DISCRETE/TRANSISTOR CIRCUIT SOURCEMASTER

Kendall Webster Sessions

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PREFACE

A well-planned digest of schematics is to the engineer and technician what a cookbook is to the chef. It is a timesaver in that it pays for itself many times over if it is used at all. The enterprising circuit designer need not start each project from scratch—he can begin his effort by employing the devices and circuit arrangements that have been pioneered and exploited by those who have "been there before." He can concentrate the bulk of his preliminary work in selection of time-tested circuit blocks or stages and then devote some of that precious time saved to the rational piecing together of those blocks.

That in itself is sufficient justification for keeping a circuit book on the workbench, as near as the tools.

But I wanted this book to be something more—to offer something not offered by other books that might seem comparable from the standpoint of the circuit content alone. It seemed to me during the planning of this volume that, although circuit "recipes" alone could offer the kind of building-block information the experimenter needs to transform his ideas into hardware quickly, to be equally valuable to student and engineer there should be a kind of theoretical cohesiveness to the whole; there should be sufficient information to explain at least in a general way how things work. Such treatment, I reasoned, would result in a more innovative utilization of the circuits and the devices they employ.

Obviously, however, a detailed theoretical discussion couldn't be presented for every included circuit, for the book would wind up as a Brobdignagian book of words, most of which would be tiresomely repetitious. The alternative was to present *representative* theoretical discussions for circuits of a given genre; but even this approach posed problems, not the least of which would be the "production" restrictions on layout and order of circuit presentation.

The approach finally selected was to offer descriptions of what the devices are doing in their respective circuits but to avoid repetitive explanations when a device is used the same way in a variety of comparable circuits. What you *won't* see in this book are those kinds of general theory to be found in any available textbook—details, for example, on why an audio amplifier has to be biased to operate in the center of its linear region or why an electronic switching transistor is made to spend most of its time in cutoff or saturation. Instead, I've tried to include explanations of the reasons for including certain devices in circuits when their functions are not particularly obvious.

The circuits themselves have been supplied by the engineering staffs of the firms who make the devices featured. In the main, the text that accompanies the circuits has been distilled from application notes which contain considerably more information than is required for understanding and duplicating the schematic diagrams. My involvement with this book has been more of overseer, compiler, and editor than of author.

It is my conviction that this book can impart more important and meaningful technical information to the interested reader than many times the volume in textbook theory. The reason? Simply this: In a book of theory the reader must be exposed to *general* and usually quite basic circuits that very likely have no relation to any specific problem at hand. Studies show that facts fed to students shotgun fashion aren't well remembered. But give the student a quest, a *need* to learn, and the job's half done; give him sorted-out facts, facts that relate to his own particular problem, and he'll respond by retaining a *substantially* larger percentage of their total.

So it is that this book is not *just* a book of circuits; it is rather a collection of circuits in 9 broad categories, with salient facts presented for the reader who wants or needs more information than a given diagram can impart by itself. Even the practicing engineer, who very likely will already know the how and why of these circuits and the devices they use, will appreciate having this kind of information available for reference; it should help him know when and where to employ certain devices as he adapts these circuits to his own needs. And, of course, there exists a strong likelihood that he will be able to become better acquainted with some of those active devices that have come along since his scholastic days.

In most cases the circuits in this book contain references to manufacturers' part numbers rather than to generic number assignments. Despite the fact that most "house" catalog numbers could have been changed to the "2N" equivalents, I refrained from making this alteration—for three reasons:

First, the maker of the device in most cases paid an engineer to design, prototype, and perfect the circuits featuring that device, so it seems only reasonable to expect those who want to duplicate such circuits to do it with the semiconductors of that manufacturer. After all, isn't this why the engineer devoted his time to the design effort in the first place?

The second reason is really more important than the first, and this is one that seasoned experimenters will be able to identify with readily: the *unrestricted* use of equivalents in circuit construction can lead to plenty of trouble. I'll always remember the pride of my early days in ham radio—a Multi-Elmac tube-type mobile transceiver with an instruction booklet that stipulated replacement of the driver stage with a Tung-Sol 6AQ5. A tube is *a* tube, I reasoned, and when replacement time came, I purchased whatever brand the nearest electronics distributor carried. When the set exhibited insufficient drive, I attributed the problem to just about everything but the obvious one. I dug into the chassis, knifed apart the appropriate tank coil, played with the coupling, and diddled endlessly, trying vainly to squeeze out of that rig the kind of performance I got "when it was new." But it wasn't until I replaced the stage with a Tung-Sol 6AQ5 that the final amplifier received enough drive to pack out a respectable signal.

Accuracy is the final reason for leaving the original diagrams alone—retaining the original part numbers and values. Few of us can take a schematic and build the circuit it represents so that it works correctly the first time. And we're experienced constructionists who have a personal interest in getting it right. We'll omit a connection. We'll solder a wire to the wrong terminal. We'll forget a bypass capacitor or use the wrong value of resistor. We make mistakes despite our huge incentive for accuracy. Well, consider this: The draftsman who copies a circuit or substitutes generic numbers for the identifiers employed by the original designers has to go through essentially the same process as the builder. The process is faster for him, of course, because he doesn't have to actually dress the leads or apply solder or worry about what part goes where. But he does have to route the "wires" correctly, to apply "solder dots" at the proper circuit junctions, and to correctly identify the devices and their positions. Is not the draftsman, conscientious though he is, many times more likely to err than the individual who builds a circuit to satisfy his own needs?

Unfortunately, there are nearly as many device symbols and standards as there are manufacturers. So you're apt to see a *diac* pictured in one diagram as a baseless, collectorless transistor with two emitters, and in another as a gateless *triac*. Forgive the inconsistencies and bear in mind that these circuits are, for the most part, photographic reproductions of the diagrams contributed by the semiconductor makers. A compromise? To be sure—but I think it's one you'd want us to make, for it virtually eliminates what would otherwise certainly be the largest single source of error.

I am extremely grateful to the manufacturers who cooperated with me in preparing this circuit collection; in alphabetical order they are:

Amperex, Solid State and Active Devices Division
Delco Electronics, Division of General Motors
Fairchild, Semiconductor Division
General Electric, Semiconductor Products Department
General Instrument, Semiconductor Components Division
GTE/Sylvania
Motorola Semiconductor Products Inc.
National Semiconductors, Inc.
RCA, Solid State Division
Siliconix Incorporated
Sprague Electronics
Texas Instruments Incorporated
Workman Electronics (source of devices preceded by IR designator)

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SECTION 1
POWER CONVERSION AND REGULATION

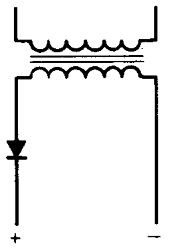
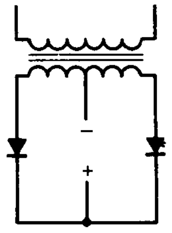
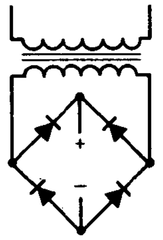
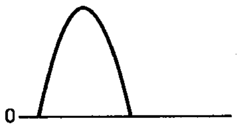
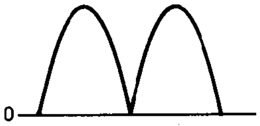
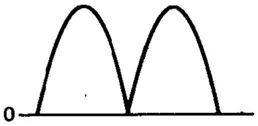
Every electronic circuit requires power—even the simple "crystal set," which draws its energy from the radio signal it detects. It is fitting, then, that the first section contains those circuit arrangements that have been designed to provide a source of electrical power for operating other circuits. To make it easier for you to browse through appropriate circuit candidates for your own applications, the circuits in this section are subclassified into four divisions: regulators and current sources, power supplies and rectifiers, dc-to-dc converters, and dc-to-ac inverters.

The characteristics of a rectifier system contained in a power source depend to a large extent on the electrical characteristics of the load or filter it drives. The following table, adapted from a large and comprehensive wall chart prepared and distributed by the General Electric Semiconductor Products Department, gives all the specification values you need to ascertain diode and transformer requirements on a per-volt-of-output basis. Although the original of this chart lists values for multiphase and interphase circuitry, the information here applies only to the "basic" rectifiers: half-wave, full-wave, and bridge. Bear in mind as you use this table for power supply design that the information is necessarily based on a zero forward voltage drop and zero reverse current in rectifiers, and no ac line or source reactance. Also, remember that all figures are based on a dc output voltage of 1.0, which means that values must be scaled upward to reflect the circuit conditions imposed by your own requirements.

The chart for rectifier design does not include information for selecting diodes for circuit applications where voltage transients might be encountered. Transient voltage surges as high as 440V are not uncommon in 117V ac lines, the result of switching highly inductive circuits or circuits that use a phase-controlling element such as silicon controlled switches and rectifiers.

Probably the most common approach to compensating for these occasional transients is to employ diodes with a peak reverse voltage rating high enough to permit passage of such transients without diode destruction. In practice, however, diodes rated for higher voltages cost more than low-voltage types; so some engineers choose an approach that allows automatic shunting of voltage transients around the rectifying devices. The following alternatives have been suggested by the engineering staff at National Semiconductors; although application of the techniques presupposes that the ICs will be powered, the information is generally applicable to any power conversion circuit.

5505616

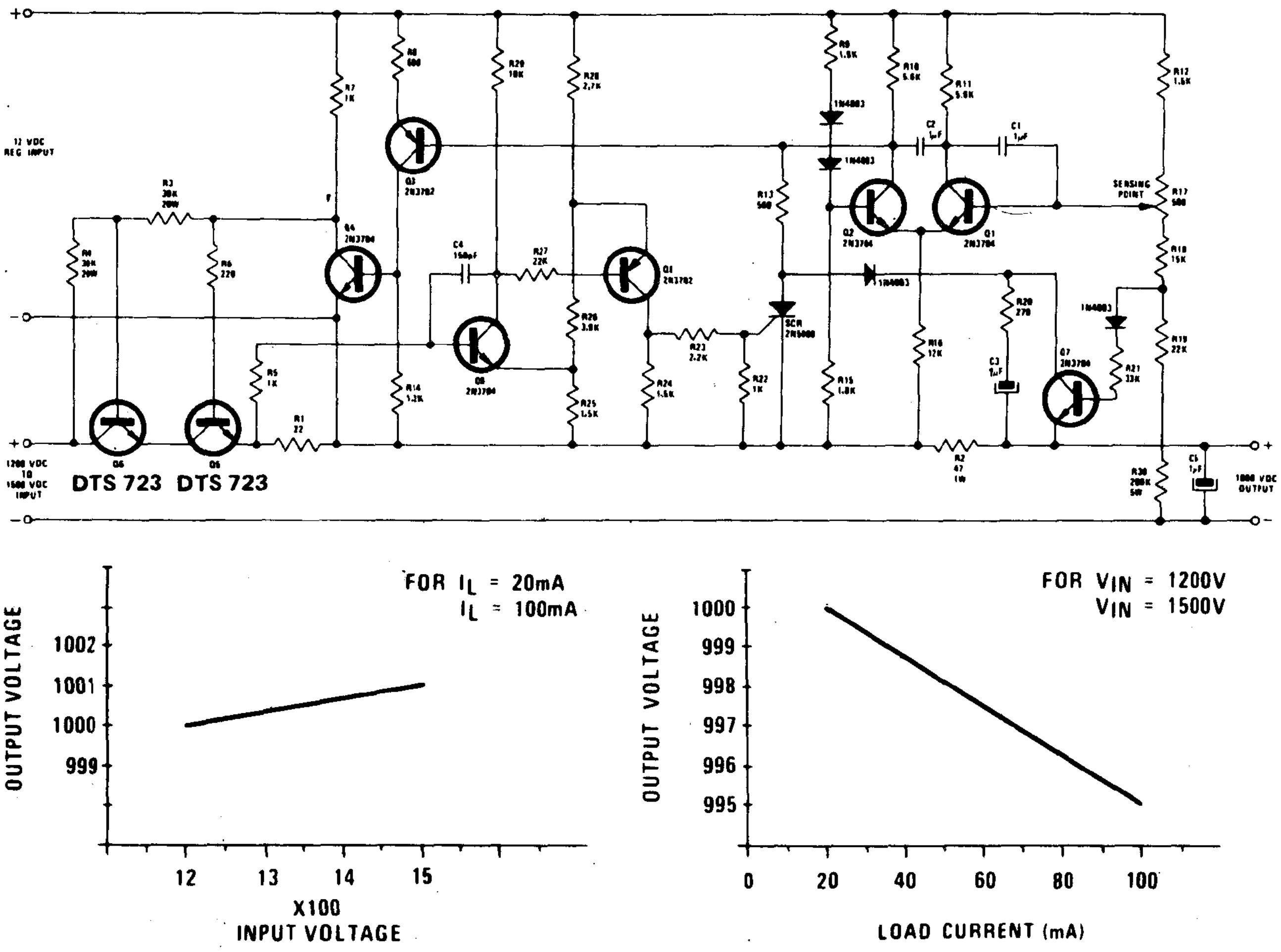
Type of Circuit			**Single Phase Half Wave (1-1-1-H)**	**Single Phase Center-Tap (2-1-1-C)**	**Single Phase Bridge (4-1-1-B)**
Primary					
Secondary					
One Cycle Wave of Rectifier Output Voltage (No Overlap)					
Number of Rectifier Elements in Circuit			1	2	4
Average D.C. Volts Output		=	1.00	1.00	1.00
RMS D.C. Volts Output		=	1.57	1.11	1.11
Peak D.C. Volts Output		=	3.14	1.57	1.57
Peak Reverse Volts per Rectifier Element		=	3.14	3.14	1.57
		=	1.41	2.82	1.41
		=	1.41	1.41	1.41
Average D.C. Output Current		=	1.00	1.00	1.00
Average D.C. Output Current per Rectifier Element		=	1.00	0.500	0.500
RMS Current per Rectifier Element	Resistive Load	=	1.57	0.785	0.785
	Inductive Load	=	—	0.707	0.707
Peak Current per Rectifier Element	Resistive Load	=	3.14	1.57	1.57
	Inductive Load	=	—	1.00	1.00
Ratio: Peak to Average Current Per Element	Resistive Load		3.14	3.14	3.14
	Inductive Load		—	2.00	2.00
% Ripple $\left(\frac{\text{RMS of Ripple}}{\text{Average Output Voltage}}\right)$			121%	48%	48%
			Resistive Load		Inductive
Transformer Secondary RMS Volts per Leg		=	2.22	1.11 (To Center-Tap)	1.11 (Total)
Transformer Secondary RMS Volts Line-to-Line		=	2.22	2.22	1.11
Secondary Line Current		=	1.57	0.707	1.00
Transformer Secondary Volt-Amperes per Leg		=	3.49	1.57	1.11
Transformer Primary RMS Amperes per Leg		=	1.57	1.00	1.00
Transformer Primary Volt-Amperes per Leg		=	3.49	1.11	1.11
Average of Primary and Secondary Volt-Amperes		=	3.49	1.34	1.11
Primary Line Current		=	1.57	1.00	1.00
Line Power Factor			—	0.900	0.900

1. Insert a low-value resistor in series with one of the transformer primary windings and a shunt capacitor across the primary.
2. Insert a series inductance in the primary winding of the power transformer along with a shunt capacitor across the primary.
3. Install a shunt or buffer capacitor across the secondary winding of the power transformer.
4. Install a capacitor across the half-wave rectifying diode so that the power represented by the transient is dissipated in the total circuit series resistance.
5. Install a shunt varistor such as a GE MOV device across the secondary, in the same manner as a buffer capacitor.
6. Other schemes, such as the installation of a dual-diode shunt clipper, zener, or diode-and-capacitor combination across the rectifying elements.

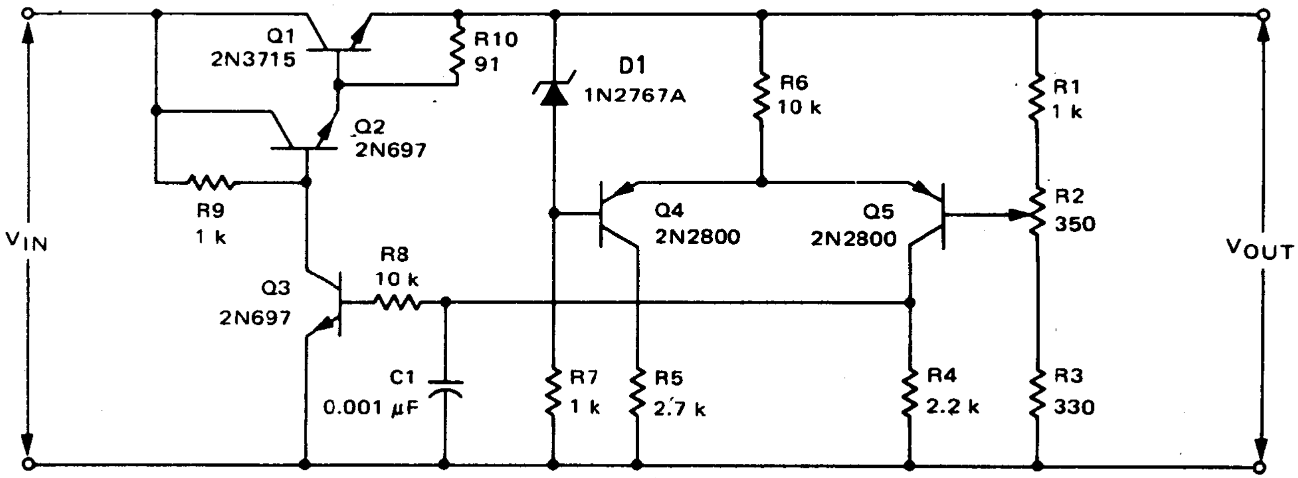
Unless the transient problem is quite severe, any of the first four alternative methods should prove satisfactory, even though these approaches do not offer full protection against high-voltage surges.

1.1 Regulators and Current Sources

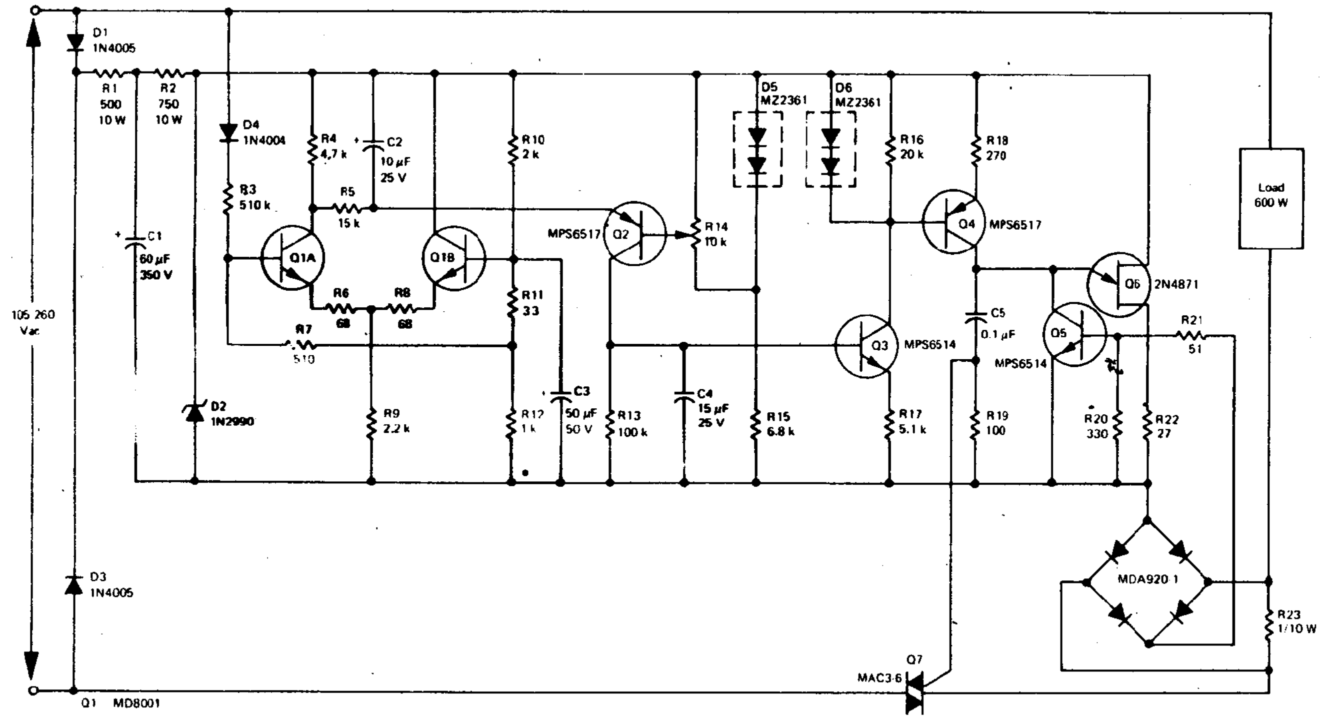
The 25 or 30 circuits featured in this section are representative of the regulation methods typically employed in solid-state power systems; additional regulators may be found as part of the power supply circuits in the subsequent subsections.



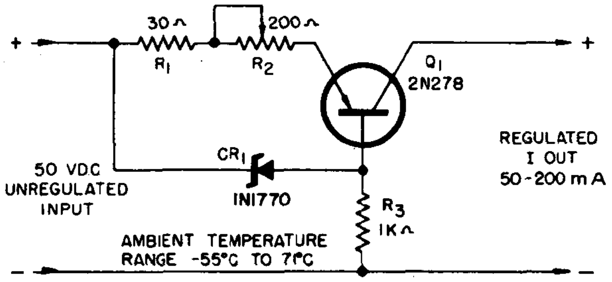
1.1.1 1000V 100W dc regulator with two series Delco DTS-723 transistors functioning as the pass element. The input voltage of the regulator may vary from 1200 to 1500V with 0.1% regulation at full load.



1.1.2 Motorola basic series-pass regulator. The drive for the series-pass transistor is derived by sampling the output voltage of the regulator with the voltage divider R1, R2, and R3. This sampled voltage is compared to the reference voltage provided by zener D1. The difference between the reference voltage and the sampled voltage is amplified and provides drive to the series-pass transistor, which compensates for any change in the output voltage.



1.1.3 Motorola closed-loop rms regulator will hold the output voltage at 90V (±2V) rms with any input voltage between 105 and 260V. The sensing circuit uses a differential amplifier employing a dual transistor, shown as Q1A and Q1B. Q1A is biased to operate in the nonlinear cutoff region of the differential amplifier transfer function, where the output current varies approximately as the square of the input voltage. The signal input magnitude is necessary for the sensing circuit to operate properly above and below cutoff. R11 is provided to hold the base of Q1A 300 mV below the base of Q1B, which is sufficient to insure that Q1A does operate about cutoff.



COMPONENT PARTS LIST

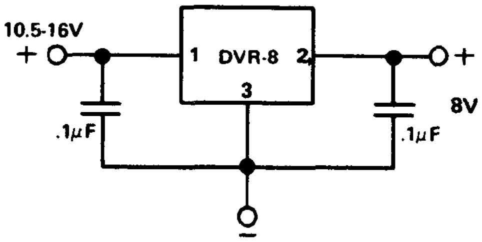
R_1 – 30 Ω, 5 W, wire wound
R_2 – 200 Ω, 4 W, wire wound
R_3 – 1000 Ω, 5 W, wire wound
Q_1 – 2N278 Delco power transistor
CR_1 – high power 8 volt Zener diode, G.E. type 1N1770 or equivalent
Heat sink – Delco Radio 7281366 or equivalent (This size permits opration in ambient temperatures up to 71°C.)

1.1.4 Delco current regulator uses a grounded-base circuit. The collector current is essentially equal to the emitter current because of the high current-gain characteristic of the transistor. When the emitter current is held constant, the collector current will remain approximately constant. The emitter current is determined by the voltage V_1 applied across the resistors R1 and R2. This voltage is equal to $V_1 = V_{VR} - V_{EB}$, where V_{VR} is the voltage across the voltage reference diode CR1, and V_{EB} is the voltage appearing between the emitter and base on the transistor. For the current and voltage range considered, V_{EB} is small. A typical value for V_{EB} is 0.2V. In this circuit, V_{VR} is approximately 8V. Voltage V_1 appearing across resistances R1 and R2 is approximately equal to V_{VR} and we have for the emitter current:

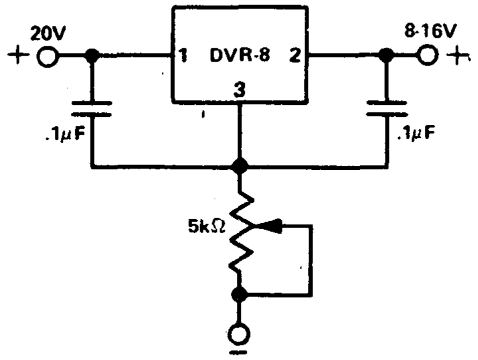
$$I_E \frac{V_{VR}}{R1 + R2}$$

As noted on the schematic diagram, R2 is variable. By changing the value of R2, a change in the emitter current is possible. R3 provides a keep-alive current for the reference diode. With loading, the transistor supplies a small portion of the current drawn by R3; therefore, less current will flow through the reference diode. R3 must draw enough current through the reference diode so that the voltage drop across the diode will remain at 8V as the current regulator is loaded.

The current supplied to the load will remain essentially constant until R_L is increased in size to the point where the voltage drop across R_L is as large as the voltage drop across R3.

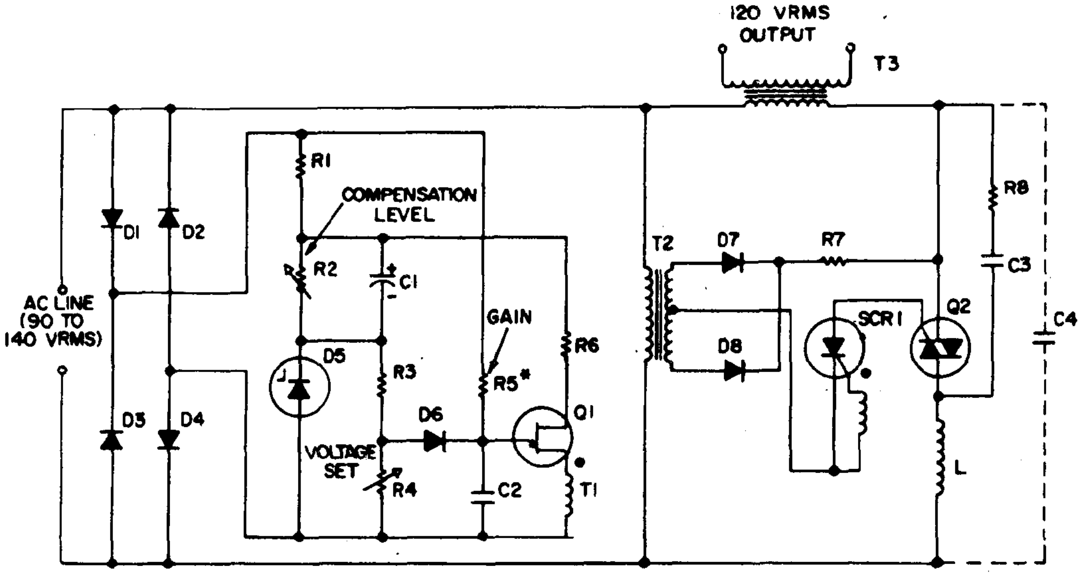


8V Regulator



Adjustable Regulator

1.1.5 Delco dc voltage regulators employ 100 mA monolithic devices. The circuit at the right provides control of the output from 8 to 16V.



R1 = 5K OHMS
R2 = 500 OHMS
R3 = 3.3 K OHMS
R4 = 10 K OHMS

R5 = 4.7M OHMS*
R6 = 1K OHMS
R7 = 100 OHMS
R8 = 100 OHMS

D1,D2
D3,D4 ALL
D6,D7 A13 OR
D8 A14

D5 = GE-Z4XL20
Q1 = GE-2N2646
Q2 = GE-TRIAC SC41B
SCR1 = GE-C6U,C106Y2

C1 = 200μf,10V
C2 = .1μf
C3 = .1μf
C4 = .1μf
L ≅ 100μH

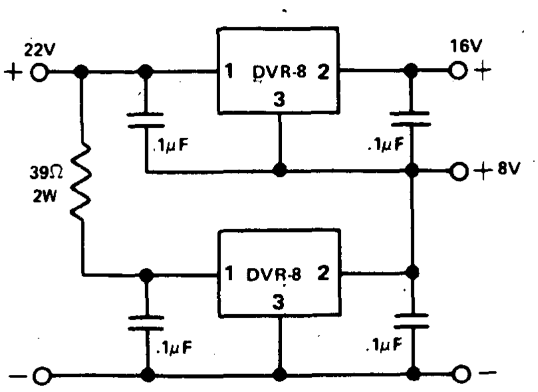
T1 = PULSE TRANSFORMER, SPRAGUE NO. 11Z12
T2 = 24 VOLTS CT 300mA, KNIGHT #612476
* FOR ADJUSTABLE GAIN, USE VARIABLE RESISTOR HERE.

1.1.6 GE 500W switching type ac line-voltage regulator provides ±2% regulation for a fixed load as line voltage varies over ±20%. The regulator employs a phase-controlled triac to control voltage applied to transformer T3. The addition of 24V transformer T2, which drives the gate of the triac when pilot SCR1 is fired, provides a continuous gate signal for the triac, avoiding possible half-wave operation whenever the output of the circuit feeds an inductive load.

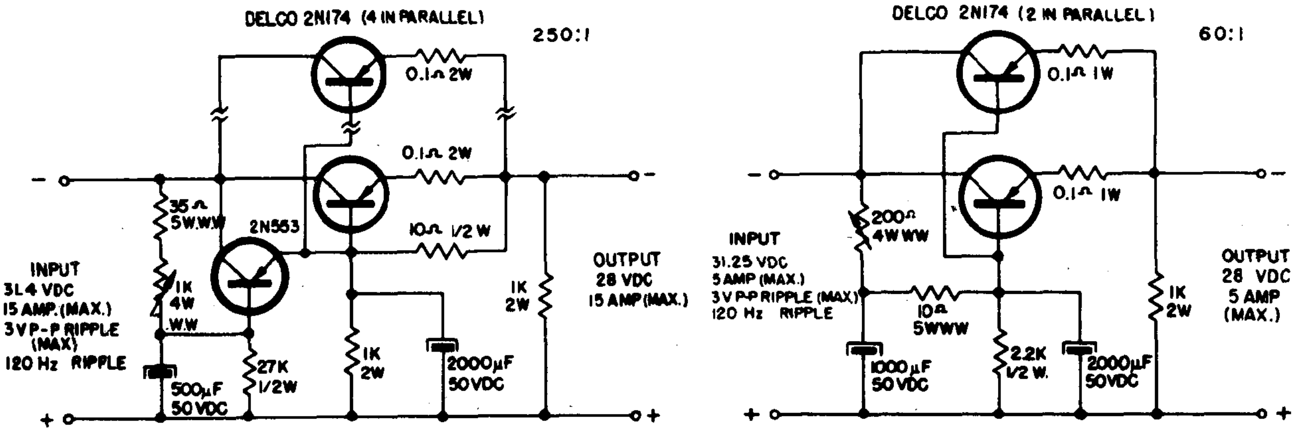
Adjusting the regulation: After applying 90V at the input, adjust R4 to obtain 120V on the output for the desired load conditions. Now raise the input voltage to 140V. If the output voltage increases, adjust R2 to bring the voltage down to its correct value. Now adjust the input to 90V and repeat the adjustment there.

Either root-mean-square or *average* voltage can be regulated, depending on the type of load. The adjustments should be made with a suitable voltmeter across the load. Each time the load impedance is changed, the circuit must be readjusted.

Since this type of circuit regulates by phase control, some loads (e.g., certain types of ac motors) may not function properly on the output waveform because of its harmonic content.

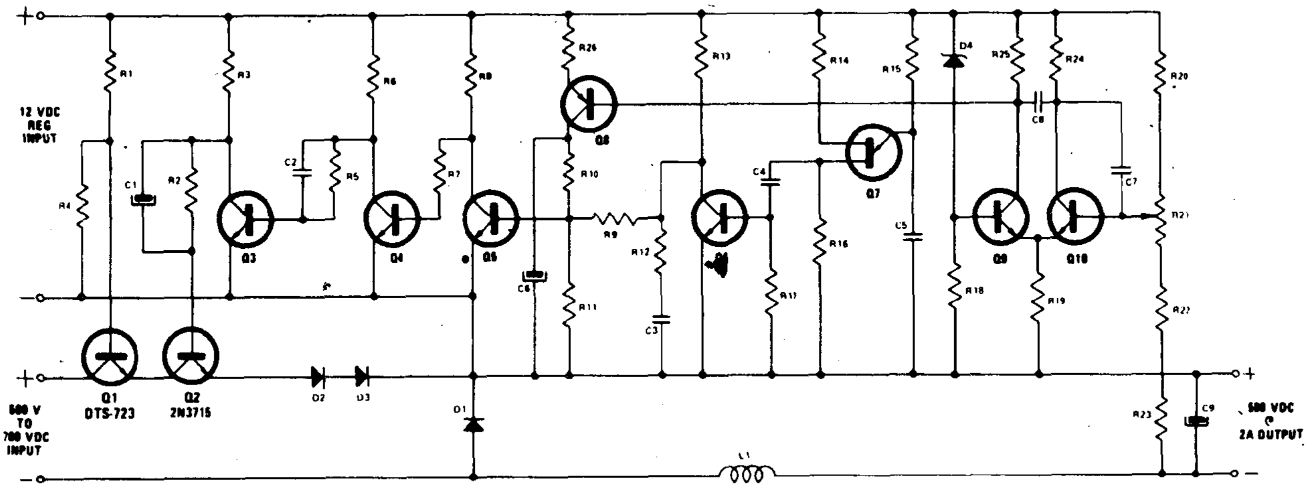


1.1.7 Delco dual-level regulator supplies 8 and 16V dc at 100 mA. Short-circuit output current: 200 mA minimum.



1.1.8 Delco electronic ripple filters provide 28V output. Electronic filters do not take the place of conventional LC filter networks; rather, they supplement the LC filter to achieve very low values of power supply ripple. To apply these circuits efficiently, reduce the ripple to a value of 3V or less before using the electronic filter.

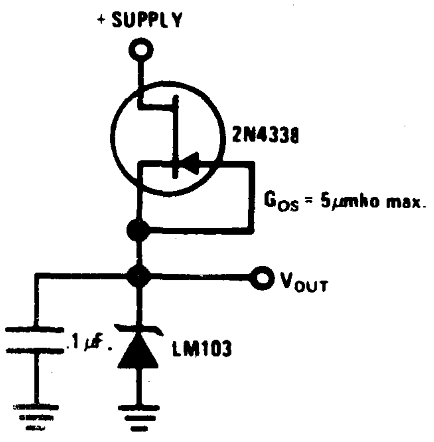
The circuits shown will reduce ripple by a factor of about 250:1. If the ripple is reduced to 250 mV by LC filters, the output from the electronic filter will contain only about 1 mV ripple. The simpler circuit shown at right will reduce ripple by a factor of about 60:1.



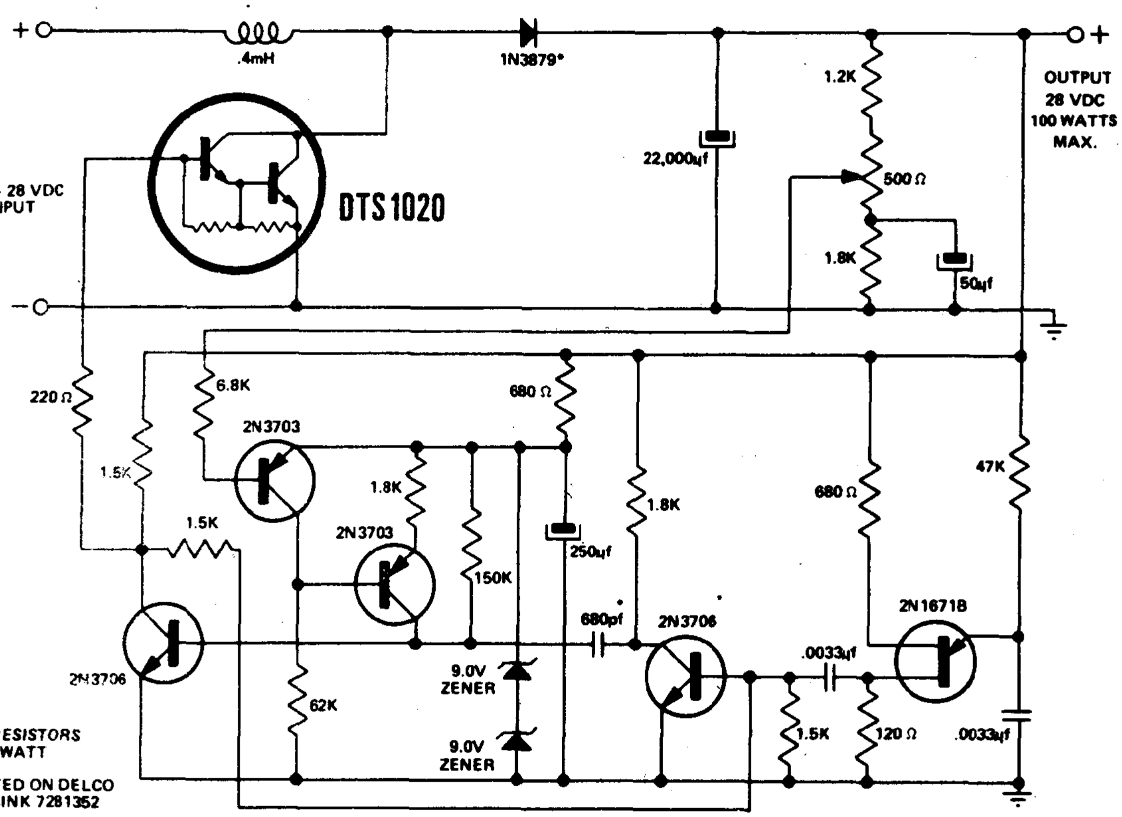
Parts List

Q_1	DTS-723
Q_2	2N3715
Q_3, Q_4, Q_5, Q_6, Q_9, Q_{10}	2N3706
Q_7	TIS 43
Q_8	2N3703
D_1	As required
D_2, D_3	1N4001
D_4	5.6V zener
R_1	6.8, 25W (noninductive)
R_2	2.7
R_3	47, 2W
R_4	100, 1W
R_5	560
R_6, R_{17}	1.5k
R_7	8.2k
R_8, R_{24}, R_{25}	5.6k
R_9, R_{13}, R_{20}	2.2k
R_{10}	6.8k
R_{11}	1k
R_{14}	620
R_{15}	47k
R_{16}	220
R_{18}	10k
R_{19}	15k
R_{21}	2k potentiometer
R_{22}	22k
R_{23}	200k, 5W (wirewound)
R_{26}	820
C_1	100 μF
C_2	0.082 μF
C_3	0.33 μF
C_4	0.033 μF
C_5	1500 pF
C_6	5 μF
C_7, C_8	0.1 μF
C_9	2 μF
L_1	7 mH

1.1.9 Delco low-cost switching regulator circuit useful in the 1 kW range employs a single DTS-723 silicon transistor as a series switching element. At 500V and 1A output, regulation of 0.4% can be achieved; at 2A output, the regulation is better than 1%. Regulation is accomplished by pulse-width modulation at a constant switching frequency. Efficiency is more than 90% at a switching frequency of 13 kHz. At output levels up to 500W, switching frequencies up to 20 kHz would be practical with small size components at slightly reduced efficiency.



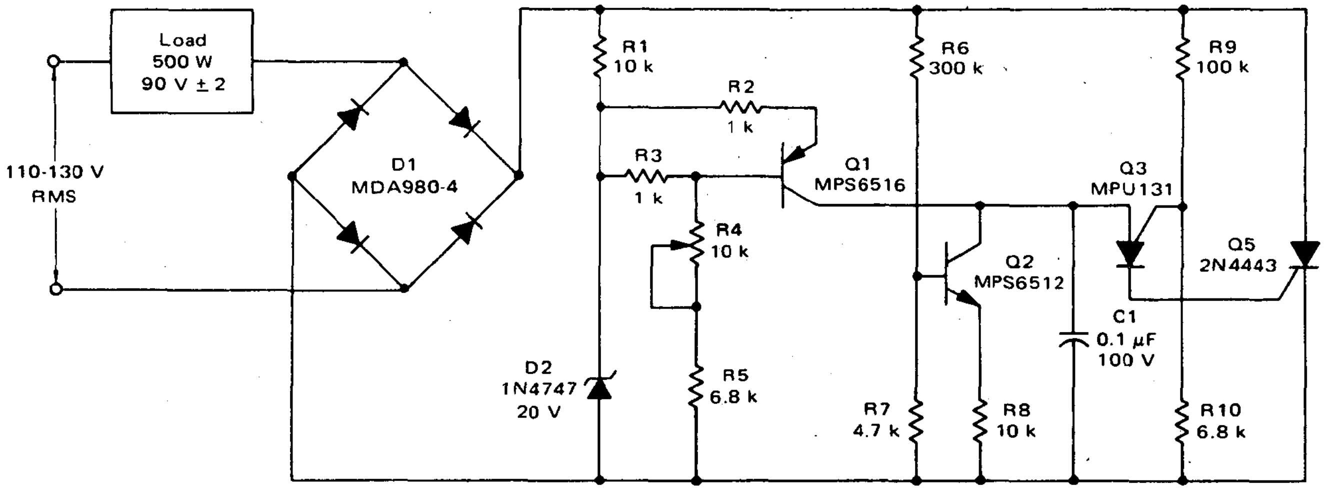
1.1.10 National low-power regulator reference circuit provides a stable voltage reference almost totally free of supply voltage hash. Typical power supply rejection exceeds 100 dB.



INDUCTOR

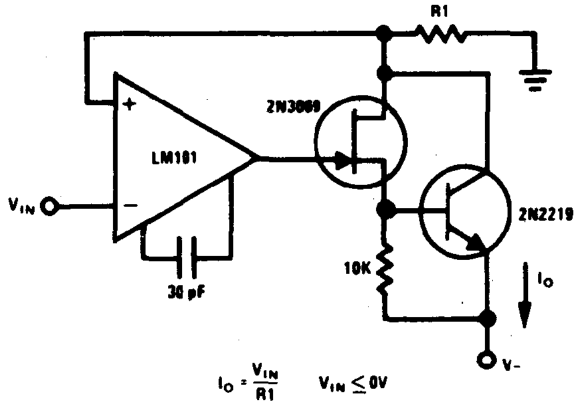
Core: Powdered Iron
Arnold B079024-3
Wire: 124 Turns, No. 17

1.1.11 Delco miniature 100W flyback switching regulator uses a DTS-1020 Darlington silicon power transistor. Efficient regulation by pulse-width modulation is achieved at an output voltage as high as 6V above the input voltage. The switching rate is 9 kHz; it operates with an input of 22 to 28V. Regulation and ripple are less than 1% at full output.



1.1.12 Motorola open-loop rms voltage regulator provides 500W 90V rms with good regulation for an input voltage range of 110 to 130V rms.

With the input voltage applied, capacitor C1 charges until the firing point of Q3 is reached, causing it to fire. This turns Q5 on, which allows current to flow through the load. As the input voltage increases, the voltage across R10 increases, which increases the firing point of Q3. This delays the firing of Q3 because C1 now has to charge to a higher voltage before the peak-point voltage is reached. Thus the output voltage is held fairly constant by delaying the firing of Q5 as the input voltage increases. For a decrease in the input voltage, the reverse occurs.



1.1.13 National precision current source in which the 2N3069 JFET and 2N2219 bipolar serve as voltage isolation devices between the output and the current sensing resistor, R1. The LM101 provides a large amount of loop gain to assure that the circuit acts as a current source. For small values of current, the 2N2219 and 10K resistor may be eliminated with the output appearing at the source of the 2N3069.