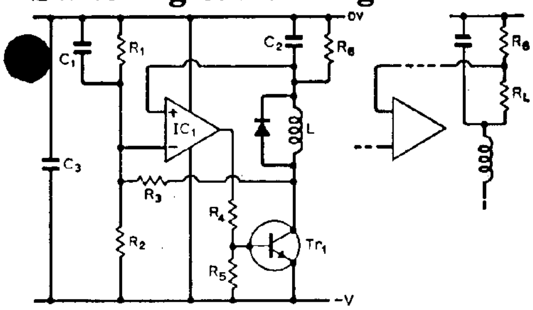
Wireless World Circard Series 6: Constant-current Circuits 7

Switching current regulator



Typical data

IC: 301
Tr: TIP3055
D: SD2 (1A 25V diode)
C_1: 1nF
C_2: 22μF 6.3V Tantalum
C_3: 22μF 20V Tantalum
R_1: 1kΩ; R_2: 5.6kΩ
R_3: 470kΩ; R_4: 220Ω
R_5: 150Ω
L: 5mH (Ferrite core)*
For $R_6 = 2\Omega$, $V_s = -10V$
load voltage: 1.2V,
supply current: 150mA
switching frequency: 4kHz
*See component changes
ripple voltage: 100mV
stability: output change $< \pm 4\%$ for supply 5 to 20V
output change $< \pm 1\%$ for load resistance 2 to 15Ω.

Circuit description

The key difference between switching regulators and conventional types lies in the discontinuous operation of power stage which is isolated from the load by an LC network. The power transistor delivers current for short periods to the inductor and during its non-conducting period the current flow in the inductor is sustained through the diode. The resulting voltage step across the inductor (approximately equal to the supply voltage) defines the rate-of-change of current in terms of the inductance. If the period is short enough, the current is relatively constant, and together with the filtering action provided by the capacitor, the ripple voltage across R_1 can be small compared with its mean p.d. The circuit may be alternatively viewed as a simple astable in which the inversion due to the output transistor interchanges the functions of the op.amp. input terminals, while an LR circuit replaces the conventional CR version. Hysteresis provided by R_3 defines the pk-pk swing that will occur across R_6. The smaller this hysteresis, i.e. the larger R_3, the smaller the resulting ripple. This brings with it increased frequency of operation, as the rate-of-change of voltage is a function of L, C_2, R_6 as outlined above. Mean level across R_6 is fixed by that across R_1 and is a fixed fraction of the supply voltage. In most applications this potential divider is replaced by stable reference voltage of suitable value (see cards 5, 9). As shown, the circuit acts as a voltage regulator for a load at R_6. To be used as a constant-current source the load may be placed series with the resistor across while a constant p.d. is developed. Switching regulators may be driven by an external oscillator with the internal positive feedback eliminated.

Component changes

L: Frequency of operation is a compromise; too high and amplifier switching times limit performance, too low and increased inductance brings reduced efficiency because of

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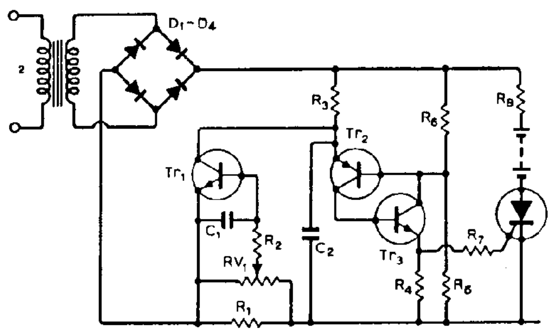
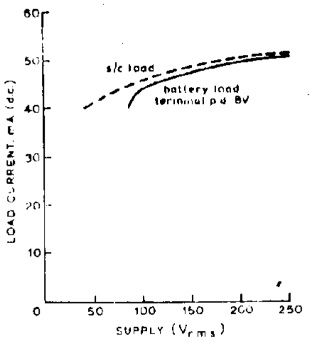
Thyristor control current regulator



Typical performance

T: 240V r.m.s. 50Hz primary
30V r.m.s. secondary
D_1 to D_4: 50V 1A bridge rectifier
Tr_1, Tr_3: BC 125
Tr_2: BC 126
Tr_4: 50V 1A (mean d.c.) thyristor (2N1595 etc)
R_1: 12Ω; R_2, R_5, R_6: 10kΩ
R_3: 150kΩ; R_4: 470Ω
R_7: 100Ω; R_8: 15Ω
C_1: 470μF; C_2: 22nF
Supply: 200V r.m.s.
Battery terminal p.d.: 8V
Charging current set to: 50mA (mean)
Change in current for supply voltage ±25% $\approx +4\%$
Change in current for terminal p.d. changed by $\pm 2V \approx \pm 0.5\%$

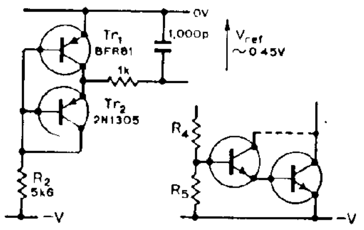


Circuit description

The circuit consists of four sections: a full-wave bridge-rectified power supply; a thyristor in series with the load with the angle of conduction varying the mean load current; a pulse-generating circuit which delivers a series of pulses to the thyristor starting at a particular instant in each half-cycle; and a current-sensing transistor that varies the pulsing circuit to control the mean current via the firing angle. Once the thyristor has fired, the remainder of the circuitry has no influence on the instantaneous current (determined only by the elements in series across the supply: R_1 thyristor, load, R_8). Any increase in the mean current causes the mean p.d. across R_1 to increase and via RV_1, smoothed by R_2, C_1, brings Tr_1 into conduction. This by-passes some charging current from C_2 delaying the onset of firing of the unijunction-equivalent composed of Tr_2, Tr_3, R_5, R_6 (see Series 3, card 4). The minimum p.d. wasted across current-sensing resistor R_1 need only be $\approx 0.6V$, giving good efficiency. Accuracy of control is limited by relatively low gain of control element, its temperature dependence, etc. Adding a zener diode in emitter of Tr_1 and dispensing with RV_1 would define control point more accurately at expense of increased voltage/dissipation in R_1.

Component changes

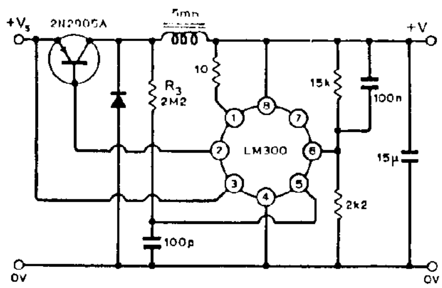
T, D_1 to D_4: Diodes must carry peak current much greater than mean current where conduction angles are small (high supply voltages, low load voltages) i.e. if mean load current is to be 1A peak currents might have to be >5A. Similarly for transformer, thyristor.



winding resistance. Coils wound on ferrite rings/cores offer wide range of operating frequencies with minimum radiation of switching harmonics if shielded units used. Typical range 200μH to 10mH.
IC_1: Uncompensated op.amp. 748, etc. Possibility of 741,301 compensated amplifiers at low frequency with suitable choice of ferrite.
Tr_1: For currents < 500mA: BFR41, BFY50 with reduced efficiency; somewhat higher frequencies at moderate currents: MJE521.
R_1, R_2, R_3: Set reference voltage/hysteresis. R_1, R_2 replaced normally by separate reference circuit.

Circuit modifications

- To stabilize load voltage/current some stable reference voltage must be added. A simple circuit that allows operation down to very low supply voltages, tolerates high voltages and gives reasonable stability against temperature changes, matches the V_{be} characteristics of a silicon against a germanium transistor. Unselected units give a variation in reference voltage against supply of $<2\%$ over the whole supply range of the regulator (e.g. 3 to 20V), and a typical temperature drift of $<0.1\%$ per deg. C.



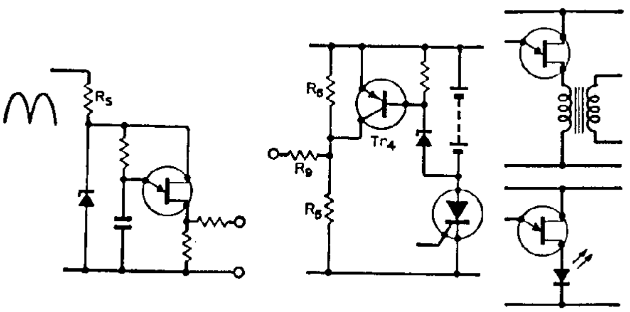
- Output current can be increased by replacing the drive transistor by any high gain combination such as the Darlington pair provided frequency is not too high (charge storage problems) and the increased losses due to saturation are acceptable. At low supply voltages the collector of the first transistor may be returned to the zero line.
- A positive voltage regulator using a standard i.c. is given in the first reference below. It operates at a higher switching frequency and contains its own voltage reference circuit. Pin 6 compares a portion of the output voltage with the internal reference, the error amplifier driving the transistor with positive feedback via pin 6 and defining the hysteresis.

Further reading

Designing Switching Regulators, National Semiconductor application note AN-2, 1969.
Nowicki, J. R., Power Supplies for Electronic Equipment, vol. 2, Leonard Hill, 1971, pp. 153-81.

Cross references

Series 6, cards 8 & 10.



R_1: At max. setting of RV_1, mean voltage across R_1 is 0.6V approx. and mean current = $0.6V/R_1$. Setting RV_1 to 50% doubles mean current, and p.d. across R_1, quadrupling power in R_1.
C_1: Smooths bias to Tr_1, 50 to 1000μF low-voltage electrolytic.
R_2: Increased value allows lower C_1 for given smoothing but decreases accuracy of current. Typical range: 2.2 to 47kΩ.
R_3, C_2: To give free running frequency ≫ 100Hz so that firing can occur early in each cycle. R_3: 47 to 470kΩ; C_2: 10 to 100nF.
Tr_2, Tr_3, R_5, R_6: Can be replaced by single unijunction transistor e.g. 2N2646, 2N2160, etc. Any other general-purpose silicon transistors in place of Tr_2, Tr_3.
R_4, R_7: Reduce R_4 to 100 for some unijunctions. R_7 not critical.
Thyristor: Any medium sensitivity, low-voltage thyristor. For higher peak currents reduce R_1, R_8 proportionately. Resistor R_8 can be omitted if very high peaks can be tolerated by thyristor, load.

Circuit modifications

- The supply to the sensing/firing circuits may be limited and/or stabilized by a zener diode to improve control over the firing point, and to protect the circuitry when the thyristor supply is too great. For example, this would be necessary if constant-current action were desired directly from mains with no intervening transformer. Dissipation in R_5 would be high. In this, as in main diagram, a unijunction may be substituted for the complementary bistable.
- Where the circuit is to be used for battery charging, over-voltage protection might be desired. One possibility is to monitor the battery voltage directly (or better via an RC filter to eliminate spikes, as with R_2, C_1 over) using a zener diode or other suitable reference to define onset of conduction in Tr_4. The latter can then be used to raise the potential at the junction of R_5, R_6, delaying and eventually preventing firing. Addition of a series resistor R_9 to the junction of Tr_2 base/Tr_3 collector prevents excessive current flow via Tr_4, Tr_3.
- Alternative coupling methods including pulse transformation, light-emitting diodes, etc., may be used if thyristor is at an inconvenient potential relative to firing circuit.

Further reading

Low-cost constant-current battery charger with voltage limiting, *Semiconductors* (Motorola), vol. 3, 1972, no. 1, pp. 15/6.
400V constant-current source, Electronic Circuit Design Handbook, Tab. 1971, p. 298.
Nowicki, J. E., Power Supplies for Electronic Equipment, vol. 2, Leonard Hill, 1971, pp. 182-93.

Cross references

Series 2, card 5. Series 3, card 4. Series 6, card 7.