User Guide for

FEBFHR1200_SPG01A
Evaluation Board

High-Performance Shunt Regulator

Featured Fairchild Product:
FHR1200

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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

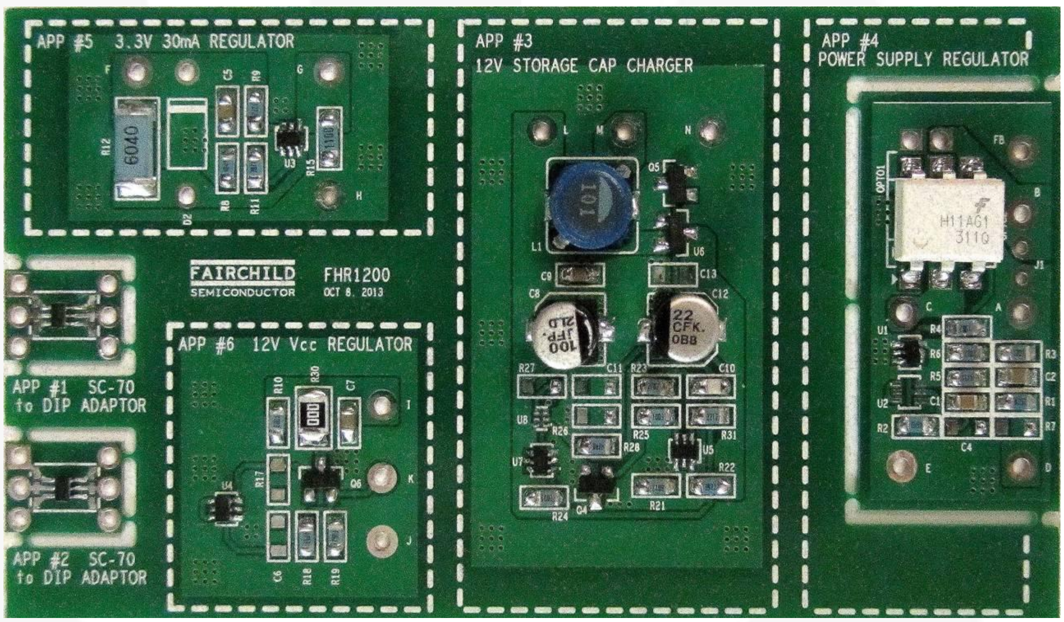

Figure 1. Evaluation Board Photograph (Enlarged)

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.

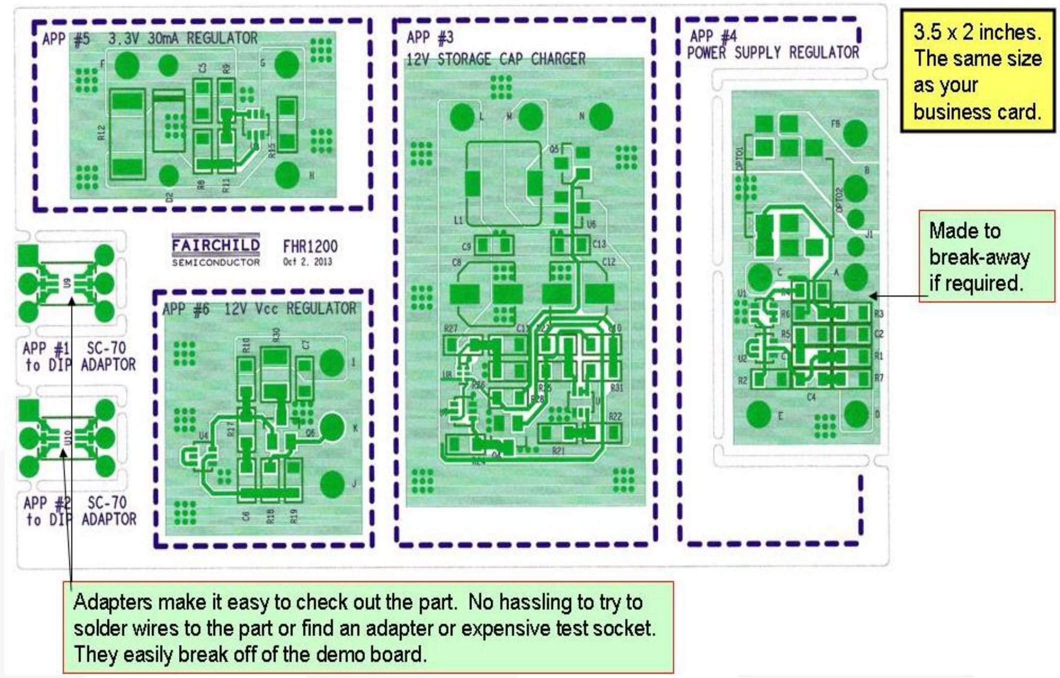

Figure 2. Evaluation Board Floor Plan

2. Evaluation Board Specifications

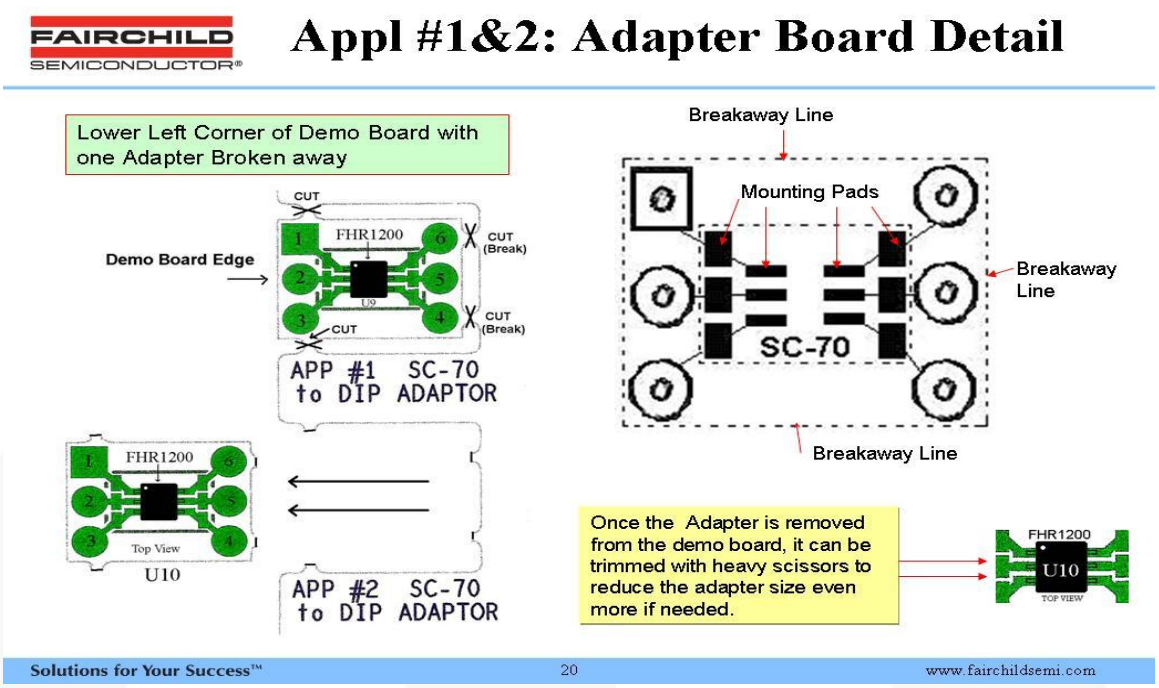

Figure 3. Break-Away Part Adapters

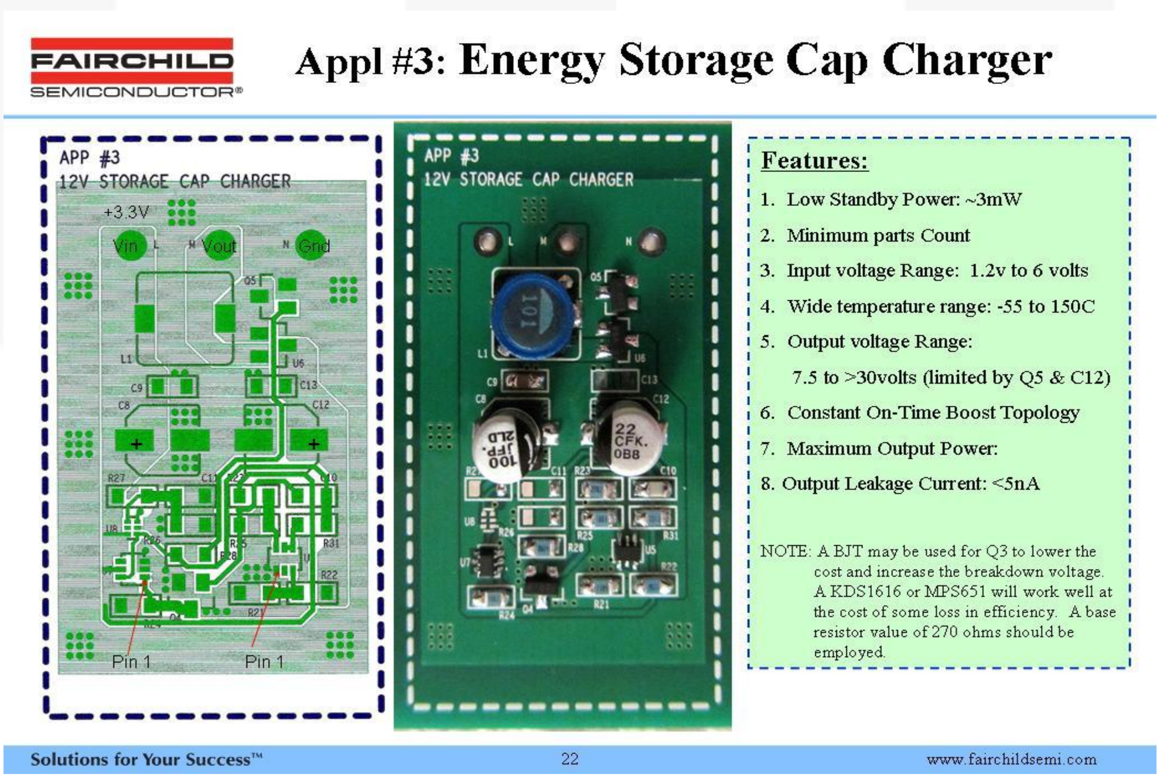

Figure 4. Energy Storage Capacitor Charger

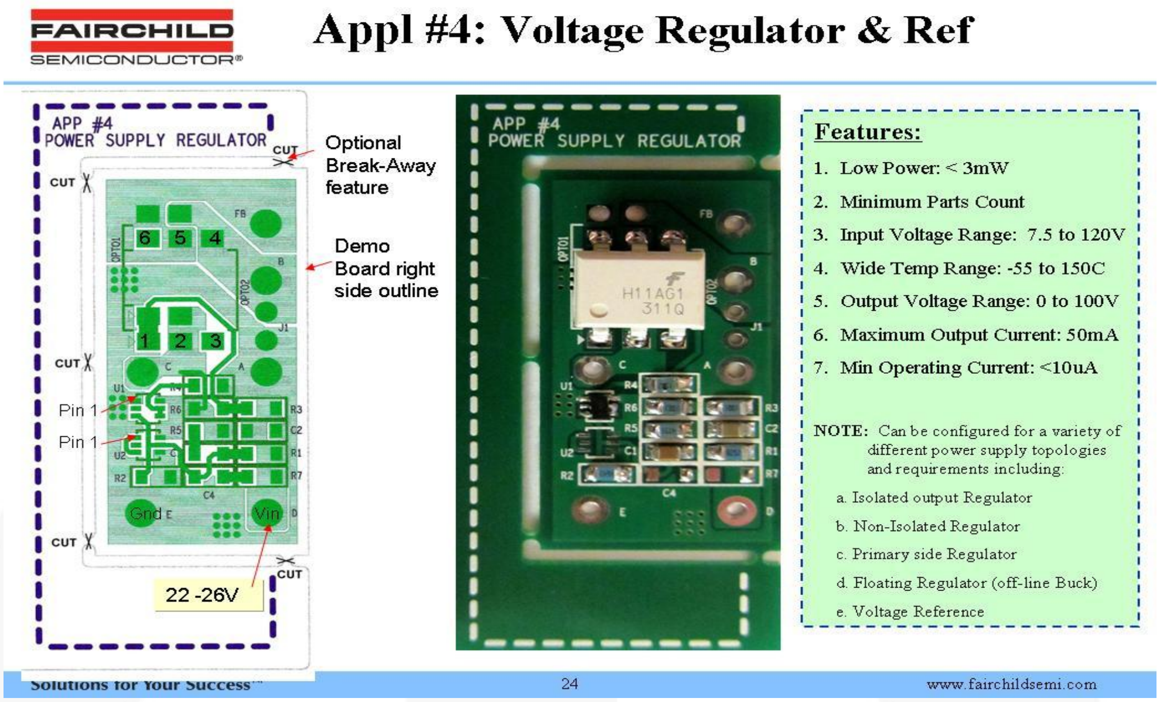

Figure 5. Power Supply Voltage Regulator

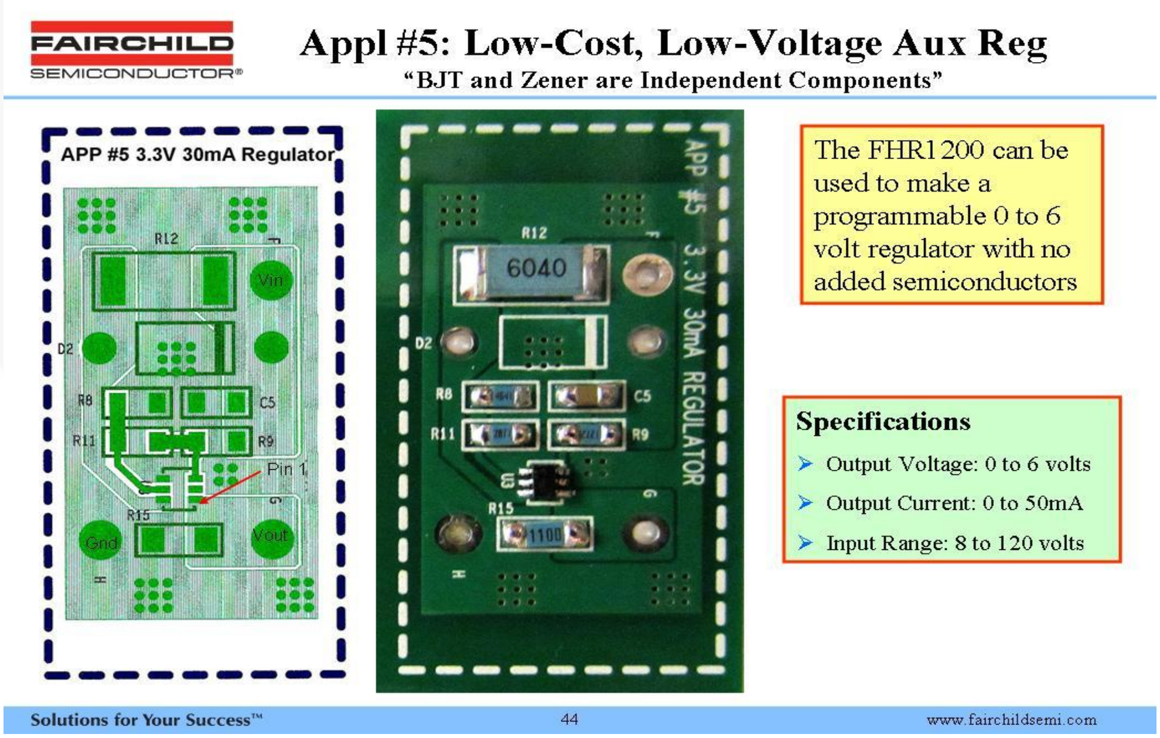

Figure 6. Low-Voltage Auxiliary Regulator

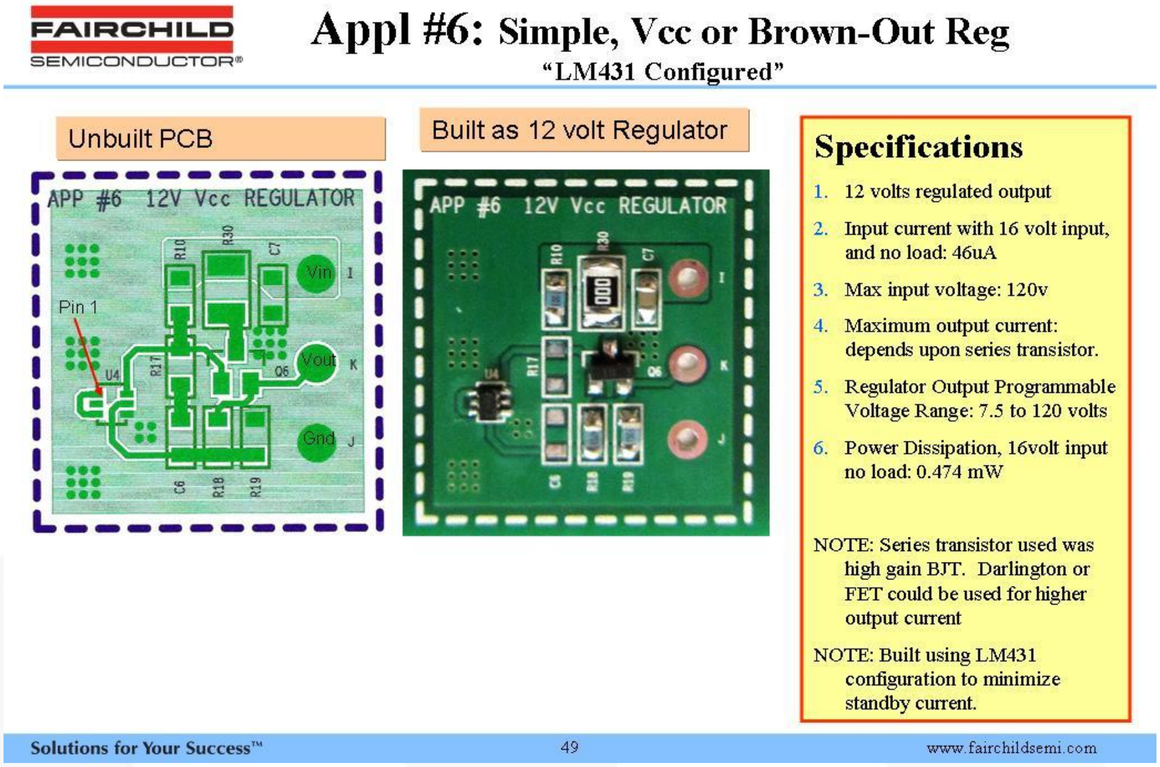

Figure 7. Low-Cost V_{CC} or Brownout Regulator

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.

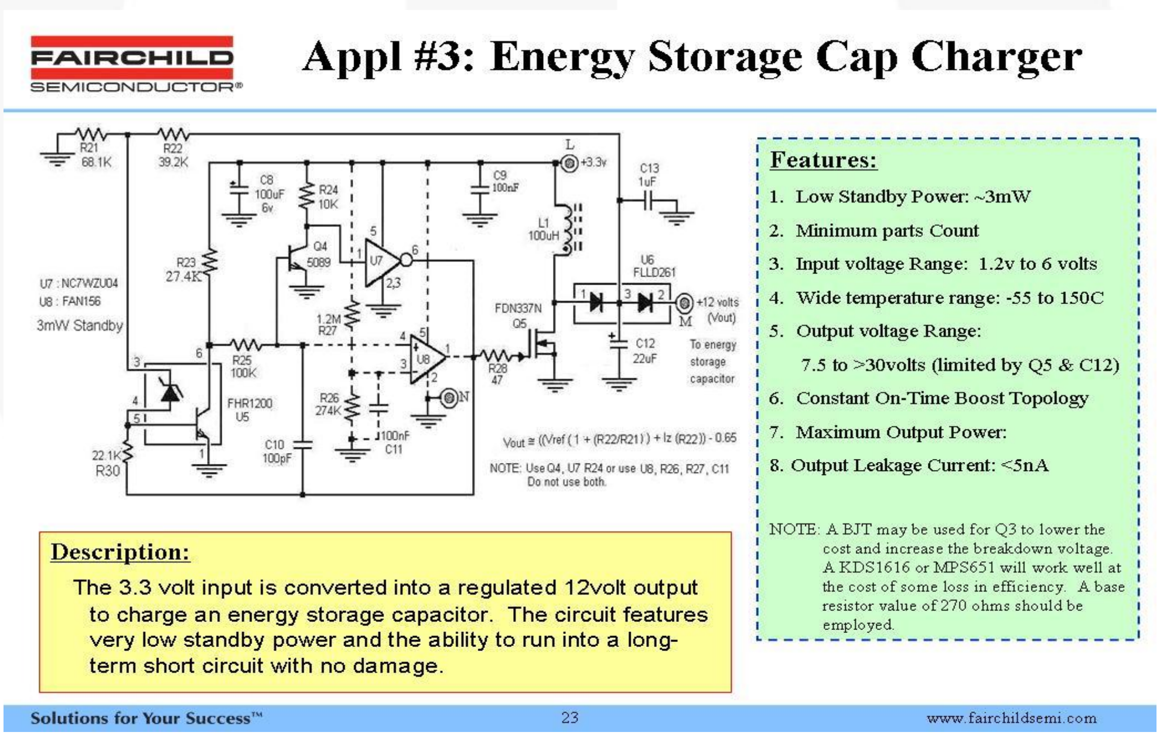

Figure 8. Energy Storage Capacitor, Regulated High-Efficiency Charger

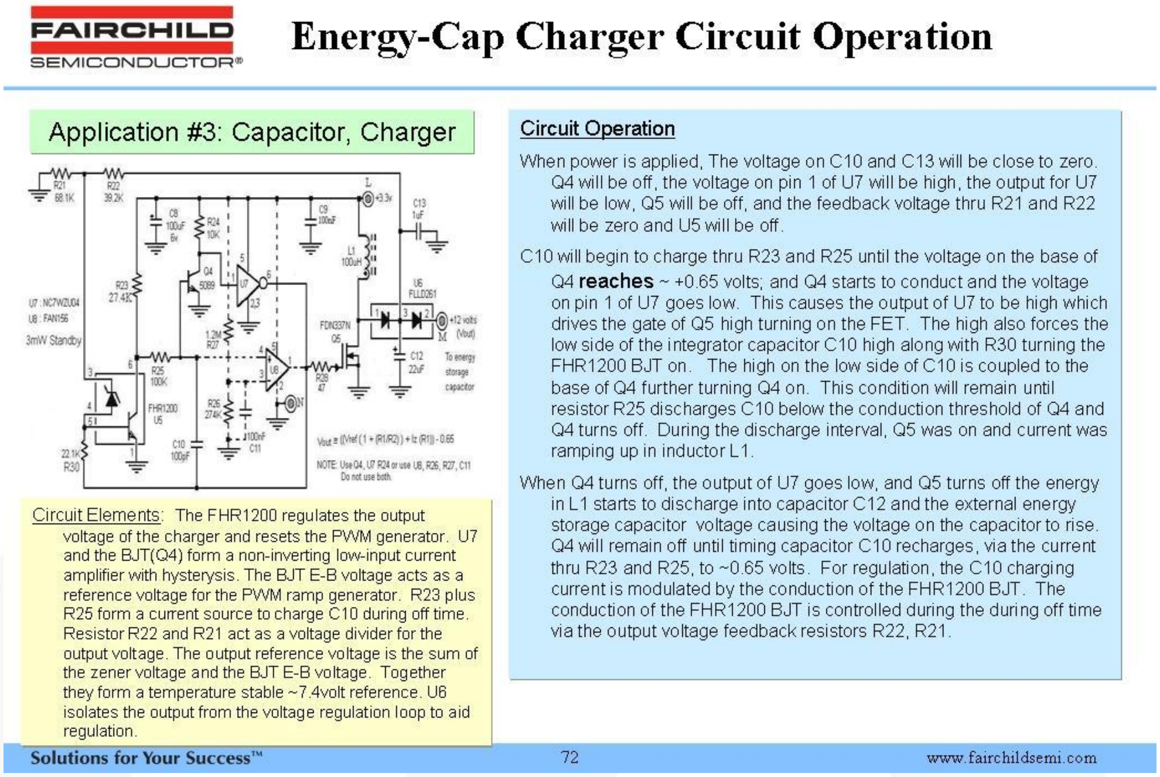

Figure 9. Energy Storage Capacitor Charger, Circuit Operation

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.

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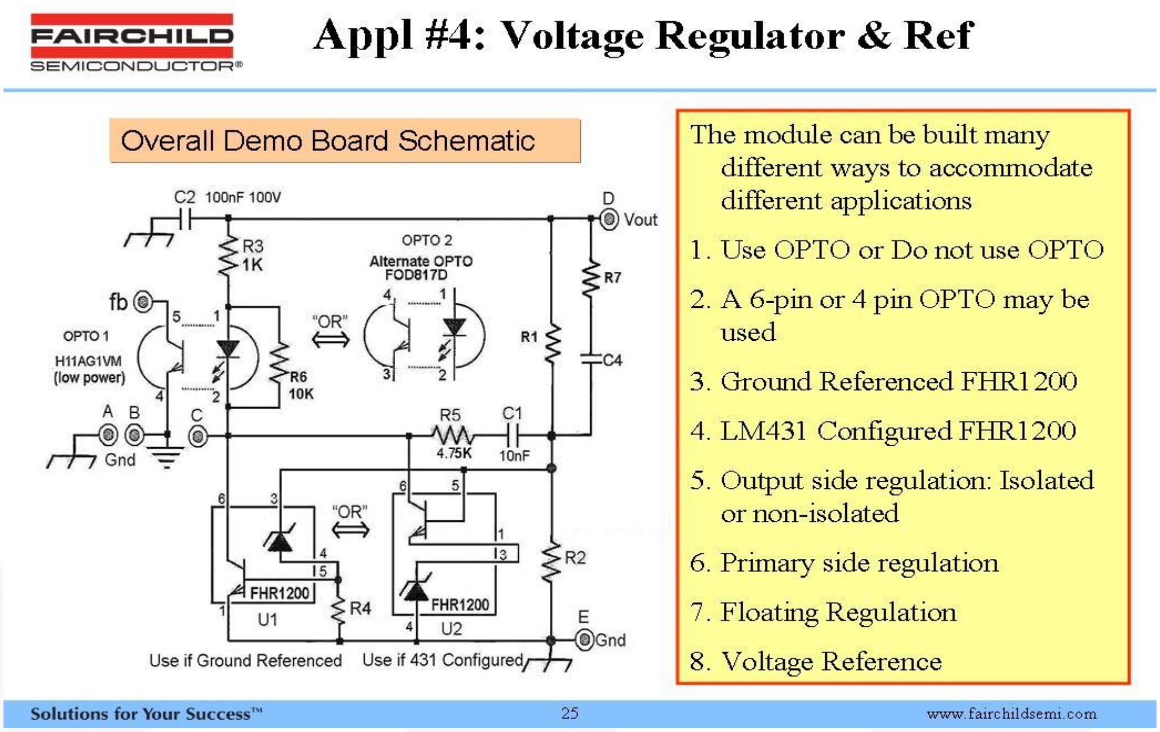


Figure 10. Application Circuit #4: Overall Schematic

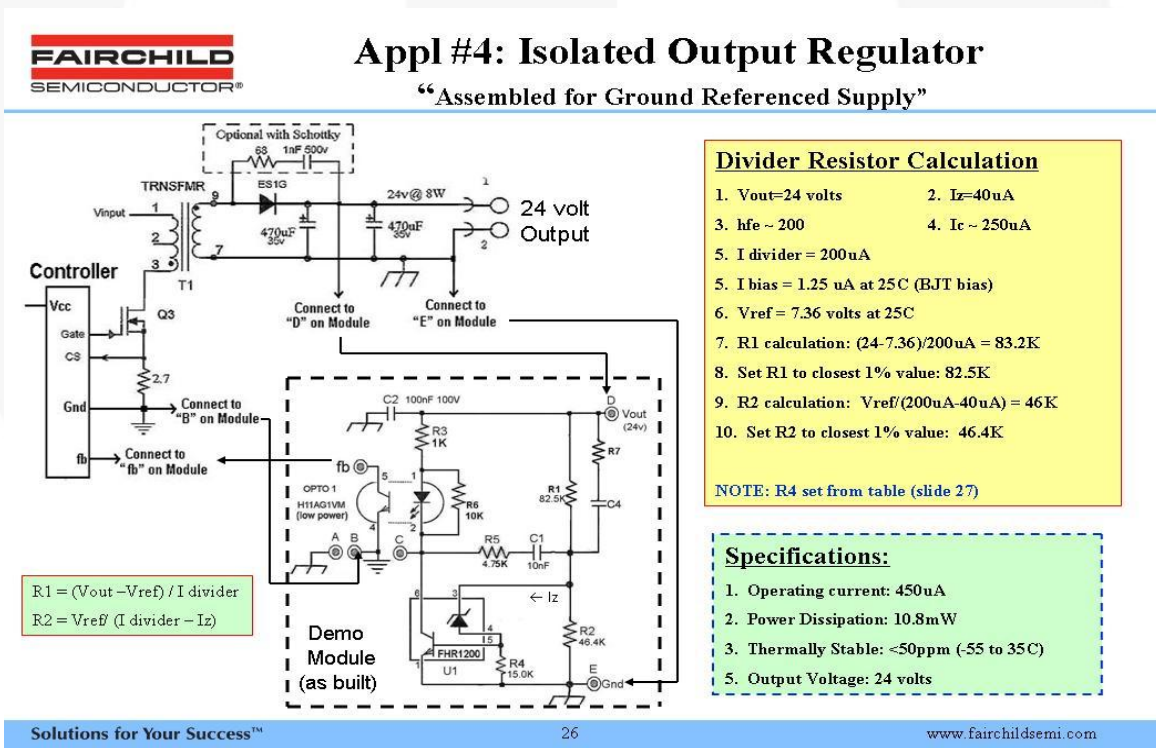


Figure 11. Application Circuit #4: Isolated Output, Grounded Output Regulator

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

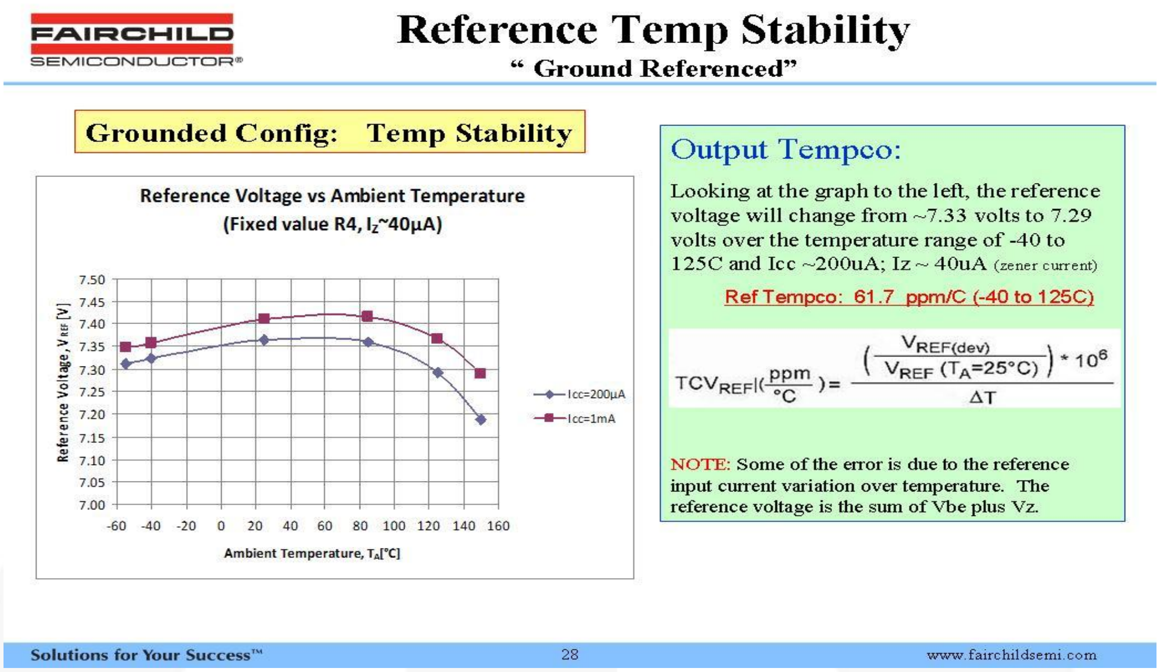


Figure 12. Reference Temperature Stability at 200 µA & 1 mA: Grounded Configuration

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.

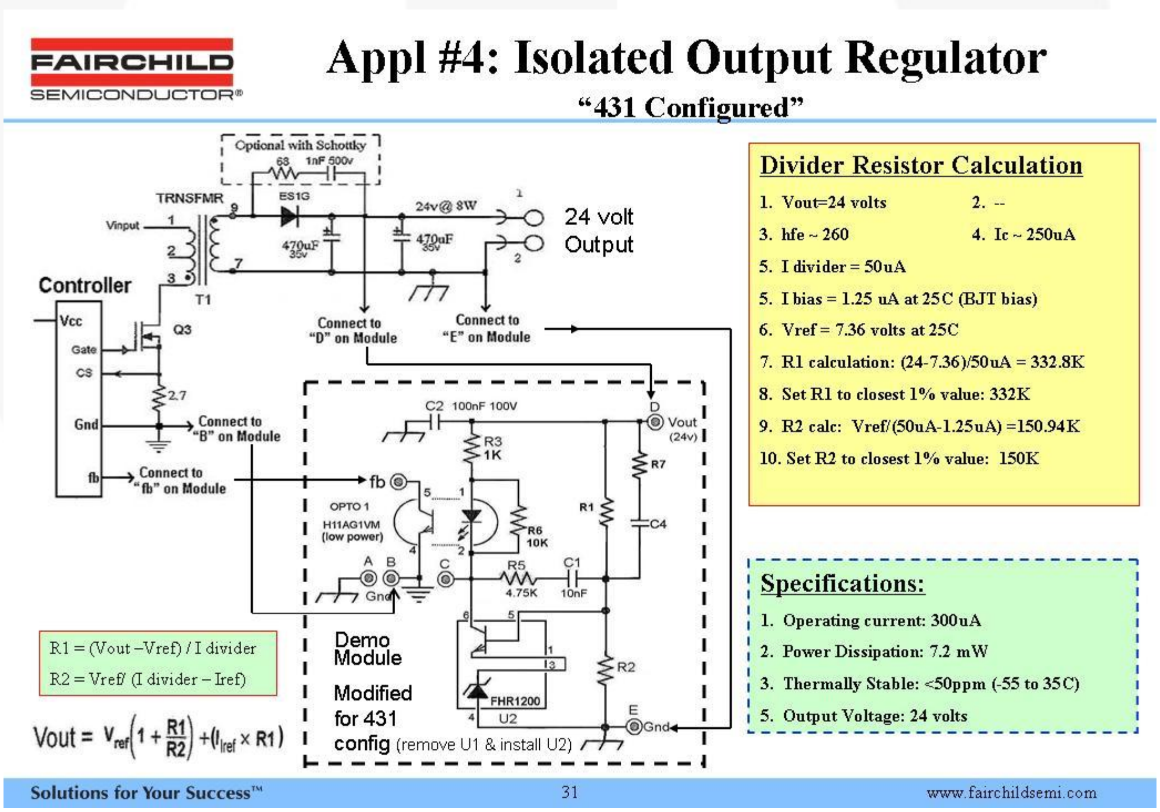


Figure 13. Isolated Output Regulator: 431 Configuration

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.

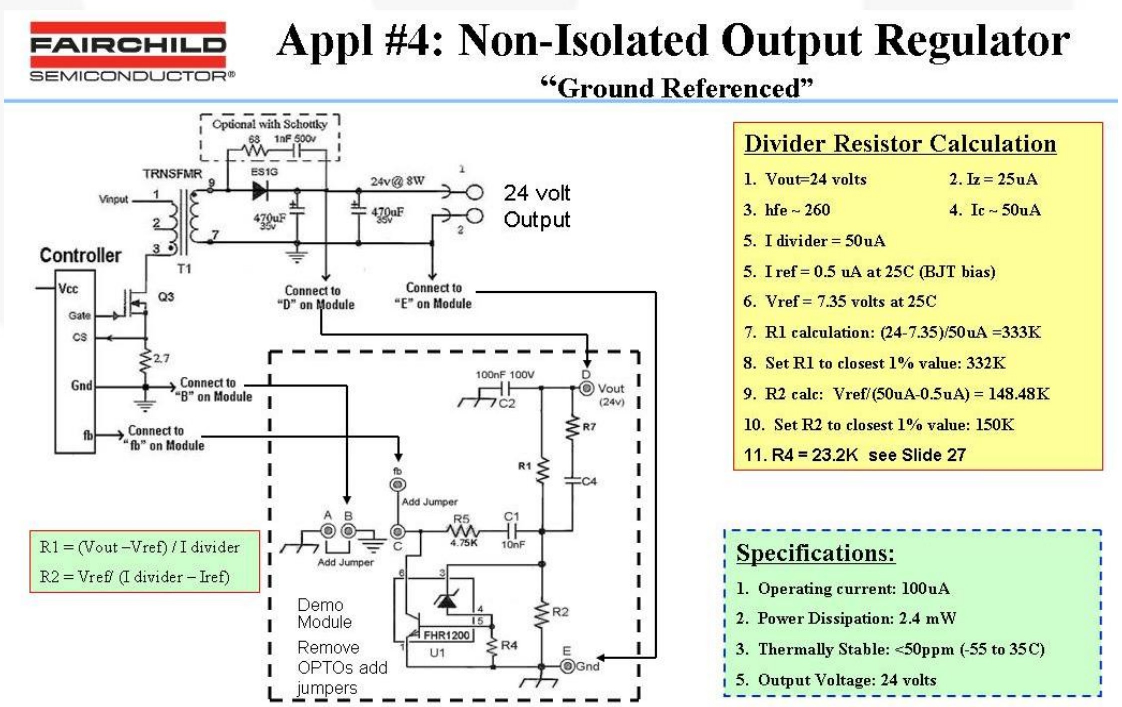


Figure 14. Non-Isolated Output Regulator: Grounded Configuration

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 (V)	-40 (V)	25 (V)	85 (V)	125 (V)	150 (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 (V)	-40 (V)	25 (V)	85 (V)	125 (V)	150 (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

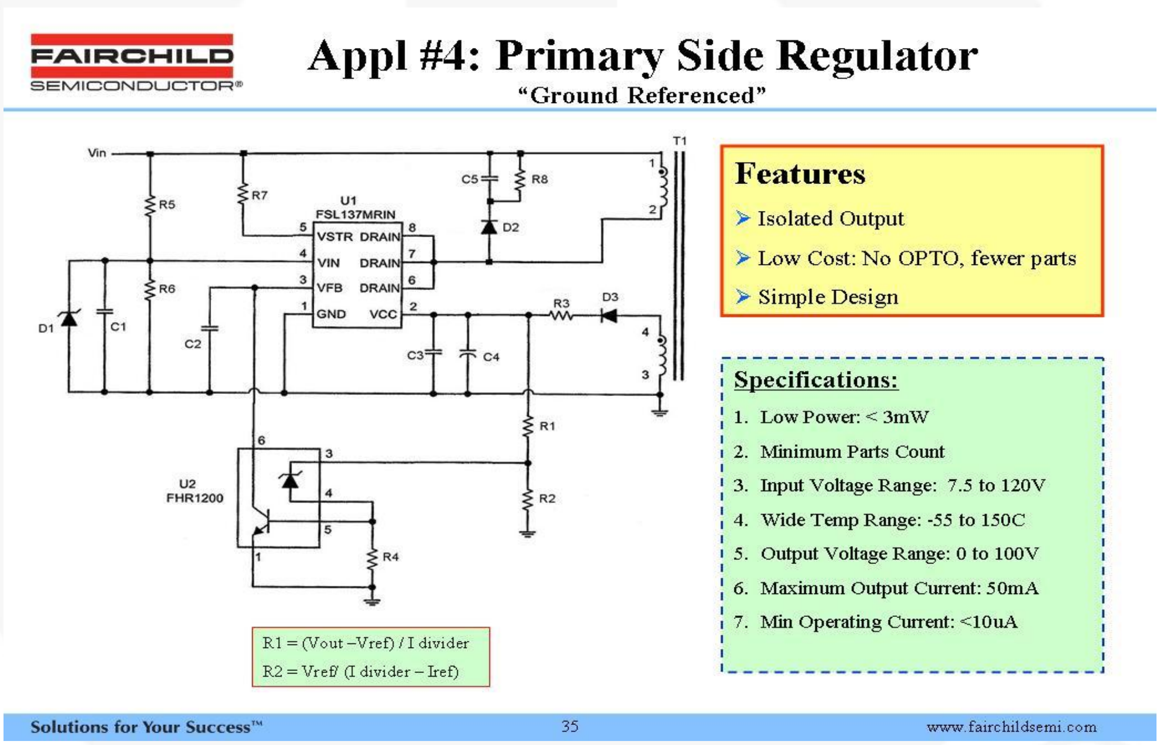


Figure 15. Basic Concept of Primary-Side Regulator: Grounded Configuration

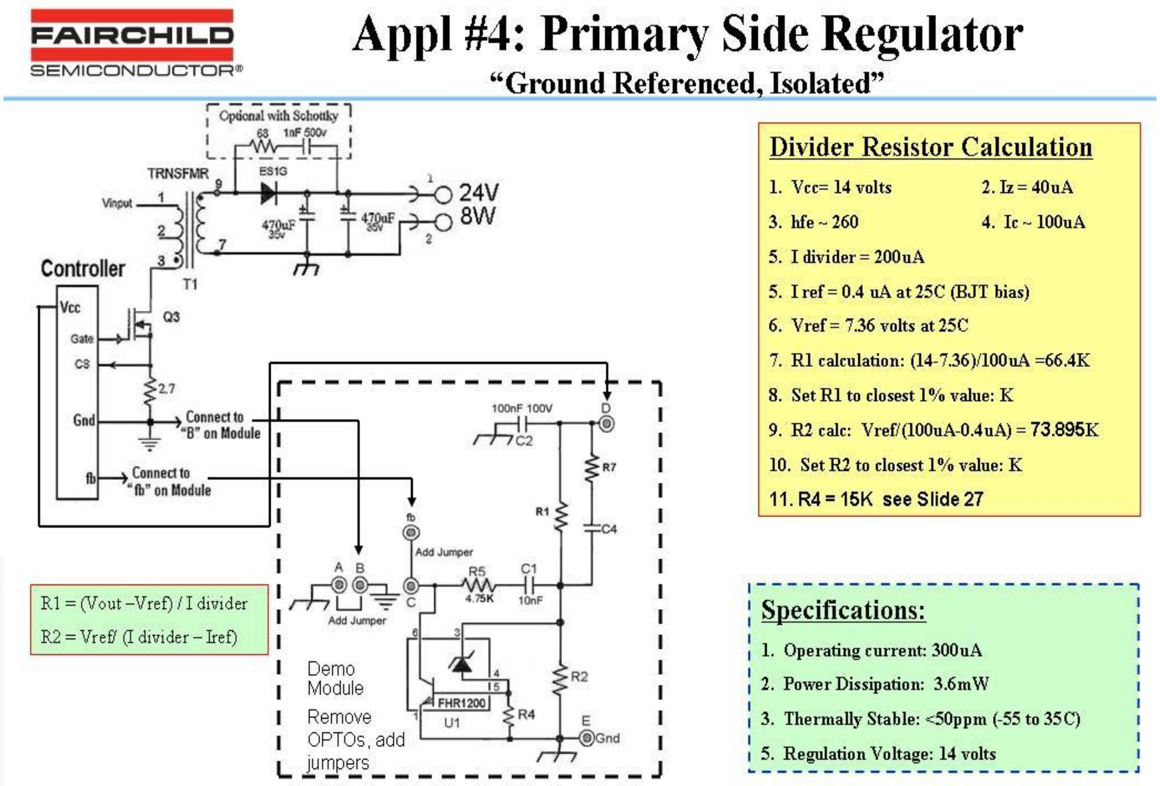


Figure 16. Primary-Side Regulator Based on App #4: Grounded Configuration

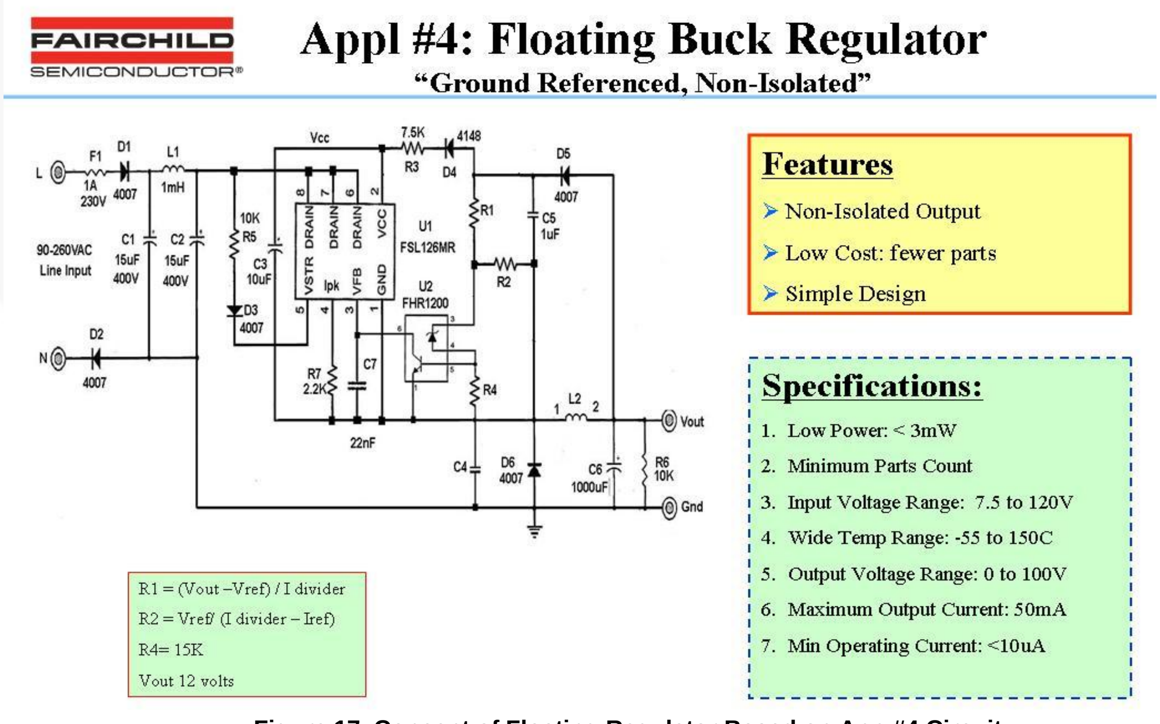


Figure 17. Concept of Floating Regulator Based on App #4 Circuit

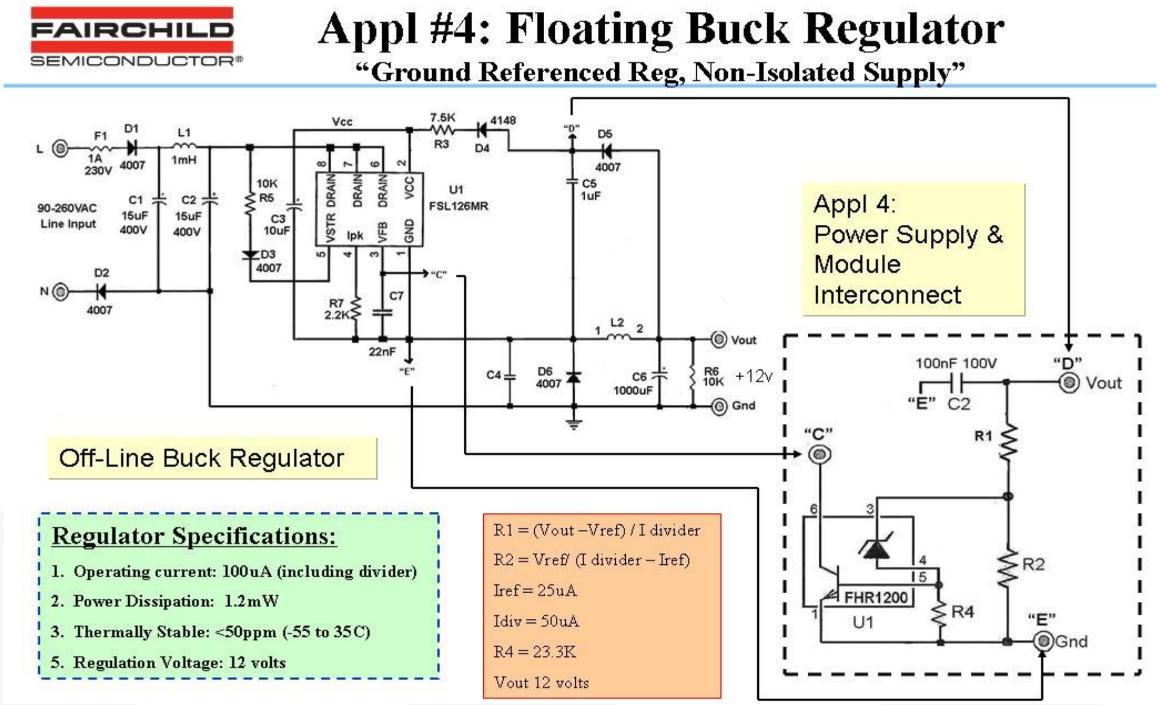


Figure 18. Floating Regulator Using App #4 Circuit: Grounded Configuration

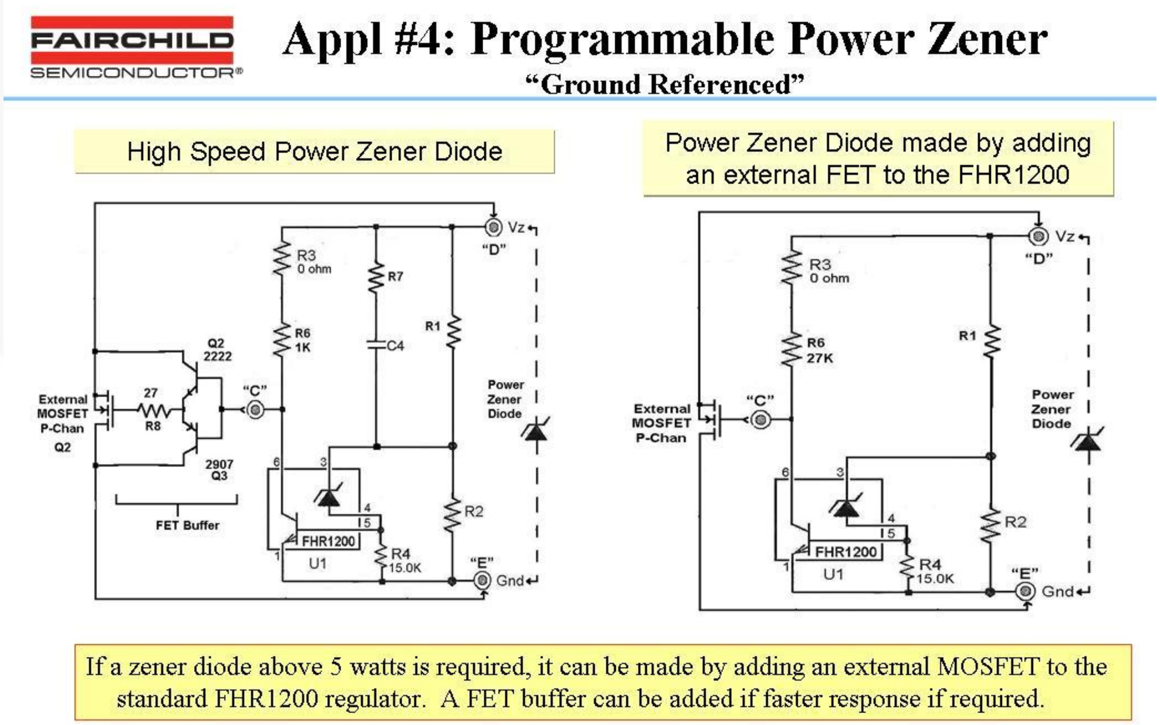
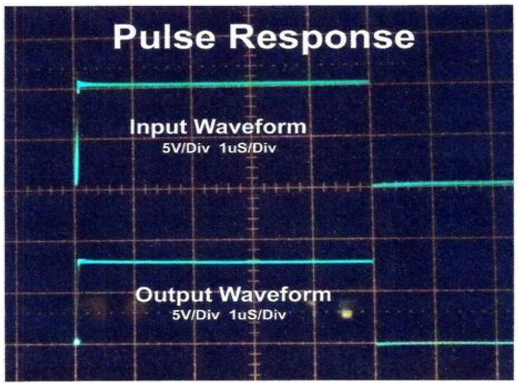
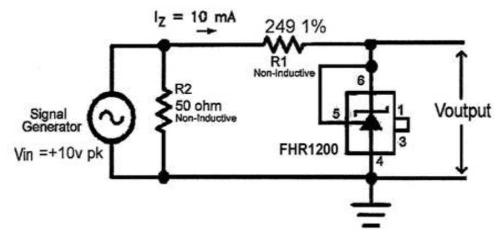


Figure 19. Concept for Programmable Power Zener: App #4 Circuit

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.

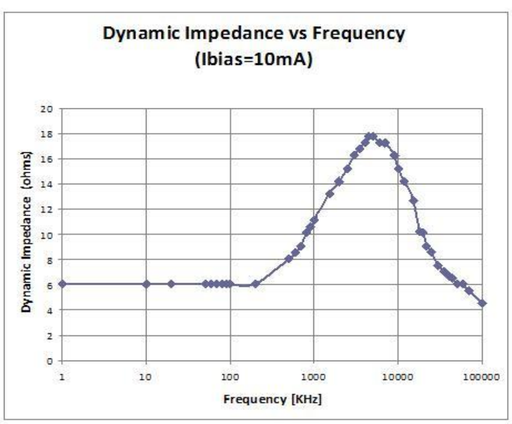


1. Pulse Generator Risetime <2nS.
2. Pulse Generator output Z= 50 ohms
3. Pulse Generator output = >12 volts into 50 ohms

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.



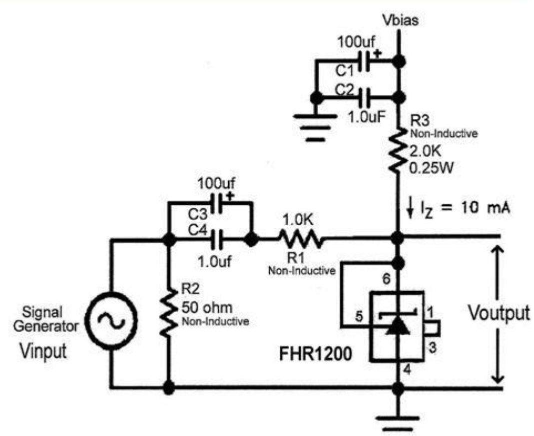


Figure 21. FHR1200 Dynamic Impedance

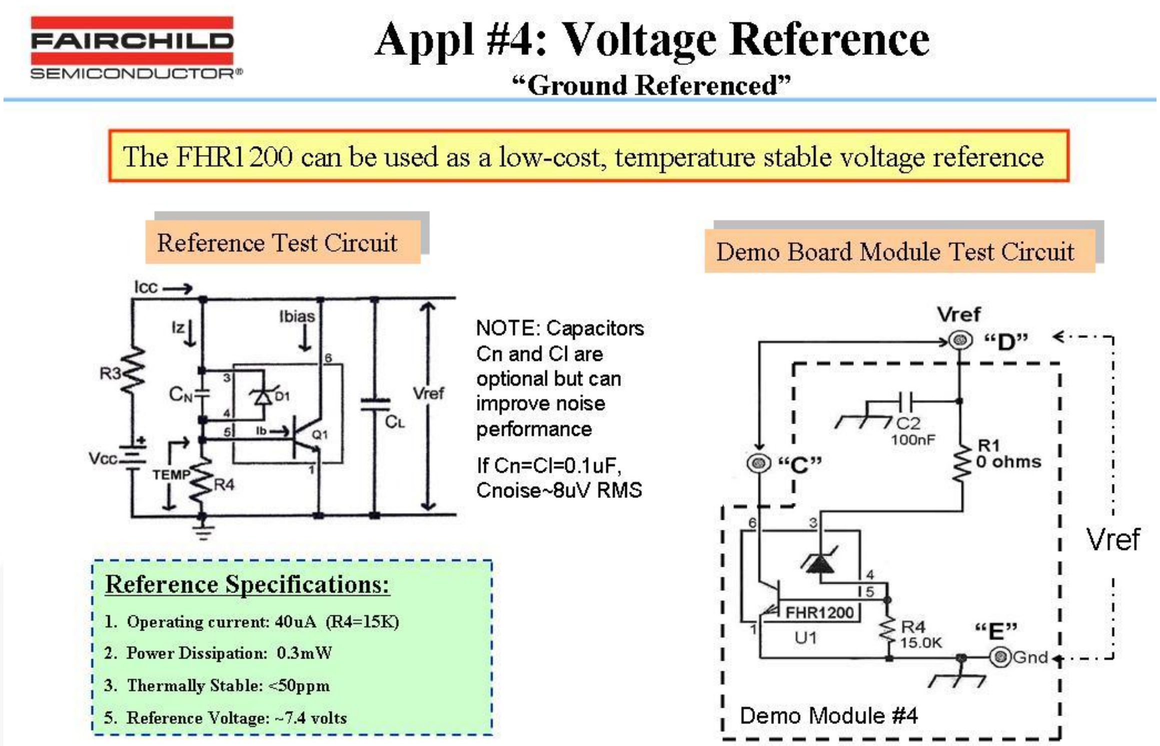


Figure 22. Concept and Actual Voltage Reference Using App #4 Circuit

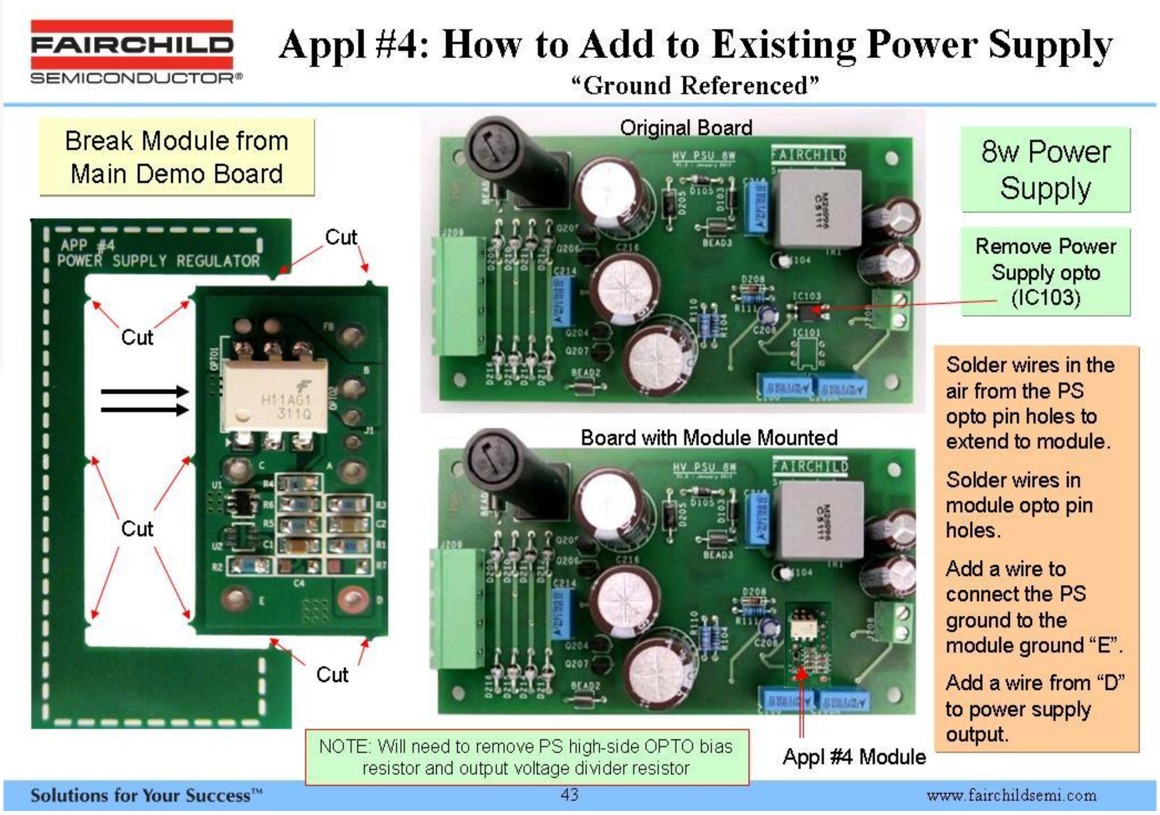


Figure 23. How to Add the App #4 Module to an Existing Power Supply

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.

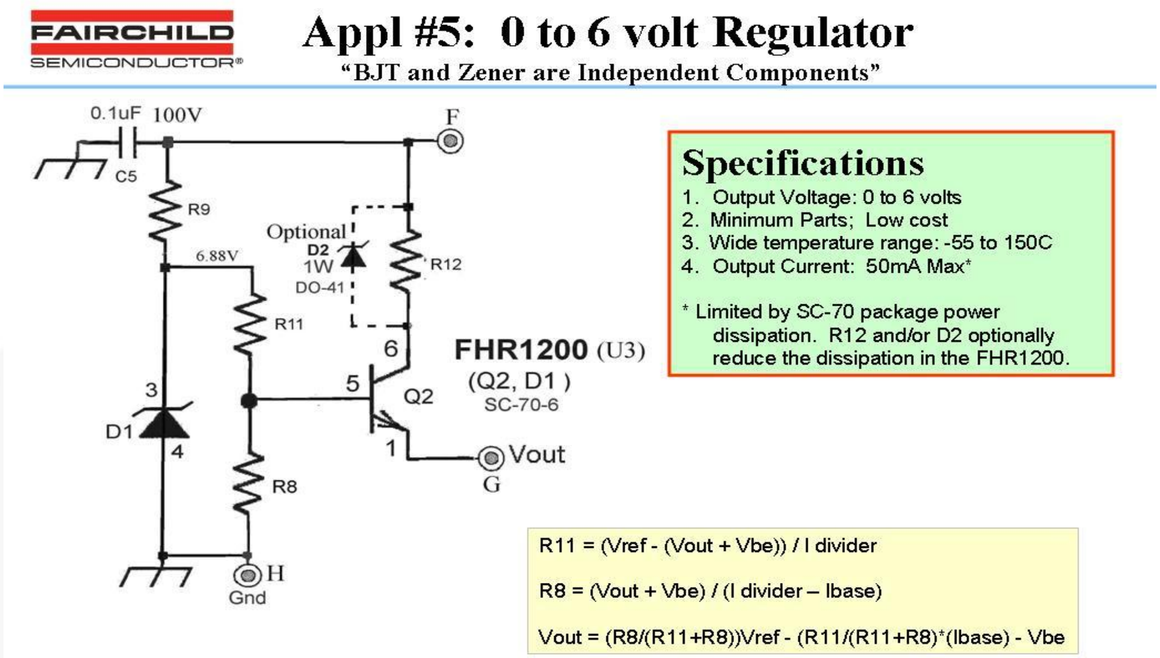


Figure 24. Simple, Low-Cost 0 to 6 V Regulator: Application Circuit #5

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)

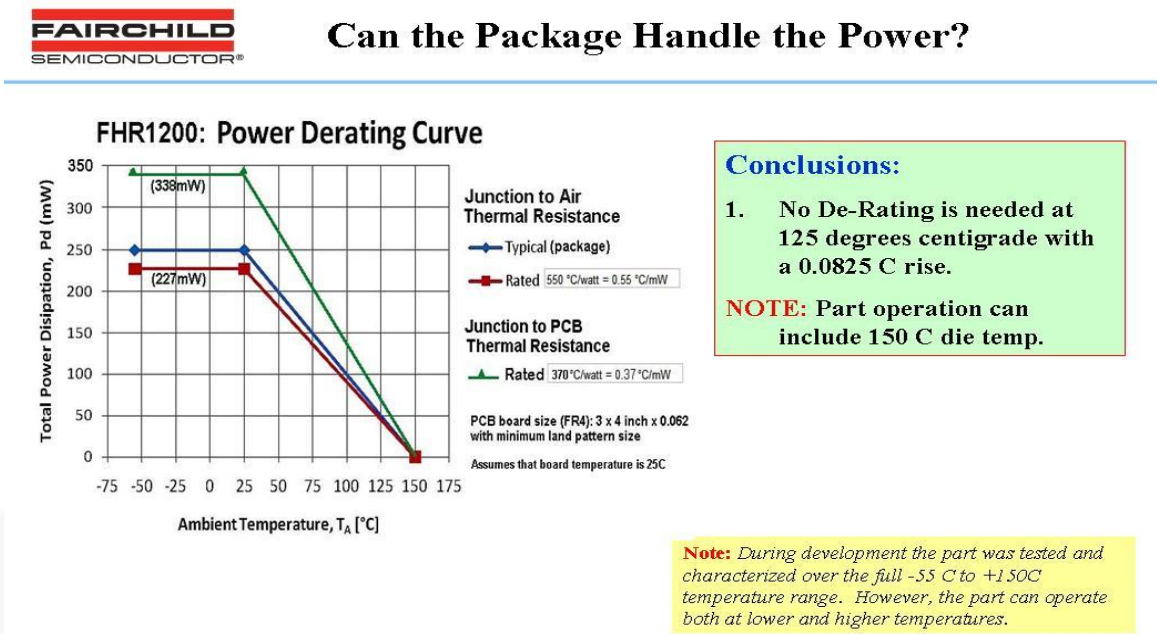


Figure 25. FHR1200 Thermal De-Rating

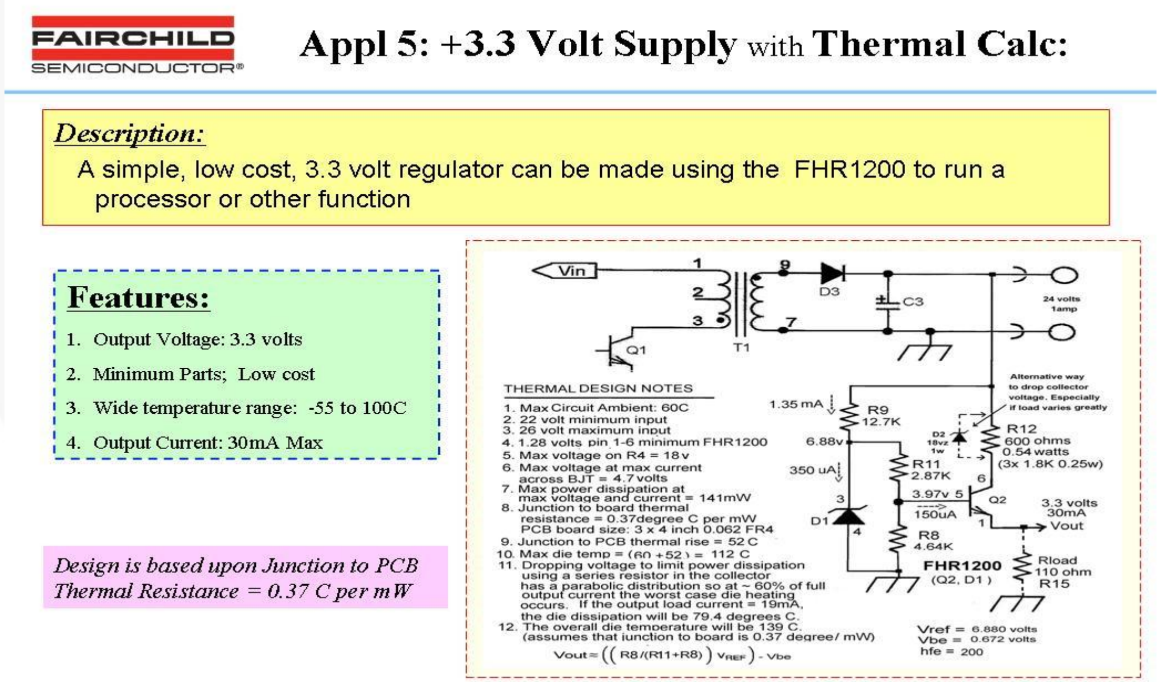


Figure 26. Application #5: 3.3 V Power Supply Thermal Calculation

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.

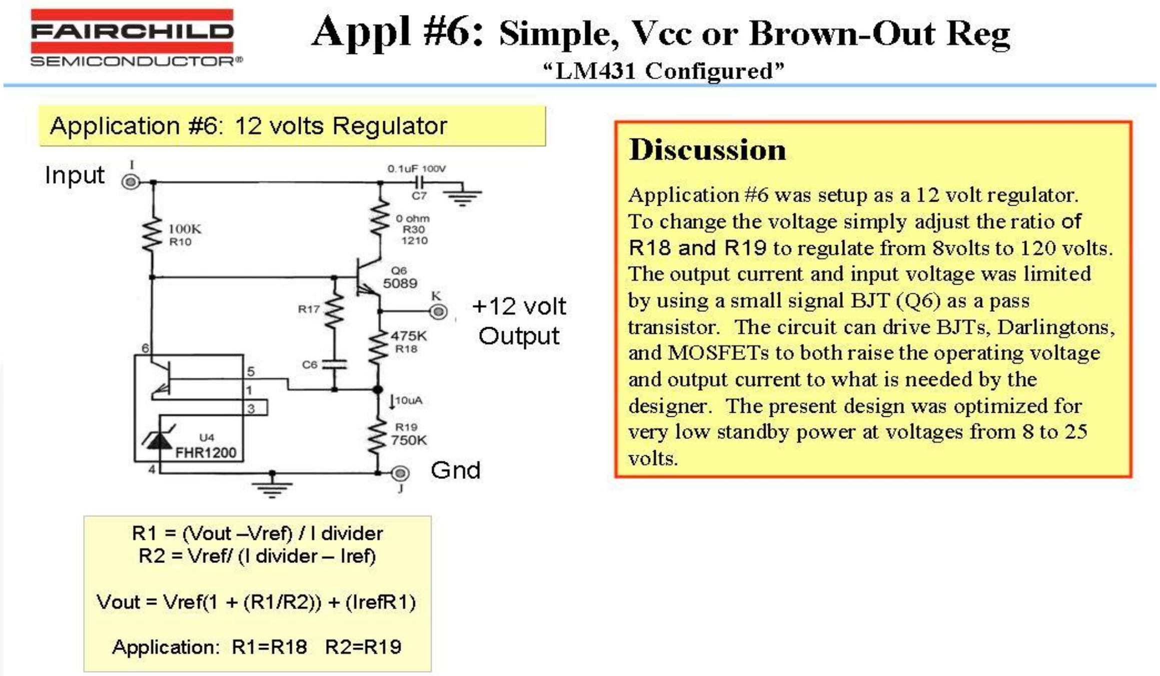


Figure 27. Application #6: V_{CC} or Brownout Regulator Design

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.

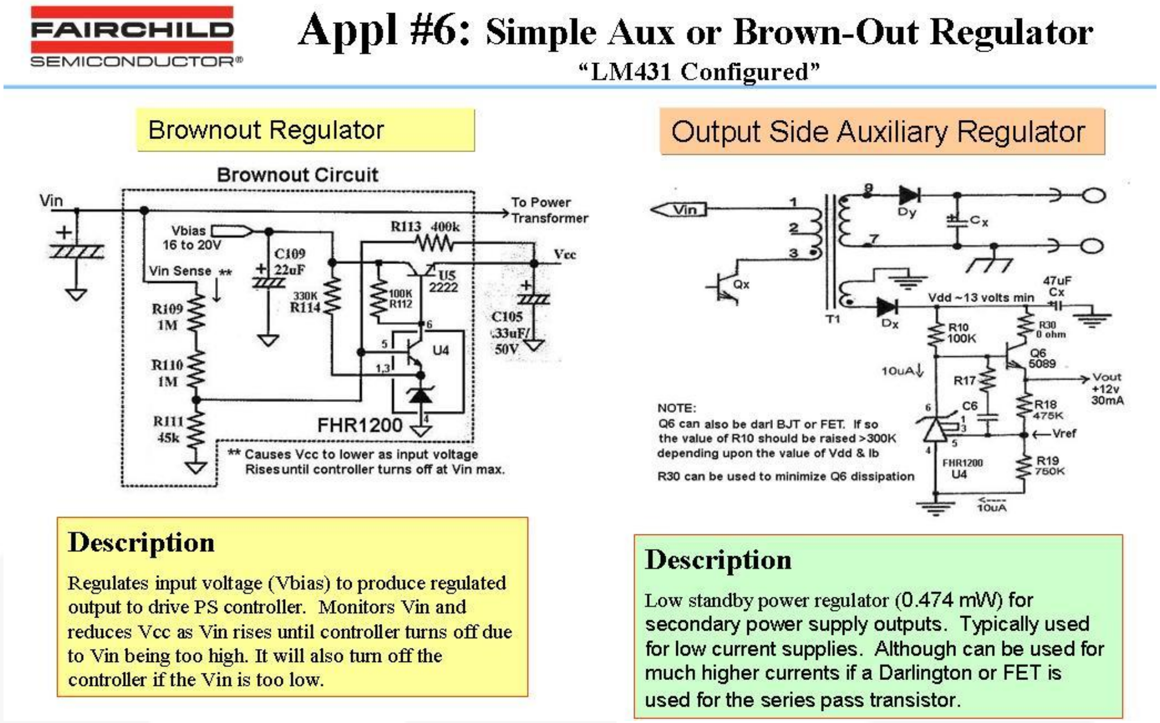


Figure 28. Application #6: Brownout & Auxiliary Regulator: LM431 Configured

4. Schematic

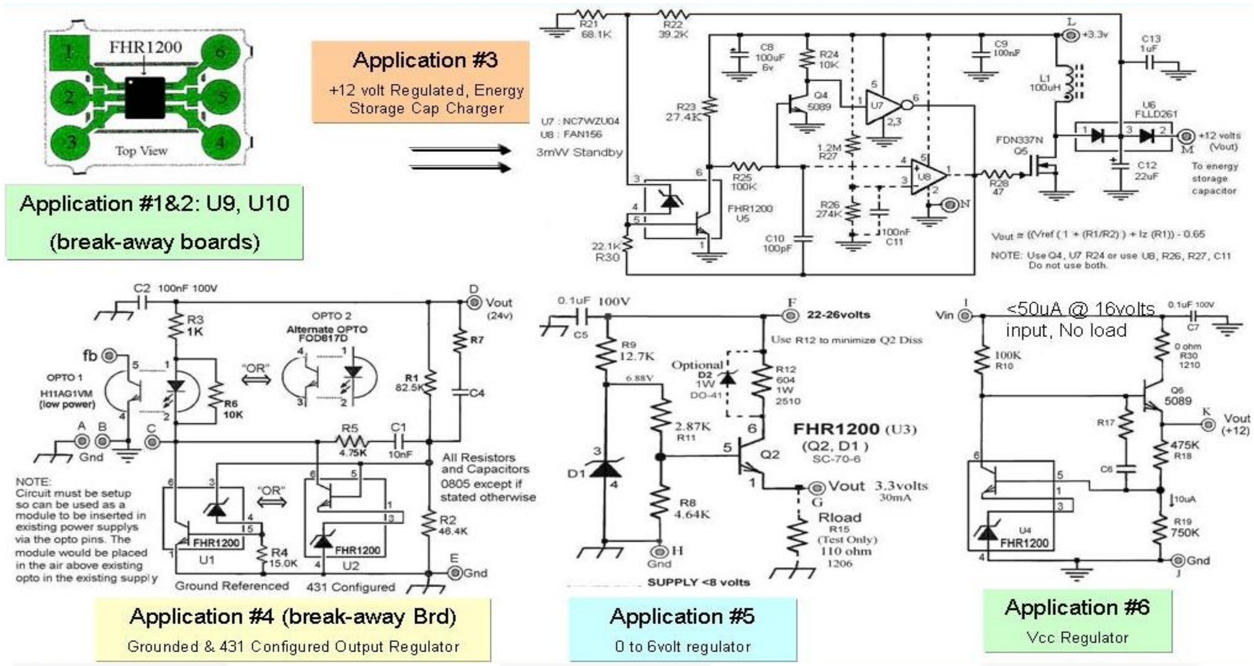


Figure 29. Evaluation Board Schematics

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

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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.

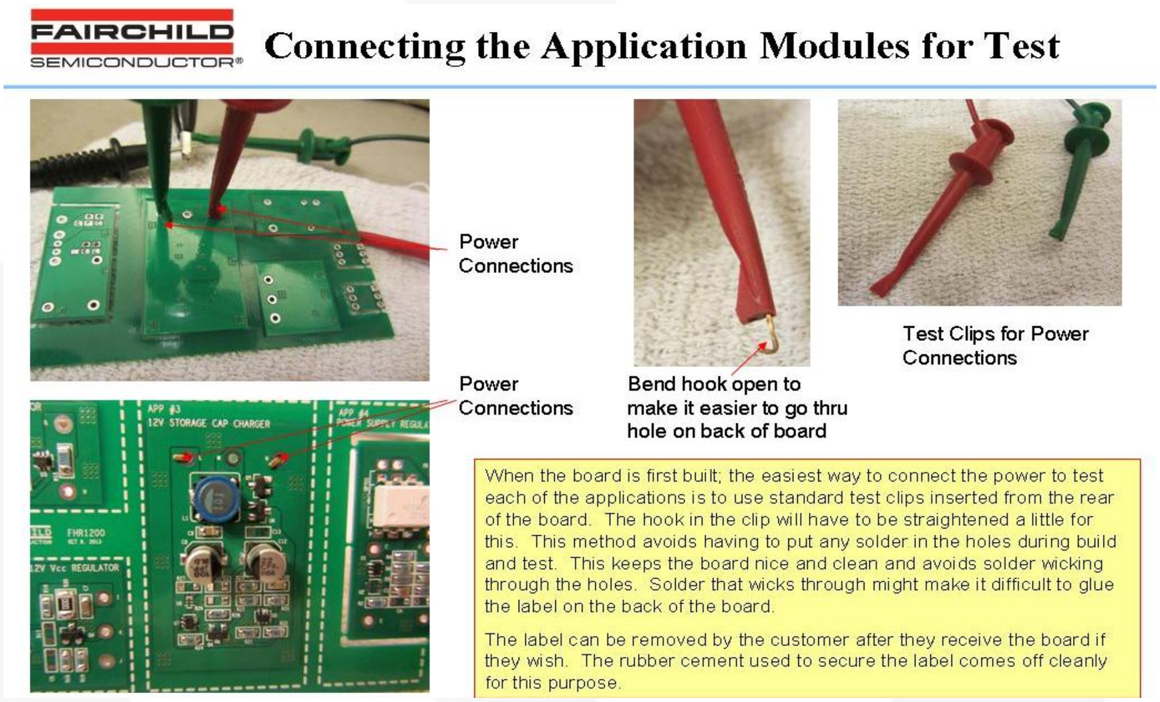


Figure 30. Connecting the Evaluation Board for Test

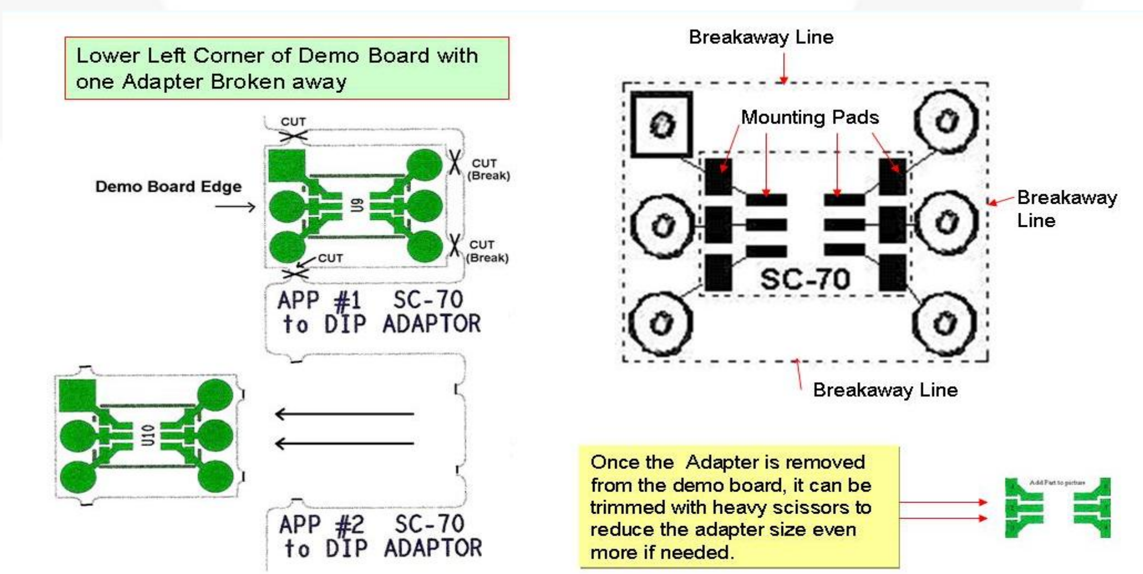


Figure 31. Break-Away Detail for Socket Adapters

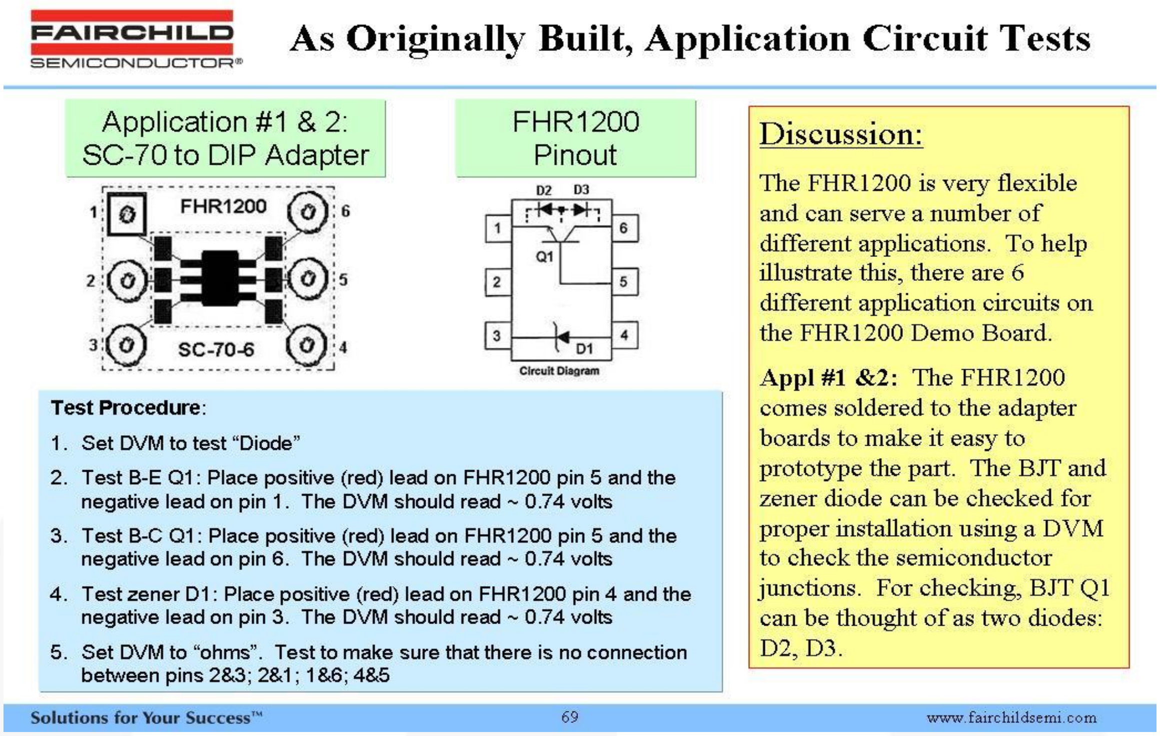


Figure 32. Testing the FHR1200 Devices on the Socket Adapters

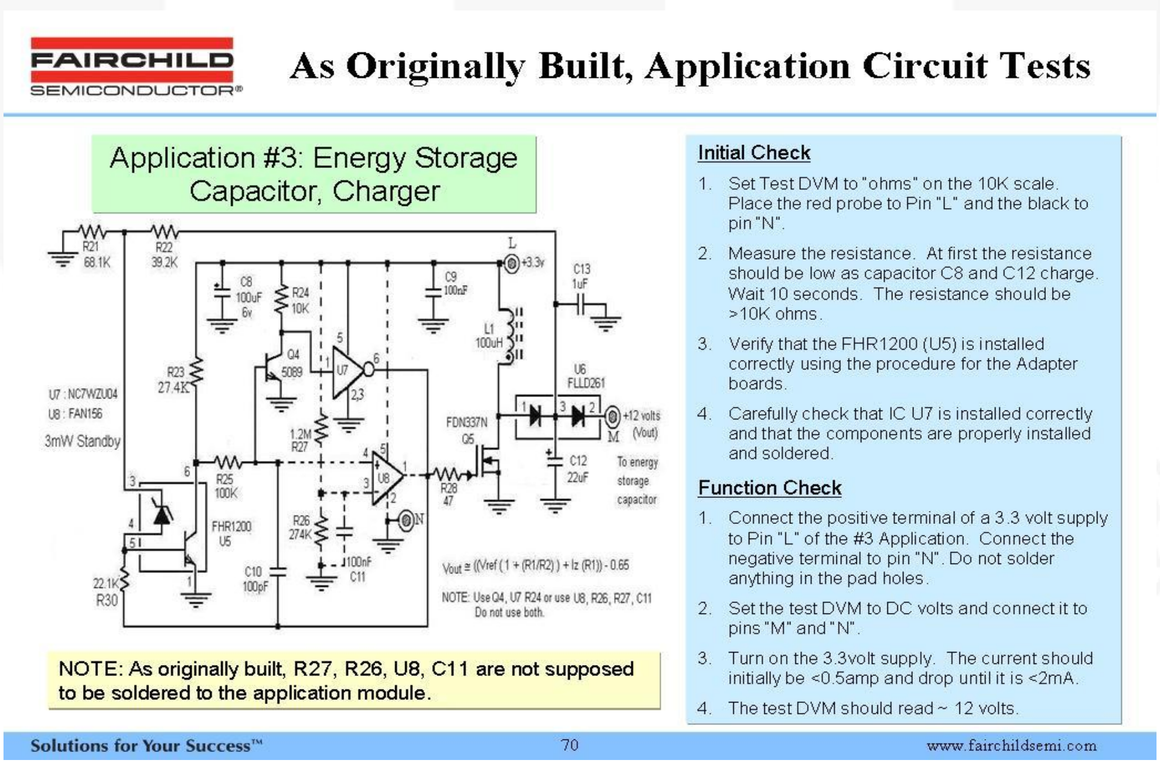
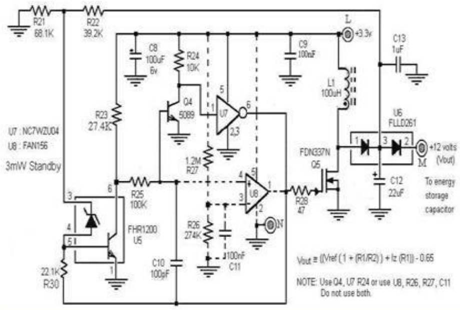


Figure 33. Test of the Energy Capacitor Charger Operation

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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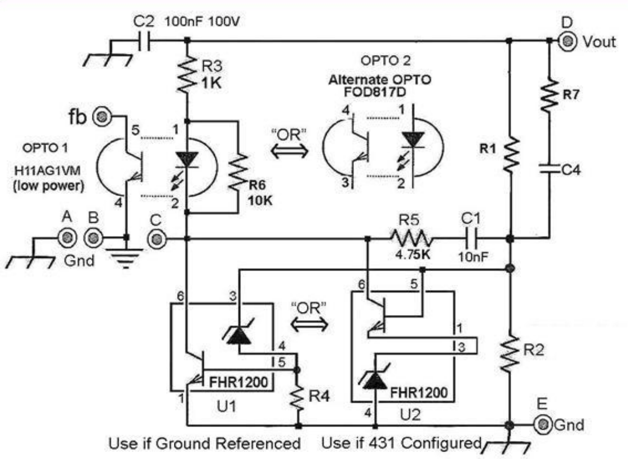
Figure 34. Energy Capacitor Charger Circuit Operation Description

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

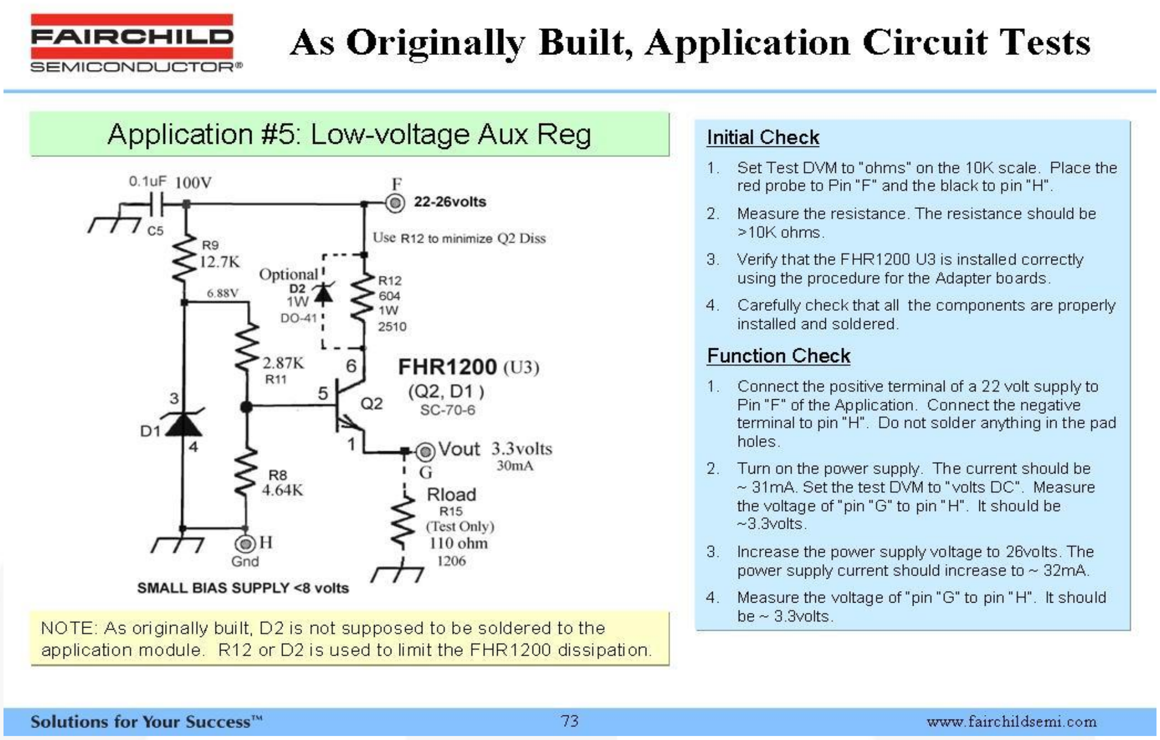


Figure 36. 3.3 V Low-Voltage Regulator Checkout

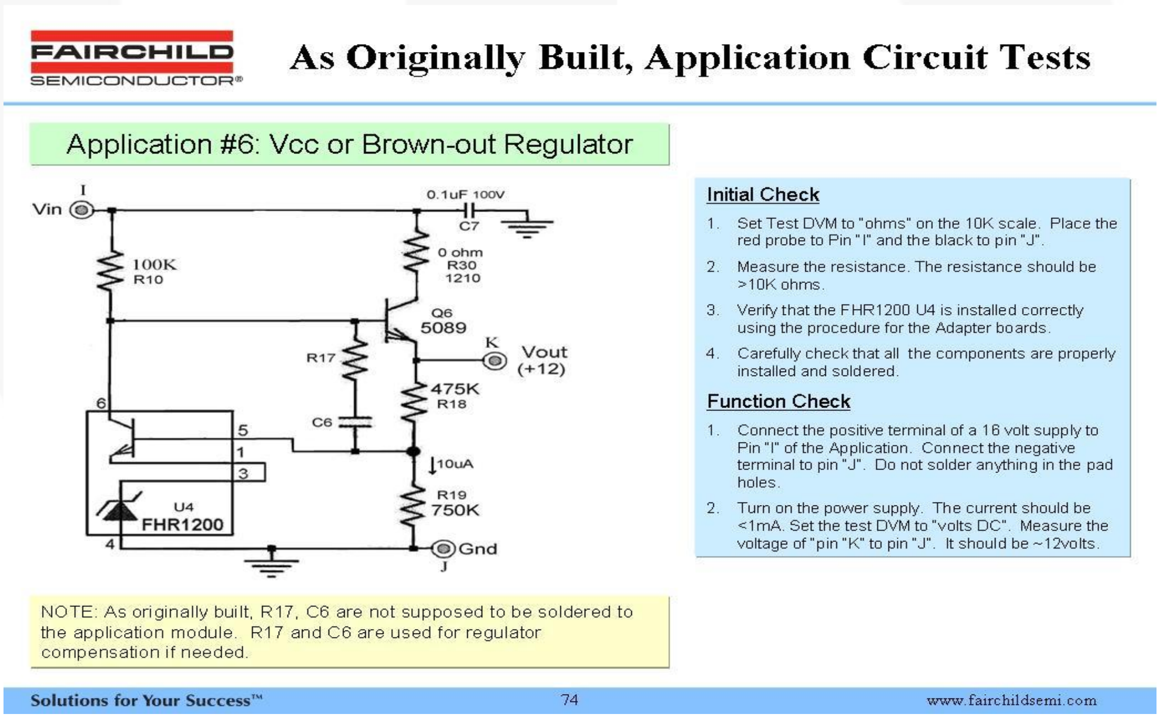


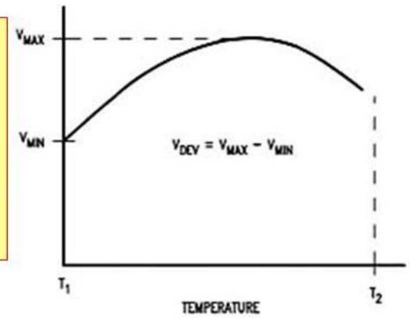
Figure 37. V_{CC} or Brownout Regulator Circuit Checkout

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

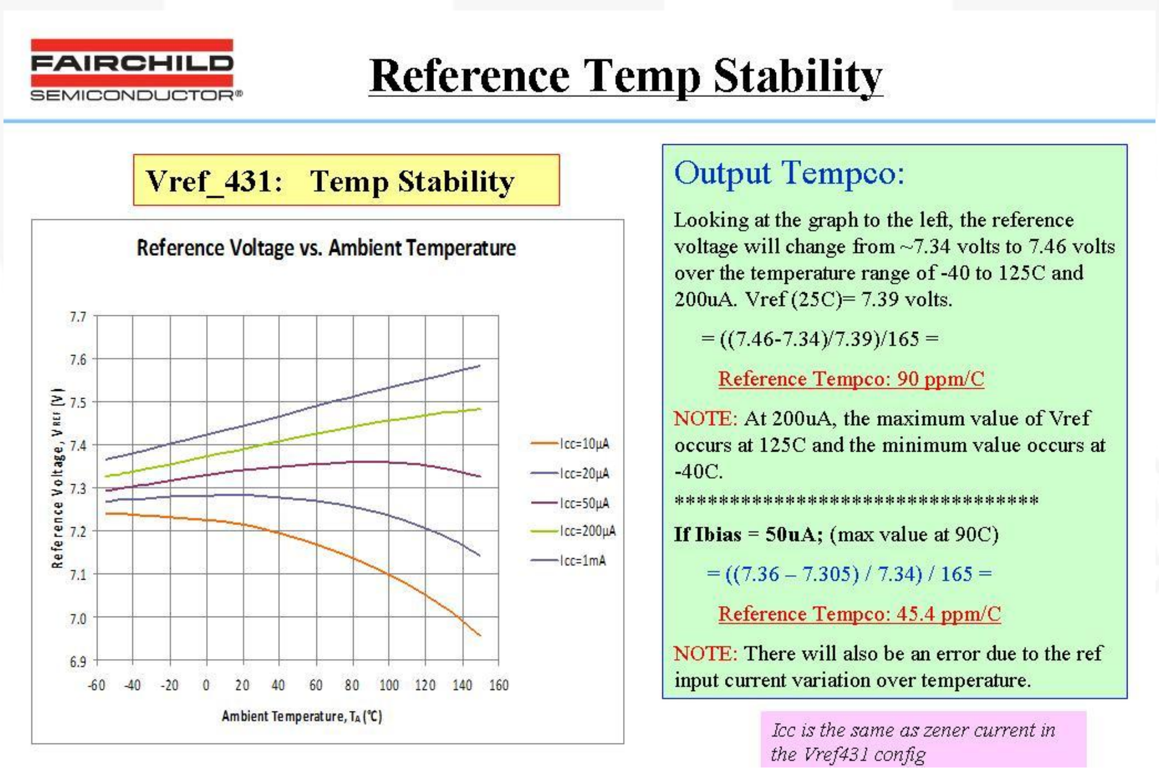


Figure 39. LM431 Configured Reference Temperature Stability

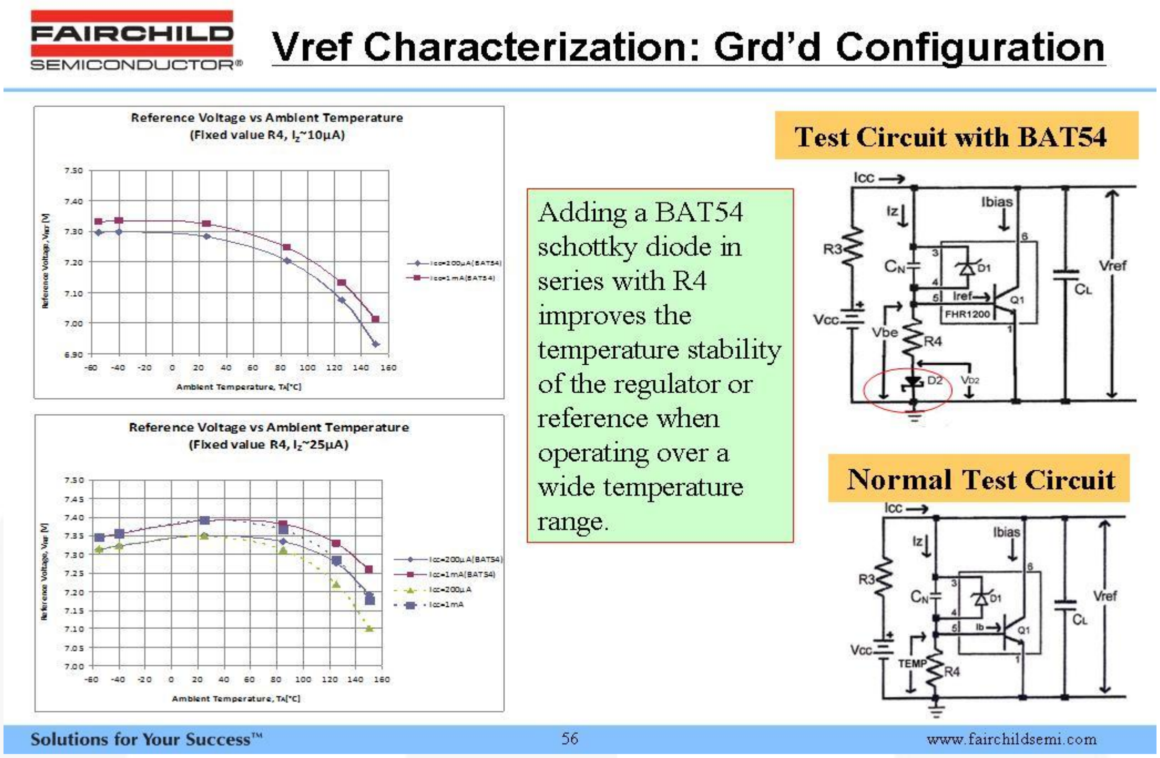


Figure 40. V_{REF}; 10 µA, 25 µA I_Z Temperature Stability: Grounded Configuration

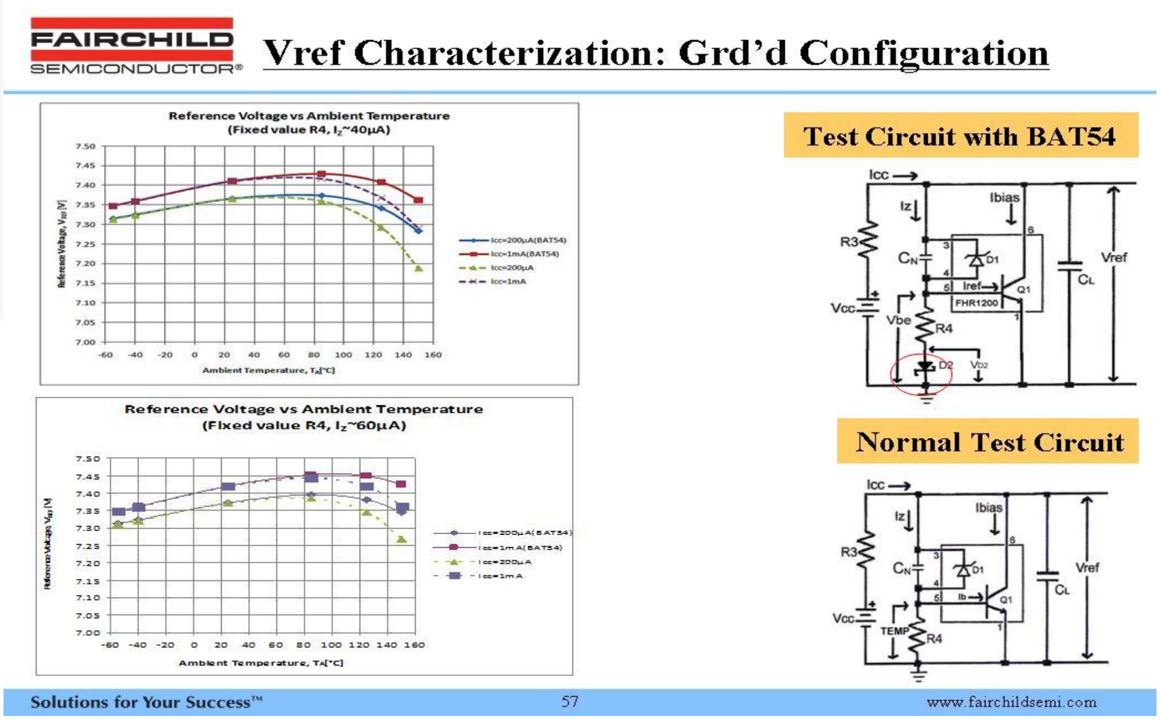


Figure 41. V_{REF}; 40 µA, 60 µA I_Z Temperature Stability: Grounded Configuration

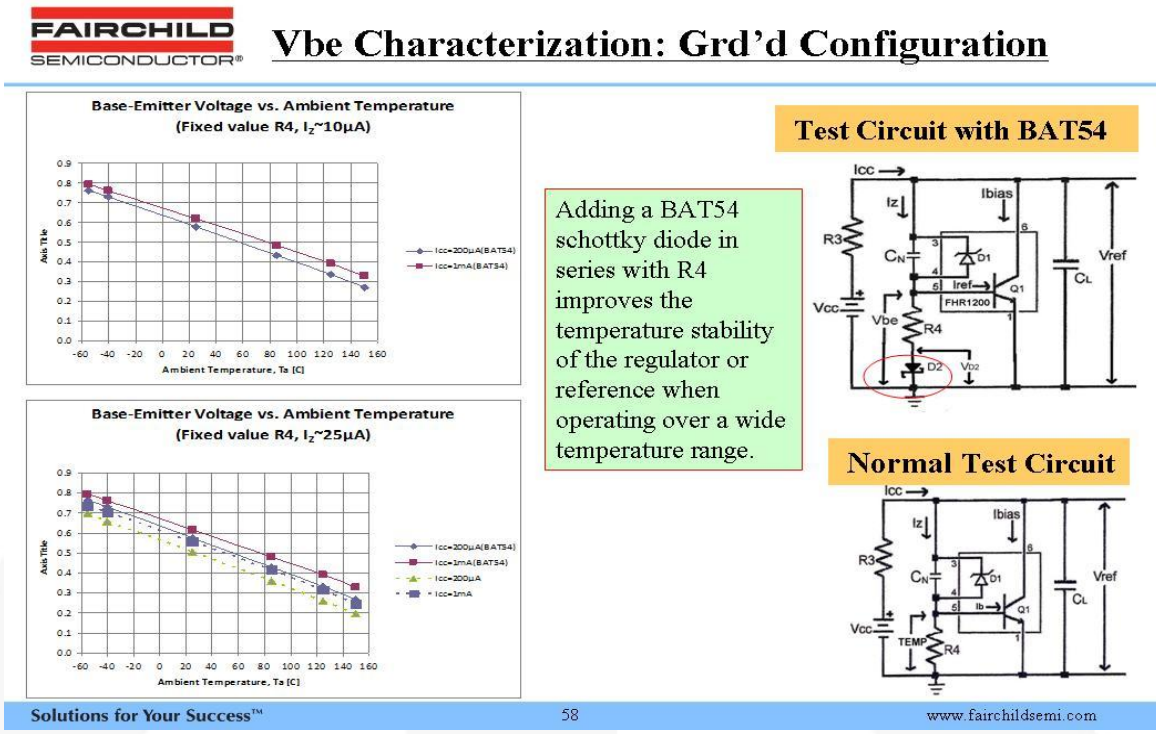


Figure 42. V_{BE}; 10 µA, 25 µA I_Z Temperature Stability: Grounded Configuration

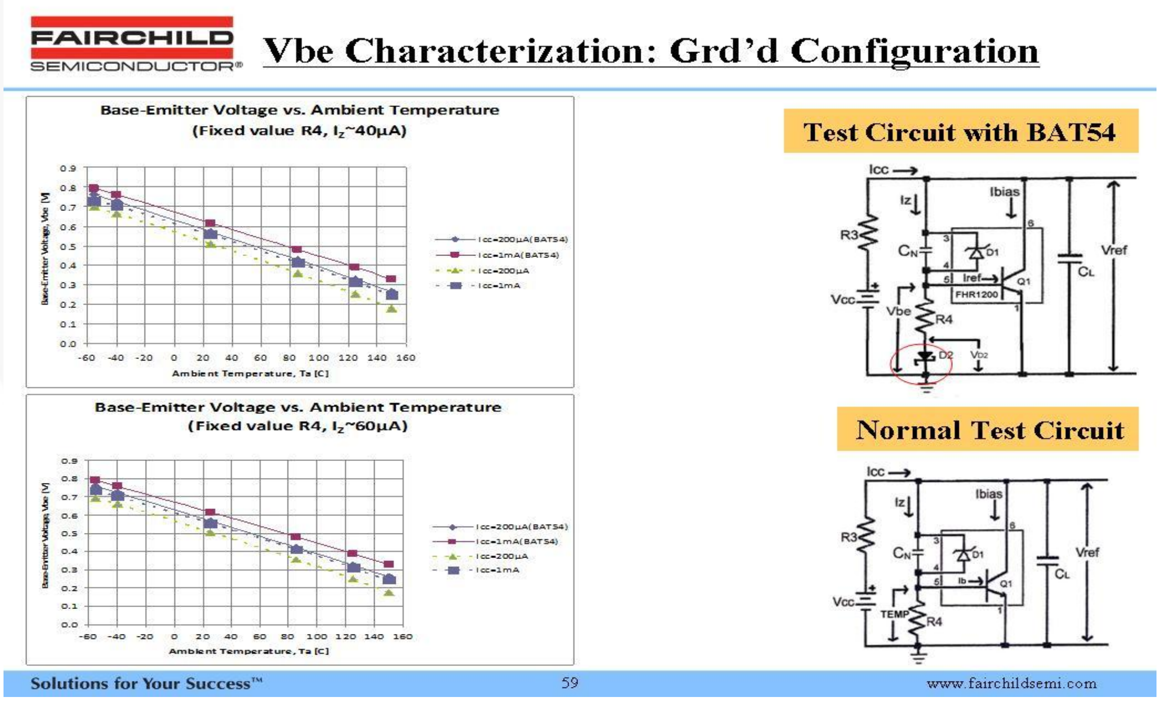


Figure 43. V_{BE}; 40 µA, 60 µA I_Z Temperature Stability: Grounded Configuration

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

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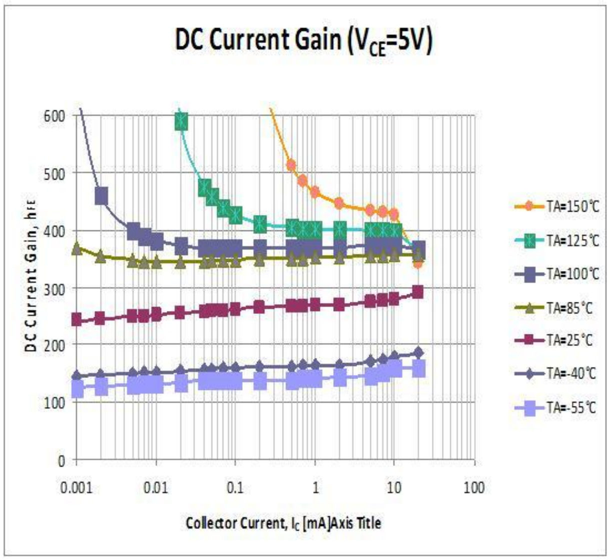
Ref Input Current Due to hfe Tempco

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

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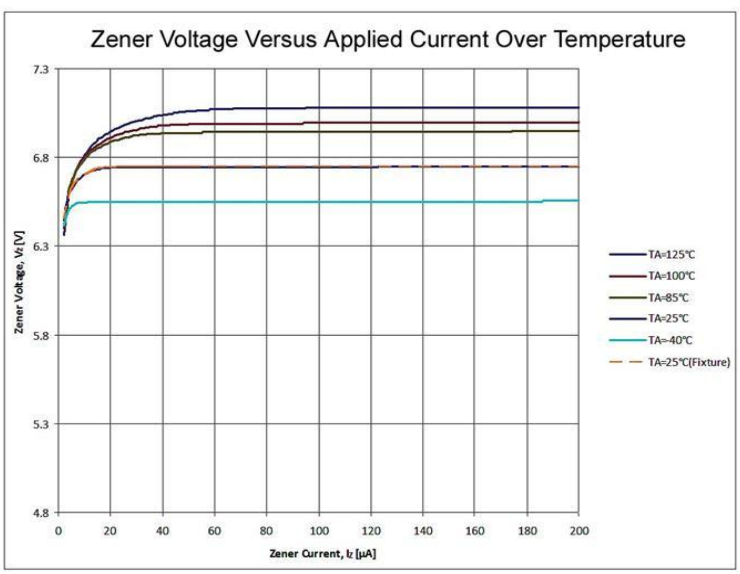
How Low a Current Can it Operate?)



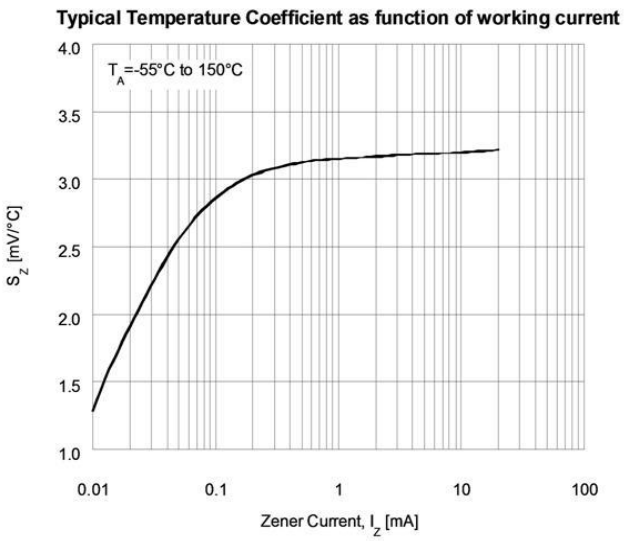
Answer:

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?)



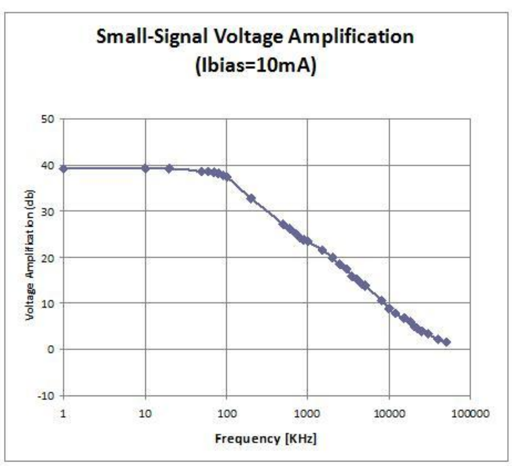
The data indicates that the part is still usable down below 10uA but the tempco changes quite a bit below 200uA or so. This is fortunate since the tempco of a BJT B-E junction tends to be around -2.2mV/C over a moderate range of current.

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



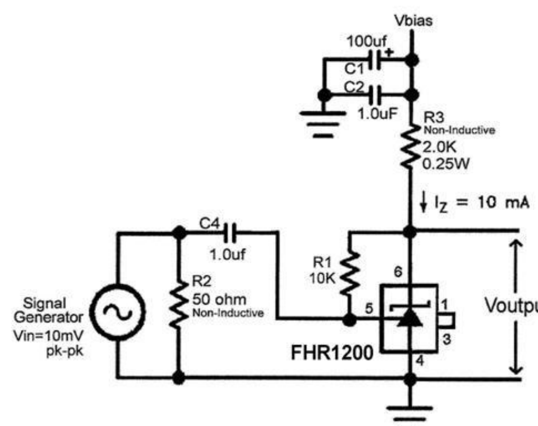


Figure 47. FHR1200 Small-Signal Response

8. Revision History

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

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