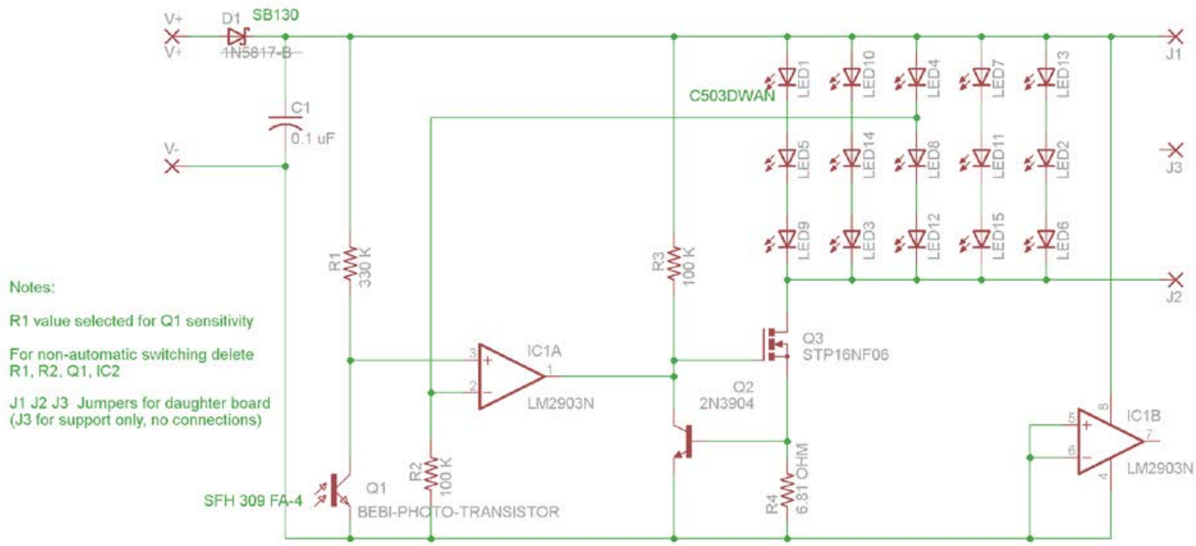
FrankenBebi Circuit Description, Ver 0.12.04

Document Rev 1.1



Overview

The FrankenBebi circuit consists of two main sections: The constant-current LED driver (LED 1-15, Q2, Q3, R3, and R4), and the optional light-sensing switch (Q1, R1, R2, and IC1). In addition, the power input is protected from accidental reverse-polarity connection by D1. Capacitor C1 provides power filtering and suppression of interference from nearby radio transmitters (such as from a masthead VHF antenna). The FrankenBebi generates no radio interference, since it uses a linear regulator rather than a switching regulator.

Current Regulator and LEDs

The FrankenBebi has fifteen white LEDs configured as five paralleled strings of three series-connected LEDs. The current regulator is designed to operate at 100mA, and this current is split evenly by the five LED strings, for an individual LED current of 20mA. These LEDs each have a forward voltage drop of approximately 3V, or 9V for the array. These LEDS are matched by the manufacturer for forward voltage drop, so the LED currents are well-matched.

The current regulator consists of:

- Q3 – an N-channel MOSFET as a series-pass element
- R4 – a current-sense resistor
- Q2 – a general-purpose NPN transistor which provides negative feedback in the regulator
- R3 – a bias resistor that provides the control voltage to the Q3 gate

The regulator uses the base-emitter junction of Q2 to sense the voltage across R4. When this voltage exceeds the 0.68V forward bias voltage of this junction, Q2 begins to conduct current through R3, reducing the gate voltage on Q3 and reducing the current through the LEDs. If the current drops slightly, the base-current in Q2 is reduced, which causes the voltage at the gate of Q3 to rise, increasing the LED current.

This current regulator is insensitive to battery-voltage variation, maintaining a fairly constant LED current between 11.25V and over 20V

Light-Sensing Switch

The light-sensing switch consists of:

- Q1 – an infrared phototransistor
- R1 – the Q1 collector resistor, used to sense the phototransistor current
- IC1 – a dual comparator (only one section is used)
- R2 – this provides a minimum bias current to LED4, which is used as a voltage reference

If automatic switching is not desired, Q1, IC1, R1, and R2 should be omitted.

The optional light-sensing switch uses an infrared photo-transistor (Q1) as an ambient-light sensor, where the current through this phototransistor is proportional to the light level. This current flows through resistor R1, and the voltage drop across R1 is sensed by the non-inverting input of comparator IC1. The inverting input of the comparator is connected to LED4 and bias resistor R2. R2 draws a small amount of current through LED4 (about 80 uA) which provides a minimum forward-bias current to the LED and provides a voltage reference of about 3V below the supply rail to the comparator.

When the sky is dark and the phototransistor is not illuminated, the voltage drop across R1 is less (more positive) than the LED4 forward voltage. This drives the comparator open-collector output to a high-impedance state, allowing the current regulator to operate.

When the phototransistor is illuminated sufficiently, the voltage drop across R1 exceeds that across LED4, driving the comparator open-collector output and the gate of Q3 low. This forces Q3 to turn off, and extinguishes the LEDs.

The voltage drop across LED4 is not constant. When the LEDs are conducting full current the LED forward drop is slightly greater than when the LEDs are off and only the R2 bias current is flowing. This change in voltage drop acts as positive feedback, or hysteresis, in the comparator circuit. Hysteresis prevents the light-sensing switch from flickering or oscillating when the ambient light is at the switching threshold.

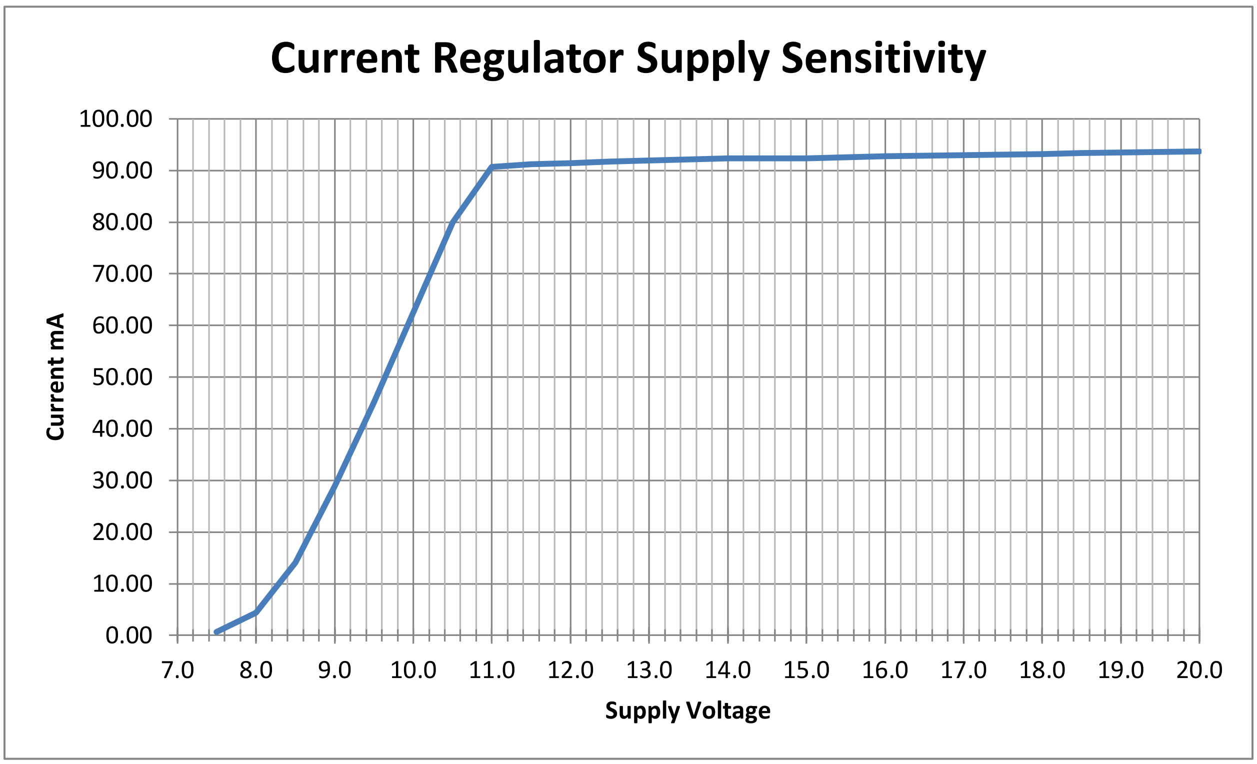
By the way, the LED used for the voltage reference could have been either LED1, LED4, LED 7, LED 10, or LED13. LED4 was chosen to simplify the board layout.

Current Regulator Design Details

The current regulator is a simple design, and while its performance is more than adequate for the job, it is not a high-precision circuit. For example, an LM-317 regulator connected as a current source will have better initial accuracy and lower temperature sensitivity. However, the LM-317 requires approximately 3 volts of "overhead" to maintain regulation, which means that a battery voltage of over 13.25V would be required for proper operation. The FrankenBebi regulator only needs 0.7V of overhead, allowing the design to function down to a battery voltage of about 11.2V.

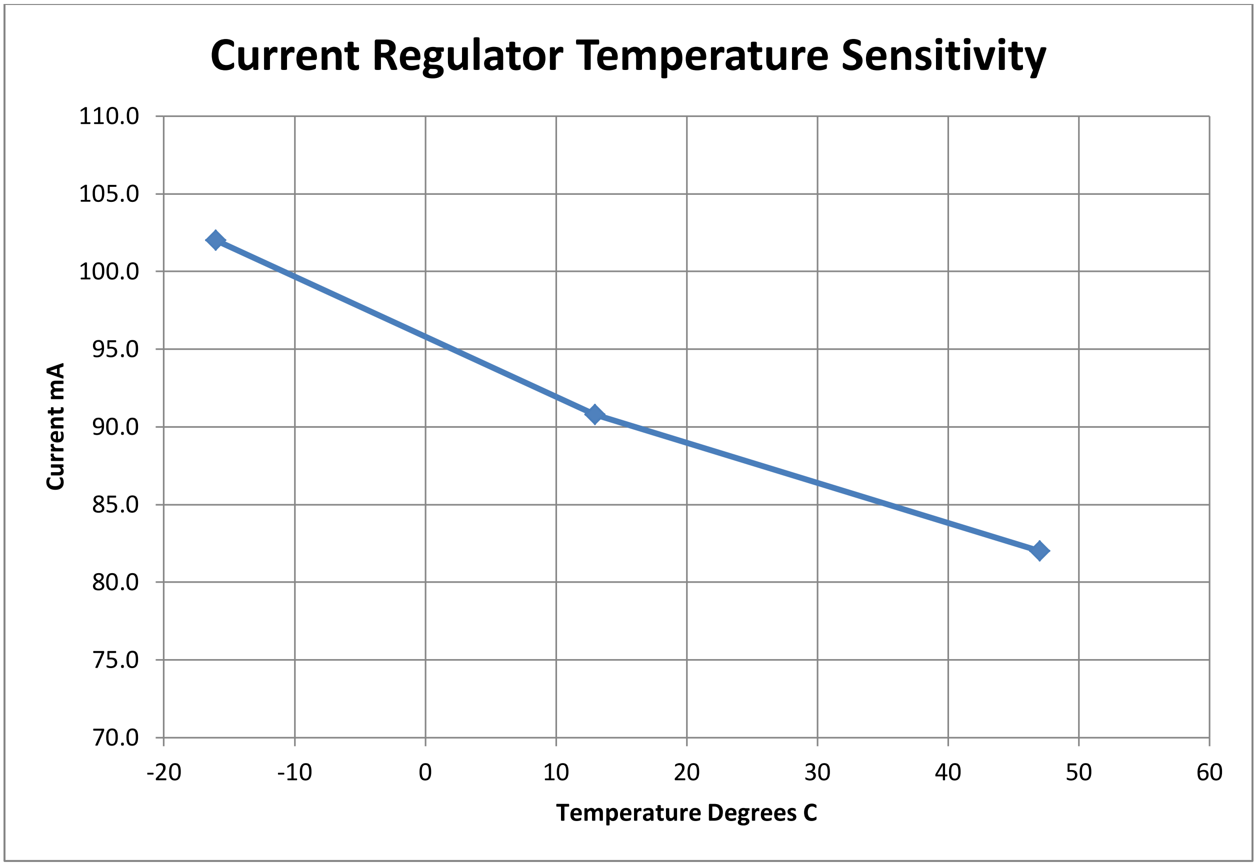
Supply Sensitivity

The chart below shown the typical current regulation vs supply voltage for the FrankenBebi regulator. Note that this data was taken without the Shottky diode D1 in place, so in order to estimate battery voltage approximately 0.25V should be added to the supply voltage shown.



Temperature Sensitivity

The FrankenBebi regulator is also somewhat sensitive to temperature. The current-sense circuit relies on the base-emitter junction of Q2, and in a Silicon transistor this junction has a forward voltage drop variation of about -2 mV per degree Celsius. This means that the regulator current will drop as the temperature rises. The chart below shows the typical current variation as a function of temperature:



Component Values

The critical components in this circuit are Q2 and R4. The voltage drop across R4 and the base-emitter voltage of Q2 establish the regulator current set-point. The gain of transistors Q2 and Q3 are not particularly critical, although they will very slightly affect the degree of regulation. Q2 is a general-purpose NPN transistor, and there are many other transistors that could be used here. If a substitution is made the value of R4 may need to be adjusted to compensate for the slight change in V_{BE} of the different transistor.

Q3 is a high-power N-channel MOSFET. The important parameter is the On-resistance R_{DS}(on), which is less than 0.1 Ohm. Most power MOSFETs will have a similar on-resistance.

R3 (100K) is a non-critical component. The value is high enough to provide good gain, but low enough that leakage currents and stray capacitance will not be an issue.

Linear vs Switching Regulators

Many LED light controllers use a high-efficiency switching regulator. There are advantages to a switching regulator, principally reduced current consumption and a very wide battery voltage range.

There are also disadvantages to a switching design. The switcher may be more expensive, but generally not outrageously so. The more important disadvantage is that switchers often generate Radio Frequency Interference, which can dramatically affect your ability to use SSB, VHF FM, or AIS. Since the

VHF or AIS antenna is often located in very close proximity to the anchor light, even a very small amount of switcher-generated interference can cause a big problem.

The FrankenBebi regulator is a pure linear design, and generates no Radio Frequency noise. Because of the low-overhead regulator, and the LED array configuration, there is little power lost in the regulator when operating from a 12V battery.

24 Volt Operation

The FrankenBebi has not been characterized for 24V operation. It will function up to 30V battery voltage, but at this high voltage the power dissipation may cause the temperature of Q3 to exceed its limits. This will depend on the thermal characteristics of the potting compound, which remain to be determined.

Light Sensing Switch Design Details

The critical component in this circuit is the phototransistor Q1. This is an infrared-sensitive device, with a manufacturer-guaranteed sensitivity range of 2:1, which allows for a no-adjustment design. Ungraded phototransistors often exhibit lot-to-lot sensitivity variations of 50:1. If a different phototransistor us used, the value of R1 will likely require adjustment.

The voltage drop of LED4 is approximately 2.97V when switched on, and 2.52V when switched off (with only the R2 bias current flowing). With the value of R1 being 330K, this means that a phototransistor current of 7.6uA is needed to switch the light ON, and a current of 9uA is needed to turn the light OFF. This gives us about 18% hysteresis.

Note that R1 and LED4 are each connected to the positive supply voltage. The phototransistor is effectively a light-controlled current-source, and so its current is not significantly affected by the battery voltage. This configuration greatly reduces any sensitivity to battery voltage so the light-level switching threshold should remain constant regardless of battery voltage.

An infrared device was chosen to eliminate self-sensitivity, where a reflection from the anchor light's LEDs might cause the light to oscillate on and off (turn itself off). The light from the sun is fairly broad-spectrum, so an IR-sensitive device functions well as a daylight detector.

Typical Light Levels

The light-sensing switch is set to turn on/off at a light level of approximately 100 lux. This is the brightness of a "very dark overcast day", and comfortably between the light levels of "Civil Twilight" (3.4 lux) and "Sunrise or Sunset on a clear day" (400 lux).

10^{-5} lux	Light from Sirius, the brightest star in the night sky
10^{-4} lux	Total starlight, overcast sky
0.002 lux	Moonless clear
0.01 lux	Quarter moon
0.27 lux	Full moon on a clear night
1 lux	Full moon overhead at tropical latitudes
3.4 lux	Dark limit of civil twilight under a clear sky
100 lux	Very dark overcast day
400 lux	Sunrise or sunset on a clear day
1000 lux	Overcast day
10,000 lux to 25,000 lux	Full daylight (not direct sun)
32,000 lux to 130,000 lux	Direct sunlight