AN-6612

A Novel JFET Micro-Power Voltage Regulator

Many systems require a stable voltage supply to maintain constant performance. When these systems are battery-operated, a regulator is needed to stabilize the system voltage as the battery decays with time. Unfortunately, IC voltage regulators require several milliamps of quiescent current, making them impractical for micro-power applications. Zener diodes may also be impractical because of short term peak current requirements of the system. This could require additional buffering or high standby currents, but both increase the battery drain. An inexpensive micro-power voltage regulator is needed to fill the gap between IC regulators (high quiescent current) and Zener diodes (high standby current).

Instead of the traditional bipolar approach, the regulator shown in Figure 1 uses a JFET as the series pass element. This offers several advantages: first, no pre-regulation is needed for the pass element as with an NPN bipolar because the drive comes from the regulated output. Next, the gate-source is isolated from the line via the drain, thus offering excellent line regulation. This is not the case with PNP bipolar pass elements, where the emitter is the input. Finally, and possibly the most important feature for micro-power regulators, is JFETs require no current drive.

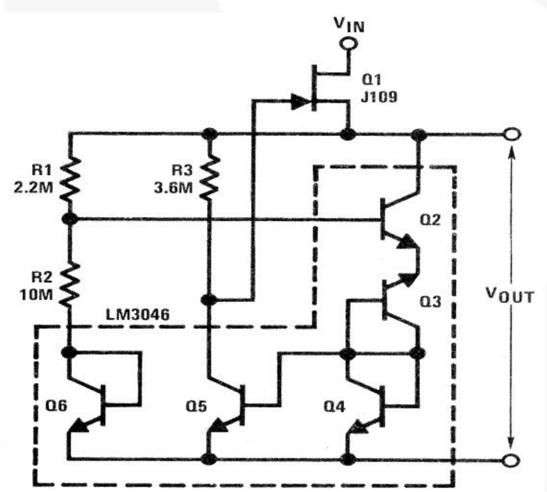

Figure 1. Micro-power Regulator

Output Voltage

$$V_{OUT} = V_{BE}\left(2 + \frac{R1}{R2}\right) + BV_{EB}\left(1 + \frac{R1}{R2}\right)$$

Drift

$$\frac{\partial V_{OUT}}{\partial T} = \frac{\partial V_{BE}}{\partial T}\left(2 + \frac{R1}{R2}\right) + \frac{\partial BV_{EB}}{\partial T}\left(1 + \frac{R1}{R2}\right)$$

Quiescent Current $\simeq 4\ \mu A$

The emitter-base breakdown voltage of Q3 is used as a reference (~7.2 V) in conjunction with Q2 to form a shunt regulator. The shunt current drives a current mirror, Q4-Q5, which creates the gate drive voltage of the pass JFET. The value of the shunt current is determined by R3 and the V_{GS} of the pass JFET ($I_{R3} \sim I_{SHUNT}$). High load currents will reduce the shunt current because the JFET V_{GS} is lower. Temperature stability is achieved by cancelling the drift of Q2 and Q3's V_{BE} (~-2 mV/°C/transistor) with the BV_{EB} drift of Q3 (~3 mV/°C) resulting in a negative drift at the base of Q2, and the output, of 1 mV/°C.

Selection of the JFET requires some care. Ideally, the JFET I_{DSS} needs to be greater than the load current at all temperatures (I_{DSS} has a temperature coefficient of ~−0.7%/°C) and the breakdown voltage should be greater than the maximum input voltage. Practically, the JFET I_{DSS} needs to be much larger than the maximum load current. Linear operation requires the JFET's drain to gate voltage (V_{DG}) to be greater than the pinch-off voltage V_P. By operating the JFET at currents much less than I_{DSS}, the gate to source voltage (V_{GS}) will be close to V_P ($V_{GS} = V_P (1-(I_D/I_{DSS})^{1/2})$) allowing small drain to source voltages (V_{DS}). For linear operation:

$$|V_{DG}| > |V_P|$$

$$V_{DG} = V_{DS} - V_{GS}$$

It should be noted that N channel JFET's can be paralleled for higher load current requirements without matching the devices.

Actual performance of the regulator is quite good. With a 10 V typical output, the line regulation is within ±0.05% for a range of VIN-VOUT of 0.3 V to 10 V. The load regulation is 0.2% with a load range of 10 µA to 10 mA (Z_O ~ 10 Ω) and the temperature stability is −0.01%/°C (~1 mV/°C). The output voltage can be easily trimmed by adding a pot at the R1 R2Q2$_{BASE}$ junction to eliminate BV_{EB} variations or to make the output adjustable over a limited range. Also, the temperature stability can be improved by replacing Q3 with an 8.2 V Zener diode, because its temperature drift (~4 mV/°C) would nearly match the combined V_{BE} drift of Q2 and Q4. The regulator is good enough to be used as a reference in low accuracy (6-7-bit) or limited temperature range applications if current drain is important.

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References:

1. "Voltage Regulator Handbook", National Semiconductor Corporation, May 1975.
2. "Zener Diode Handbook", Motorola, Inc., May 1967.
3. Williams, P., "D.C. Voltage-Reference Circuits with Minimum Input-Output Differentials", Proc. IEEE pp. 1280–1281, December, 1969.