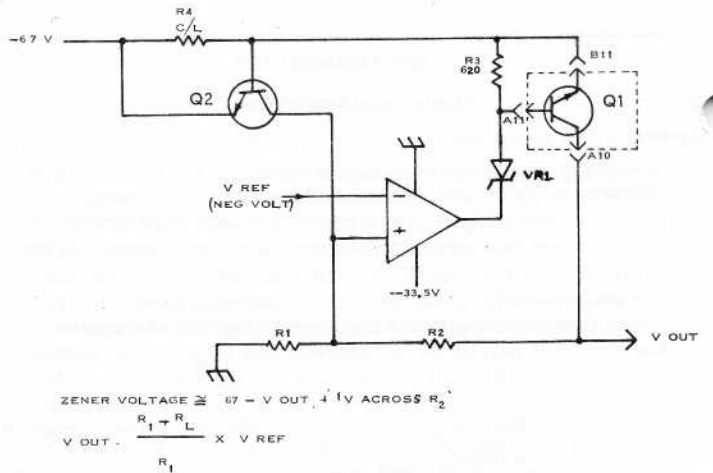

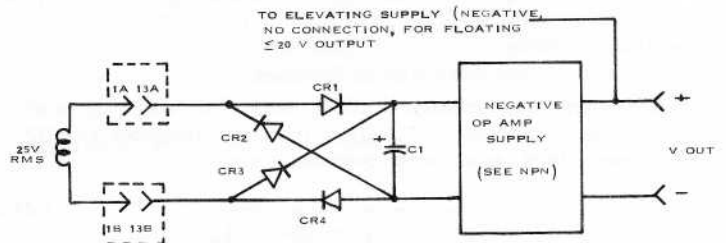**Circuit 25-1**

Circuit 25-2   **−20 to −50 V Supplies**

The voltage rating of the operational amplifier is inadequate for direct operation up to 50 volts. This problem may be solved by either:

(1) Stacking one supply on top of another (limited to about 40 V maximum output) or

(2) Operating the operational amplifier nearer ground or common potential, with a Zener diode used as a level-shifter.

ZENER VOLTAGE ≥ 67 − V OUT + V ACROSS R₂

$$V\ OUT = \frac{R_1 + R_L}{R_1} \times V\ REF$$

Circuit 26-1   **Dual or Tracking Supplies**

Many solid state circuits require complementary positive/negative supplies which have to stay closely balanced. A common approach is to use one supply as the reference for the other, so that the second supply's variations closely track those of the first. However, if both supplies have very good line and load regulation, the main concern is reference voltage drift with time and temperature. The dual tracking supply shown in this operational amplifier section of this note utilizes the common reference technique in which a single reference voltage and an operational amplifier inverter supply both polarities of reference voltage from a single source. Note, $R_9 = R_{19}$.

Transistors Q3 and Q13 are optional added circuitry for mutual shutdown control. If either circuit loses output voltage (due to current limiting, load short or other cause), the other supply's reference voltage is clamped to ground (by Q3 or Q13) and its output drops to less than a volt.
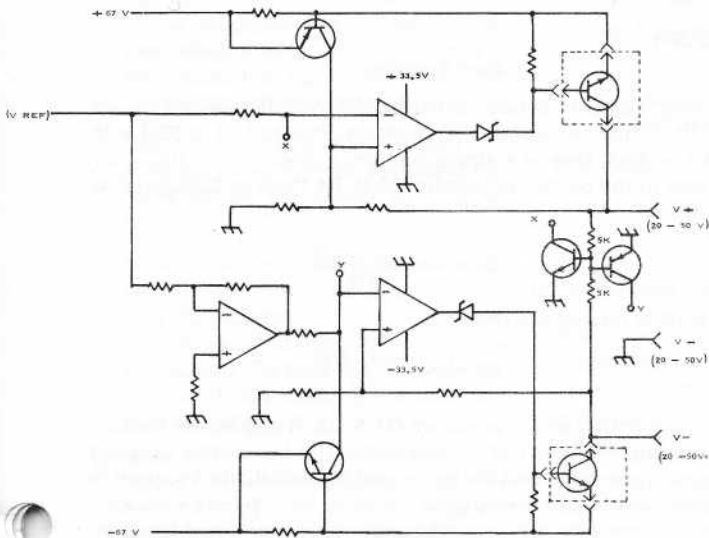
Diagram on following page.
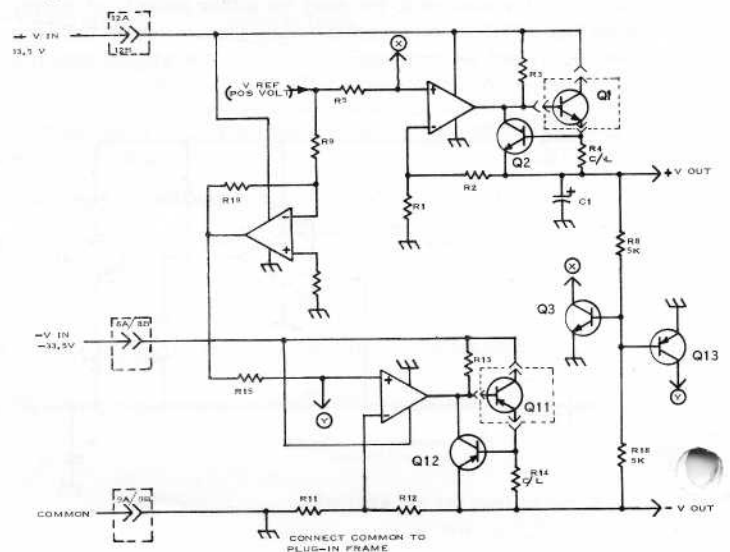
Circuit 27-1

Dual Refverence supplies, 20 to 50 V

Circuit 27-1 shows construction of dual reference supplies applicable up to the plus and minus 50 V level. Note that this circuit is a combination of elements from the other circuits in this section.

SECTION C-4

Discrete Devices

General

Very useful power supply circuits may be built using a small number of discrete transistors. Due to the limited number of active devices in these circuits, their performance level tends to be somewhat less than that of circuits using IC's. The discrete circuits have the advantages of low cost, parts availability, and ready adaptability to higher voltages determined by the break-down limits of the devices used.
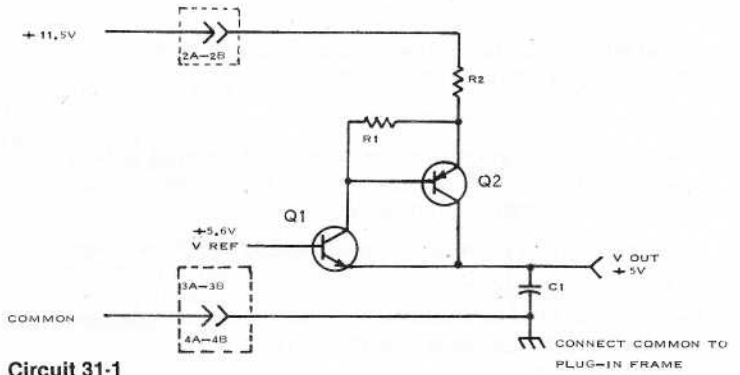
Circuit 30-1

+ 5 V (Logic Level) Circuits

This two-transistor circuit shown has adequate performance for logic circuitry where the total current drain is rather low (about 50 mA maximum). The current range can be increased some by the use of high beta transistors.

Due to V_{be} change in Q1 with temperature, the output voltage has a definite temperature dependence. This may be compensated for in the reference voltage (V_{ref}).

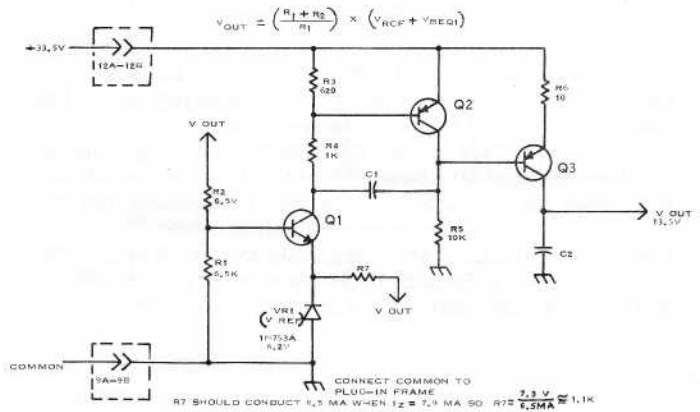For higher current loads, any of the IC-based circuits are preferable.

Note that the reference voltage (V_{ref}) must exceed the desired output voltage by one diode drop (V_{be} of Q1).

Circuit 31-1

+ 7 to 20 V Circuit

The three-transistor circuit shown here is somewhat lower in performance than some of the IC-based circuits, but has higher performance than the two-transistor logic level regulators. The addition of the third transistor increases loop gain and allows the reference voltage diode (VR1) to complement the Temperature Coefficient of Q1's base-emitter junction. As a result, output voltage is much more stable with temperature, but the minimum output voltage is raised to about seven volts since the reference voltage is effectively equal to VR1's drop plus the V_{be} of Q1. VR1 is a zener diode with a nominal voltage of 6.2 V and a temperature coefficient of 2.2 mV/°C.

Circuit 32-1

+ 20 to 50 V Circuit

Please refer to Circuit 31-1 text and note further: Adaptation of this circuit to higher voltage levels is simple. A higher raw voltage is required, and in addition, all components must have adequate voltage and wattage ratings. Techniques for obtaining higher voltage raw supplies are described in section D of this writeup.

NOTE

For diagram refer to circuit 31-1, page 39.
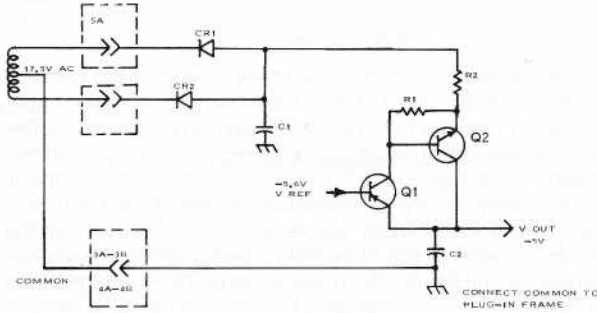
Circuit 33-1

-5 V (Logic Level) Circuits

This two-transistor circuit shown has adequate performance for logic circuitry where the total current drain is rather low

(about 50 mA maximum). The current range can be increased some by use of high beta transistors.

Due to V_{be} change in Q1 with temperature, the output voltage has a definite temperature dependence. This may be compensated for in the reference voltage (V_{ref}).

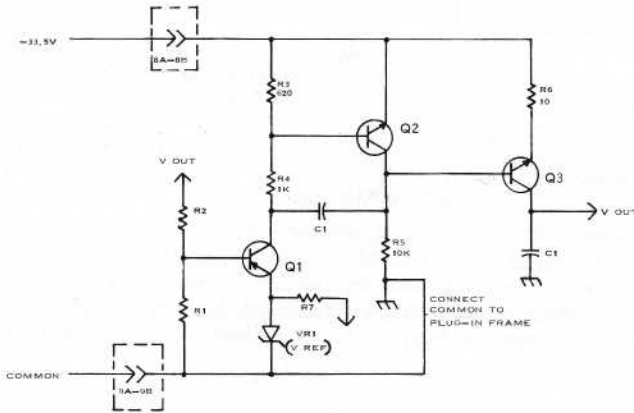For higher current loads, any of the IC-based circuits are preferable.

Note that the reference voltage (V_{ref}) must exceed the desired output voltage by one diode drop (V_{be} of Q1).

Circuit 34-1

−7 to −20 V Circuit

The three-transistor circuit shown here is somewhat lower in performance than some of the IC-based circuits, but has higher performance than the two-transistor logic level regulators. The addition of the third transistor increases loop gain and allows the reference voltage diode (VR1) to complement the Temperature Coefficient of Q1's base-emitter junction. As a result, output voltage is much more stable with temperature, but the minimum output voltage is raised to about seven volts since the reference voltage is effectively equal to VR1's drop plus the V_{be} of Q1. VR1 is a Zener diode with a nominal voltage of 6.2 V and a temperature coefficient of 2.2mV/°C.
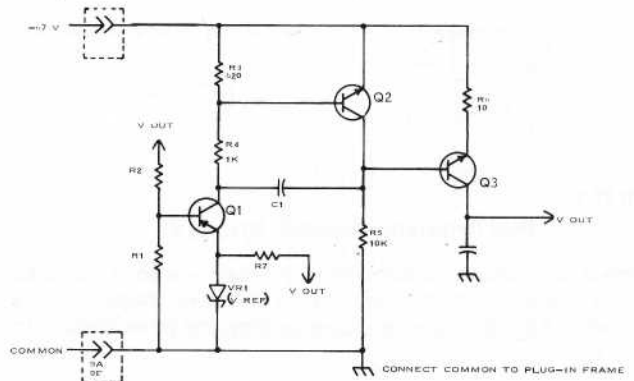

Circuit 35-1

−20 to −50 V Circuit

Please refer to circuit 34-1 text and note further: Adaptation of this circuit to higher voltage levels is simple. A higher raw voltage is required, and in addition, all components must have adequate voltage and wattage ratings. Techniques for obtaining higher voltage raw supplies are described in section D of this write-up.

Diagram on following page.

Circuit 36-1

Circuit 37-1

Dual Supplies

Where complementary positive and negative supplies are used, it may be desirable to combine circuits 31-1 or 32-1 with 34-1 or 35-1. Use of a single reference diode, you'll find illustrated in the partial schematic (36-1). R1 there is calculated as follows:

$$R1 \approx \frac{(+V\,out - 6.2)}{.006}$$

and R2 is figured like this:

$$R2 \approx \frac{(+V\,out - 0.6)}{.002}$$

In conjunction with transistors Q1 & Q2, R and R2 set the currents thru VR1 and CR1 respectively. The transistors conduct about 1 mA each, and the remainder of each diode's current is conducted by the associated resistor. VR1 is only indirectly the reference for the negative supply, as the output of the positive supply is the direct reference. Except for minor differences in temperature coefficient, the negative supply will closely follow the positive supply.

1 mA each, and the remainder of each diode's current is conducted by the associated resistor. VR1 is only indirectly the reference for the negative supply, as the output of the positive supply is the direct reference. Except for minor differences in temperature coefficient, the negative supply will closely follow the positive supply.
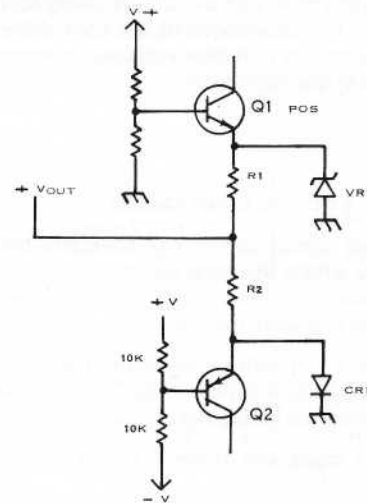
SECTION D
Series Pass

(1) Series Pass Transistors, General

(a) Voltage and Current ratings.

In selecting a device to use as series pass transistor in any of the circuits in this note, be sure that the breakdown voltage is adequate. High line, no load voltages of windings or raw supplies may exceed the nominal value by 10% to 20%, and there should still be some margin for safety. Normally, the voltage across the transistor is equal to raw dc volts minus regulated output volts. However, when a current-limiting circuit is employed, the full value of raw dc voltage may be encountered.

The current rating must exceed the maximum load current, including the value set by the current-limiting resistor.

Most pass transistors have a safe operating area which is bounded not only by maximum current, voltage, and power, but also by secondary breakdown. Be sure that all possible points of operation are inside the safe area curve.

(b) Beta

Power transistors typically are not high beta devices. Since the driver stage (and the current limit stage in some designs) must supply at least the base current of the pass device adequately, beta is important to assure that the driver is not overloaded. For example, a pass transistor with a beta of 40 and a load current of one ampere requires 25 mA of base current — too much current for an operational amplifier or for some small signal transistors. Many of the circuits in this note may in fact require a second transistor in Darlington connection with the pass device, for operation with high load currents. Evaluate the circuit accordingly, and add the Darlington transistor when necessary.

(c) Power

The maximum power ratings of transistors are frequently based on operating conditions which are not realistic for this type of application. Evaluate temperature rise (and subsequent chip temperature) based on input power, and total thermal resistance to ambient. A flat, plastic power transistor mounted to a plug-in rail should preferably not be expected to dissipate more than two or three watts. The pass devices in the mainframe should be held to 7.5 W, although this may be exceeded temporarily when current limiting occurs.

(d) Pass and driver transistors

The following list of transistors is a brief, arbitrary listing of types which have been used successfully as auxiliary pass transistors in the low current ranges, or as driver or Darlington transistors for higher current devices. For higher currents, use the mainframe pass transistors. Use any of the devices below as a driver or Darlington transistor if one is needed:

Drive or pass:

M 340 (NPN)	Motorola Semi-
MJE 370 (PNP)	Semiconductor
	Products Inc.
TI P29C (NPN)	Texas
TI P30C (PNP)	Instruments Inc.

Driver only: 2N3904 (NPN)
                2N3906 (PNP)
                2N2219A (NPN)
                2N2905A (PNP)

(2) Series pass transistors, mainframe

For complete characterization of mainframe pass transistors, refer to data sheets on the Motorola types MJE 2801 and MJE 2901.

The mainframe transistors are adequate for the circuits shown in this note, with the following precautions or exceptions:

(a) A Darlington transistor may be needed to protect the driver, even though it is not shown in the schematic. The beta is at least 40, from 100 mA to 1 A, even at low junction temperatures.

(b) Dissipation should be held to 7.5 W, except for temporary overload conditions.

(c) If the device is used in a circuit where the full voltage of a 67 V raw supply may be impressed, caution should be exercised, as the nominal breakdown voltage is 60 volts.

(3) Reference voltage circuits

(a) Voltage dividers

The simplest way to obtain reference voltage is with a resistive voltage divider tied to some previously regulated voltage, Fig. D1. If the load current into the reference point is high, or if it varies considerably, a buffer stage (an emitter follower), can be used Fig. D2, but changes in V_{be} with load current and temperature may be too great for some applications. An even more elaborate but highly effective approach is to use an operational amplifier follower, Fig. D3.
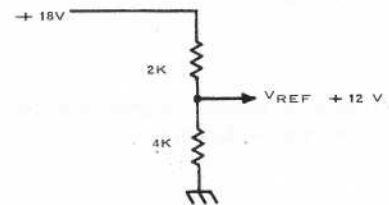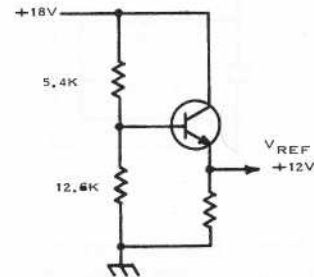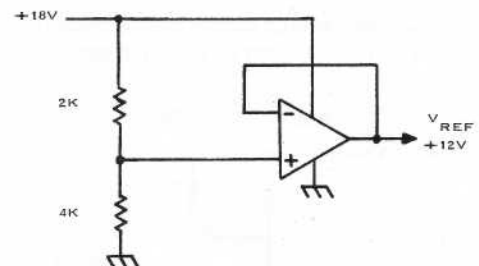

FIG. D1

FIG. D2

FIG. D3

The precision and stability of a reference voltage derived from a zener diode depend on both the diode and its application. Low TC zeners usually have a nominal voltage of 6.2 or 9.0 V, and a test current of 7.5 mA. The IN821 (6.2 V; 5%; .01%/°C) and the IN3497 (6.2 V; 5%; .002%/°C) provide good performance at moderate cost. The most important circuit consideration is to set and maintain the zener current close to the specified test current. It follows from this, that the zener should be well buffered from line and load influences. The error amplifier and series pass device largely determine isolation from the load. Line isolation is accomplished by furnishing current from a proper source. The least acceptable source is a resistor connected directly to the raw dc supply; that configuration will cause a percentage variation in I_z usually greater than the percentage change in raw dc, which in turn fol-
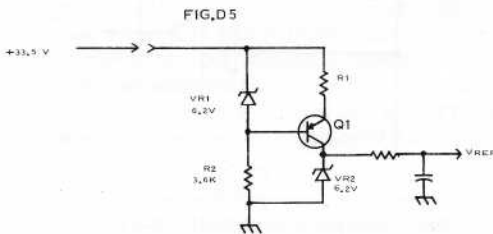
lows percentage changes in line voltage. The preferred configurations are as follows:

**(a)** Precision resistor to previously regulated supply. Example:
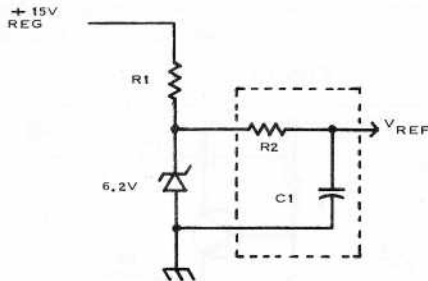
R₂–C₁ form a filter network to suppress noise generated by the zener.

(b) Current source (active device circuit) connected to raw dc supply. Example:

FIG. D5

In this case, Q1 acts as a current source for VR_2, which is the source of V_{REF}. VR_1 is not operating under optimum conditions but provides adequate regulation of current to VR_2.

(c) Precision resistor to output of supply operating from V_{REF}. Example.

FIG. D6
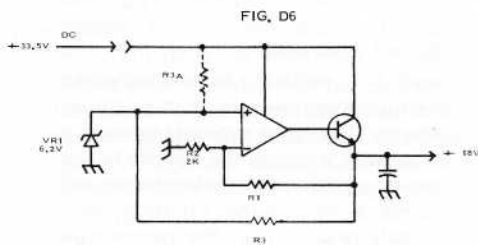
NOTE

If R3A is not required, let R3 = 1.573k. If R3A is required let R3 = 1.74k and R3A = 36k.

R3 supplies current to VR_1, the reference source. Since the overall effect of the circuit is to regulate the output at 18 V, the current to VR_1 is well regulated. In some designs there may be a "start-up" problem, i.e. at turn-on the output is at zero; no current flows to VR_1, which remains at zero volts; since the reference voltage is zero the output is held to zero. The solution to this problem is to assure that some small amount of current is available for start-up, such as from R3A.

(4) Overvoltage Protection

There are a number of conditions which can cause excessive voltage to appear on a power supply buss, including failure of components in the power supply. In order to protect circuits or devices connected to the buss (including the power supply's own devices, if the cause is external), it is sometimes desirable to protect the buss from overvoltage. In this circuit, an SCR is connected in parallel with the normal load. When the buss voltage exceeds some preset level (determined by a zener diode), the SCR fires and presents a very low resistance in parallel with the load. The supply protected by the SCR must have some form of current limiting to protect it when the overvoltage source is external, and should have a fuse to protect the raw supply if the fault is internal to the regulator. A typical schematic is as follows:

Q1 fires when the buss's output reaches a voltage equal to the zener voltage of VR1, plus the gate voltage required to fire the SCR, Q1. This voltage should be set to have a reasonable margin above the maximum voltage normally on the buss.

(5) Reverse Voltage Protection

Just as accidents or failures can cause overvoltage to be impressed on a regulated voltage buss, they may also tend to force a reverse voltage. This is particularly true in modern semiconductor circuitry with complementary positive-negative supplies. Therefore it is common practice to connect a back-biased rectifier diode to the buss which "catches" the supply and limits any reverse voltage to the forward drop of the diode. The reverse voltage rating of the diode should exceed the maximum voltage of the buss, preferably, the maximum voltage of the raw supply. Forward current rating should be compatible with the load capacity of any supply likely to cause reversal. A reverse protection diode is shown as CR1 in Fig. D-7.

(6) "DC/F" and "OP/F" Capacitors
    (Refer to Section C)

Capacitors noted "DC/F" are Input Filter Capacitors in bridge rectifier circuits. The size of such a capacitor depends on load current; for low ripple and good line regulation use at least 5–10 μF per mA of load current (including bleeder current and standby current in regulator circuit). Keep in mind that voltage will vary with line voltage and load current; allow a reasonable margin.

FIG. D7
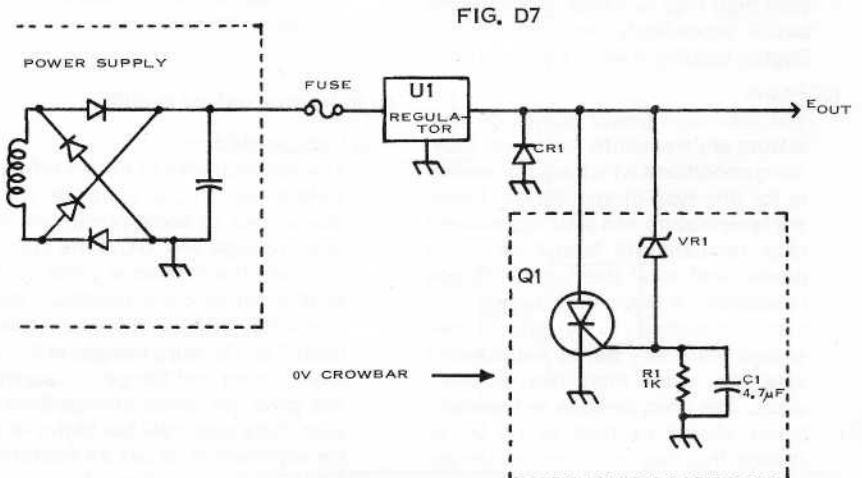
Capacitors noted "OP/F" are Output Filter Caps on regulated dc busses. The function of such a capacitor is to bypass ac components of load current, especially at higher frequencies. Usually the value is not critical, and may be estimated or determined empirically. Values generally range from 1 to 100 μF. Some types of aluminum electrolytic may require a smaller value of low inductance capacitor in parallel. DC working voltage rating should equal or exceed buss voltage.

(7) Decoupling Networks

Decoupling networks, for specific load points, are not shown in these schematics, as they are entirely dependent on layout, speed, types of devices, etc.

(8) Source/Sink Capability

The circuits in this note are source type supplies having only one output transistor. They will sink current only on the condition that the net load current is "sourced" rather than "sunk." However, the TM 500 mainframe scheme is well suited to the construction of either sink, source, or combination type supplies.

(9) Precision Resistors

Precision resistors should be used for voltage dividers which set the output of a supply. In many cases it will be desirable to select values or include a trimming potentiometer to obtain the exact desired voltage since reference zeners usually have ±5 percent tolerance. The ratio of such a divider is more important than the specific resistance value, although the resistance value should be low enough that changes in bias currents will have a negligible effect. Metal film fixed resistors are best for such an application. Use potentiometers with cermet elements for trimming.

(10) Current Limit Resistors (C/L)

Resistors designated "C/L" are resistors whose value determines the amount of current required to shut down the supply for overload protection. Consider the overload current to be about 1.5 times the maximum operating current, to allow for tolerances and temperature effects.

$$R_a = \frac{0.6}{I_{overload}}$$

To avoid runaway effects or premature shut down, the C/L resistor should be conservatively rated for wattage and should have a relatively small temperature coefficient.

(11) Floating Supplies: Higher Voltage Supplies

Floating supplies and higher voltage supplies may be constructed using the floating windings. (Other methods such as oscillators and supplementary line frequency transformers are feasible but will not be discussed here.) The simplest method of obtaining higher voltages is to rectify the output of a winding and "stack" the resulting dc voltage on another raw or regulated voltage. Example
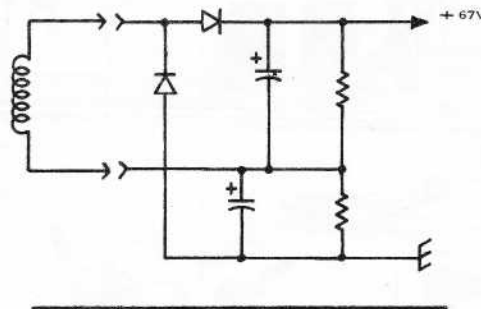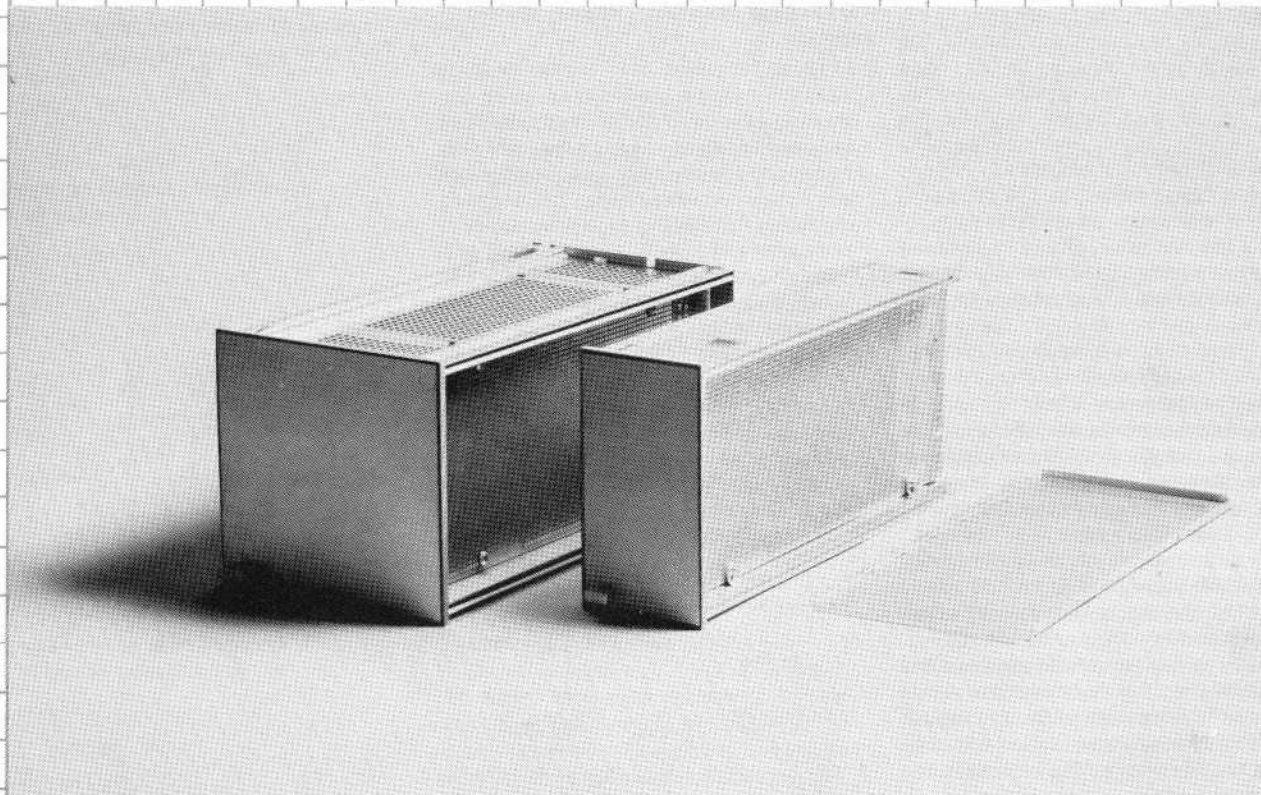
FIG. D8
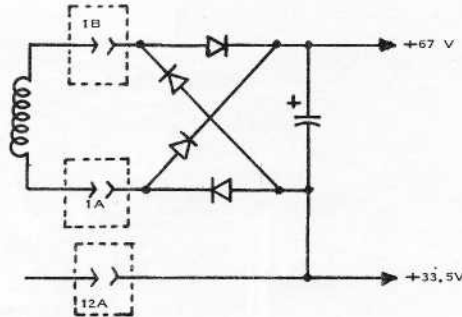
By rectifying another winding and stacking again, even higher voltage may be obtained. The same principle applies for negative supplies. Each floating supply is analogous to a cell which may be connected to other cells to form a battery.

Another approach is to construct a voltage doubler. Keep in mind that current rating must be sacrificed to achieve voltage. Basic doubler schematic:

FIG. D9