## User Guide for

# FEBFHR1200_SPG01A
# Evaluation Board

## High-Performance Shunt Regulator

## Featured Fairchild Product:
## FHR1200

***Direct questions or comments***
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***"Worldwide Direct Support"***

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This user guide supports four applications for the FHR1200. It should be used in conjunction with the FHR1200 datasheet as well as Fairchild's application notes and technical support team. Please visit Fairchild's website at www.fairchildsemi.com.

# 1. Introduction

This document describes four proposed applications for the FHR1200 high-performance shunt regulator. These include:

A. Two each SC70-to-DIP adapters: The small size of the SC70 can make it difficult to solder to the part for prototyping. Each adapter is supplied with a FHR1200 already soldered down.

B. A 3.3 V-to-12 V regulated energy-storage-capacitor charger. Some smart meters only consume around 250 mW 99% of the time so can use a single 3.3 V low-power offline supply. However, to transmit, they require much higher power for a few milliseconds and can pull this voltage from a storage capacitor charged to a higher voltage.

C. Voltage regulator and reference: This module can be used with most power supply topologies and on isolated, non-isolated, primary-side, and floating applications.

D. Low-cost, low-voltage auxiliary regulator: Some designs need a regulated voltage in the 0 to 6 V range at just a few milliamps. The FHR1200 makes it possible to create a low-cost regulator for this application and can operate with an input voltage to >100 V.

E. Simple $V_{CC}$ or brownout regulator: Many power supply designs require that the $V_{CC}$ voltage be regulated for the controller. The low operating current, high voltage and wide temperature range make the FHR1200 a good choice for general regulation applications.

This document contains a general description of the FHR1200, the specifications for each application circuit, schematics, bill of materials, and the typical operating characteristics.

## 1.1. Description

The FHR1200 is a high-efficiency regulator that outperforms a typical shunt regulator in applications where low operating power, wide temperature range, and wide voltage range are important. The regulator also features better stability and faster response than many existing regulators.

The FHR1200 can be used for isolated and non-isolated secondary side regulation plus, primary side, and floating regulation because the regulator can directly drive a power supply controller. This reduces parts count and circuit complexity in many applications. Non-isolated secondary-side regulation saves the cost of OPTOs and simplifies the power supply design.

The FHR1200 can be used in many diverse applications. For example: $V_{CC}$ regulators to >100 V, small additional auxiliary power supplies, programmable precision Zener diodes (both high and low power), plus numerous analog circuits.

The FHR1200 can also be used as a standalone, low-cost, thermally stable, ~7.5 V voltage reference.

## 1.2. Features

- Low Current Operation: <10 µA
- Programmable Output: 7.5 to >100 V
- Fewest External Component Count
- Temperature Compensated: Typical <50 ppm
- Low Dynamic Impedance
- Fast Turn-On
- Low Output Noise
- Sink Current Capability: 10 µA to 50 mA
- Reference Voltage Accuracy: ±2%
- Wide Operating Temperature Range: -55 to 150°C
- Available in the 6-Lead SC70 Package

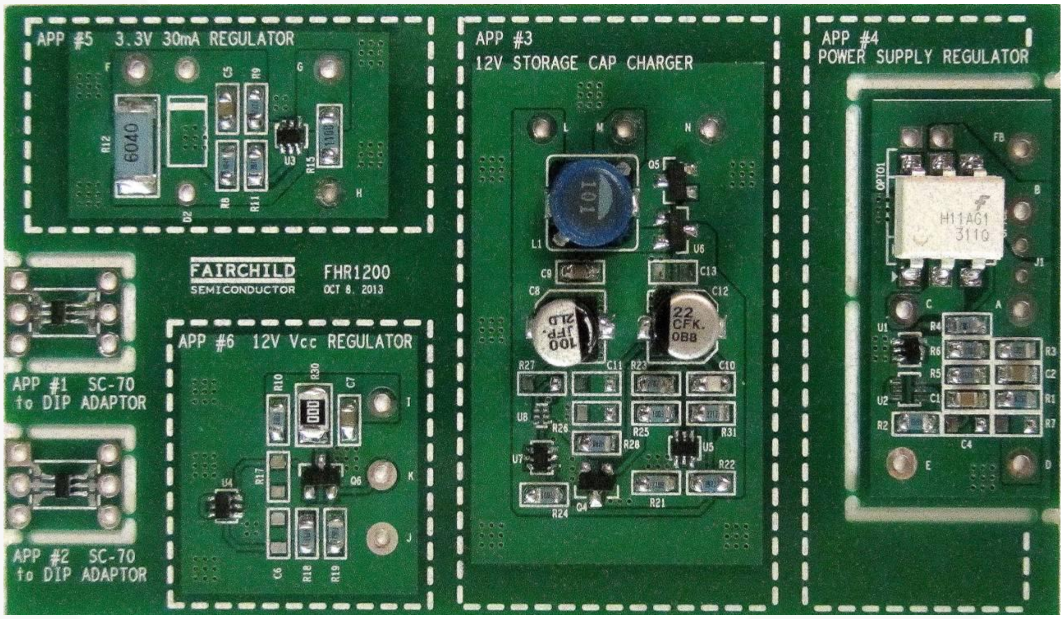
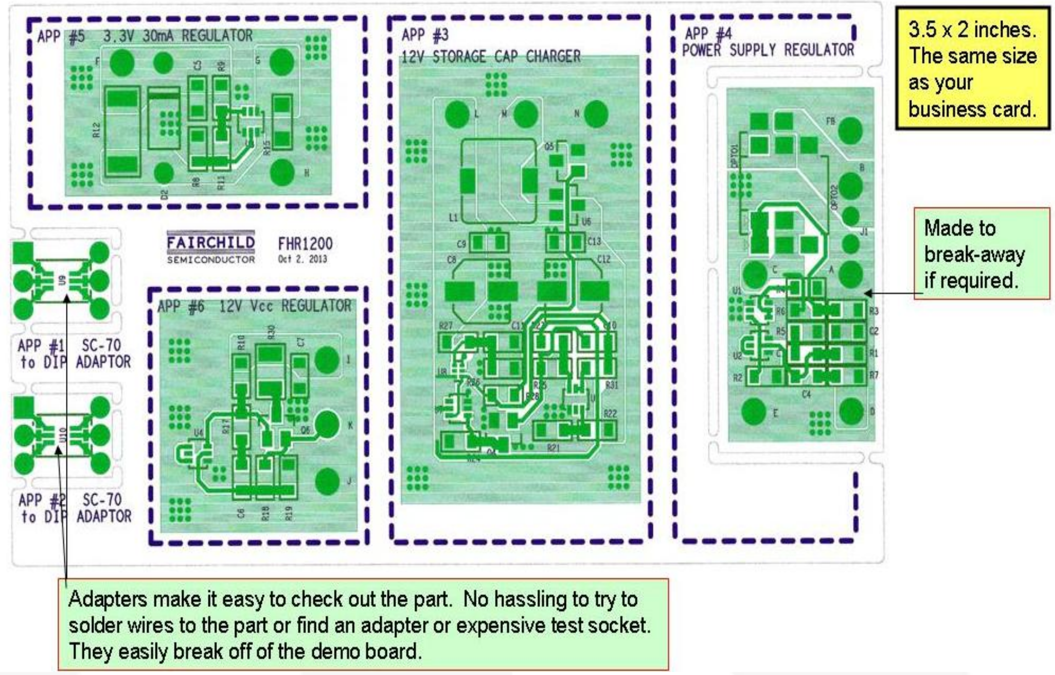


**Figure 1. Evaluation Board Photograph (Enlarged)**

The evaluation board is the size of an average business card, yet consists of six isolated PCB circuits that can make it quicker and easier to evaluate many potential applications. For example, the designer can use the break-away voltage regulator (app #4) to substitute for the existing output regulator on the power supply to evaluate the improvement over a current design; saving the cost and time of a PCB update to evaluate the part.



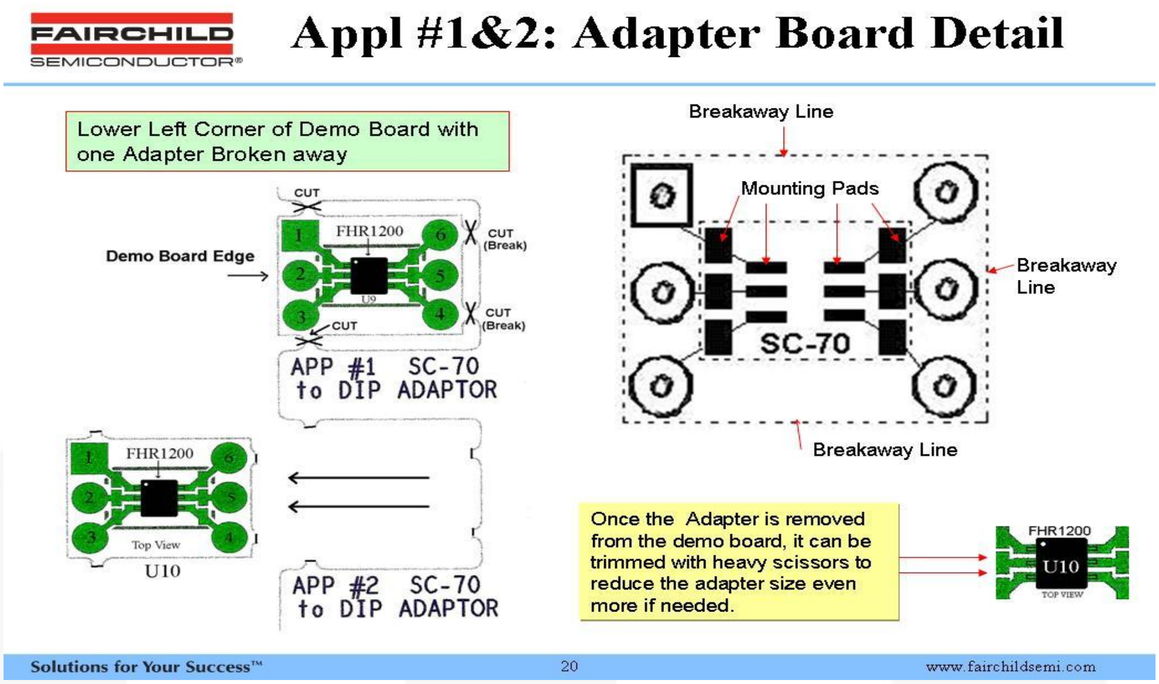
3.5 x 2 inches. The same size as your business card.

Made to break-away if required.

Adapters make it easy to check out the part. No hassling to try to solder wires to the part or find an adapter or expensive test socket. They easily break off of the demo board.

Figure 2. Evaluation Board Floor Plan

## 2. Evaluation Board Specifications



Appl #1&2: Adapter Board Detail

Lower Left Corner of Demo Board with one Adapter Broken away

Once the Adapter is removed from the demo board, it can be trimmed with heavy scissors to reduce the adapter size even more if needed.

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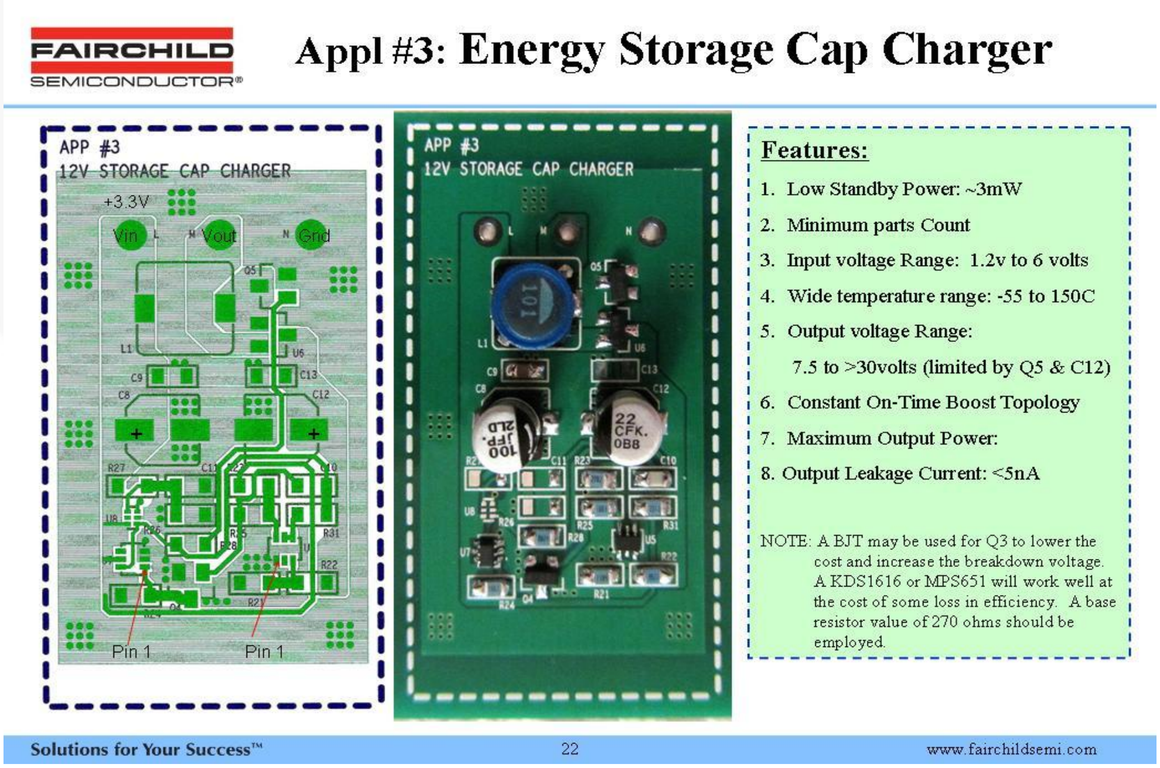
Figure 3. Break-Away Part Adapters



Appl #3: Energy Storage Cap Charger

**Features:**

1. Low Standby Power: ~3mW
2. Minimum parts Count
3. Input voltage Range: 1.2v to 6 volts
4. Wide temperature range: -55 to 150C
5. Output voltage Range:
   7.5 to >30volts (limited by Q5 & C12)
6. Constant On-Time Boost Topology
7. Maximum Output Power:
8. Output Leakage Current: <5nA

NOTE: A BJT may be used for Q3 to lower the cost and increase the breakdown voltage. A KDS1616 or MPS651 will work well at the cost of some loss in efficiency. A base resistor value of 270 ohms should be employed.

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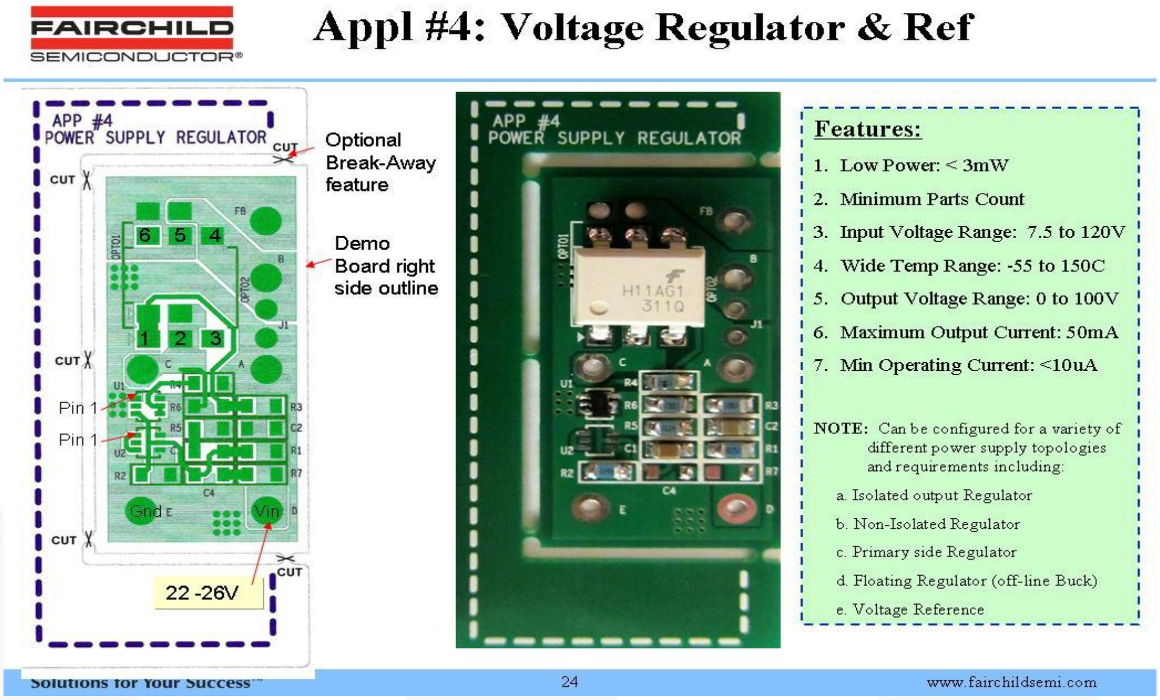
Figure 4. Energy Storage Capacitor Charger



## Appl #4: Voltage Regulator & Ref

**Features:**

1. Low Power: < 3mW
2. Minimum Parts Count
3. Input Voltage Range: 7.5 to 120V
4. Wide Temp Range: -55 to 150C
5. Output Voltage Range: 0 to 100V
6. Maximum Output Current: 50mA
7. Min Operating Current: <10uA

NOTE: Can be configured for a variety of different power supply topologies and requirements including:

a. Isolated output Regulator
b. Non-Isolated Regulator
c. Primary side Regulator
d. Floating Regulator (off-line Buck)
e. Voltage Reference

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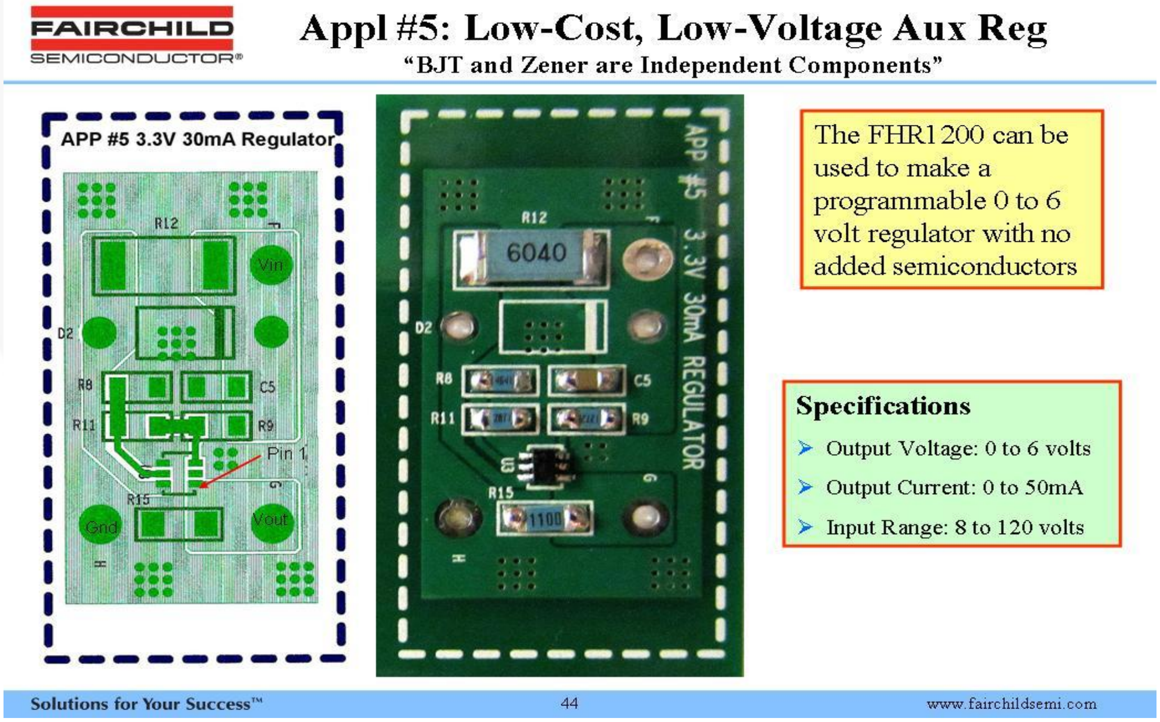
Figure 5. Power Supply Voltage Regulator



## Appl #5: Low-Cost, Low-Voltage Aux Reg

"BJT and Zener are Independent Components"

The FHR1200 can be used to make a programmable 0 to 6 volt regulator with no added semiconductors

**Specifications**

- Output Voltage: 0 to 6 volts
- Output Current: 0 to 50mA
- Input Range: 8 to 120 volts

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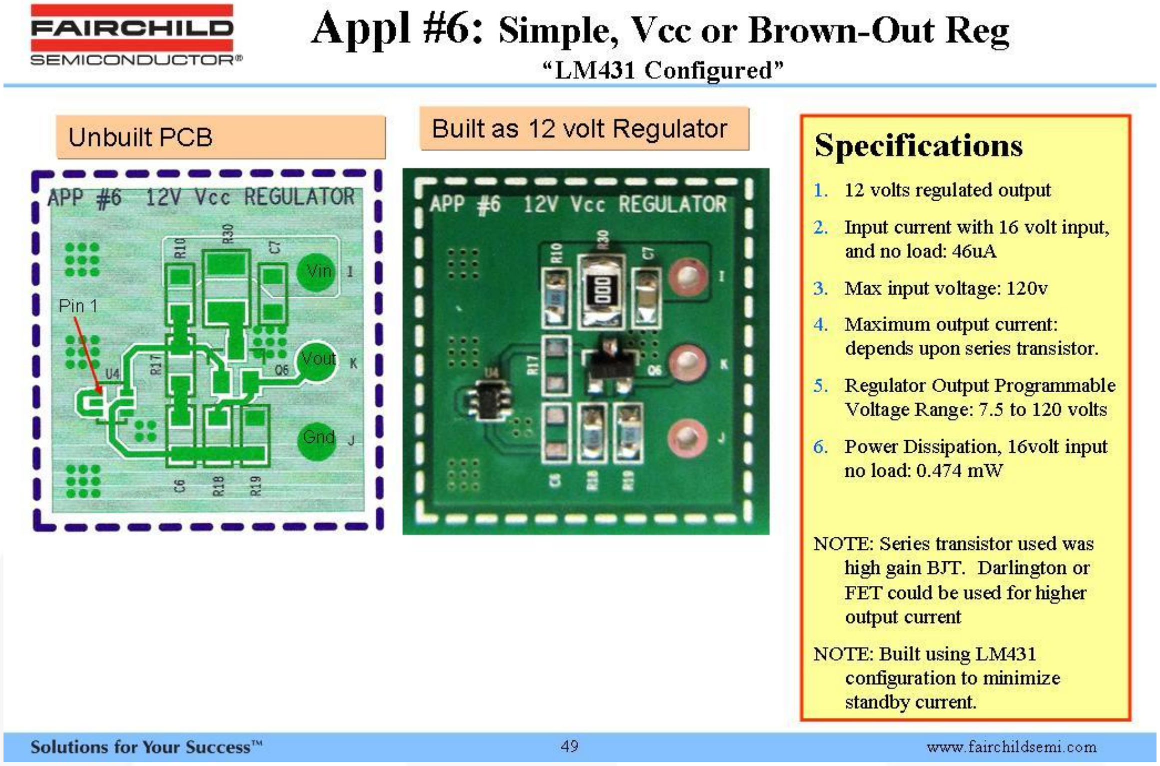
Figure 6. Low-Voltage Auxiliary Regulator



**Appl #6: Simple, Vcc or Brown-Out Reg**

"LM431 Configured"

Unbuilt PCB

Built as 12 volt Regulator

**Specifications**

1. 12 volts regulated output
2. Input current with 16 volt input, and no load: 46uA
3. Max input voltage: 120v
4. Maximum output current: depends upon series transistor.
5. Regulator Output Programmable Voltage Range: 7.5 to 120 volts
6. Power Dissipation, 16volt input no load: 0.474 mW

NOTE: Series transistor used was high gain BJT. Darlington or FET could be used for higher output current

NOTE: Built using LM431 configuration to minimize standby current.

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Figure 7. Low-Cost $V_{CC}$ or Brownout Regulator

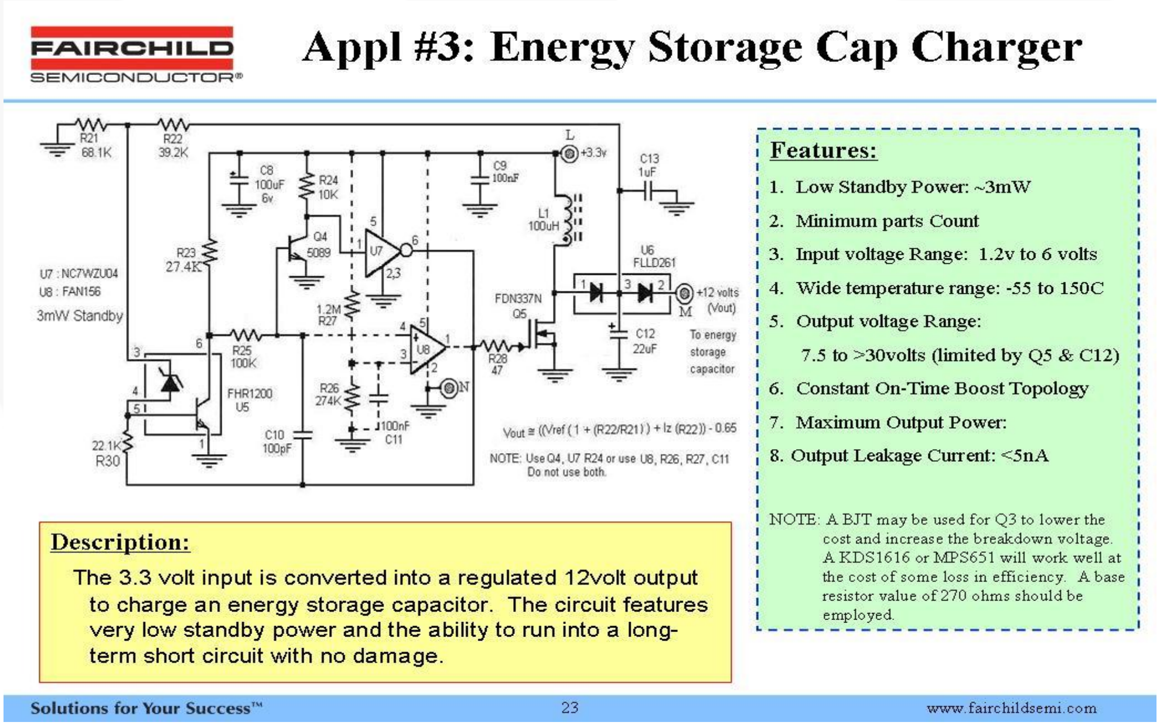
# 3. Application Circuit Details

## 3.1. Application #3: Energy Storage Capacitor Charger

This circuit is used to charge an energy storage capacitor to 12 V. This voltage was selected based on the requirements of a smart meter customer. Other voltages could have been used by modifying the value of resistor R22. The maximum regulated output voltage is limited by the breakdown voltage of the switch transistor, Q5, and of diodes, U6. Some smart meters only consume around 250 mW, 99% of the time, so can use a single 3.3 V low-power offline supply to maximize overall efficiency. However, to transmit, they require much higher voltage for a few milliseconds. This can be pulled from a storage capacitor charged to a higher voltage. The charger must be very efficient and consume little power once the capacitor is charged to the pre-determined voltage.

The PCB layout allows the circuit to be built two ways. The supplied board uses the BJT, Q4, and the logic inverter, U7. An alternate method using the comparator, U8, would have a lower parts count and improved efficiency, but had not been tested at the time the board was built and verified.

Dual diodes, U6, minimize the output leakage current of the charger to minimize the discharge of the outboard energy storage capacitor. During operation, the circuit charges the energy storage capacitor until the capacitor voltage reaches 12 V. The circuit then starts to pulse very slowly to overcome the circuit leakages.



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**Appl #3: Energy Storage Cap Charger**

Vout ≅ ((Vref ( 1 + (R22/R21) ) + Iz (R22)) - 0.65

NOTE: Use Q4, U7 R24 or use U8, R26, R27, C11
Do not use both.

**Features:**

1. Low Standby Power: ~3mW
2. Minimum parts Count
3. Input voltage Range: 1.2v to 6 volts
4. Wide temperature range: -55 to 150C
5. Output voltage Range:
   7.5 to >30volts (limited by Q5 & C12)
6. Constant On-Time Boost Topology
7. Maximum Output Power:
8. Output Leakage Current: <5nA

NOTE: A BJT may be used for Q3 to lower the cost and increase the breakdown voltage. A KDS1616 or MPS651 will work well at the cost of some loss in efficiency. A base resistor value of 270 ohms should be employed.

**Description:**

The 3.3 volt input is converted into a regulated 12volt output to charge an energy storage capacitor. The circuit features very low standby power and the ability to run into a long-term short circuit with no damage.

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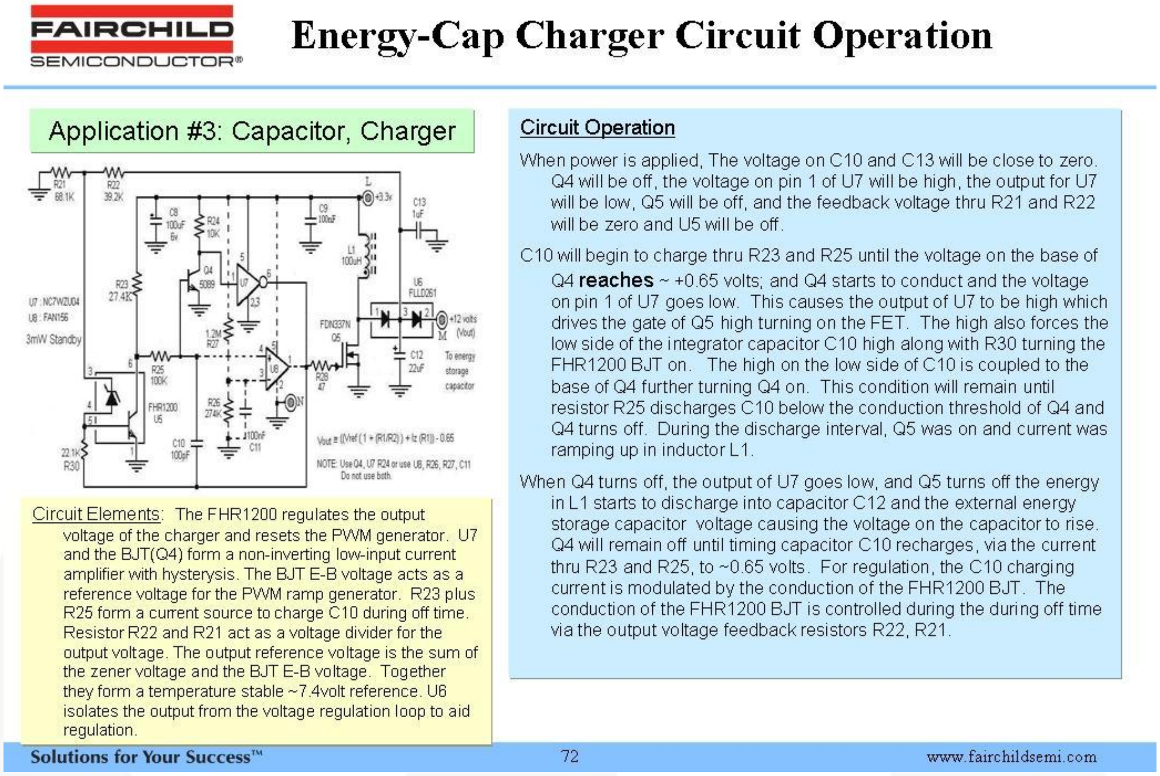
**Figure 8. Energy Storage Capacitor, Regulated High-Efficiency Charger**



**Energy-Cap Charger Circuit Operation**

**Application #3: Capacitor, Charger**

Circuit Elements: The FHR1200 regulates the output voltage of the charger and resets the PWM generator. U7 and the BJT(Q4) form a non-inverting low-input current amplifier with hysterysis. The BJT E-B voltage acts as a reference voltage for the PWM ramp generator. R23 plus R25 form a current source to charge C10 during off time. Resistor R22 and R21 act as a voltage divider for the output voltage. The output reference voltage is the sum of the zener voltage and the BJT E-B voltage. Together they form a temperature stable ~7.4volt reference. U6 isolates the output from the voltage regulation loop to aid regulation.

Circuit Operation

When power is applied, The voltage on C10 and C13 will be close to zero. Q4 will be off, the voltage on pin 1 of U7 will be high, the output for U7 will be low, Q5 will be off, and the feedback voltage thru R21 and R22 will be zero and U5 will be off.

C10 will begin to charge thru R23 and R25 until the voltage on the base of Q4 **reaches** ~ +0.65 volts; and Q4 starts to conduct and the voltage on pin 1 of U7 goes low. This causes the output of U7 to be high which drives the gate of Q5 high turning on the FET. The high also forces the low side of the integrator capacitor C10 high along with R30 turning the FHR1200 BJT on. The high on the low side of C10 is coupled to the base of Q4 further turning Q4 on. This condition will remain until resistor R25 discharges C10 below the conduction threshold of Q4 and Q4 turns off. During the discharge interval, Q5 was on and current was ramping up in inductor L1.

When Q4 turns off, the output of U7 goes low, and Q5 turns off the energy in L1 starts to discharge into capacitor C12 and the external energy storage capacitor voltage causing the voltage on the capacitor to rise. Q4 will remain off until timing capacitor C10 recharges, via the current thru R23 and R25, to ~0.65 volts. For regulation, the C10 charging current is modulated by the conduction of the FHR1200 BJT. The conduction of the FHR1200 BJT is controlled during the during off time via the output voltage feedback resistors R22, R21.

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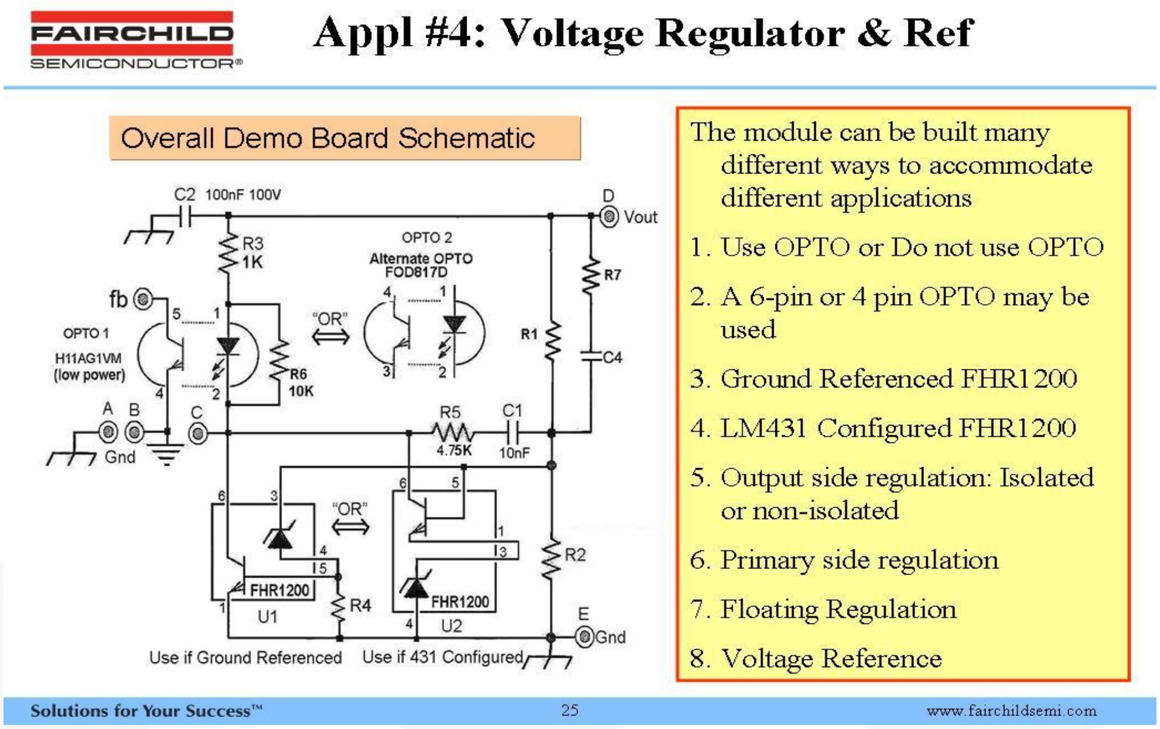
Figure 9. Energy Storage Capacitor Charger, Circuit Operation

## 3.2. Application #4: Voltage Regulator & Reference

Application circuit #4 can be used for voltage regulation on many power supply topologies and on isolated, non-isolated, primary side, and floating applications. It can also be used as a 7.5 V thermally stable, wide temperature range, low-current, voltage reference. The small circuit allows it to directly replace existing regulators on power supplies for evaluation. The circuit is arranged to be broken off the main board to facilitate prototyping.

The PCB layout allows the circuit to be built in a variety of ways to facilitate:

1. Isolated regulation using one of two possible OPTO isolators. The FOD817D OPTO isolator provides the lowest cost regulation. The H11AG1VM OPTO isolator provides the highest efficiency regulation. H11AG1VM is specified to operate to less than 200 µA, while the FOD817D is specified to operate to a minimum of 1.0 mA.
2. Non-isolated operation by removing both OPTOs.
3. Grounded-output operation that directly drives a controller to minimize parts count and cost, or to configure the FHR1200 regulator as an LM431-type stacked regulator.
4. Isolated output-side regulation. It may also be configured for: non-isolated output-side regulation, primary-side regulation, or floating regulation with a buck regulator.
5. Building a thermally compensated, wide input range, voltage reference.



## Appl #4: Voltage Regulator & Ref

Overall Demo Board Schematic

The module can be built many different ways to accommodate different applications

1. Use OPTO or Do not use OPTO
2. A 6-pin or 4 pin OPTO may be used
3. Ground Referenced FHR1200
4. LM431 Configured FHR1200
5. Output side regulation: Isolated or non-isolated
6. Primary side regulation
7. Floating Regulation
8. Voltage Reference

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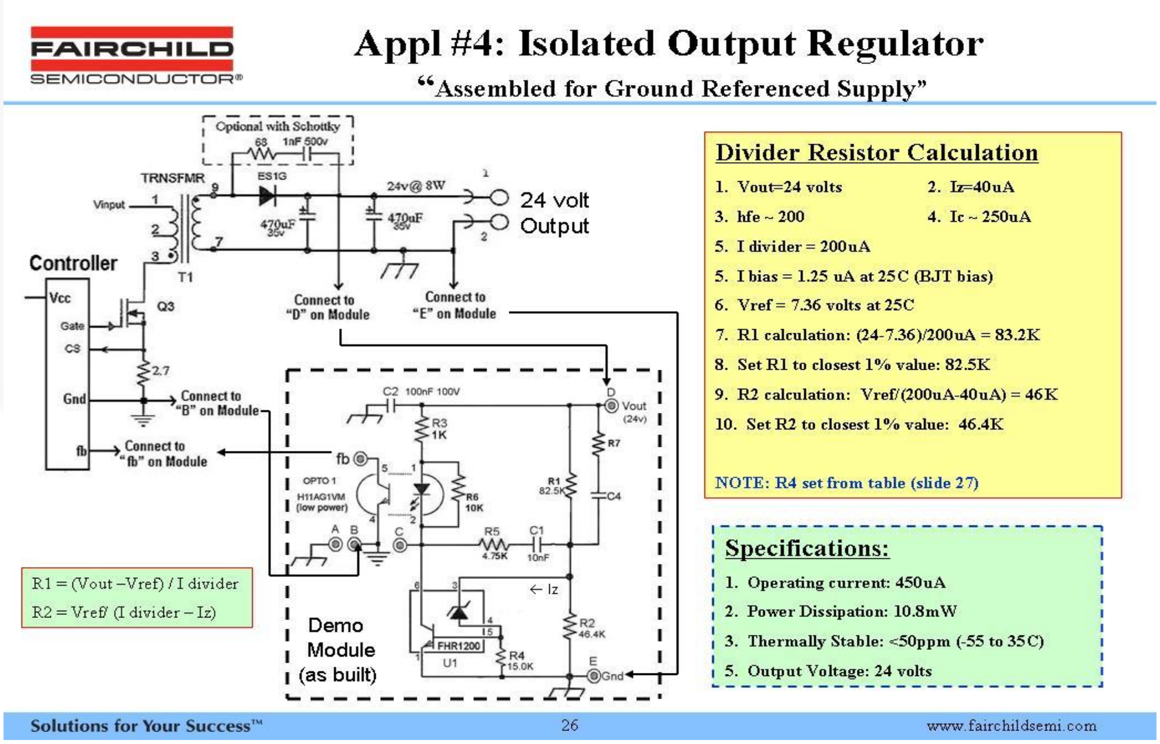
**Figure 10. Application Circuit #4: Overall Schematic**



## Appl #4: Isolated Output Regulator

"Assembled for Ground Referenced Supply"

R1 = (Vout – Vref) / I divider
R2 = Vref/ (I divider – Iz)

**Divider Resistor Calculation**

1. Vout=24 volts
2. Iz=40uA
3. hfe ~ 200
4. Ic ~ 250uA
5. I divider = 200uA
5. I bias = 1.25 uA at 25C (BJT bias)
6. Vref = 7.36 volts at 25C
7. R1 calculation: (24-7.36)/200uA = 83.2K
8. Set R1 to closest 1% value: 82.5K
9. R2 calculation: Vref/(200uA-40uA) = 46K
10. Set R2 to closest 1% value: 46.4K

NOTE: R4 set from table (slide 27)

**Specifications:**

1. Operating current: 450uA
2. Power Dissipation: 10.8mW
3. Thermally Stable: <50ppm (-55 to 35C)
5. Output Voltage: 24 volts

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**Figure 11. Application Circuit #4: Isolated Output, Grounded Output Regulator**

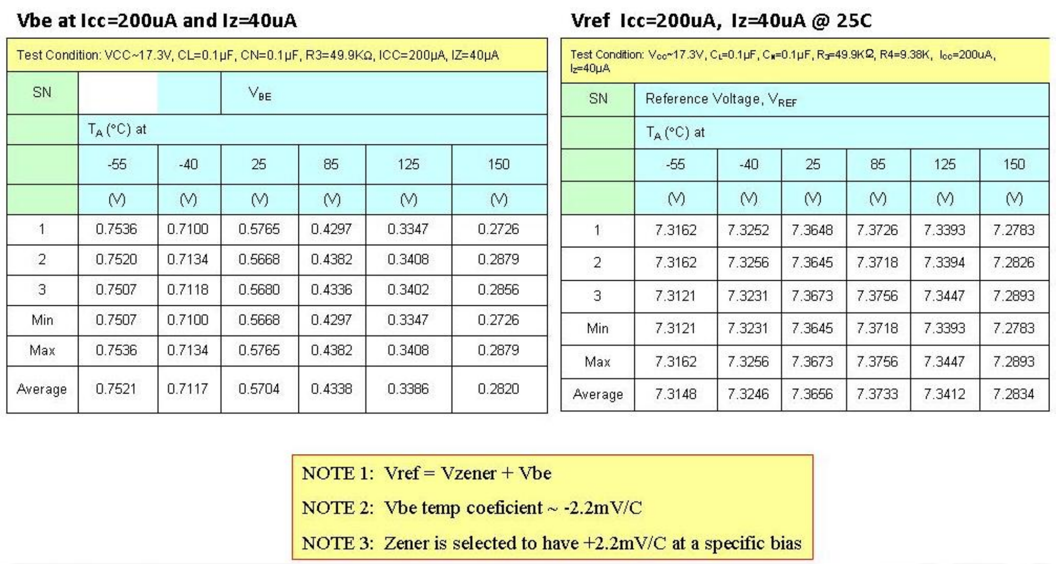
Table 1 illustrates how the FHR1200 reference $V_{BE}$ and $V_{REF}$ voltages are related at 40 µA reference current in the grounded configuration over temperature. At 40 µA, the reference is very stable, as shown in Figure 12. Table 2 provides additional data for designers to determine the optimum operating currents for a design and gives the optimum value for resistor R4. R4 sets the Zener current in the grounded configuration.

Figure 12 illustrates the stability of the FHR1200 reference at 200 µA or 1.0 mA collector current and 40 µA Zener current in the grounded configuration. The FHR1200 reference voltage is the sum of the Zener voltage plus the base emitter voltage of the BJT, which also serves as the error amplifier. The BJT base-emitter temperature coefficient ("tempco") is approximately -2.2 mV/°C. The Zener was selected to have a tempco that closely matches the BJT base-emitter tempco, but in the opposite direction. Note: Zener temperature coefficients vary widely from one Zener voltage to the next, from manufacture to manufacture, and over applied current. The FHR1200 Zener was selected to provide the most consistent $V_{BE}$ match over temperature.

Table 2 helps determine the optimum resistor values to properly bias the Zener and BJT over temperature. Table 3 provides resistor divider values versus output voltage in the Grounded Configuration.

Table 1-Table 3 and Figure 12 provide the data to set up the FHR1200 regulator.

**Table 1. $V_{BE}$ and $V_{REF}$ Values at 40 µA: Grounded Configuration**



**Vbe at Icc=200uA and Iz=40uA**

Test Condition: VCC~17.3V, CL=0.1µF, CN=0.1µF, R3=49.9KΩ, ICC=200µA, IZ=40µA

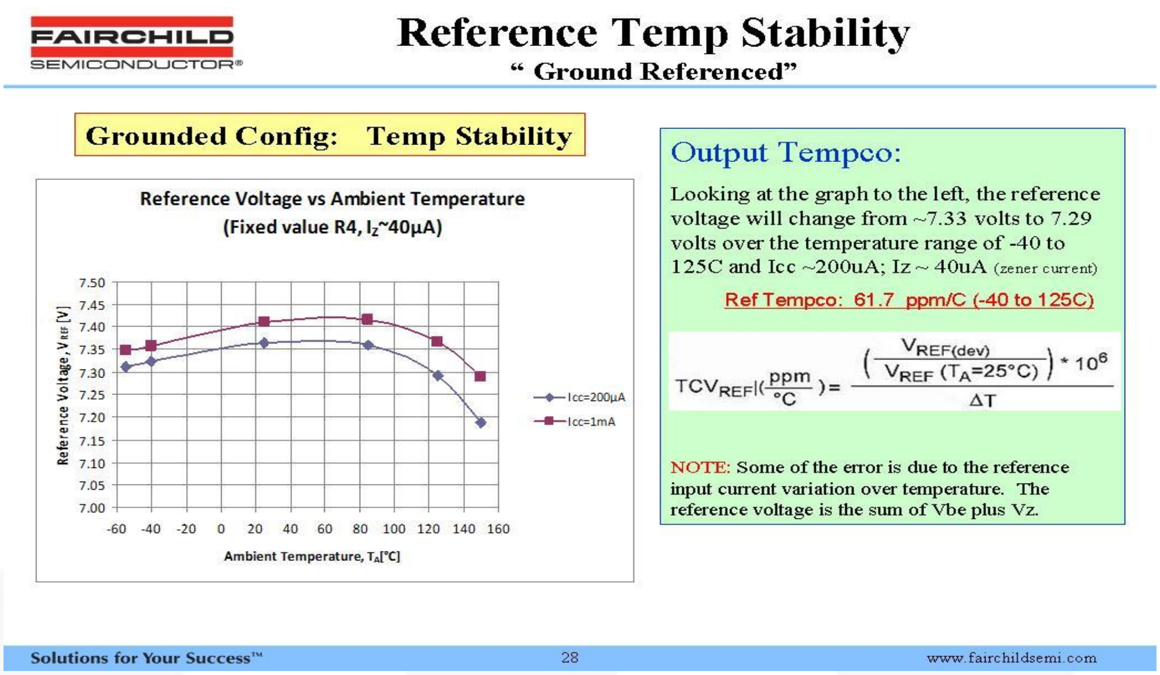
| SN | | | $V_{BE}$ | | | |
|---|---|---|---|---|---|---|
| | $T_A$ (°C) at | | | | | |
| | -55 | -40 | 25 | 85 | 125 | 150 |
| | (V) | (V) | (V) | (V) | (V) | (V) |
| 1 | 0.7536 | 0.7100 | 0.5765 | 0.4297 | 0.3347 | 0.2726 |
| 2 | 0.7520 | 0.7134 | 0.5668 | 0.4382 | 0.3408 | 0.2879 |
| 3 | 0.7507 | 0.7118 | 0.5680 | 0.4336 | 0.3402 | 0.2856 |
| Min | 0.7507 | 0.7100 | 0.5668 | 0.4297 | 0.3347 | 0.2726 |
| Max | 0.7536 | 0.7134 | 0.5765 | 0.4382 | 0.3408 | 0.2879 |
| Average | 0.7521 | 0.7117 | 0.5704 | 0.4338 | 0.3386 | 0.2820 |

**Vref Icc=200uA, Iz=40uA @ 25C**

Test Condition: $V_{CC}$~17.3V, $C_L$=0.1µF, $C_N$=0.1µF, $R_3$=49.9KΩ, R4=9.38K, $I_{CC}$=200uA, $I_Z$=40µA

| SN | Reference Voltage, $V_{REF}$ | | | | | |
|---|---|---|---|---|---|---|
| | $T_A$ (°C) at | | | | | |
| | -55 | -40 | 25 | 85 | 125 | 150 |
| | (V) | (V) | (V) | (V) | (V) | (V) |
| 1 | 7.3162 | 7.3252 | 7.3648 | 7.3726 | 7.3393 | 7.2783 |
| 2 | 7.3162 | 7.3256 | 7.3645 | 7.3718 | 7.3394 | 7.2826 |
| 3 | 7.3121 | 7.3231 | 7.3673 | 7.3756 | 7.3447 | 7.2893 |
| Min | 7.3121 | 7.3231 | 7.3645 | 7.3718 | 7.3393 | 7.2783 |
| Max | 7.3162 | 7.3256 | 7.3673 | 7.3756 | 7.3447 | 7.2893 |
| Average | 7.3148 | 7.3246 | 7.3656 | 7.3733 | 7.3412 | 7.2834 |

NOTE 1: Vref = Vzener + Vbe
NOTE 2: Vbe temp coeficient ~ -2.2mV/C
NOTE 3: Zener is selected to have +2.2mV/C at a specific bias



## Reference Temp Stability

“ Ground Referenced”

**Grounded Config: Temp Stability**

**Output Tempco:**

Looking at the graph to the left, the reference voltage will change from ~7.33 volts to 7.29 volts over the temperature range of -40 to 125C and Icc ~200uA; Iz ~ 40uA (zener current)

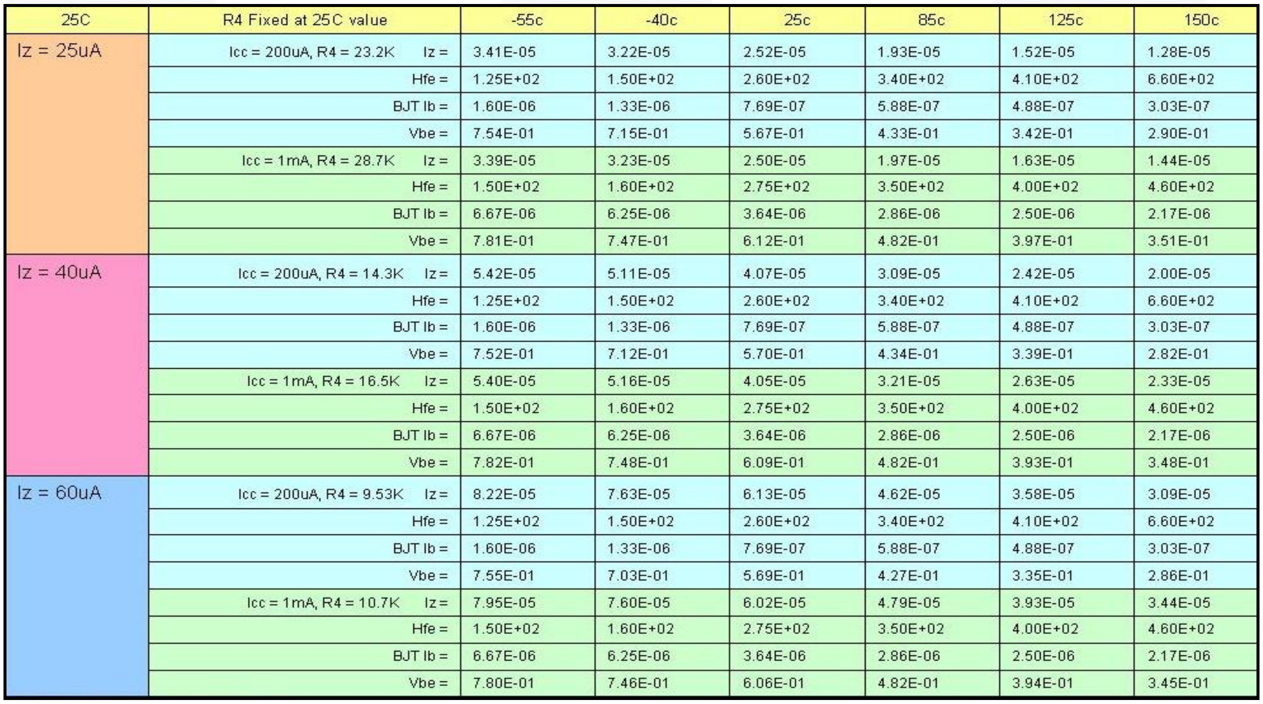
Ref Tempco: 61.7 ppm/C (-40 to 125C)

$$TCV_{REF}\left(\frac{ppm}{°C}\right) = \frac{\left(\frac{V_{REF(dev)}}{V_{REF}\ (T_A=25°C)}\right) * 10^6}{\Delta T}$$

NOTE: Some of the error is due to the reference input current variation over temperature. The reference voltage is the sum of Vbe plus Vz.

Figure 12. Reference Temperature Stability at 200 µA & 1 mA: Grounded Configuration

**Table 2. Resistor Divider Values vs. Output Voltage: Grounded Configuration ($I_Z$, hfe, $I_B$, $V_{BE}$, $T_A$=55°C to 150°C, $I_{CC}$=200 µA, 1 mA)**

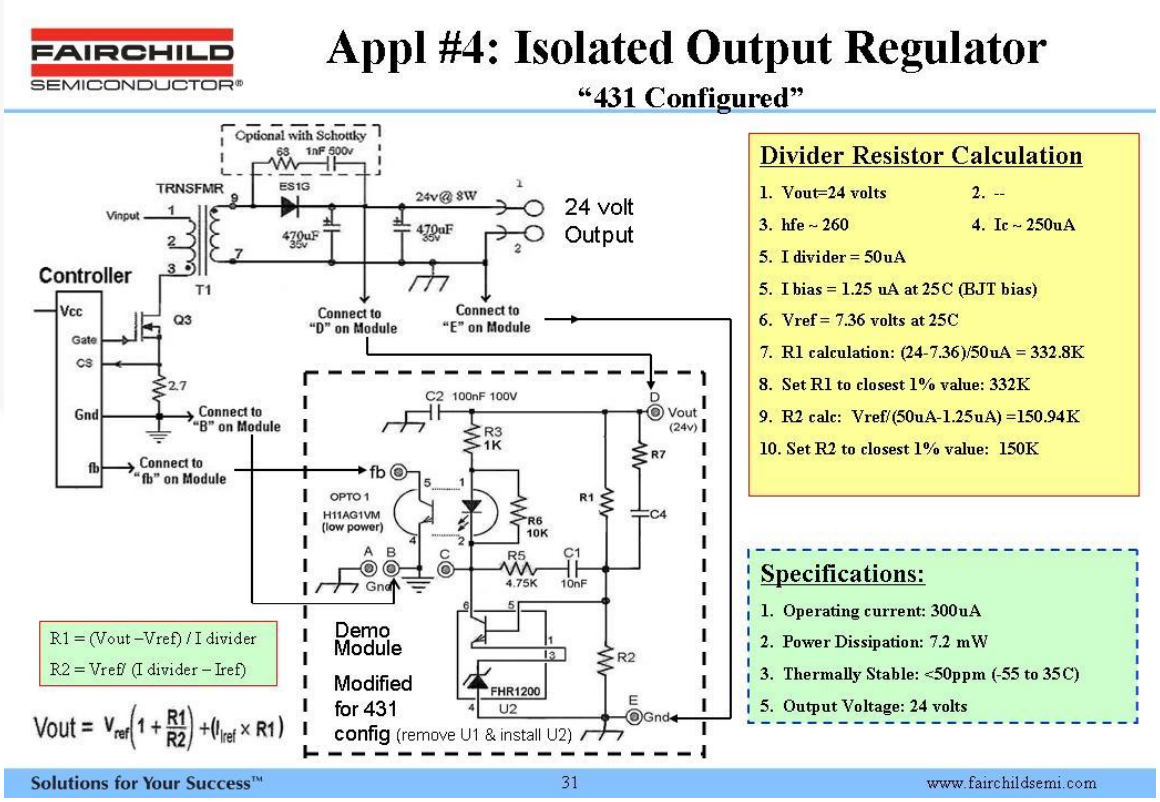


| 25C | R4 Fixed at 25C value | -55c | -40c | 25c | 85c | 125c | 150c |
|---|---|---|---|---|---|---|---|
| Iz = 25uA | Icc = 200uA, R4 = 23.2K Iz = | 3.41E-05 | 3.22E-05 | 2.52E-05 | 1.93E-05 | 1.52E-05 | 1.28E-05 |
| | Hfe = | 1.25E+02 | 1.50E+02 | 2.60E+02 | 3.40E+02 | 4.10E+02 | 6.60E+02 |
| | BJT Ib = | 1.60E-06 | 1.33E-06 | 7.69E-07 | 5.88E-07 | 4.88E-07 | 3.03E-07 |
| | Vbe = | 7.54E-01 | 7.15E-01 | 5.67E-01 | 4.33E-01 | 3.42E-01 | 2.90E-01 |
| | Icc = 1mA, R4 = 28.7K Iz = | 3.39E-05 | 3.23E-05 | 2.50E-05 | 1.97E-05 | 1.63E-05 | 1.44E-05 |
| | Hfe = | 1.50E+02 | 1.60E+02 | 2.75E+02 | 3.50E+02 | 4.00E+02 | 4.60E+02 |
| | BJT Ib = | 6.67E-06 | 6.25E-06 | 3.64E-06 | 2.86E-06 | 2.50E-06 | 2.17E-06 |
| | Vbe = | 7.81E-01 | 7.47E-01 | 6.12E-01 | 4.82E-01 | 3.97E-01 | 3.51E-01 |
| Iz = 40uA | Icc = 200uA, R4 = 14.3K Iz = | 5.42E-05 | 5.11E-05 | 4.07E-05 | 3.09E-05 | 2.42E-05 | 2.00E-05 |
| | Hfe = | 1.25E+02 | 1.50E+02 | 2.60E+02 | 3.40E+02 | 4.10E+02 | 6.60E+02 |
| | BJT Ib = | 1.60E-06 | 1.33E-06 | 7.69E-07 | 5.88E-07 | 4.88E-07 | 3.03E-07 |
| | Vbe = | 7.52E-01 | 7.12E-01 | 5.70E-01 | 4.34E-01 | 3.39E-01 | 2.82E-01 |
| | Icc = 1mA, R4 = 16.5K Iz = | 5.40E-05 | 5.16E-05 | 4.05E-05 | 3.21E-05 | 2.63E-05 | 2.33E-05 |
| | Hfe = | 1.50E+02 | 1.60E+02 | 2.75E+02 | 3.50E+02 | 4.00E+02 | 4.60E+02 |
| | BJT Ib = | 6.67E-06 | 6.25E-06 | 3.64E-06 | 2.86E-06 | 2.50E-06 | 2.17E-06 |
| | Vbe = | 7.82E-01 | 7.48E-01 | 6.09E-01 | 4.82E-01 | 3.93E-01 | 3.48E-01 |
| Iz = 60uA | Icc = 200uA, R4 = 9.53K Iz = | 8.22E-05 | 7.63E-05 | 6.13E-05 | 4.62E-05 | 3.58E-05 | 3.09E-05 |
| | Hfe = | 1.25E+02 | 1.50E+02 | 2.60E+02 | 3.40E+02 | 4.10E+02 | 6.60E+02 |
| | BJT Ib = | 1.60E-06 | 1.33E-06 | 7.69E-07 | 5.88E-07 | 4.88E-07 | 3.03E-07 |
| | Vbe = | 7.55E-01 | 7.03E-01 | 5.69E-01 | 4.27E-01 | 3.35E-01 | 2.86E-01 |
| | Icc = 1mA, R4 = 10.7K Iz = | 7.95E-05 | 7.60E-05 | 6.02E-05 | 4.79E-05 | 3.93E-05 | 3.44E-05 |
| | Hfe = | 1.50E+02 | 1.60E+02 | 2.75E+02 | 3.50E+02 | 4.00E+02 | 4.60E+02 |
| | BJT Ib = | 6.67E-06 | 6.25E-06 | 3.64E-06 | 2.86E-06 | 2.50E-06 | 2.17E-06 |
| | Vbe = | 7.80E-01 | 7.46E-01 | 6.06E-01 | 4.82E-01 | 3.94E-01 | 3.45E-01 |

**Table 3. Resistor Divider Values vs. Output Voltage: Grounded Configuration**

| Vout (volts) | Vref (volts) | Idiv (uA) | Icc (uA) | Ic (uA) | Vbe (volts) | Iz (uA) | R1 (K) | R2 (K) | R4 (K) | R1 1% (K) | R2 1% (K) | R4 1% (K) | Power (mW) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 3.2 | 46 | 14.261 | 3.24 | 46.4 | 15 | 3.6 |
| 9 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 8.2 | 46 | 14.261 | 8.25 | 46.4 | 15 | 4.05 |
| 10 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 13.2 | 46 | 14.261 | 13.3 | 46.4 | 15 | 4.5 |
| 12 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 23.2 | 46 | 14.261 | 23.2 | 46.4 | 15 | 5.4 |
| 15 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 38.2 | 46 | 14.261 | 38.3 | 46.4 | 15 | 6.75 |
| 18 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 53.2 | 46 | 14.261 | 53.6 | 46.4 | 15 | 8.1 |
| 19 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 58.2 | 46 | 14.261 | 57.6 | 46.4 | 15 | 8.55 |
| 20 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 63.2 | 46 | 14.261 | 63.4 | 46.4 | 15 | 9 |
| 24 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 83.2 | 46 | 14.261 | 82.5 | 46.4 | 15 | 10.8 |
| 36 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 143 | 46 | 14.261 | 143 | 46.4 | 15 | 16.2 |
| 48 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 203 | 46 | 14.261 | 205 | 46.4 | 15 | 21.6 |
| 75 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 338 | 46 | 14.261 | 340 | 46.4 | 15 | 33.75 |
| 100 | 7.36 | 200 | 450 | 250 | 0.5704 | 40 | 463 | 46 | 14.261 | 464 | 46.4 | 15 | 45 |

Figure 13 illustrates how Application Circuit #4 can be modified for an LM431-type configuration. This configuration stacks the Zener and the BJT so that the same current that flows through the Zener flows through the base-emitter of the BJT. The circuit uses one less component and can operate at currents below 10 µA.



Appl #4: Isolated Output Regulator

"431 Configured"

**Divider Resistor Calculation**

1. Vout=24 volts
2. --
3. hfe ~ 260
4. Ic ~ 250uA
5. I divider = 50uA
5. I bias = 1.25 uA at 25C (BJT bias)
6. Vref = 7.36 volts at 25C
7. R1 calculation: (24-7.36)/50uA = 332.8K
8. Set R1 to closest 1% value: 332K
9. R2 calc: Vref/(50uA-1.25uA) =150.94K
10. Set R2 to closest 1% value: 150K

**Specifications:**

1. Operating current: 300uA
2. Power Dissipation: 7.2 mW
3. Thermally Stable: <50ppm (-55 to 35C)
5. Output Voltage: 24 volts

R1 = (Vout –Vref) / I divider

R2 = Vref/ (I divider – Iref)

$$\text{Vout} = V_{ref}\left(1 + \frac{R1}{R2}\right) + (I_{Iref} \times R1)$$

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Figure 13. Isolated Output Regulator: 431 Configuration

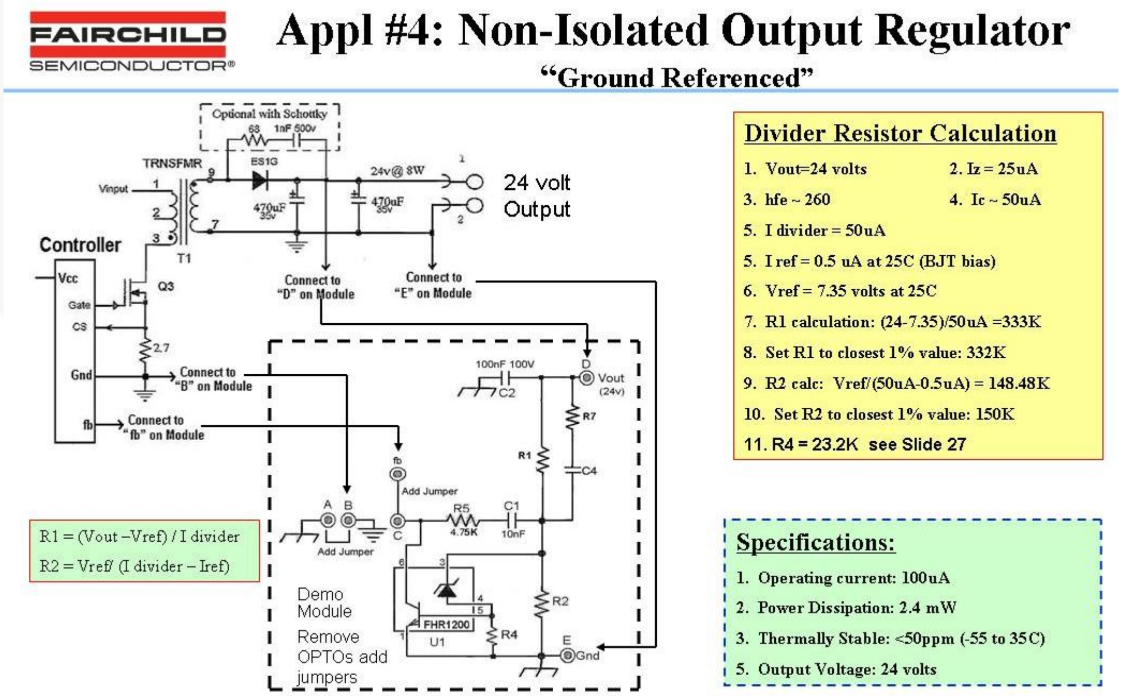
Table 4 gives the voltage divider values for different regulator voltages given a 200 µA collector current and a 50 µA divider current.

**Table 4. Resistor Divider Values for Isolated Output Regulator**

| Vout (volts) | Vref (volts) | Idivider (uA) | Icc (uA) | Ic (uA) | Iref (uA) | Temp 'C | R1 (K) | R2 (K) | R1 1% Value | R2 1% Value |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 12.2 | 150.11 | 12.1 | 150 |
| 9 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 32.2 | 150.11 | 32.4 | 150 |
| 10 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 52.2 | 150.11 | 52.3 | 150 |
| 12 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 92.2 | 150.11 | 93.1 | 150 |
| 15 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 152.2 | 150.11 | 154 | 150 |
| 18 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 212.2 | 150.11 | 210 | 150 |
| 19 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 232.2 | 150.11 | 232 | 150 |
| 20 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 252.2 | 150.11 | 243 | 150 |
| 24 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 332.2 | 150.11 | 332 | 150 |
| 36 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 572.2 | 150.11 | 576 | 150 |
| 48 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 812.2 | 150.11 | 806 | 150 |
| 75 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 1352.2 | 150.11 | 1370 | 150 |
| 100 | 7.39 | 50 | 200 | 250 | 1.25 | 25 | 1852.2 | 150.11 | 1870 | 150 |

Figure 14 shows how application circuit #4 can be used to make a non-isolated output regulator. The grounded configuration is used because the output of the regulator must directly drive a power supply controller to ground on the feedback pin. The values of R1 and R2 were selected for an output voltage of 24 V. R4 was selected to set the Zener current to 25 µA.

Table 5 provides the $V_{BE}$ and $V_{REF}$ voltage when the Zener current ($I_Z$) is set to 25 µA and the collector current is set to 200 µA. This biasing reduces the regulator power dissipation to 2.4 mW with a 24 V output voltage.



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**Appl #4: Non-Isolated Output Regulator**

**"Ground Referenced"**

**Divider Resistor Calculation**

1. Vout=24 volts 2. Iz = 25uA
3. hfe ~ 260 4. Ic ~ 50uA
5. I divider = 50uA
5. I ref = 0.5 uA at 25C (BJT bias)
6. Vref = 7.35 volts at 25C
7. R1 calculation: (24-7.35)/50uA =333K
8. Set R1 to closest 1% value: 332K
9. R2 calc: Vref/(50uA-0.5uA) = 148.48K
10. Set R2 to closest 1% value: 150K
11. R4 = 23.2K see Slide 27

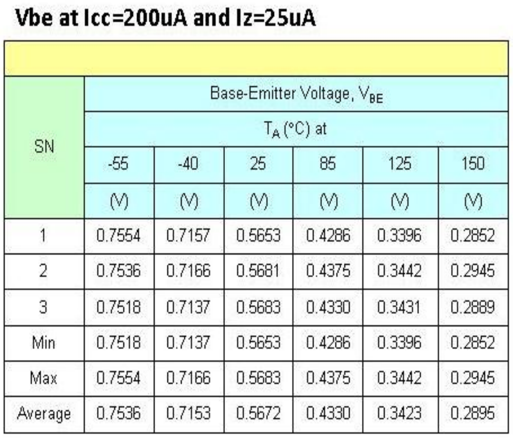
R1 = (Vout –Vref) / I divider
R2 = Vref/ (I divider – Iref)

**Specifications:**

1. Operating current: 100uA
2. Power Dissipation: 2.4 mW
3. Thermally Stable: <50ppm (-55 to 35C)
5. Output Voltage: 24 volts

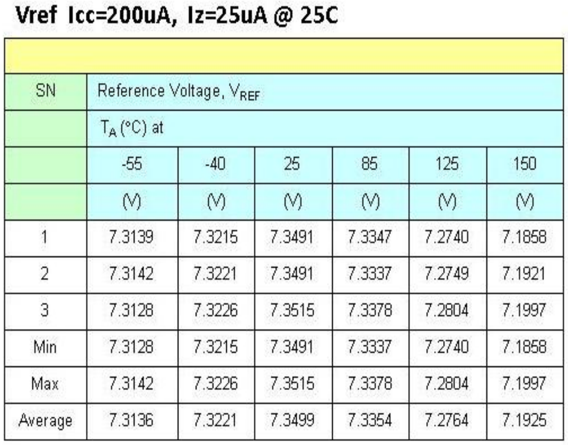
Figure 14. Non-Isolated Output Regulator: Grounded Configuration

## Table 5. $V_{BE}$ & $V_{REF}$ Performance Over-Temperature: Grounded Configuration



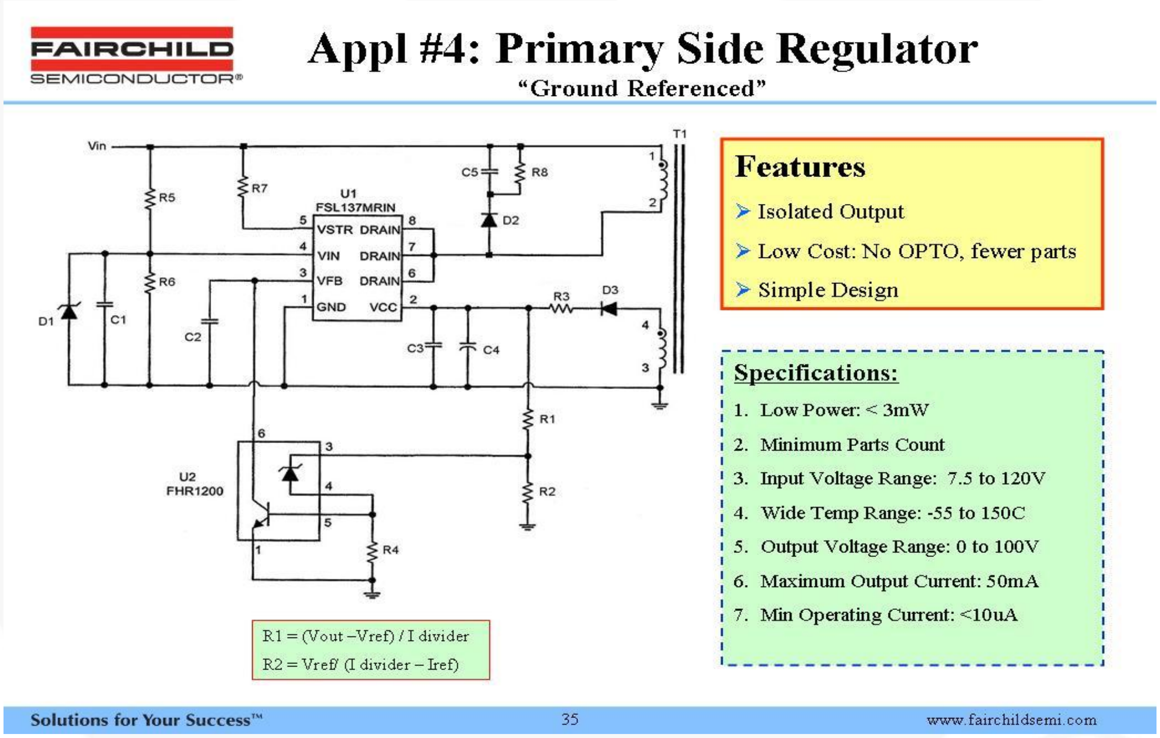
**Vbe at Icc=200uA and Iz=25uA**

| SN | Base-Emitter Voltage, $V_{BE}$ | | | | | |
|---|---|---|---|---|---|---|
| | $T_A$ (°C) at | | | | | |
| | -55 | -40 | 25 | 85 | 125 | 150 |
| | (V) | (V) | (V) | (V) | (V) | (V) |
| 1 | 0.7554 | 0.7157 | 0.5653 | 0.4286 | 0.3396 | 0.2852 |
| 2 | 0.7536 | 0.7166 | 0.5681 | 0.4375 | 0.3442 | 0.2945 |
| 3 | 0.7518 | 0.7137 | 0.5683 | 0.4330 | 0.3431 | 0.2889 |
| Min | 0.7518 | 0.7137 | 0.5653 | 0.4286 | 0.3396 | 0.2852 |
| Max | 0.7554 | 0.7166 | 0.5683 | 0.4375 | 0.3442 | 0.2945 |
| Average | 0.7536 | 0.7153 | 0.5672 | 0.4330 | 0.3423 | 0.2895 |



**Vref Icc=200uA, Iz=25uA @ 25C**

| SN | Reference Voltage, $V_{REF}$ | | | | | |
|---|---|---|---|---|---|---|
| | $T_A$ (°C) at | | | | | |
| | -55 | -40 | 25 | 85 | 125 | 150 |
| | (V) | (V) | (V) | (V) | (V) | (V) |
| 1 | 7.3139 | 7.3215 | 7.3491 | 7.3347 | 7.2740 | 7.1858 |
| 2 | 7.3142 | 7.3221 | 7.3491 | 7.3337 | 7.2749 | 7.1921 |
| 3 | 7.3128 | 7.3226 | 7.3515 | 7.3378 | 7.2804 | 7.1997 |
| Min | 7.3128 | 7.3215 | 7.3491 | 7.3337 | 7.2740 | 7.1858 |
| Max | 7.3142 | 7.3226 | 7.3515 | 7.3378 | 7.2804 | 7.1997 |
| Average | 7.3136 | 7.3221 | 7.3499 | 7.3354 | 7.2764 | 7.1925 |



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**Appl #4: Primary Side Regulator**

“Ground Referenced”

R1 = (Vout –Vref) / I divider
R2 = Vref/ (I divider – Iref)

**Features**

- Isolated Output
- Low Cost: No OPTO, fewer parts
- Simple Design

**Specifications:**

1. Low Power: < 3mW
2. Minimum Parts Count
3. Input Voltage Range: 7.5 to 120V
4. Wide Temp Range: -55 to 150C
5. Output Voltage Range: 0 to 100V
6. Maximum Output Current: 50mA
7. Min Operating Current: <10uA

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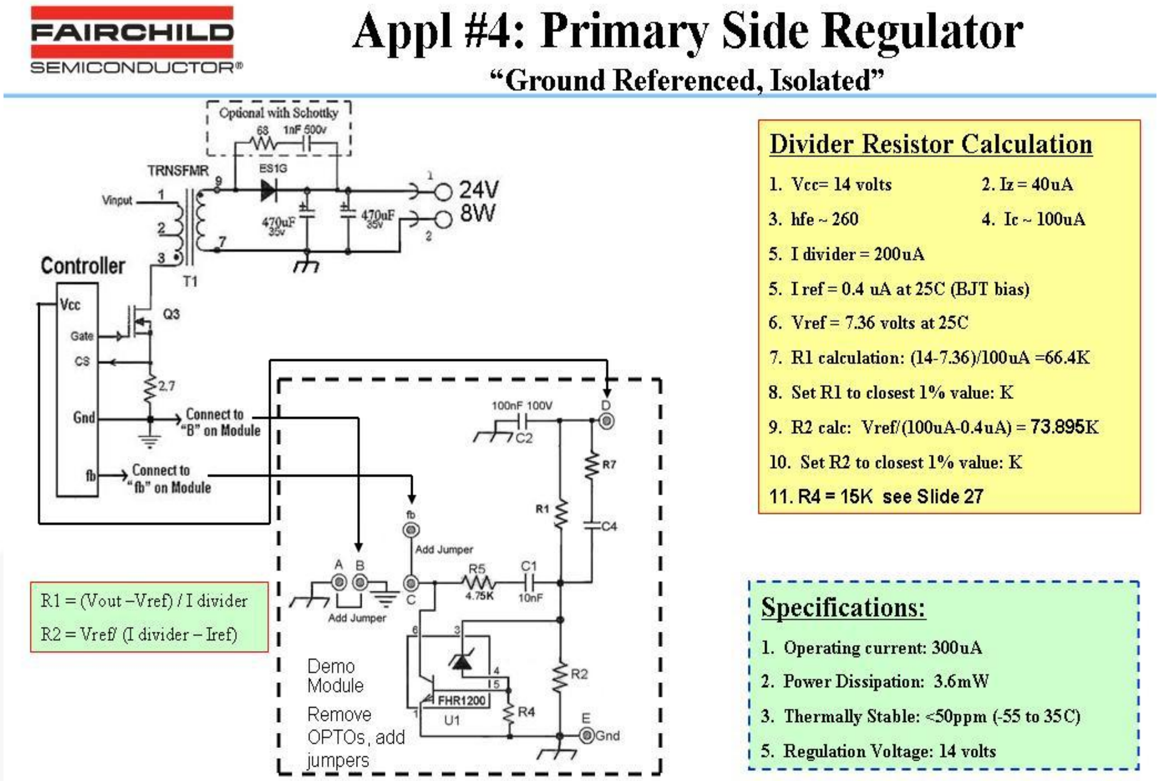
Figure 15. Basic Concept of Primary-Side Regulator: Grounded Configuration



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## Appl #4: Primary Side Regulator

“Ground Referenced, Isolated”

**Divider Resistor Calculation**

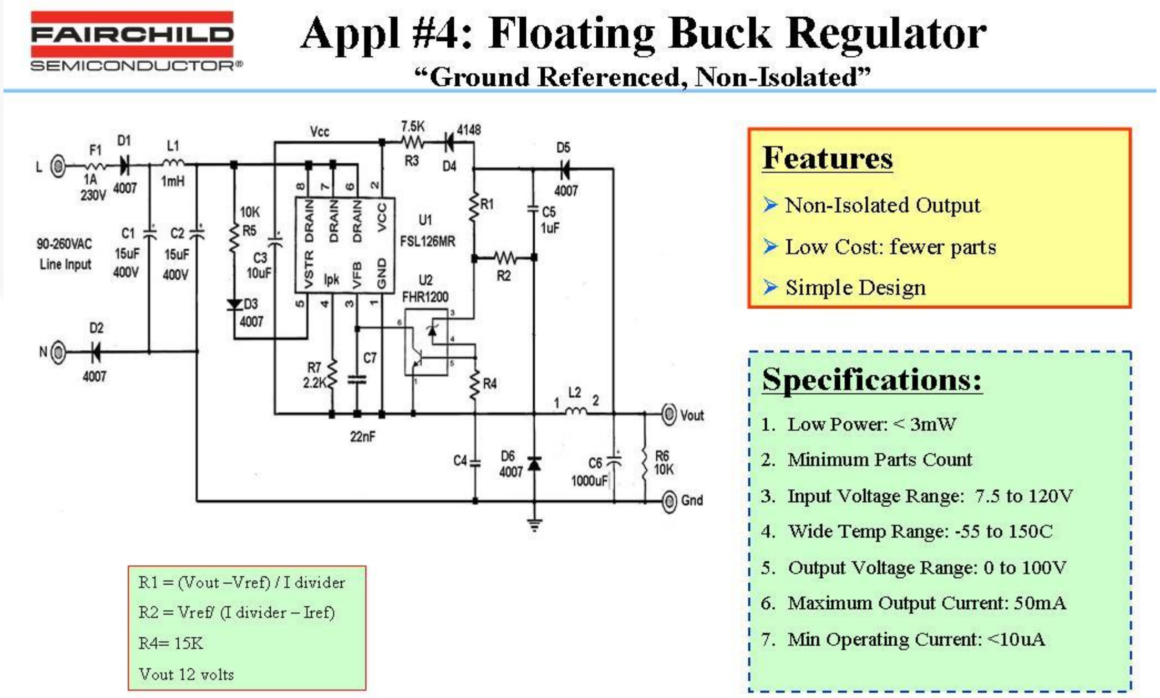
1. Vcc= 14 volts
2. Iz = 40uA
3. hfe ~ 260
4. Ic ~ 100uA
5. I divider = 200uA
5. I ref = 0.4 uA at 25C (BJT bias)
6. Vref = 7.36 volts at 25C
7. R1 calculation: (14-7.36)/100uA =66.4K
8. Set R1 to closest 1% value: K
9. R2 calc: Vref/(100uA-0.4uA) = 73.895K
10. Set R2 to closest 1% value: K
11. R4 = 15K see Slide 27

R1 = (Vout –Vref) / I divider
R2 = Vref/ (I divider – Iref)

**Specifications:**

1. Operating current: 300uA
2. Power Dissipation: 3.6mW
3. Thermally Stable: <50ppm (-55 to 35C)
5. Regulation Voltage: 14 volts

Figure 16. Primary-Side Regulator Based on App #4: Grounded Configuration



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## Appl #4: Floating Buck Regulator

“Ground Referenced, Non-Isolated”

**Features**

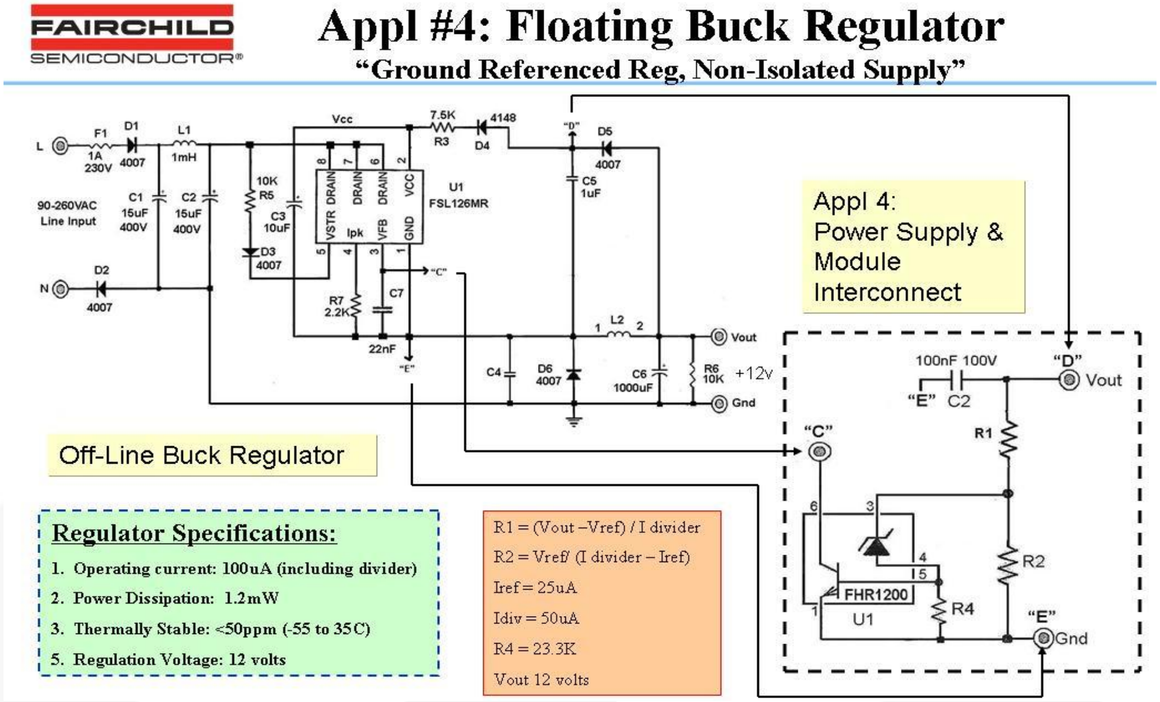
- Non-Isolated Output
- Low Cost: fewer parts
- Simple Design

**Specifications:**

1. Low Power: < 3mW
2. Minimum Parts Count
3. Input Voltage Range: 7.5 to 120V
4. Wide Temp Range: -55 to 150C
5. Output Voltage Range: 0 to 100V
6. Maximum Output Current: 50mA
7. Min Operating Current: <10uA

R1 = (Vout –Vref) / I divider
R2 = Vref/ (I divider – Iref)
R4= 15K
Vout 12 volts

Figure 17. Concept of Floating Regulator Based on App #4 Circuit



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## Appl #4: Floating Buck Regulator

"Ground Referenced Reg, Non-Isolated Supply"

Appl 4:
Power Supply &
Module
Interconnect

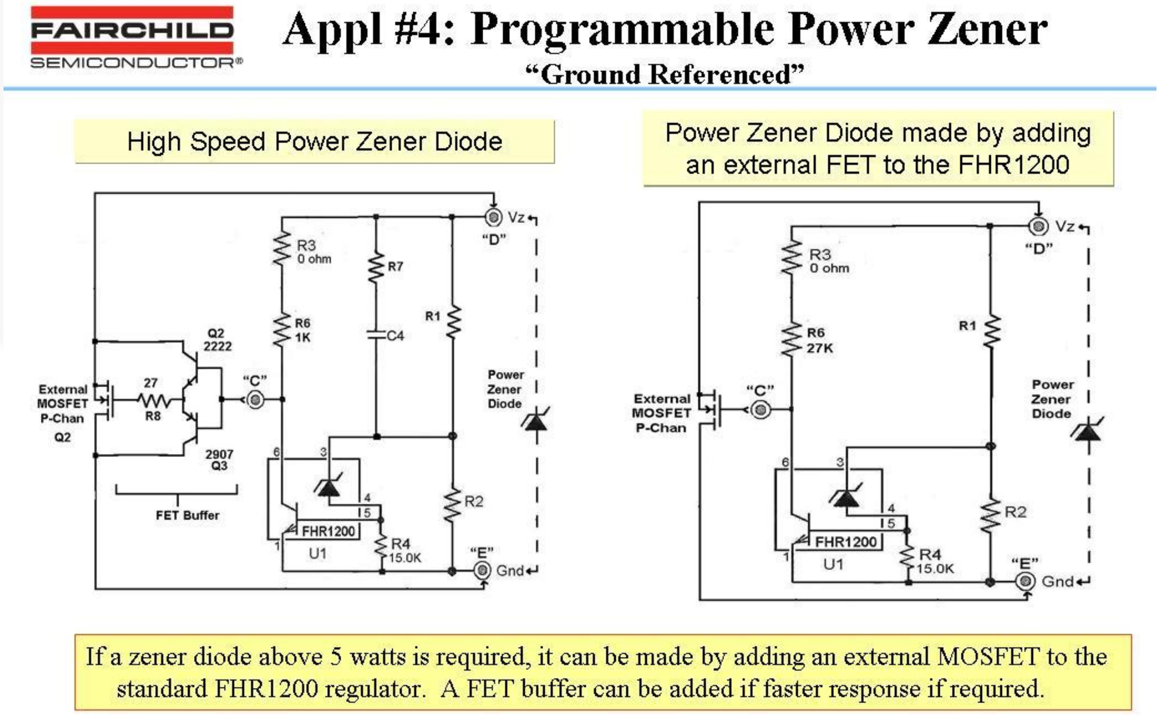
Off-Line Buck Regulator

**Regulator Specifications:**

1. Operating current: 100uA (including divider)
2. Power Dissipation: 1.2mW
3. Thermally Stable: <50ppm (-55 to 35C)
5. Regulation Voltage: 12 volts

R1 = (Vout –Vref) / I divider
R2 = Vref/ (I divider – Iref)
Iref = 25uA
Idiv = 50uA
R4 = 23.3K
Vout 12 volts

**Figure 18. Floating Regulator Using App #4 Circuit: Grounded Configuration**



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## Appl #4: Programmable Power Zener

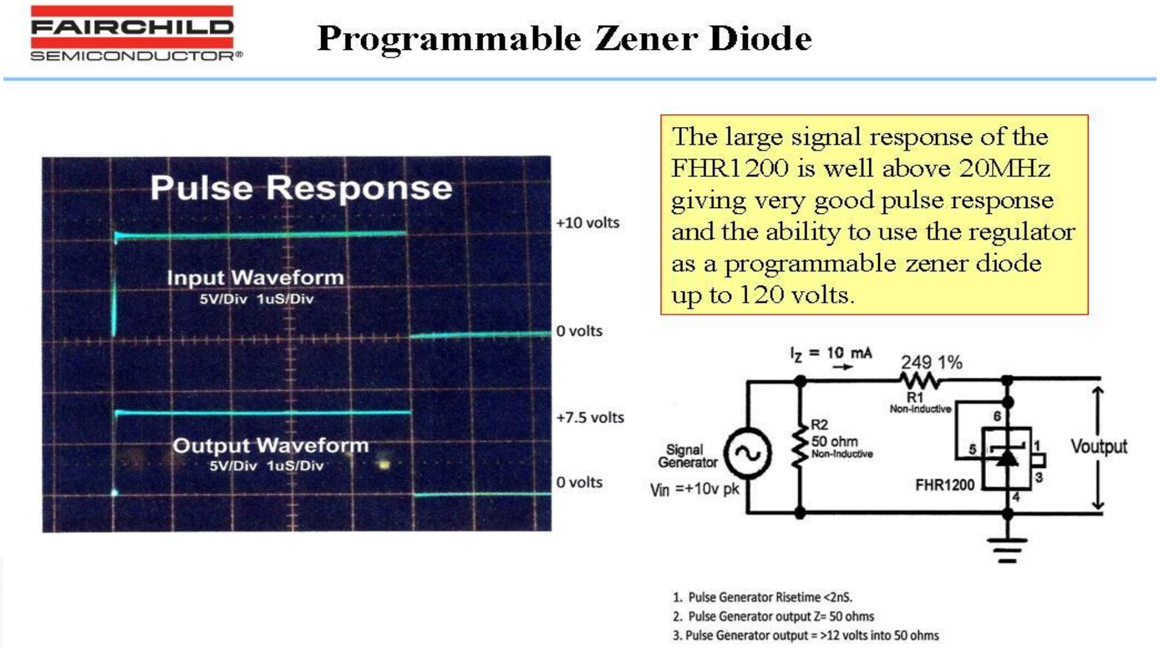
"Ground Referenced"

High Speed Power Zener Diode

Power Zener Diode made by adding an external FET to the FHR1200

If a zener diode above 5 watts is required, it can be made by adding an external MOSFET to the standard FHR1200 regulator. A FET buffer can be added if faster response if required.

**Figure 19. Concept for Programmable Power Zener: App #4 Circuit**

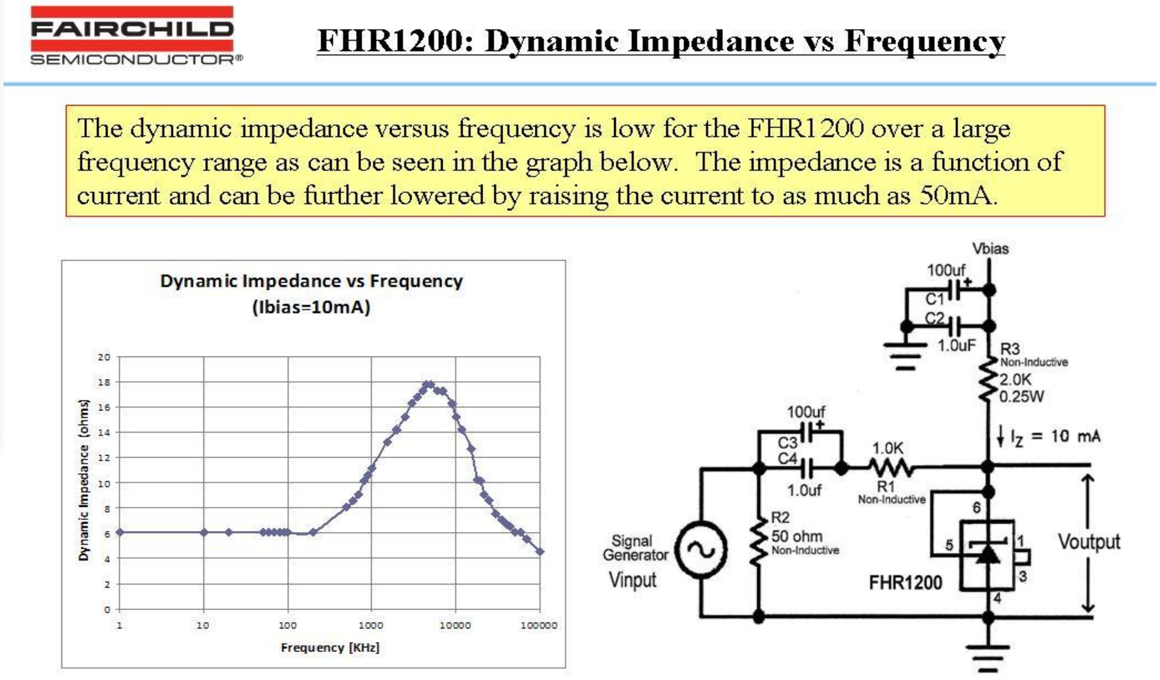


## Programmable Zener Diode

The large signal response of the FHR1200 is well above 20MHz giving very good pulse response and the ability to use the regulator as a programmable zener diode up to 120 volts.

1. Pulse Generator Risetime <2nS.
2. Pulse Generator output Z= 50 ohms
3. Pulse Generator output = >12 volts into 50 ohms

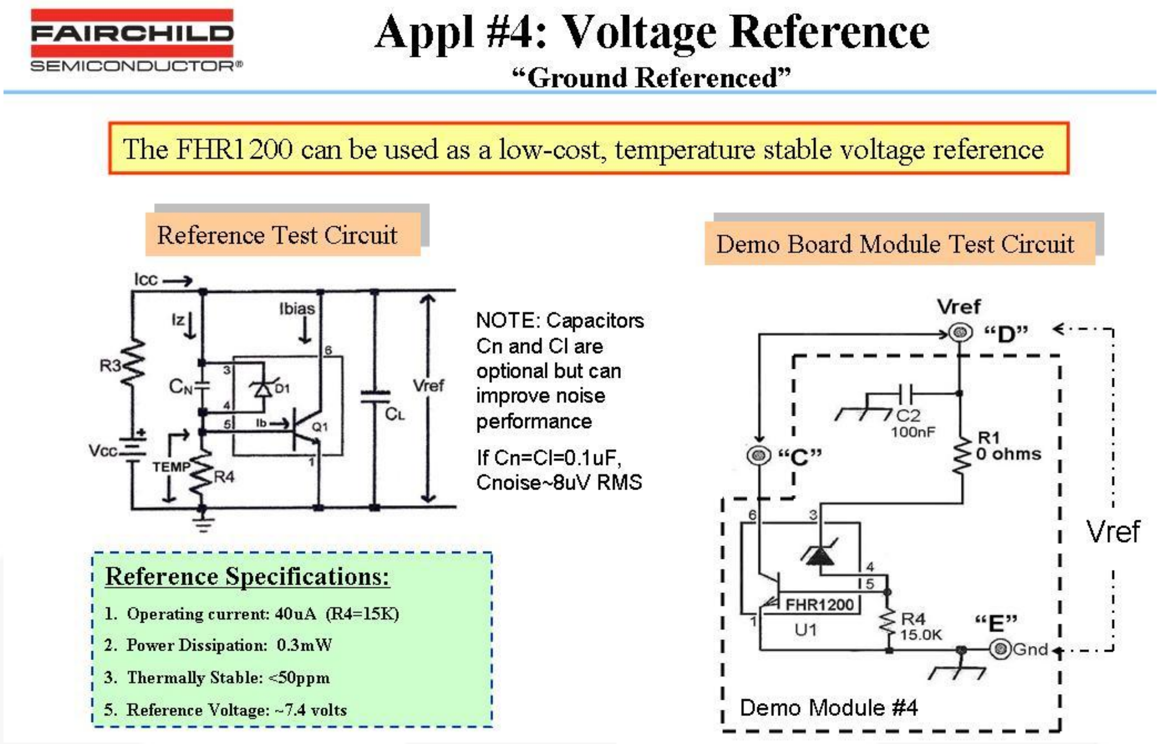
Figure 20. Characterization of FHR1200 used as Zener



## FHR1200: Dynamic Impedance vs Frequency

The dynamic impedance versus frequency is low for the FHR1200 over a large frequency range as can be seen in the graph below. The impedance is a function of current and can be further lowered by raising the current to as much as 50mA.

Figure 21. FHR1200 Dynamic Impedance



## Appl #4: Voltage Reference

“Ground Referenced”

The FHR1200 can be used as a low-cost, temperature stable voltage reference

Reference Test Circuit

NOTE: Capacitors Cn and Cl are optional but can improve noise performance

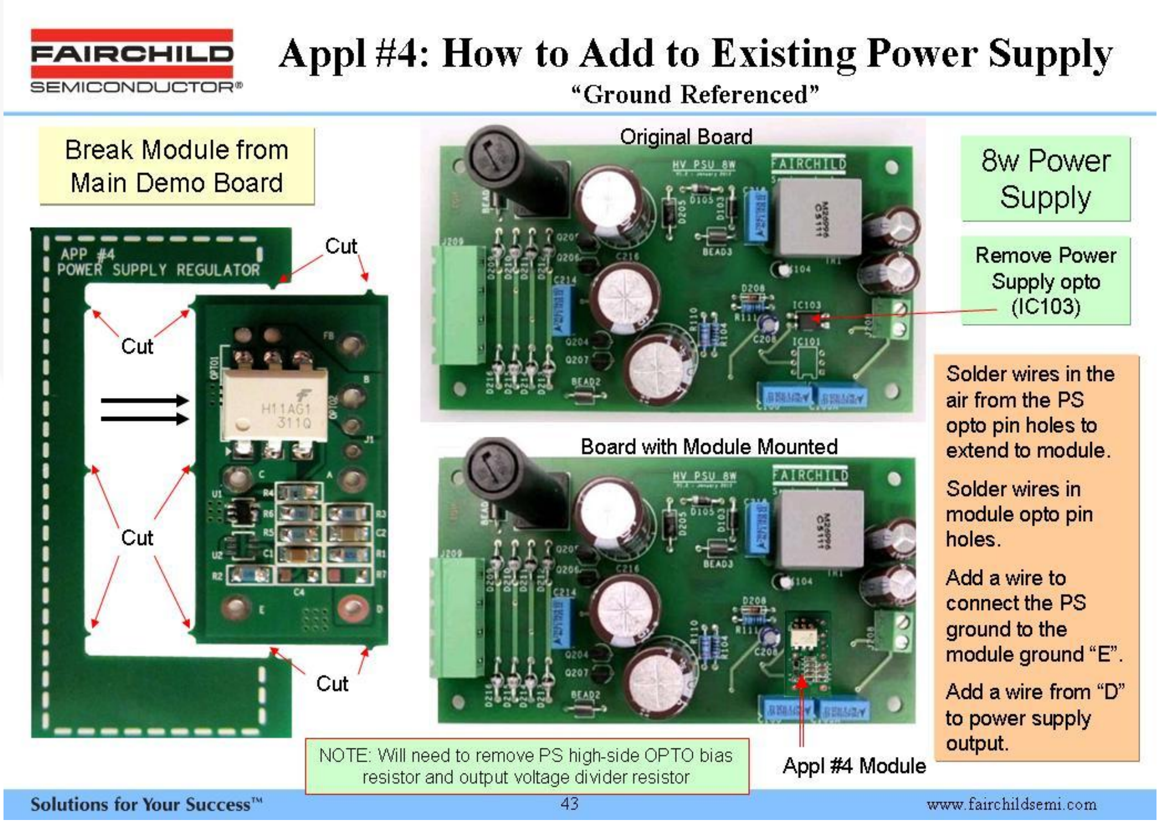
If Cn=Cl=0.1uF, Cnoise~8uV RMS

**Reference Specifications:**

1. Operating current: 40uA (R4=15K)
2. Power Dissipation: 0.3mW
3. Thermally Stable: <50ppm
5. Reference Voltage: ~7.4 volts

Demo Board Module Test Circuit

Figure 22. Concept and Actual Voltage Reference Using App #4 Circuit



## Appl #4: How to Add to Existing Power Supply

“Ground Referenced”

Break Module from Main Demo Board

8w Power Supply

Remove Power Supply opto (IC103)

Solder wires in the air from the PS opto pin holes to extend to module.

Solder wires in module opto pin holes.

Add a wire to connect the PS ground to the module ground “E”.

Add a wire from “D” to power supply output.

NOTE: Will need to remove PS high-side OPTO bias resistor and output voltage divider resistor

Appl #4 Module

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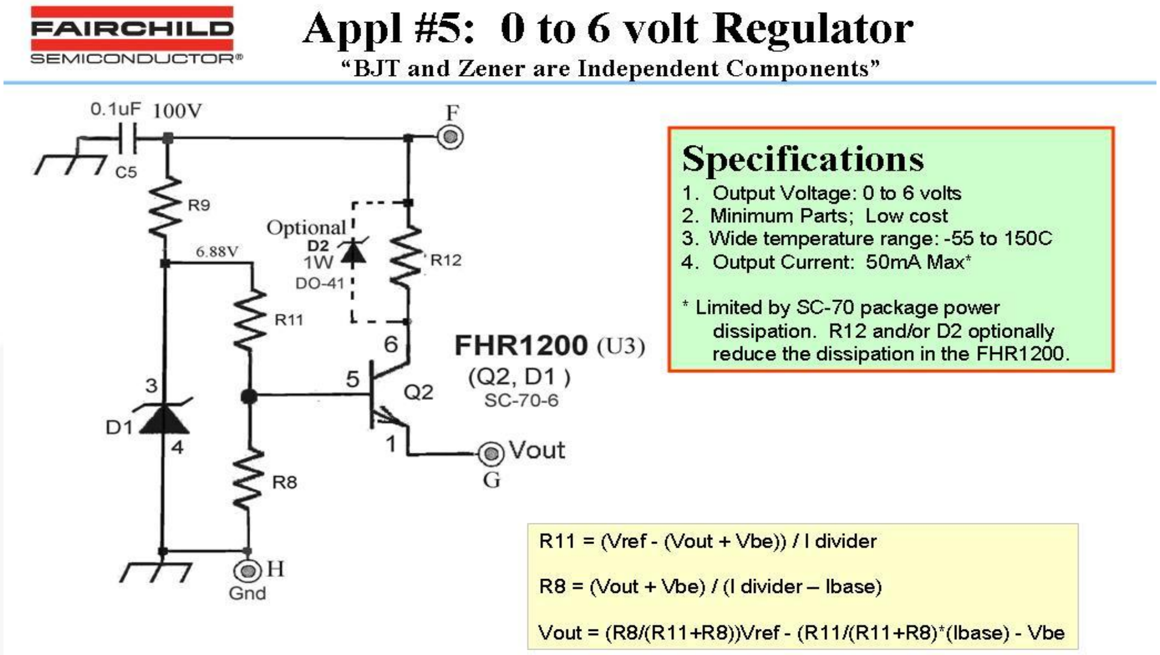
Figure 23. How to Add the App #4 Module to an Existing Power Supply

## 3.3. Application #5: 0 to 6 V Regulator

Application circuit #5 is a 0 V to 6 V, 0 mA to 50 mA voltage regulator made of an FHR1200 and a few resistors. It can be used for voltage regulation where just a few milliamps are needed for an auxiliary circuit, such as a micro-controller. The small size and low-cost of the circuit allows it to be used where space and cost is a consideration.



**Appl #5: 0 to 6 volt Regulator**

"BJT and Zener are Independent Components"

**Specifications**

1. Output Voltage: 0 to 6 volts
2. Minimum Parts; Low cost
3. Wide temperature range: -55 to 150C
4. Output Current: 50mA Max*

* Limited by SC-70 package power dissipation. R12 and/or D2 optionally reduce the dissipation in the FHR1200.

R11 = (Vref - (Vout + Vbe)) / I divider

R8 = (Vout + Vbe) / (I divider – Ibase)

Vout = (R8/(R11+R8))Vref - (R11/(R11+R8)*(Ibase) - Vbe

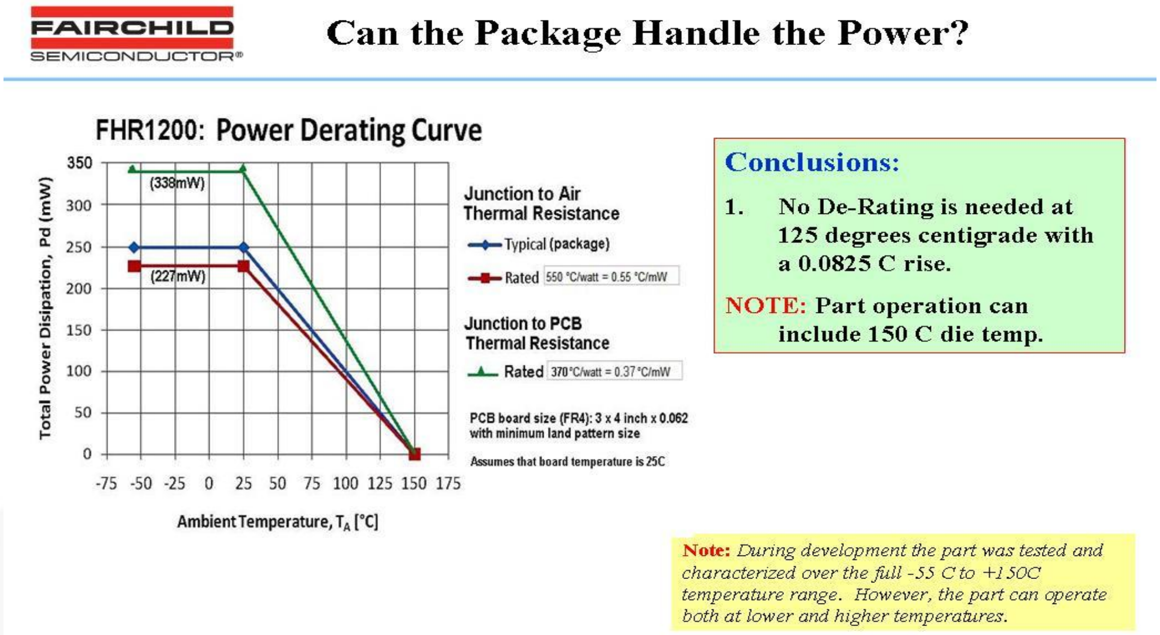
Figure 24. Simple, Low-Cost 0 to 6 V Regulator: Application Circuit #5

**Table 6. Simple, Low-Cost 0 to 6 V Regulator Resistor Values**

| Vout | hfe | Iout (mA) | Vref (volts) | Ibase (mA) | Vbase (volts) | Vbe (volts) | Idiv (ma) | R11 (K ohm) | R8 (K ohm) | R11 1% (K ohm) | R8 1% (K ohm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 250 | 30 | 6.8 | 0.12 | 6.8 | 0.68 | 1 | 0.00 | none | 0 | none |
| 5 | 250 | 30 | 6.8 | 0.12 | 5.68 | 0.68 | 1 | 1.12 | 6.45 | 1.10 | 6.49 |
| 4 | 250 | 30 | 6.8 | 0.12 | 4.68 | 0.68 | 1 | 2.12 | 5.32 | 2.10 | 5.36 |
| 3.3 | 250 | 30 | 6.8 | 0.12 | 3.98 | 0.68 | 1 | 2.82 | 4.52 | 2.87 | 4.64 |
| 2.5 | 250 | 30 | 6.8 | 0.12 | 3.18 | 0.68 | 1 | 3.62 | 3.61 | 3.65 | 3.65 |
| 2 | 250 | 30 | 6.8 | 0.12 | 2.68 | 0.68 | 1 | 4.12 | 3.05 | 4.12 | 3.09 |
| 1.25 | 250 | 30 | 6.8 | 0.12 | 1.93 | 0.68 | 1 | 4.87 | 2.19 | 4.87 | 2.21 |
| 1 | 250 | 30 | 6.8 | 0.12 | 1.68 | 0.68 | 1 | 5.12 | 1.91 | 5.11 | 1.96 |

R11 = (Vref - (Vout + Vbe)) / I divider

R8 = (Vout + Vbe) / (I divider – Ibase)



## Can the Package Handle the Power?

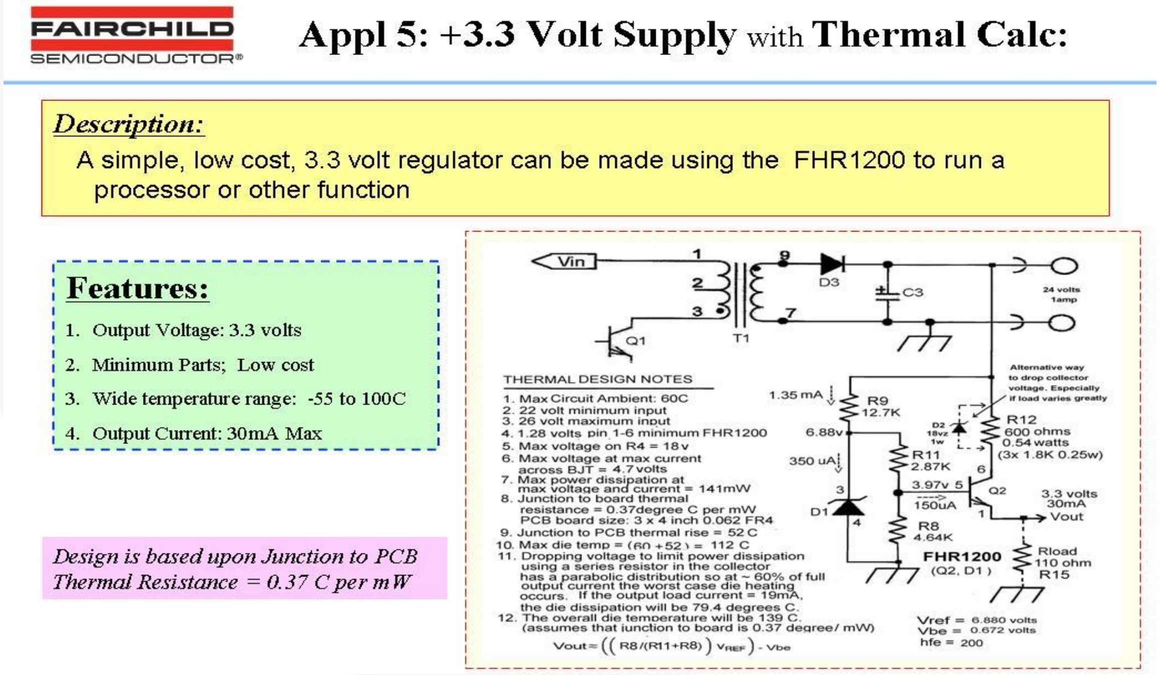
**Conclusions:**

1. No De-Rating is needed at 125 degrees centigrade with a 0.0825 C rise.

**NOTE:** Part operation can include 150 C die temp.

**Note:** *During development the part was tested and characterized over the full -55 C to +150C temperature range. However, the part can operate both at lower and higher temperatures.*

Figure 25. FHR1200 Thermal De-Rating



## Appl 5: +3.3 Volt Supply with Thermal Calc:

***Description:***

A simple, low cost, 3.3 volt regulator can be made using the FHR1200 to run a processor or other function

**Features:**

1. Output Voltage: 3.3 volts
2. Minimum Parts; Low cost
3. Wide temperature range: -55 to 100C
4. Output Current: 30mA Max

*Design is based upon Junction to PCB Thermal Resistance = 0.37 C per mW*

THERMAL DESIGN NOTES

1. Max Circuit Ambient: 60C
2. 22 volt minimum input
3. 26 volt maximum input
4. 1.28 volts pin 1-6 minimum FHR1200
5. Max voltage on R4 = 18 v
6. Max voltage at max current across BJT = 4.7 volts
7. Max power dissipation at max voltage and current = 141mW
8. Junction to board thermal resistance = 0.37degree C per mW PCB board size: 3 x 4 inch 0.062 FR4
9. Junction to PCB thermal rise = 52 C
10. Max die temp = (60 + 52) = 112 C
11. Dropping voltage to limit power dissipation using a series resistor in the collector has a parabolic distribution so at ~ 60% of full output current the worst case die heating occurs. If the output load current = 19mA, the die dissipation will be 79.4 degrees C.
12. The overall die temperature will be 139 C. (assumes that junction to board is 0.37 degree/ mW)

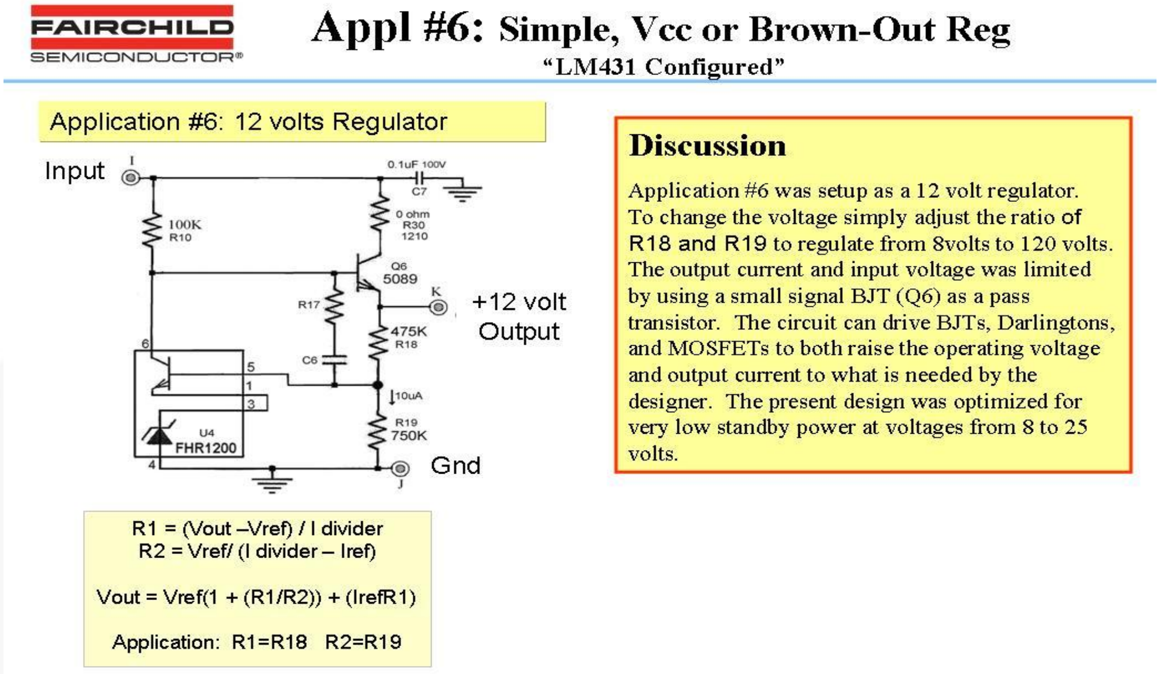
$$V_{out} = \left(\left(R8/(R11+R8)\right) V_{REF}\right) - V_{be}$$

Vref = 6.880 volts
Vbe = 0.672 volts
hfe = 200

Figure 26. Application #5: 3.3 V Power Supply Thermal Calculation

## 3.4. Application #6: $V_{CC}$ or Brownout Regulator

Many power supply designs require that the $V_{CC}$ voltage be regulated for the controller. The FHR1200 low operating current, high voltage, and wide temperature range make it a good choice for general regulation applications.


**Appl #6: Simple, Vcc or Brown-Out Reg**

"LM431 Configured"

Application #6: 12 volts Regulator

**Discussion**

Application #6 was setup as a 12 volt regulator. To change the voltage simply adjust the ratio of R18 and R19 to regulate from 8volts to 120 volts. The output current and input voltage was limited by using a small signal BJT (Q6) as a pass transistor. The circuit can drive BJTs, Darlingtons, and MOSFETs to both raise the operating voltage and output current to what is needed by the designer. The present design was optimized for very low standby power at voltages from 8 to 25 volts.

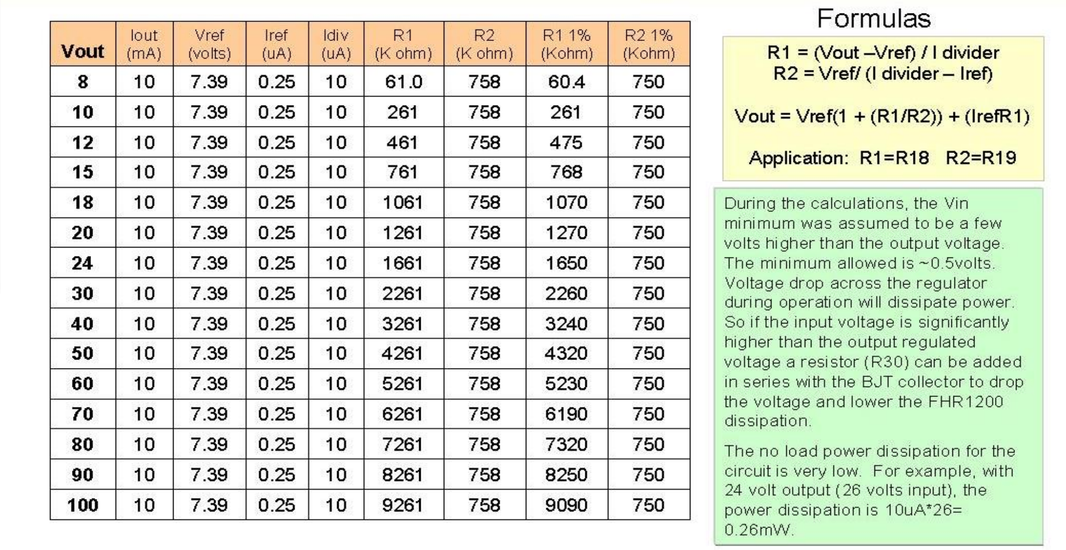
R1 = (Vout –Vref) / I divider
R2 = Vref/ (I divider – Iref)

Vout = Vref(1 + (R1/R2)) + (IrefR1)

Application: R1=R18 R2=R19

Figure 27. Application #6: $V_{CC}$ or Brownout Regulator Design

Table 7. Application #6: $V_{CC}$ or Brownout Regulator Resistor Values, LM431 Configured



| Vout | Iout (mA) | Vref (volts) | Iref (uA) | Idiv (uA) | R1 (K ohm) | R2 (K ohm) | R1 1% (Kohm) | R2 1% (Kohm) |
|---|---|---|---|---|---|---|---|---|
| 8 | 10 | 7.39 | 0.25 | 10 | 61.0 | 758 | 60.4 | 750 |
| 10 | 10 | 7.39 | 0.25 | 10 | 261 | 758 | 261 | 750 |
| 12 | 10 | 7.39 | 0.25 | 10 | 461 | 758 | 475 | 750 |
| 15 | 10 | 7.39 | 0.25 | 10 | 761 | 758 | 768 | 750 |
| 18 | 10 | 7.39 | 0.25 | 10 | 1061 | 758 | 1070 | 750 |
| 20 | 10 | 7.39 | 0.25 | 10 | 1261 | 758 | 1270 | 750 |
| 24 | 10 | 7.39 | 0.25 | 10 | 1661 | 758 | 1650 | 750 |
| 30 | 10 | 7.39 | 0.25 | 10 | 2261 | 758 | 2260 | 750 |
| 40 | 10 | 7.39 | 0.25 | 10 | 3261 | 758 | 3240 | 750 |
| 50 | 10 | 7.39 | 0.25 | 10 | 4261 | 758 | 4320 | 750 |
| 60 | 10 | 7.39 | 0.25 | 10 | 5261 | 758 | 5230 | 750 |
| 70 | 10 | 7.39 | 0.25 | 10 | 6261 | 758 | 6190 | 750 |
| 80 | 10 | 7.39 | 0.25 | 10 | 7261 | 758 | 7320 | 750 |
| 90 | 10 | 7.39 | 0.25 | 10 | 8261 | 758 | 8250 | 750 |
| 100 | 10 | 7.39 | 0.25 | 10 | 9261 | 758 | 9090 | 750 |

Formulas

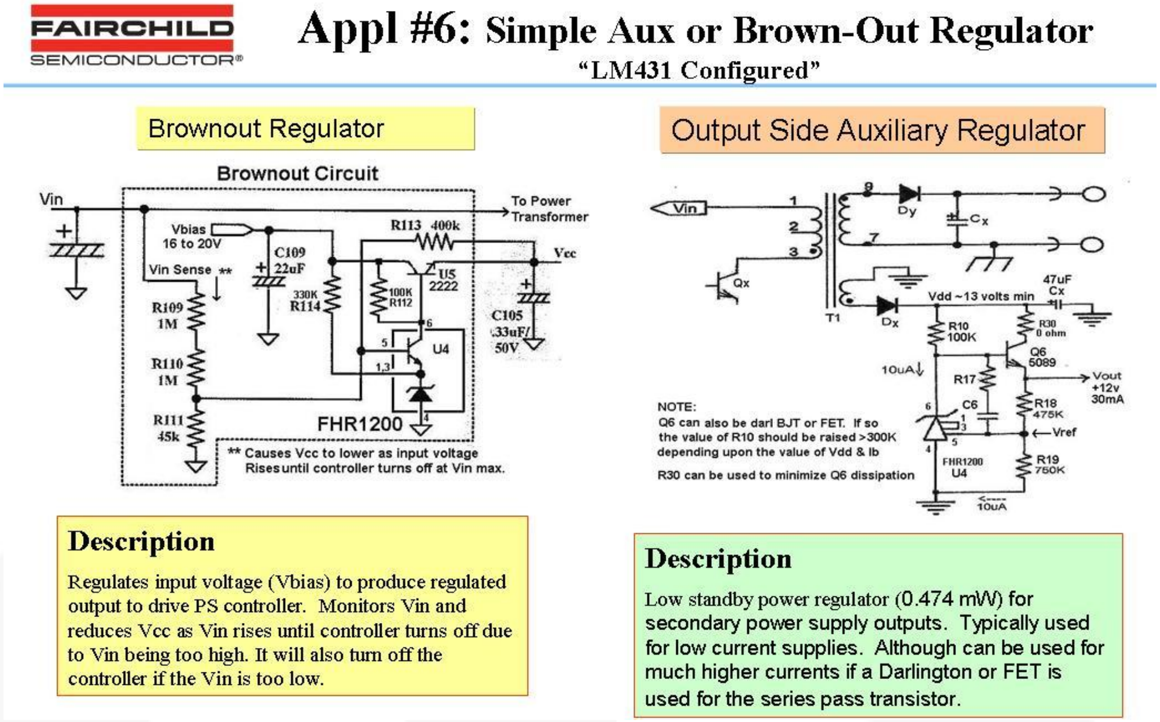
R1 = (Vout –Vref) / I divider
R2 = Vref/ (I divider – Iref)

Vout = Vref(1 + (R1/R2)) + (IrefR1)

Application: R1=R18 R2=R19

During the calculations, the Vin minimum was assumed to be a few volts higher than the output voltage. The minimum allowed is ~0.5volts. Voltage drop across the regulator during operation will dissipate power. So if the input voltage is significantly higher than the output regulated voltage a resistor (R30) can be added in series with the BJT collector to drop the voltage and lower the FHR1200 dissipation.

The no load power dissipation for the circuit is very low. For example, with 24 volt output (26 volts input), the power dissipation is 10uA*26= 0.26mW.



# Appl #6: Simple Aux or Brown-Out Regulator

“LM431 Configured”

## Brownout Regulator

** Causes Vcc to lower as input voltage Rises until controller turns off at Vin max.

### Description

Regulates input voltage (Vbias) to produce regulated output to drive PS controller. Monitors Vin and reduces Vcc as Vin rises until controller turns off due to Vin being too high. It will also turn off the controller if the Vin is too low.

## Output Side Auxiliary Regulator

NOTE:
Q6 can also be darl BJT or FET. If so the value of R10 should be raised >300K depending upon the value of Vdd & Ib

R30 can be used to minimize Q6 dissipation

### Description

Low standby power regulator (0.474 mW) for secondary power supply outputs. Typically used for low current supplies. Although can be used for much higher currents if a Darlington or FET is used for the series pass transistor.

Figure 28. Application #6: Brownout & Auxiliary Regulator: LM431 Configured

# 4. Schematic

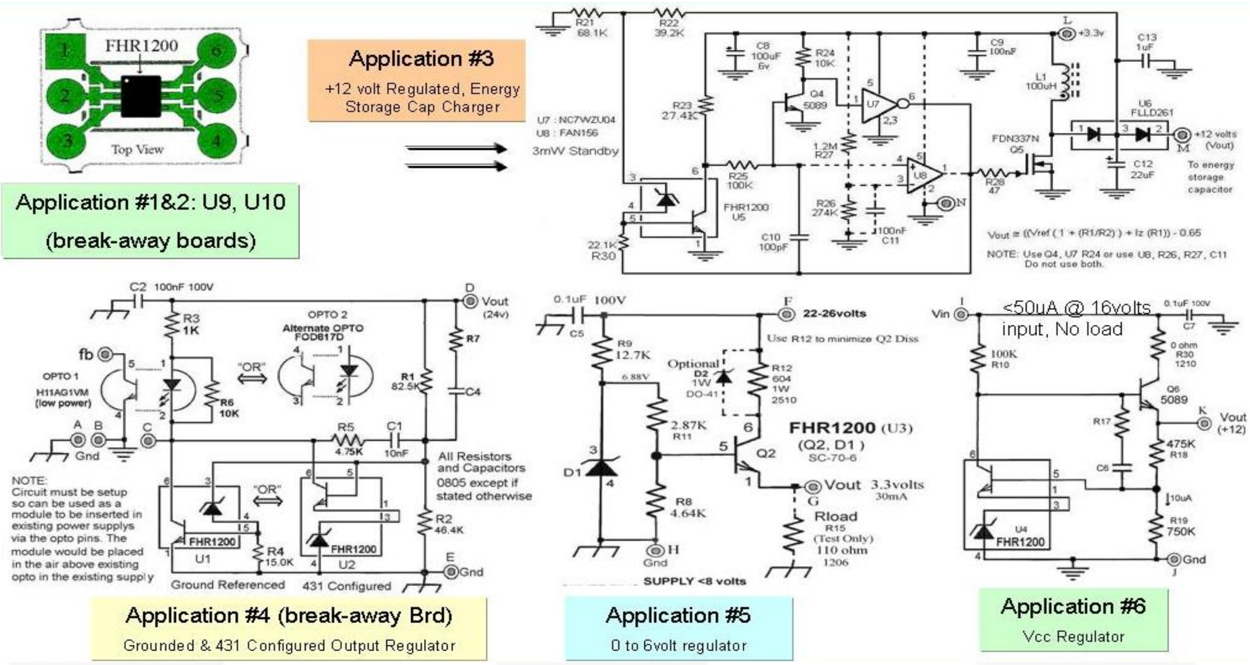


Figure 29. Evaluation Board Schematics

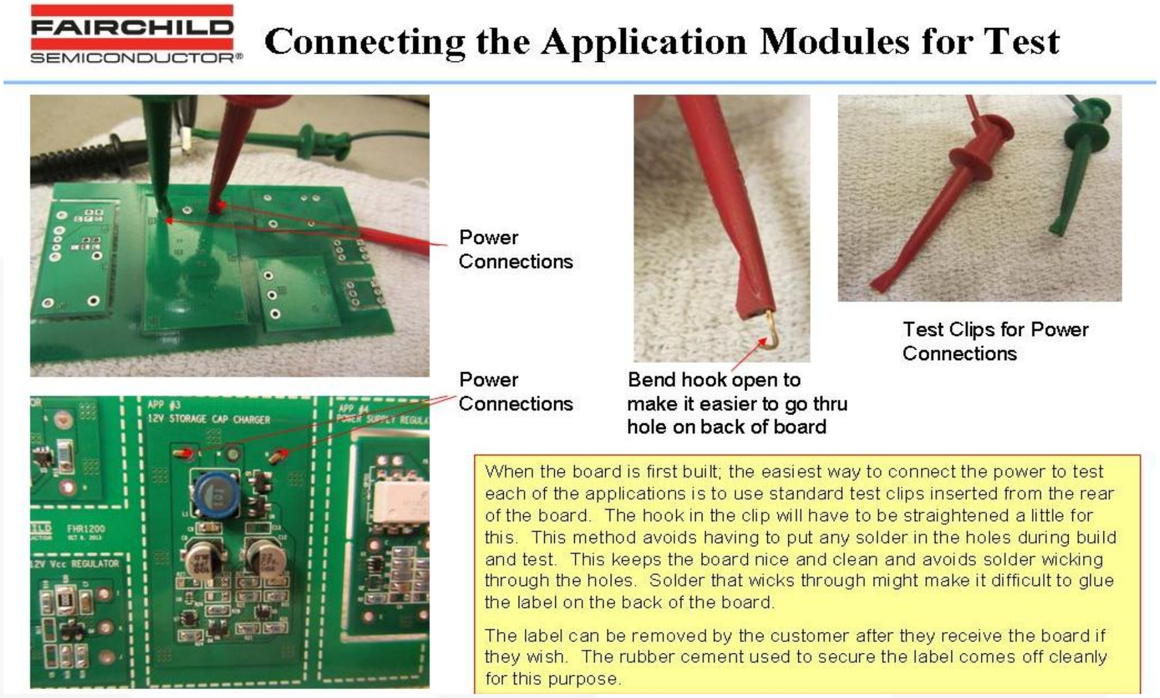
# 5. Bill of Materials

| Item | Description | Distributor | Distributor Part Number | MFG | Qty | Designator | Remarks |
|---|---|---|---|---|---|---|---|
| **Resistors and Pots** | | | | | | | |
| 1. | 0 Ω 0.5 W 1210 SMT | Mouser | 667-ERJ-14Y0R00U | Panasonic | 1 | R30 | |
| 2. | 47 Ω 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD47R0F | KOA | 1 | R28 | |
| 3. | 110 Ω 1% 0.25 W Resistor 1206 SMT | Mouser | 660-RK73H2BTTD1100F | KOA | 1 | R15 | |
| 4. | 604 Ω 1 W 2512 SMT | Mouser | 660-RK73H3ATTE6040F | KOA | 1 | R12 | |
| 5. | 1 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD1001F | KOA | 1 | R3, | |
| 6. | 2.87 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD2871F | KOA | 1 | R11 | |
| 7. | 4.64 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD4641F | KOA | 1 | R8 | |
| 8. | 4.75 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD4751F | KOA | 1 | R5 | |
| 9. | 10.0 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD1002F | KOA | 1 | R6, R24 | |
| 10. | 12.7 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD1272F | KOA | 1 | R9 | |
| 11. | 15.0 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD1502F | KOA | 1 | R4 | |
| 12. | 22.1 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD2212F | KOA | 1 | R31 | |
| 13. | 27.0 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD2702F | KOA | 1 | R23 | |
| 14. | 39.2 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD3922F | KOA | 1 | R22 | |
| 15. | 46.4 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD4642F | KOA | 1 | R2 | |
| 16. | 68.1 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD6812F | KOA | 1 | R21 | |
| 17. | 82.5 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD8252F | KOA | 1 | R1 | |
| 18. | 100 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD1003F | KOA | 2 | R10, R25 | |
| 19. | 274 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD2743F | KOA | 1 | R26 | Optional. Do not install |
| 20. | 475 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD4753F | KOA | 1 | R18 | |
| 21. | 750 kΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD7503F | KOA | 1 | R19 | |
| 22. | 1.24 MΩ 1% 0.125 W 0805 SMT | Mouser | 660-RK73H2ATTD1244F | KOA | 1 | R27 | Optional. Do not install |
| 23. | 0.125 W 0805 SMT | | Optional | | 1 | R7 | Optional. Do not install |
| 24. | 0.125 W 0805 SMT | | Optional | | 1 | R17 | Optional. Do not install |
| **Capacitors** | | | | | | | |
| 25. | 100 pF COG 5% 100 V Ceramic 0805 SMT | Mouser | 581-08051A101J | AVX | 1 | C10 | |
| 26. | 10 nF Ceramic Capacitor 50 V 0805 SMT | Mouser | 80-C0805C103K5R | Kemet | 1 | C1 | |
| 27. | 0.1 µF Ceramic Capacitor 50 V 0805 SMT | Mouser | 581-08055C104K | AVX | 5 | C2, C5, C7, C9, C11 | C11 Optional. Do not install |
| 28. | 1.0 µF Ceramic Capacitor 50 V 0805 SMT | Mouser | 963-UMK212B7105KG-T | Taiyo Yuden | 1 | C13 | Optional. Do not install |
| 29. | 22 µF 16 V SMT | Mouser | 598-AFK226M16C12T-F | Cornell Dubilier | 1 | C12 | |
| 30. | 100 µF 6 V SMT | Mouser | 667-EEE-FPJ101UAR | Panasonic | 1 | C8 | |
| 31. | 0805 SMT | | Optional | | 1 | C4 | Optional. Do not install |
| 32. | 0805 SMT | | Optional | | 1 | C6 | Optional. Do not install |

| Item | Description | Distributor | Distributor Part Number | MFG | Qty | Designator | Remarks |
|---|---|---|---|---|---|---|---|
| **Transistors** | | | | | | | |
| 33. | 2N5089 NPN Transistor SOT-23 | Mouser | 512-MMBT5089 | Fairchild | 2 | Q4, Q6 | |
| 34. | N-Channel FET SuperSOT™-6 | Mouser | 512-FDN337N | Fairchild | 1 | Q5 | |
| **Diodes & Rectifiers** | | | | | | | |
| 35. | 1 W DO-41 Zener | | Optional | | 1 | D2 | Optional. Do not install |
| 36. | Dual Diode Low Leakage SOT-23 | | 512-FLLD261 | Fairchild | 1 | U6 | |
| **Integrated Circuits** | | | | | | | |
| 37. | FHR1200 Shunt Regulator SC-70 | Mouser | 512-FHR1200 | Fairchild | 7 | U1, U2, U3, U4, U5, U9, U10 | U2 Optional. Do not install |
| 38. | Opto Isolator, H11AG1M | Mouser | 512-H11AG1M | Fairchild | 1 | OPTO 2 | |
| 39. | Opto Isolator, FOD817D | Mouser | 512-FOD817D | Fairchild | 1 | OPTO 1 | Optional. Do not install |
| 40. | NC7WZU04 Dual Inv Gate SC-70-6 | Mouser | 512-NC7WZU04P6X | Fairchild | 1 | U7 | |
| 41. | FAN156 Comparator MicroPak™ 6 | Mouser | 512-FAN156L6X | Fairchild | 1 | U8 | Optional. Do not install |
| **Inductor & Hardware** | | | | | | | |
| 42. | 100 µH SMT, 0.5 A, 0.25 Ω | Mouser | 810-SLF7045T-101M | TDK | 1 | L1 | |

# 6. Application Circuit Tests

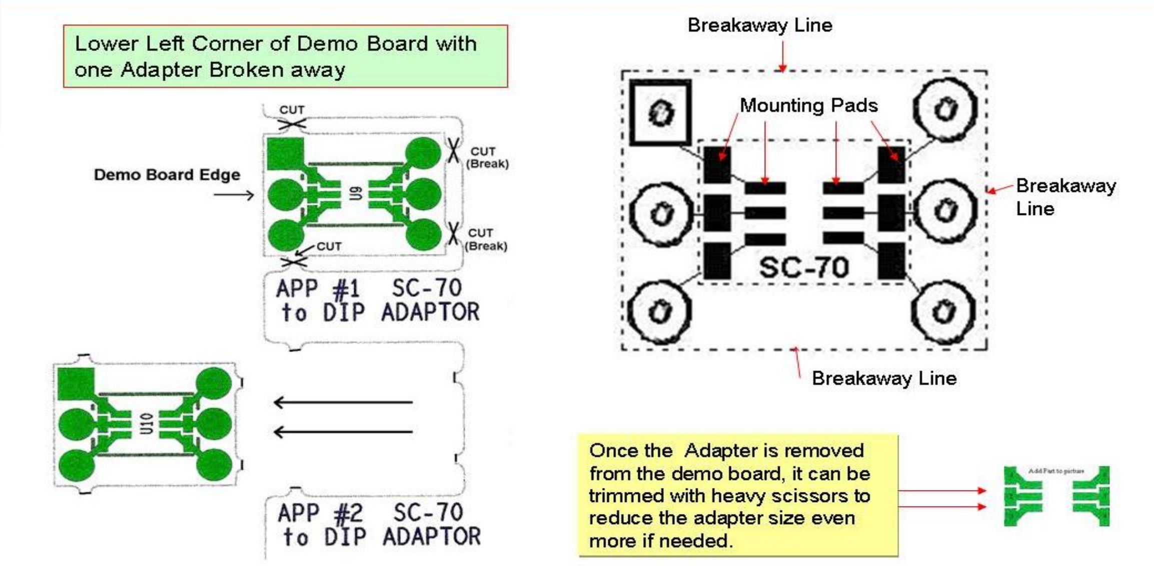
Six application circuits are provided to help designers understand the FHR1200 and how it might be used in an application. The FHR1200 is very flexible and can be used in many diverse applications. Default voltages and operating currents were selected to enable testing, but may require adjustment for a particular application. The design formulas, device curves, and data are supplied in this document and in the FHR1200 datasheet.


Connecting the Application Modules for Test

When the board is first built; the easiest way to connect the power to test each of the applications is to use standard test clips inserted from the rear of the board. The hook in the clip will have to be straightened a little for this. This method avoids having to put any solder in the holes during build and test. This keeps the board nice and clean and avoids solder wicking through the holes. Solder that wicks through might make it difficult to glue the label on the back of the board.

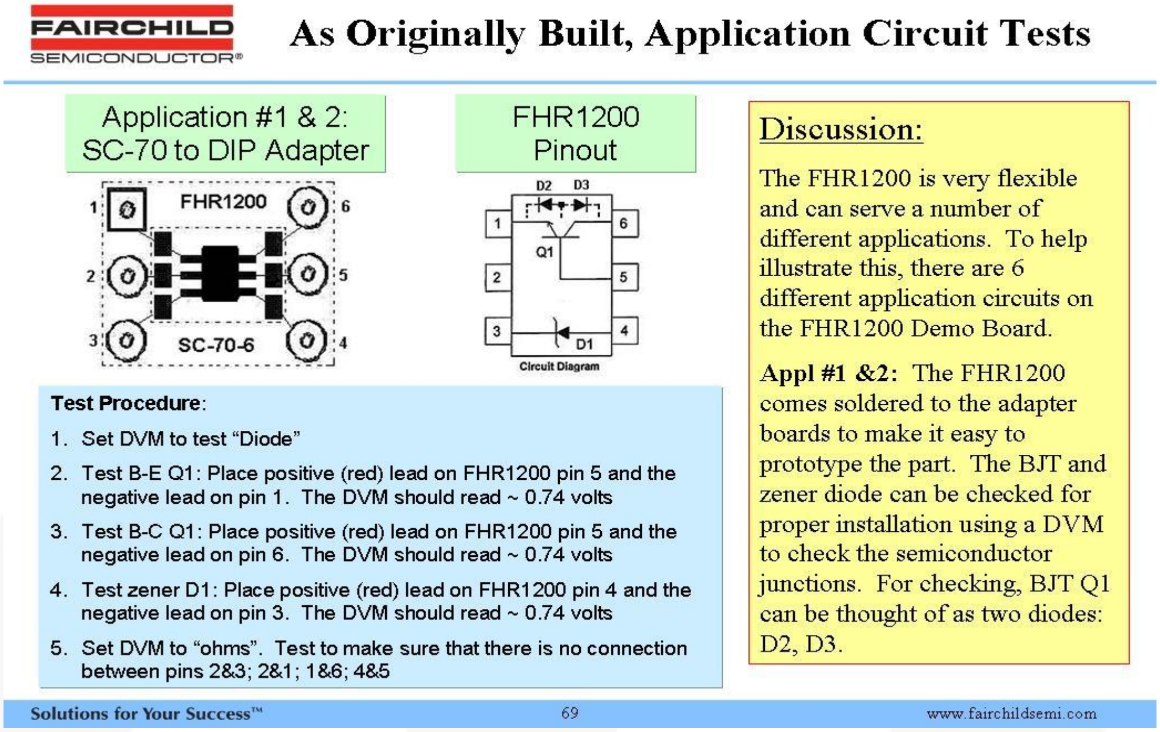
The label can be removed by the customer after they receive the board if they wish. The rubber cement used to secure the label comes off cleanly for this purpose.

Figure 30. Connecting the Evaluation Board for Test


Lower Left Corner of Demo Board with one Adapter Broken away

Once the Adapter is removed from the demo board, it can be trimmed with heavy scissors to reduce the adapter size even more if needed.

Figure 31. Break-Away Detail for Socket Adapters



## As Originally Built, Application Circuit Tests

Application #1 & 2:
SC-70 to DIP Adapter

FHR1200
Pinout

**Test Procedure**:

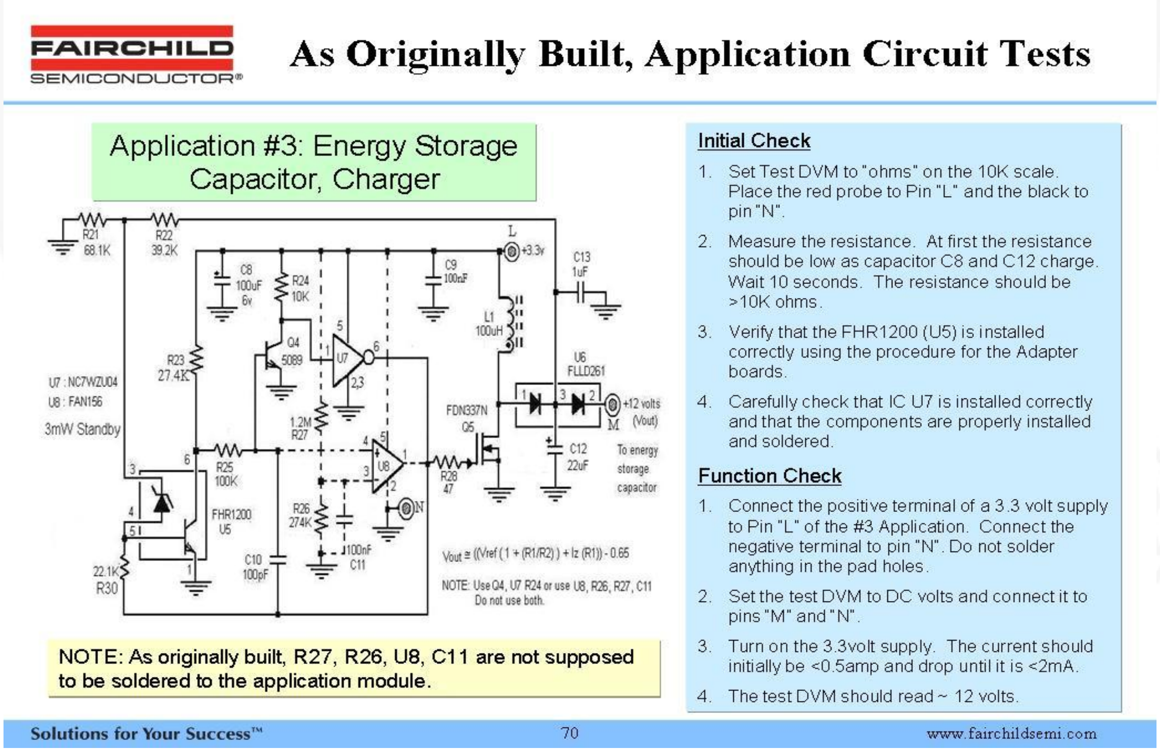
1. Set DVM to test "Diode"
2. Test B-E Q1: Place positive (red) lead on FHR1200 pin 5 and the negative lead on pin 1. The DVM should read ~ 0.74 volts
3. Test B-C Q1: Place positive (red) lead on FHR1200 pin 5 and the negative lead on pin 6. The DVM should read ~ 0.74 volts
4. Test zener D1: Place positive (red) lead on FHR1200 pin 4 and the negative lead on pin 3. The DVM should read ~ 0.74 volts
5. Set DVM to "ohms". Test to make sure that there is no connection between pins 2&3; 2&1; 1&6; 4&5

Discussion:

The FHR1200 is very flexible and can serve a number of different applications. To help illustrate this, there are 6 different application circuits on the FHR1200 Demo Board.

**Appl #1 &2:** The FHR1200 comes soldered to the adapter boards to make it easy to prototype the part. The BJT and zener diode can be checked for proper installation using a DVM to check the semiconductor junctions. For checking, BJT Q1 can be thought of as two diodes: D2, D3.

Figure 32. Testing the FHR1200 Devices on the Socket Adapters



## As Originally Built, Application Circuit Tests

Application #3: Energy Storage Capacitor, Charger

NOTE: As originally built, R27, R26, U8, C11 are not supposed to be soldered to the application module.

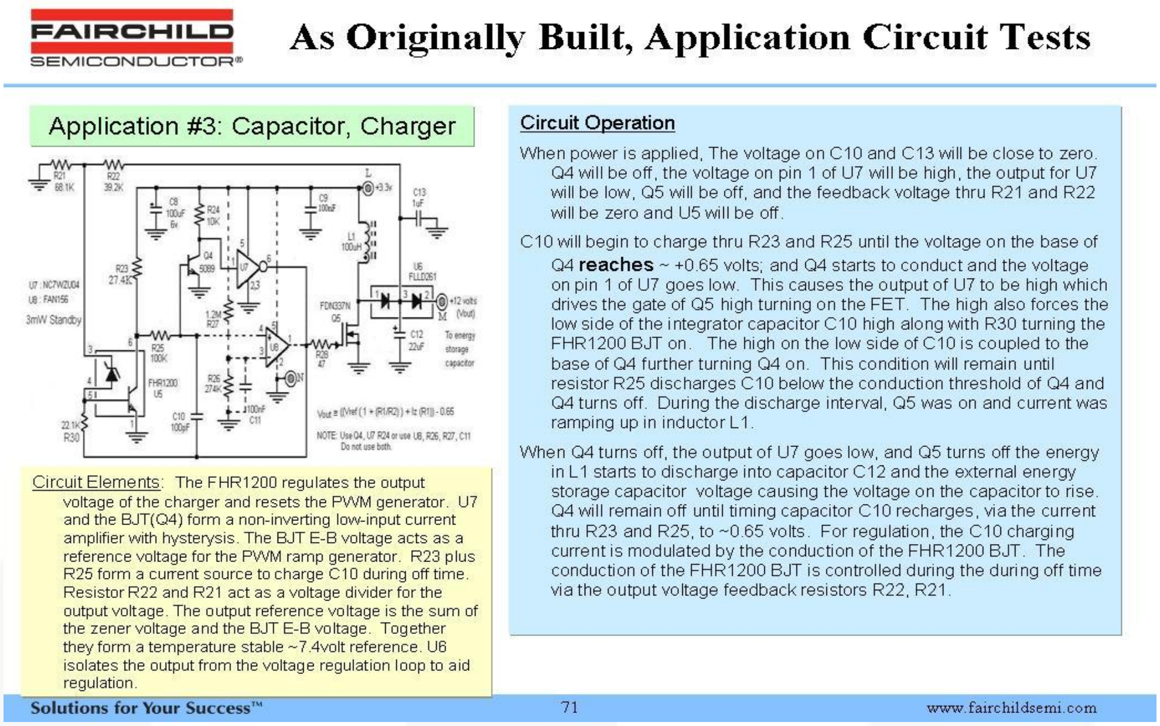
Initial Check

1. Set Test DVM to "ohms" on the 10K scale. Place the red probe to Pin "L" and the black to pin "N".
2. Measure the resistance. At first the resistance should be low as capacitor C8 and C12 charge. Wait 10 seconds. The resistance should be >10K ohms.
3. Verify that the FHR1200 (U5) is installed correctly using the procedure for the Adapter boards.
4. Carefully check that IC U7 is installed correctly and that the components are properly installed and soldered.

Function Check

1. Connect the positive terminal of a 3.3 volt supply to Pin "L" of the #3 Application. Connect the negative terminal to pin "N". Do not solder anything in the pad holes.
2. Set the test DVM to DC volts and connect it to pins "M" and "N".
3. Turn on the 3.3volt supply. The current should initially be <0.5amp and drop until it is <2mA.
4. The test DVM should read ~ 12 volts.

Figure 33. Test of the Energy Capacitor Charger Operation



## As Originally Built, Application Circuit Tests

### Application #3: Capacitor, Charger

Circuit Elements: The FHR1200 regulates the output voltage of the charger and resets the PWM generator. U7 and the BJT(Q4) form a non-inverting low-input current amplifier with hysterysis. The BJT E-B voltage acts as a reference voltage for the PWM ramp generator. R23 plus R25 form a current source to charge C10 during off time. Resistor R22 and R21 act as a voltage divider for the output voltage. The output reference voltage is the sum of the zener voltage and the BJT E-B voltage. Together they form a temperature stable ~7.4volt reference. U6 isolates the output from the voltage regulation loop to aid regulation.

#### Circuit Operation

When power is applied, The voltage on C10 and C13 will be close to zero. Q4 will be off, the voltage on pin 1 of U7 will be high, the output for U7 will be low, Q5 will be off, and the feedback voltage thru R21 and R22 will be zero and U5 will be off.

C10 will begin to charge thru R23 and R25 until the voltage on the base of Q4 **reaches** ~ +0.65 volts; and Q4 starts to conduct and the voltage on pin 1 of U7 goes low. This causes the output of U7 to be high which drives the gate of Q5 high turning on the FET. The high also forces the low side of the integrator capacitor C10 high along with R30 turning the FHR1200 BJT on. The high on the low side of C10 is coupled to the base of Q4 further turning Q4 on. This condition will remain until resistor R25 discharges C10 below the conduction threshold of Q4 and Q4 turns off. During the discharge interval, Q5 was on and current was ramping up in inductor L1.

When Q4 turns off, the output of U7 goes low, and Q5 turns off the energy in L1 starts to discharge into capacitor C12 and the external energy storage capacitor voltage causing the voltage on the capacitor to rise. Q4 will remain off until timing capacitor C10 recharges, via the current thru R23 and R25, to ~0.65 volts. For regulation, the C10 charging current is modulated by the conduction of the FHR1200 BJT. The conduction of the FHR1200 BJT is controlled during the during off time via the output voltage feedback resistors R22, R21.

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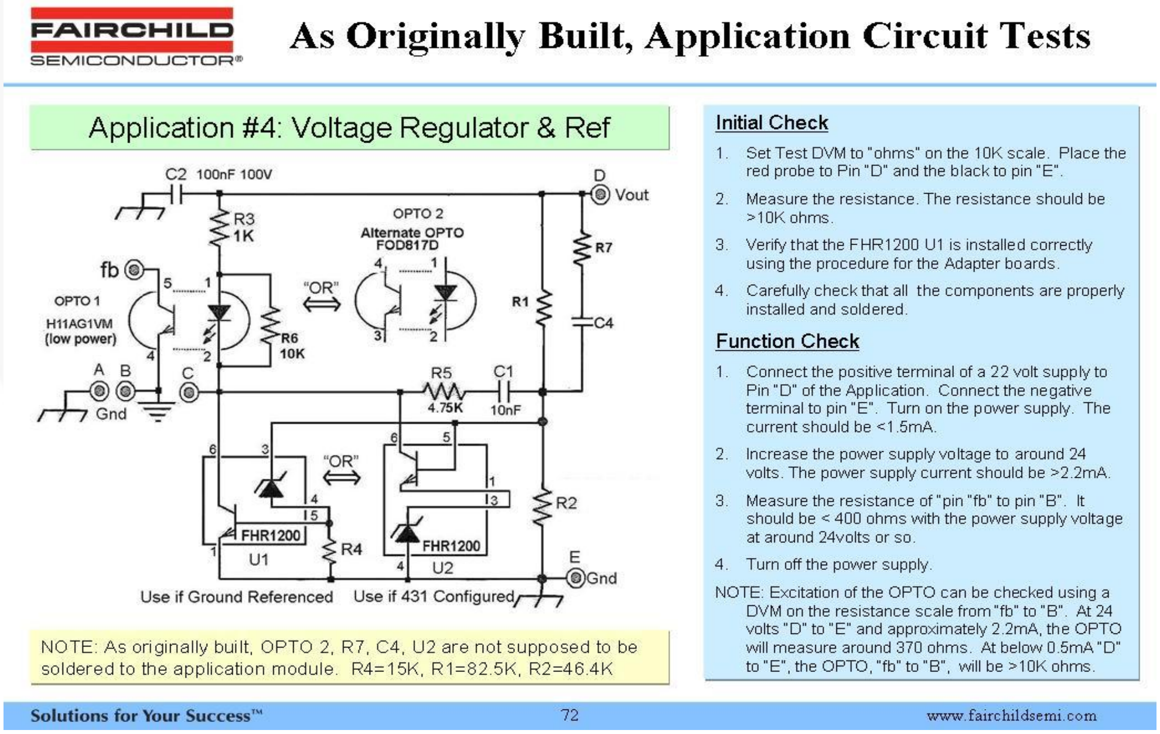
Figure 34. Energy Capacitor Charger Circuit Operation Description



## As Originally Built, Application Circuit Tests

### Application #4: Voltage Regulator & Ref

NOTE: As originally built, OPTO 2, R7, C4, U2 are not supposed to be soldered to the application module. R4=15K, R1=82.5K, R2=46.4K

#### Initial Check

1. Set Test DVM to "ohms" on the 10K scale. Place the red probe to Pin "D" and the black to pin "E".
2. Measure the resistance. The resistance should be >10K ohms.
3. Verify that the FHR1200 U1 is installed correctly using the procedure for the Adapter boards.
4. Carefully check that all the components are properly installed and soldered.

#### Function Check

1. Connect the positive terminal of a 22 volt supply to Pin "D" of the Application. Connect the negative terminal to pin "E". Turn on the power supply. The current should be <1.5mA.
2. Increase the power supply voltage to around 24 volts. The power supply current should be >2.2mA.
3. Measure the resistance of "pin "fb" to pin "B". It should be < 400 ohms with the power supply voltage at around 24volts or so.
4. Turn off the power supply.

NOTE: Excitation of the OPTO can be checked using a DVM on the resistance scale from "fb" to "B". At 24 volts "D" to "E" and approximately 2.2mA, the OPTO will measure around 370 ohms. At below 0.5mA "D" to "E", the OPTO, "fb" to "B", will be >10K ohms.

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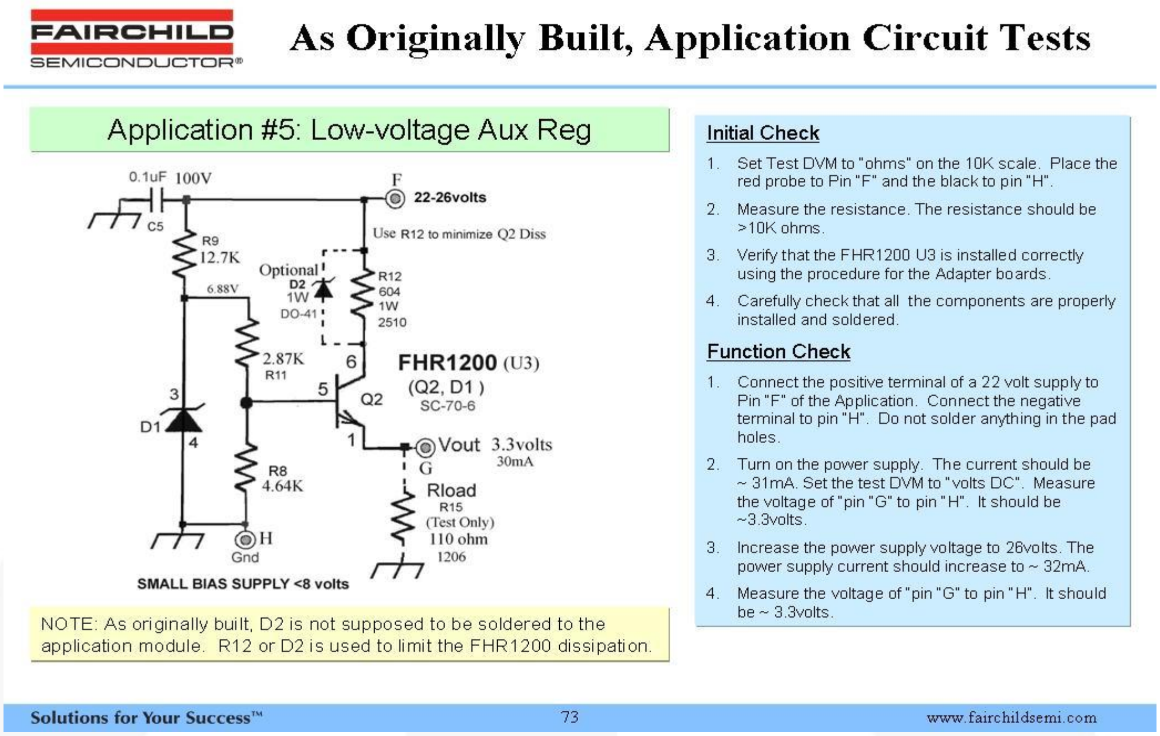
Figure 35. Voltage Regulator Circuit Checkout



## As Originally Built, Application Circuit Tests

### Application #5: Low-voltage Aux Reg

NOTE: As originally built, D2 is not supposed to be soldered to the application module. R12 or D2 is used to limit the FHR1200 dissipation.

**Initial Check**

1. Set Test DVM to "ohms" on the 10K scale. Place the red probe to Pin "F" and the black to pin "H".
2. Measure the resistance. The resistance should be >10K ohms.
3. Verify that the FHR1200 U3 is installed correctly using the procedure for the Adapter boards.
4. Carefully check that all the components are properly installed and soldered.

**Function Check**

1. Connect the positive terminal of a 22 volt supply to Pin "F" of the Application. Connect the negative terminal to pin "H". Do not solder anything in the pad holes.
2. Turn on the power supply. The current should be ~ 31mA. Set the test DVM to "volts DC". Measure the voltage of "pin "G" to pin "H". It should be ~3.3volts.
3. Increase the power supply voltage to 26volts. The power supply current should increase to ~ 32mA.
4. Measure the voltage of "pin "G" to pin "H". It should be ~ 3.3volts.

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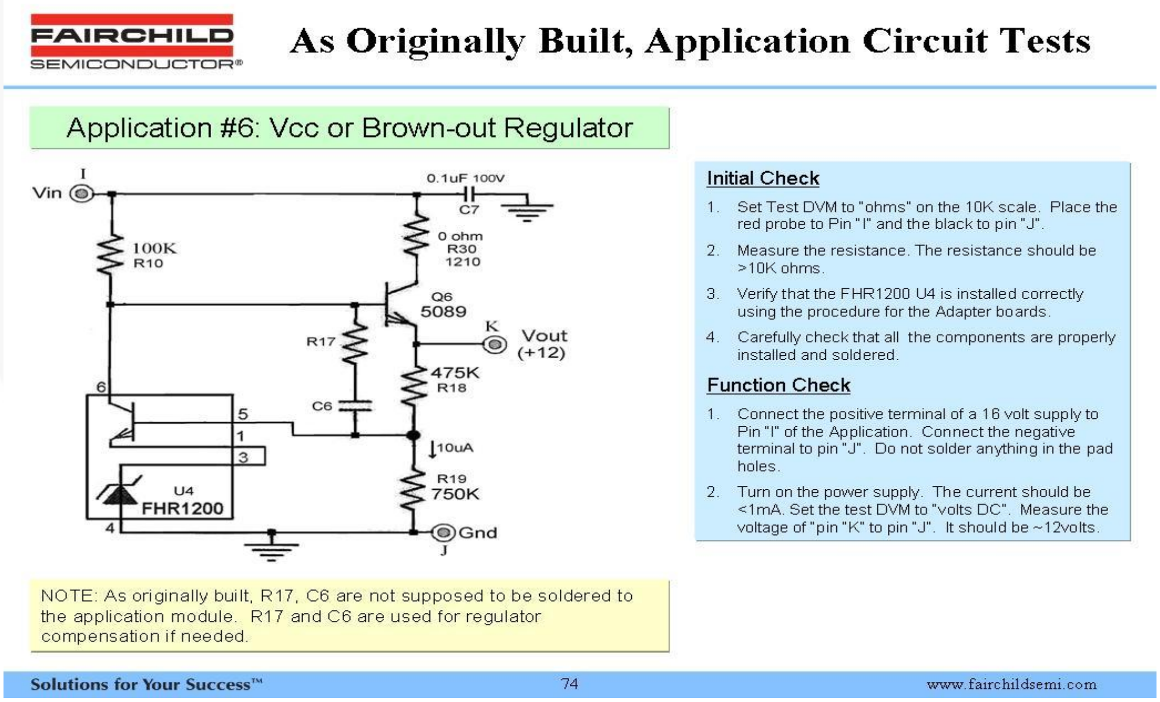
Figure 36. 3.3 V Low-Voltage Regulator Checkout



## As Originally Built, Application Circuit Tests

### Application #6: Vcc or Brown-out Regulator

NOTE: As originally built, R17, C6 are not supposed to be soldered to the application module. R17 and C6 are used for regulator compensation if needed.

**Initial Check**

1. Set Test DVM to "ohms" on the 10K scale. Place the red probe to Pin "I" and the black to pin "J".
2. Measure the resistance. The resistance should be >10K ohms.
3. Verify that the FHR1200 U4 is installed correctly using the procedure for the Adapter boards.
4. Carefully check that all the components are properly installed and soldered.

**Function Check**

1. Connect the positive terminal of a 16 volt supply to Pin "I" of the Application. Connect the negative terminal to pin "J". Do not solder anything in the pad holes.
2. Turn on the power supply. The current should be <1mA. Set the test DVM to "volts DC". Measure the voltage of "pin "K" to pin "J". It should be ~12volts.

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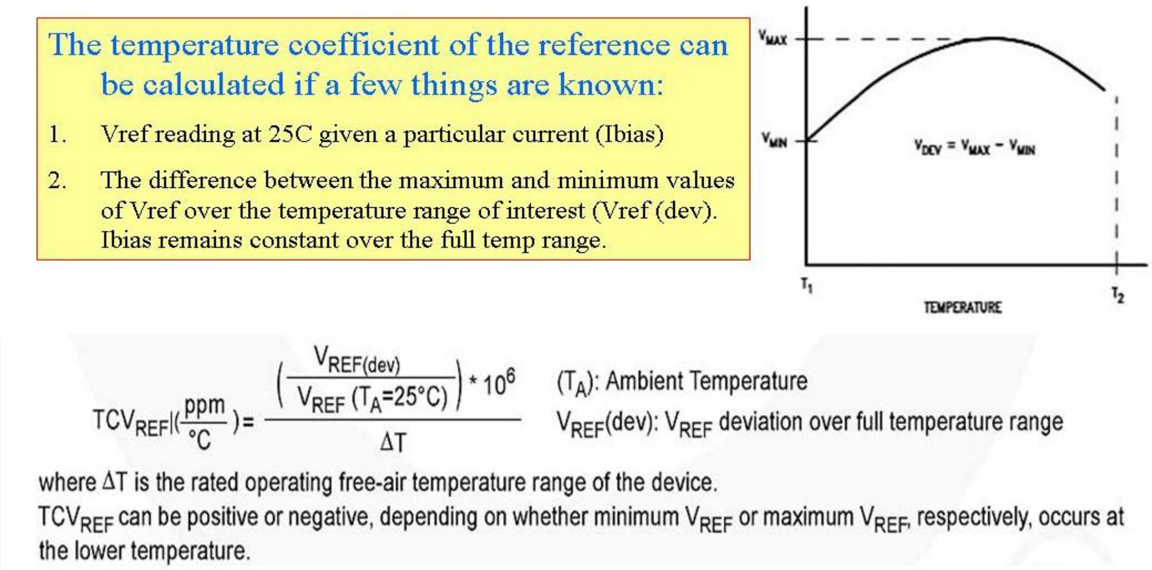
Figure 37. $V_{CC}$ or Brownout Regulator Circuit Checkout

# 7. Device Characteristic Data

The following section provides characterization data on the FHR1200. Please note that the data was selected to help designers with applications. It is not a complete set of possible curves or tables on the device. If other data is required, please feel free to ask an FAE or sales representative.



The temperature coefficient of the reference can be calculated if a few things are known:

1. Vref reading at 25C given a particular current (Ibias)
2. The difference between the maximum and minimum values of Vref over the temperature range of interest (Vref (dev). Ibias remains constant over the full temp range.

$$TCV_{REF}\left(\frac{ppm}{°C}\right) = \frac{\left(\frac{V_{REF(dev)}}{V_{REF}(T_A=25°C)}\right) * 10^6}{\Delta T}$$

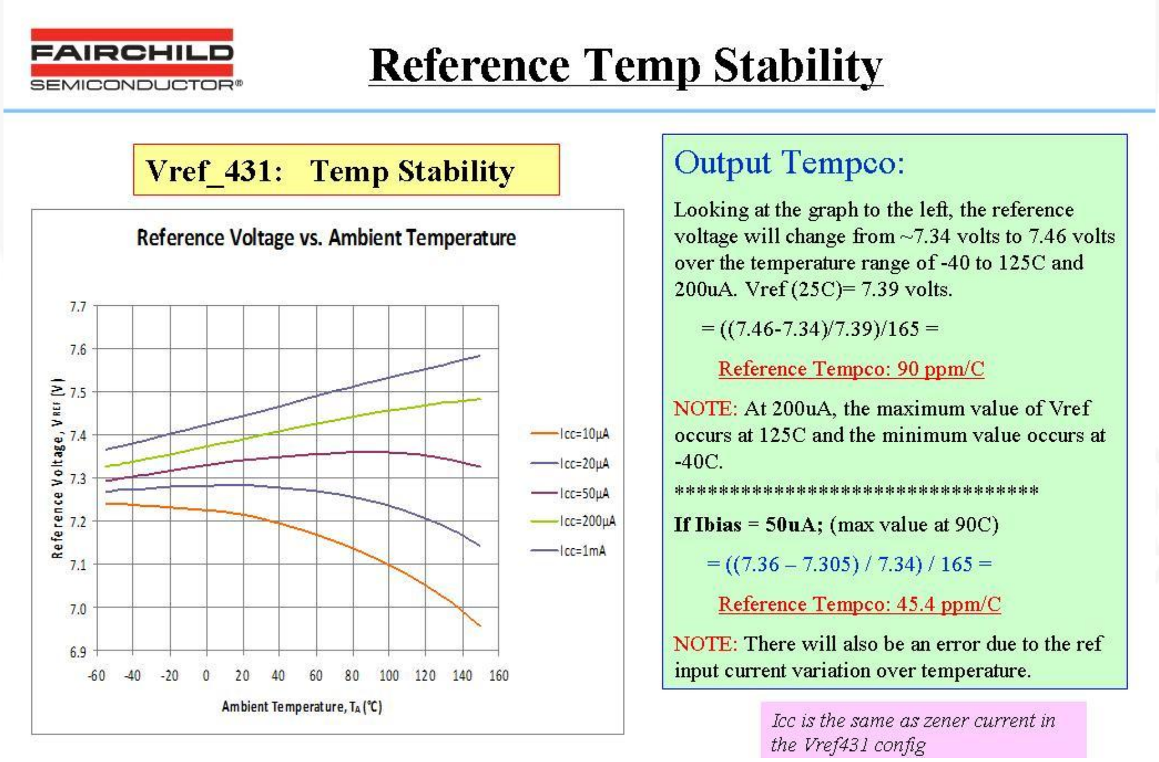
$(T_A)$: Ambient Temperature

$V_{REF}$(dev): $V_{REF}$ deviation over full temperature range

where ΔT is the rated operating free-air temperature range of the device.

$TCV_{REF}$ can be positive or negative, depending on whether minimum $V_{REF}$ or maximum $V_{REF}$, respectively, occurs at the lower temperature.

Figure 38. Calculating the FHR1200 Reference Temperature Coefficient



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Reference Temp Stability

Vref_431: Temp Stability

Output Tempco:

Looking at the graph to the left, the reference voltage will change from ~7.34 volts to 7.46 volts over the temperature range of -40 to 125C and 200uA. Vref (25C)= 7.39 volts.

= ((7.46-7.34)/7.39)/165 =

Reference Tempco: 90 ppm/C

NOTE: At 200uA, the maximum value of Vref occurs at 125C and the minimum value occurs at -40C.

************************************

**If Ibias = 50uA;** (max value at 90C)

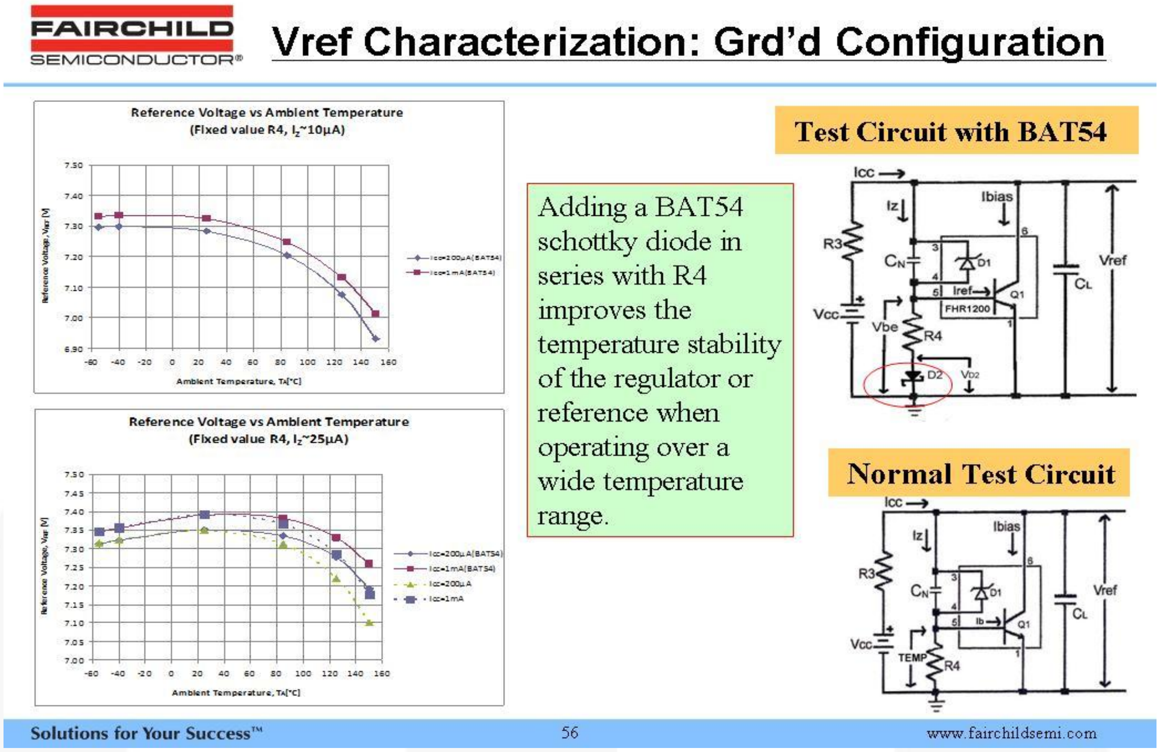
= ((7.36 – 7.305) / 7.34) / 165 =

Reference Tempco: 45.4 ppm/C

NOTE: There will also be an error due to the ref input current variation over temperature.

*Icc is the same as zener current in the Vref431 config*

Figure 39. LM431 Configured Reference Temperature Stability



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## Vref Characterization: Grd'd Configuration

Adding a BAT54 schottky diode in series with R4 improves the temperature stability of the regulator or reference when operating over a wide temperature range.

**Test Circuit with BAT54**

**Normal Test Circuit**

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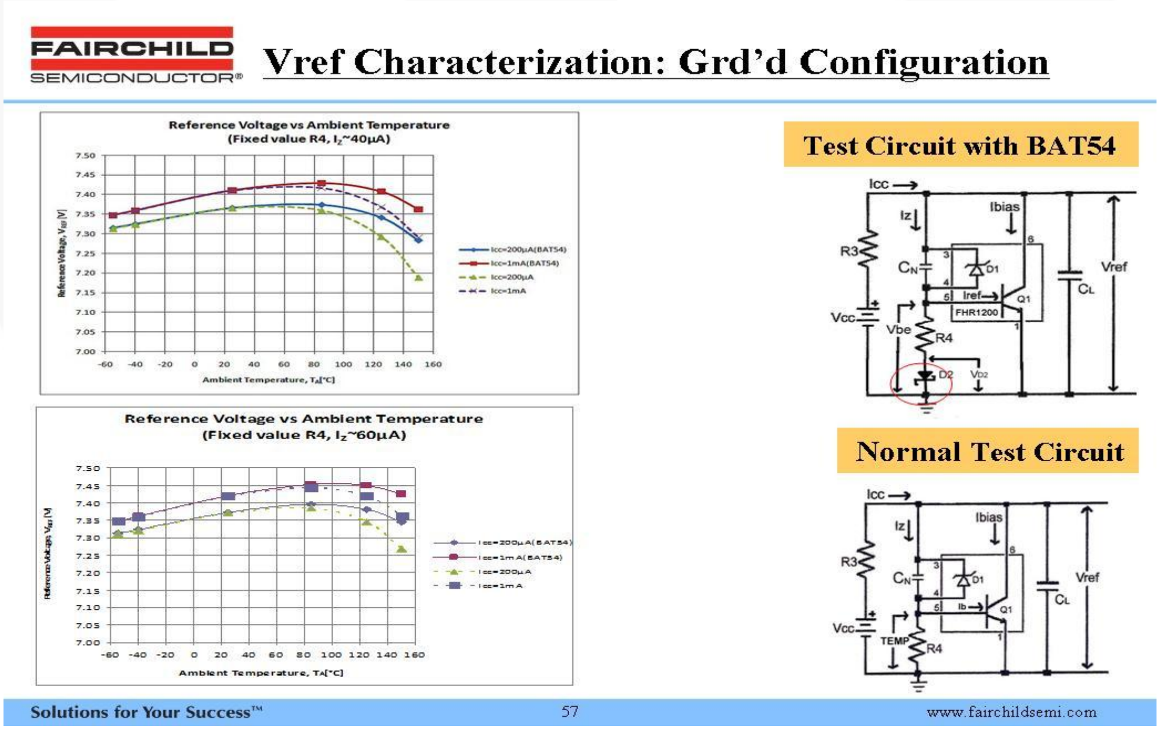
Figure 40. $V_{REF}$; 10 µA, 25 µA $I_Z$ Temperature Stability: Grounded Configuration



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## Vref Characterization: Grd'd Configuration

**Test Circuit with BAT54**

**Normal Test Circuit**

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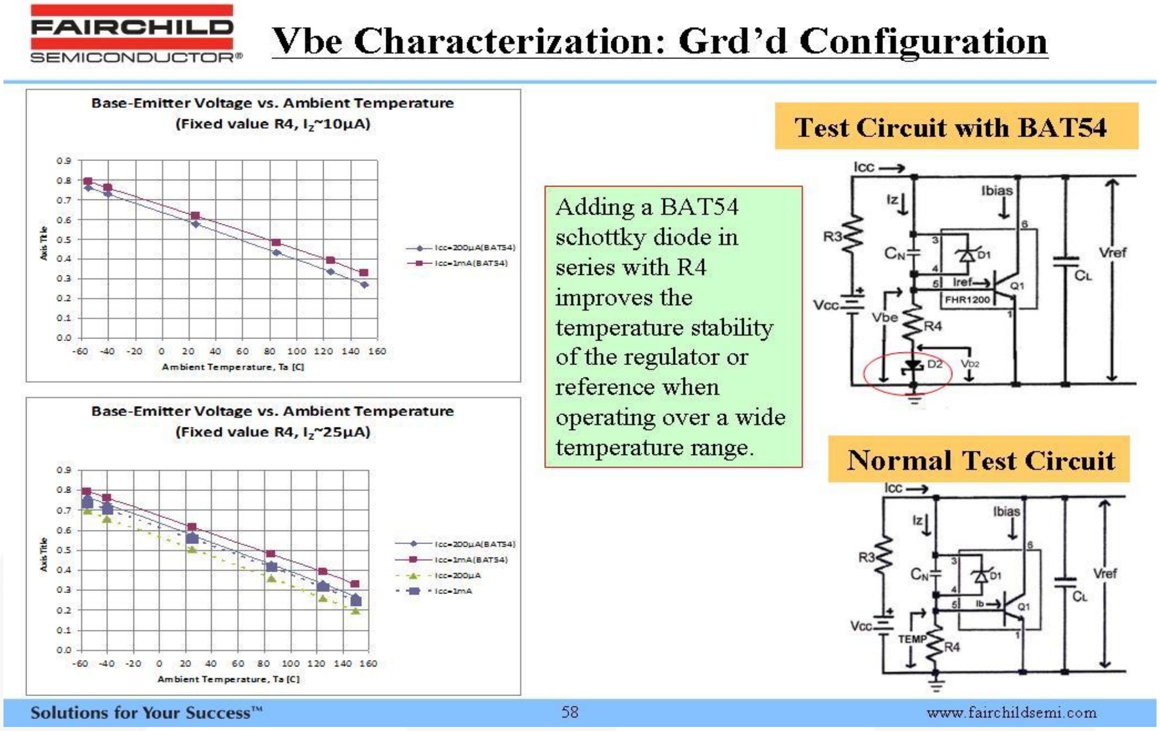
Figure 41. $V_{REF}$; 40 µA, 60 µA $I_Z$ Temperature Stability: Grounded Configuration



## Vbe Characterization: Grd'd Configuration

Adding a BAT54 schottky diode in series with R4 improves the temperature stability of the regulator or reference when operating over a wide temperature range.

**Test Circuit with BAT54**

**Normal Test Circuit**

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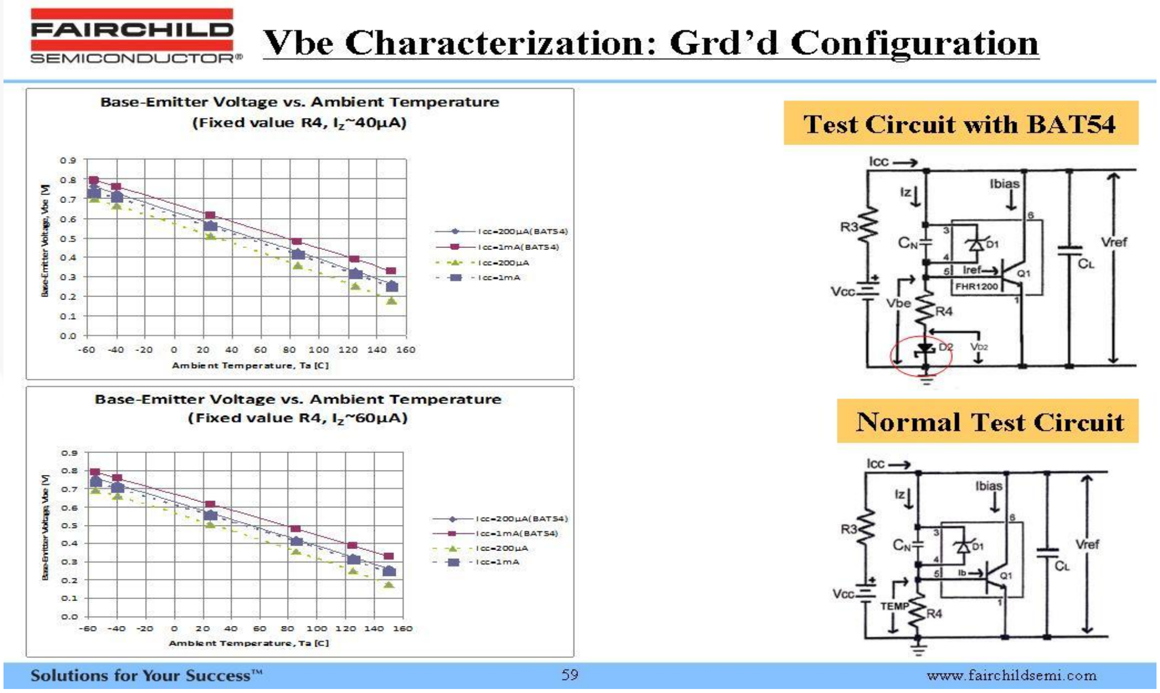
Figure 42. V$_{BE}$; 10 µA, 25 µA I$_Z$ Temperature Stability: Grounded Configuration



## Vbe Characterization: Grd'd Configuration

**Test Circuit with BAT54**

**Normal Test Circuit**

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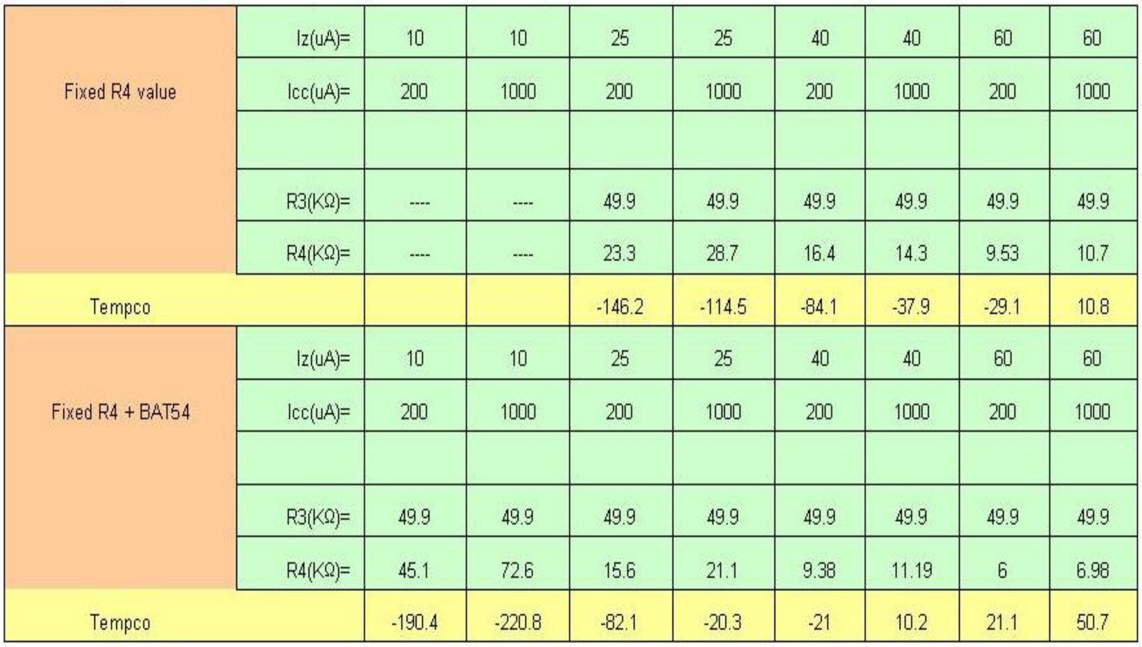
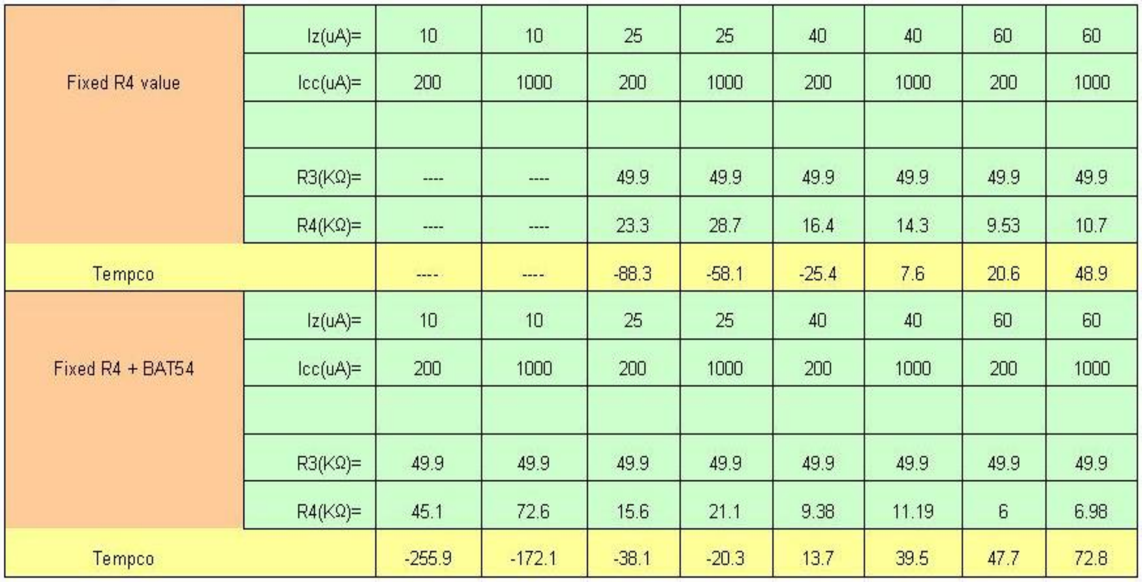
Figure 43. V$_{BE}$; 40 µA, 60 µA I$_Z$ Temperature Stability: Grounded Configuration

**Table 8. $V_{REF}$ Temp Stability vs. $I_Z$ -55°C to +150°C: Grounded Configuration**

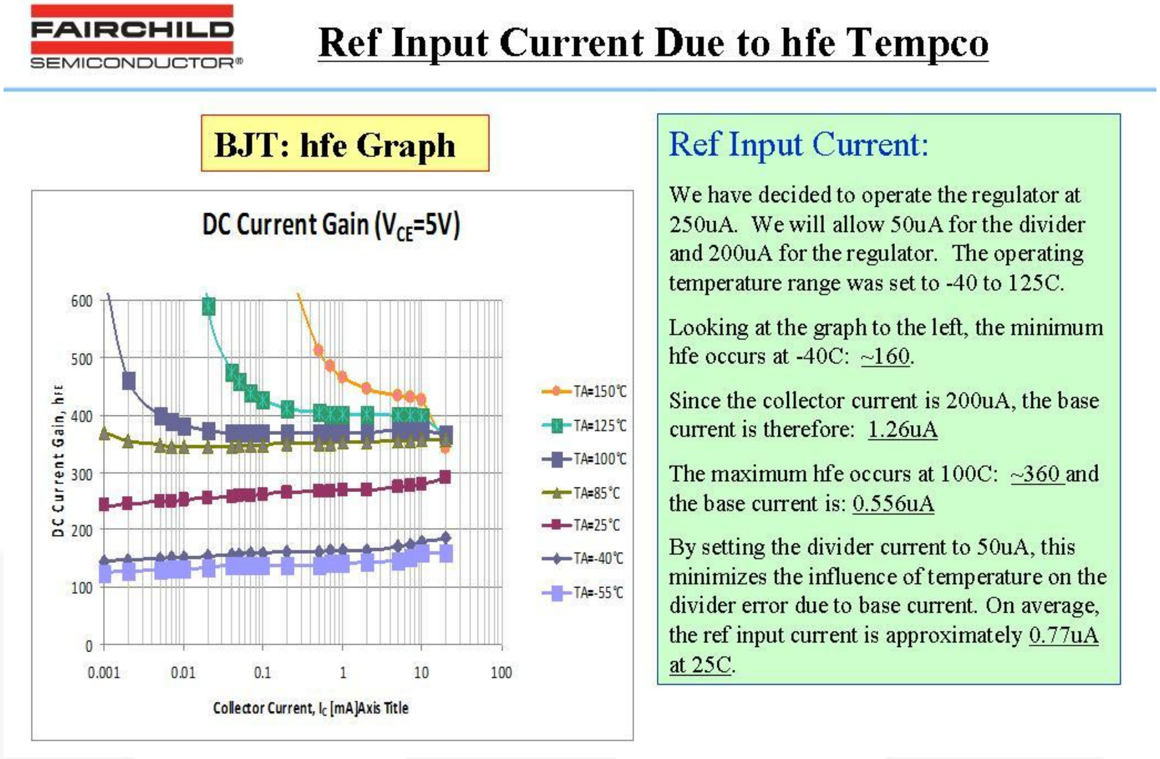


| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fixed R4 value | Iz(uA)= | 10 | 10 | 25 | 25 | 40 | 40 | 60 | 60 |
| | Icc(uA)= | 200 | 1000 | 200 | 1000 | 200 | 1000 | 200 | 1000 |
| | | | | | | | | | |
| | R3(KΩ)= | ---- | ---- | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 |
| | R4(KΩ)= | ---- | ---- | 23.3 | 28.7 | 16.4 | 14.3 | 9.53 | 10.7 |
| Tempco | | | | -146.2 | -114.5 | -84.1 | -37.9 | -29.1 | 10.8 |
| Fixed R4 + BAT54 | Iz(uA)= | 10 | 10 | 25 | 25 | 40 | 40 | 60 | 60 |
| | Icc(uA)= | 200 | 1000 | 200 | 1000 | 200 | 1000 | 200 | 1000 |
| | | | | | | | | | |
| | R3(KΩ)= | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 |
| | R4(KΩ)= | 45.1 | 72.6 | 15.6 | 21.1 | 9.38 | 11.19 | 6 | 6.98 |
| Tempco | | -190.4 | -220.8 | -82.1 | -20.3 | -21 | 10.2 | 21.1 | 50.7 |

**Table 9. $V_{REF}$ Temperature Stability vs. $I_Z$ -40°C to +125°C: Grounded Configuration**



| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fixed R4 value | Iz(uA)= | 10 | 10 | 25 | 25 | 40 | 40 | 60 | 60 |
| | Icc(uA)= | 200 | 1000 | 200 | 1000 | 200 | 1000 | 200 | 1000 |
| | | | | | | | | | |
| | R3(KΩ)= | ---- | ---- | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 |
| | R4(KΩ)= | ---- | ---- | 23.3 | 28.7 | 16.4 | 14.3 | 9.53 | 10.7 |
| Tempco | | ---- | ---- | -88.3 | -58.1 | -25.4 | 7.6 | 20.6 | 48.9 |
| Fixed R4 + BAT54 | Iz(uA)= | 10 | 10 | 25 | 25 | 40 | 40 | 60 | 60 |
| | Icc(uA)= | 200 | 1000 | 200 | 1000 | 200 | 1000 | 200 | 1000 |
| | | | | | | | | | |
| | R3(KΩ)= | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 | 49.9 |
| | R4(KΩ)= | 45.1 | 72.6 | 15.6 | 21.1 | 9.38 | 11.19 | 6 | 6.98 |
| Tempco | | -255.9 | -172.1 | -38.1 | -20.3 | 13.7 | 39.5 | 47.7 | 72.8 |



## Ref Input Current Due to hfe Tempco

**BJT: hfe Graph**

### Ref Input Current:

We have decided to operate the regulator at 250uA. We will allow 50uA for the divider and 200uA for the regulator. The operating temperature range was set to -40 to 125C.

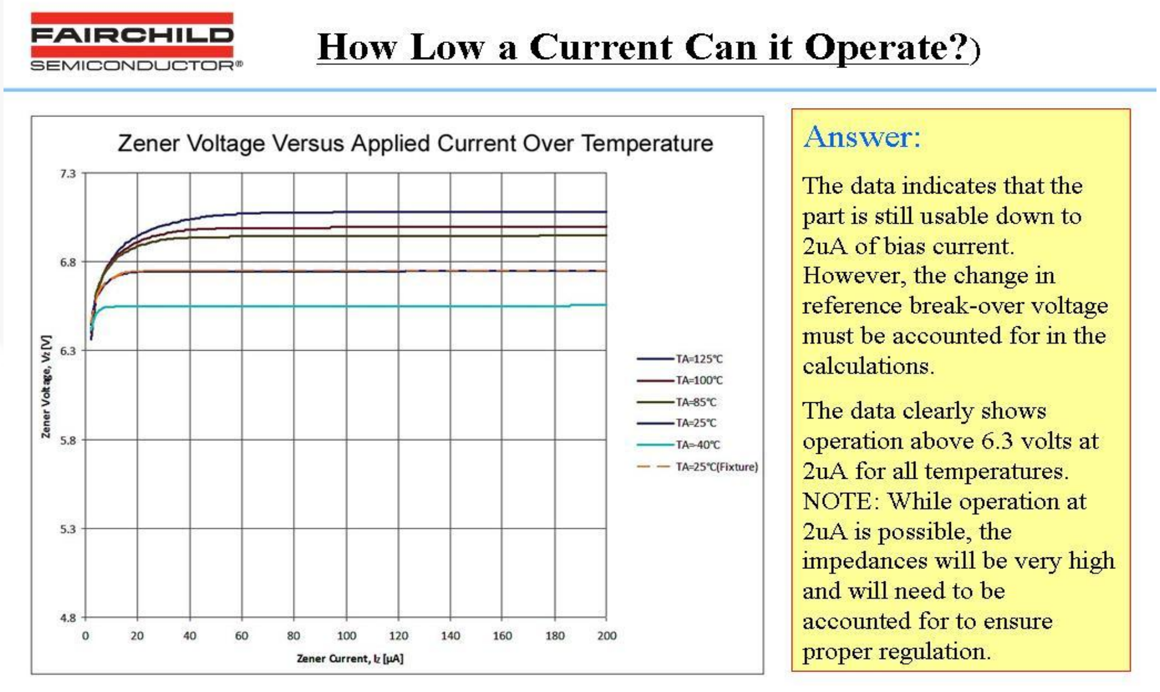
Looking at the graph to the left, the minimum hfe occurs at -40C: ~160.

Since the collector current is 200uA, the base current is therefore: 1.26uA

The maximum hfe occurs at 100C: ~360 and the base current is: 0.556uA

By setting the divider current to 50uA, this minimizes the influence of temperature on the divider error due to base current. On average, the ref input current is approximately 0.77uA at 25C.

Figure 44. BJT hfe Variation Over Temperature



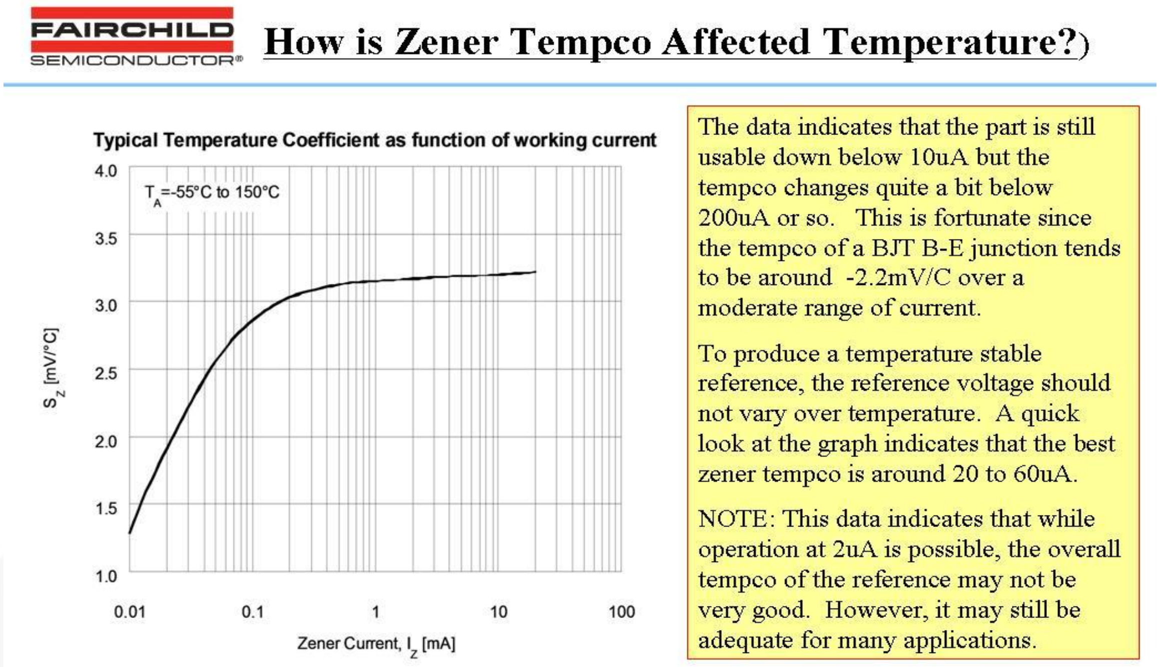
## How Low a Current Can it Operate?)

### Answer:

The data indicates that the part is still usable down to 2uA of bias current. However, the change in reference break-over voltage must be accounted for in the calculations.

The data clearly shows operation above 6.3 volts at 2uA for all temperatures. NOTE: While operation at 2uA is possible, the impedances will be very high and will need to be accounted for to ensure proper regulation.

Figure 45. Zener Voltage vs. $I_Z$ vs. Temperature



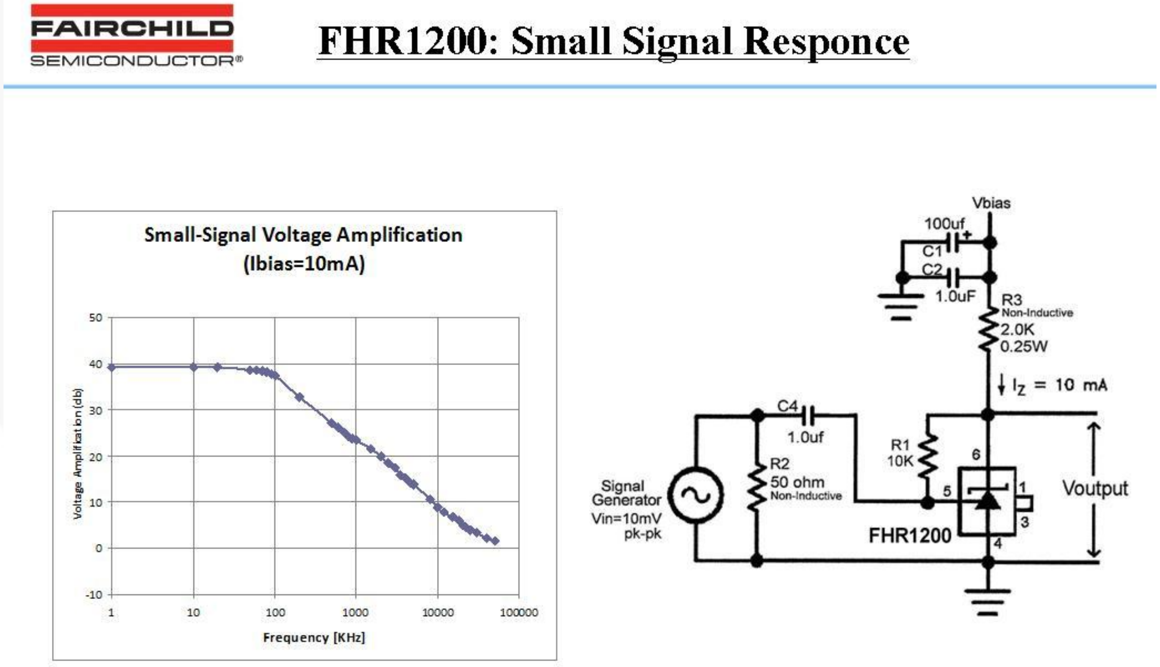
## How is Zener Tempco Affected Temperature?)

The data indicates that the part is still usable down below 10uA but the tempco changes quite a bit below 200uA or so. This is fortunate since the tempco of a BJT B-E junction tends to be around -2.2mV/C over a moderate range of current.

To produce a temperature stable reference, the reference voltage should not vary over temperature. A quick look at the graph indicates that the best zener tempco is around 20 to 60uA.

NOTE: This data indicates that while operation at 2uA is possible, the overall tempco of the reference may not be very good. However, it may still be adequate for many applications.

Figure 46. Zener Temperature Coefficient Change Over Temperature



## FHR1200: Small Signal Responce

Figure 47. FHR1200 Small-Signal Response

# 8. Revision History

| Rev. | Date | Description |
|---|---|---|
| 1.0.0 | February 2014 | Initial Release |
| 1.3 | February 2015 | Updated Links |
| | | |
| | | |

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