Voltage Regulation Design for Multiple Voltage Values in Microprocessor Circuits.

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Application Note

Introduction

Many of the current X86 microprocessors that utilize double and triple clocked internal cores are functional at higher speeds only at a higher than nominal voltage. Thus a nominal 3.3V part may actually be faster at 3.6V or 4.1V. Until the chip manufacturing processes are able to obtain a consistent high speed design at 3.3V, the board level designer is left with the problem of designing multiple voltage regulation circuits for the different voltage values required.

This application note suggests a solution for different voltage levels and for a combined circuit that will handle all of the voltages between 3.3V and 4.2V. Various circuits are shown and a combined layout and schematic are presented. Most of the work involved use of Linear Technology devices. This paper is not an endorsement or verification of that company's integrated circuits; rather it is an attempt to demonstrate the design process and subsequent solution to this problem using common devices.

Problem Statement

The IBM Blue Lightning SX2 and SX3 processors are available with voltages ranging from 3.3V to 4.2V. Some double clocked SX2s are available in 3.6V parts while some corresponding SX3s use 4.1 Volts. This means that a motherboard designer who wishes to incorporate both of these SX2 and SX3 processors in the final product mix, may have to supply two or three different voltages using the same design. The solution to this problem is a common voltage regulation circuit which is adjustable by varying some part of the design.

The solution suggested above requires several major design decisions, the first of which is the type of regulation circuit. Linear and switching regulation circuits are readily available and each type has its pluses and minuses. The type of regulation circuit that will be discussed in this application note is for linear designs. These example circuits were originally designed into upgrade cards for PS/2 motherboards. Several key requirements for a regulation circuit on these cards are the size of the components, performance, and electromagnetic interference. These cards must be placed in small areas with a minimum of additional heat, and not generate additional interference. The use of linear regulators accomplishes most of these requirements in a better fashion than a switching regulator. The switching regulation circuit would have a higher efficiency, however, it requires more components and generates RF energy. These circuits may be of use to designers of other board types; the final decision must lie with the designer.

The second design decision that must be made is that of the voltage range to be handled by the regulation circuit. The components currently available today have a limited regulation range and care must be taken in matching the correct components to the voltage range required. This paper will suggest that for a complete range of voltages a multiple design could be used. This combined circuit utilizes different regulators for different ranges. These different regulation circuits can all be included in the circuit patterns on one printed circuit board (PCB). Since one of the major costs involved in some products is in the manufacture of the printed circuit board, the cost is minimized by having a common board. By changing the parts list or bill of material, different products can be manufactured without changing the printed circuit board.

Design Methodology

In order to properly design a voltage regulation circuit, you must first know the specifics of your target system. These items include: processor type, clock rate, input voltage, processor voltage, power consumption, and heat dissipation capability. With the preceding information we can tackle this problem with a straightforward approach of determining the voltage and power requirements and then the package and heat dissipation tradeoffs.

Voltage and Power Requirements

The first item in your design of a voltage regulation circuit is to determine what voltage regulation circuit can give you the correct voltage and power levels for your processor. This should be determined by finding the worst case power consumption (at maximum case temperature) for the voltage level you will be providing. This power level should then be compared against the specifications for the various voltage regulators that you are considering. If the power level is adequate, with some margin of safety, then this voltage regulator can be considered for more analysis. For example, on a BLSX3 running at 100 MHz, the maximum I_{dd} current is 262 mA. This part runs at 3.6 volts and therefore the maximum power at a case temperature of 100°F is .9432 Watts. Rounding up to 1 Watt of power means that the voltage regulation circuit must provide about 300 milliamps of current at 3.6 volts. Since the input voltage is 5 volts and assuming a minimum of leakage current, the voltage regulator will need to dissipate .42 Watts of heat. If the heat sinking capability of the package and board layout will allow this amount of dissipation at 100°F, then this circuit is viable. However, if the system can only dissipate .31 Watts of heat, and your regulation circuit will dissipate .42 Watts of heat, then a thermal problem exists. The next section will detail the design methodology required to correctly determine the proper physical packaging and layout to insure proper heat dissipation.

Package Style and Heat Dissipation

As shown in the previous example, if voltage is dropped in the voltage regulator, then heat is generated. For any regulator the heat generated in the device must be dissipated to keep junction temperature within the operating condition specified by the manufacturer. Heat generated in the voltage regulator can be dissipated several ways depending upon the type of package, the amount of power generated by the device, the environment in which the device operates, the maximum junction temperature limits, and other components mounted on the PCB in the regulator's vicinity. For some packages, an external heatsink is required to dissipate heat generated in the device while others do not require an external heatsink.

Heat is dissipated through a combination of ways such as package surface area, through package leads to the PCB material and its copper traces, through PCB material and its copper traces to the copper enriched power planes and forced air flow over device by the system fan. Although most of the voltage regulator suppliers provide some thermal data based on experimentation performed on a specific application, additional work and or experimentation may be needed to determine the actual value for a customer's application. Now the question is how to determine that actual value. The basic methodology used to determine the actual value for the thermal management of the voltage regulator is discussed below. It also assists the system board designer and the PCB designer on the placement of other PCB components that can generate heat.

First of all, power generated in the voltage regulator needs to be determined based on vendor provided information and the customer application. For instance, if we use the Linear Technologies LT1129 voltage regulator, power generated by the regulator can be calculated from equation (1) provided by Linear Technologies in their data book. The values of output and ground current are also provided in the supplier data book. The values of input and output voltages are driven by customer application.

$$P_{wc} = I_{out\ \max} * \{V_{in\ \max} - V_{out}\} + I_{gnd} * V_{in\ \max} \qquad \ldots \text{ Watts} \quad (1)$$

Once worst case maximum power generated in the voltage regulator is determined, thermal resistance between junction and ambient air in °C per Watt can be calculated using equation (2) below.

$$\Theta_{j-a} = (T_{j\max} - T_{a\max})/P_{wc} \qquad \ldots\ {}^{0}\text{C/Watt} \quad (2)$$

Where T_{jmax} is the maximum junction temperature limit set by the voltage regulator manufacturer. This value can be found in the supplier data book. T_{amax} is the maximum ambient air temperature surrounding the voltage regulator and needs to be determined by the customer application environment. P_{wc} is the power generated in the voltage regulator estimated from equation (1). It may be noted that the maximum ambient air temperature value used in equation (2) may need to be higher than a nominal class environment value, due to the fact that some other PCB components may be generating heat.

Now thermal resistance between case and ambient air can be estimated from equation (3). This thermal resistance value will be used later to determine adequate surface area required to dissipate power generated by the voltage regulator.

$$\Theta_{j-a} = \Theta_{j-c} + \Theta_{c-a} \qquad \text{... °C / Watt} \qquad (3)$$

Where Θ_{c-a} is the thermal resistance from case to ambient air that needs to be calculated. The value of Θ_{j-c} is provided in the supplier data book.

And, finally, the minimum surface area required can be determined by substituting appropriate values in formula (4).

$$\text{Area} = 1 \div \{\Theta_{c-a} \times \text{h}\} \qquad \text{... mm}^2 \qquad (4)$$

Where h is the coefficient of convection heat transfer. The value of h depends on the air flow over the device and a few other factors. Therefore, an exact value of h for the specific customer application is hard to obtain. However, an approximate value of h from the handbook can be substituted in the previous equation to determine the approximate surface area required to dissipate heat. An additional ten to fifteen percent may be added to the calculated area in equation (4) to be conservative. If the area calculated above in the equation (4) exceeds the PC board area, an external heatsink is required to dissipate heat from the device. If this is the case, equation (5) can be used to determine the value of thermal resistance between heatsink and ambient air.

$$\Theta_{j-a} = \Theta_{j-c} + \Theta_{c-s} + \Theta_{s-a} \qquad \text{... °C / Watt} \qquad (5)$$

Where Θ_{c-s} is the thermal resistance from case to heatsink and the typical value of this resistance is approximately 0.5 °C per Watt for commercial thermally conductive interface material. Θ_{s-a} is the thermal resistance between heatsink and ambient air. The value of Θ_{s-a} derived from equation (5) needs to be substituted in equation (4) for the value of Θ_{c-a}. The resultant derived surface area can be used to determine the optimal heatsink.

3.3 and 3.6 Volt Regulation

The first voltage regulation we will discuss is a standard 3.3 or 3.6 volts. This is a straightforward design since several companies sell voltage regulators that will generate 3.3 or 3.6 volts from a 5 volt source. The design consists of the voltage regulator and a few regulation capactors. No reference resistors are needed. This design is shown in Figure 1. The only real consideration is that of power output and package type. The amount of power that your microprocessor requires in a worst-case situation should be matched with the minimum power that the regulator can supply. A regulator that meets your specification can then be selected.

The printed circuit board layout of a single voltage regulator is also straightforward. The correct placement of the capacitors and the via size for handling the current are the only critical decisions that need to be made. However, this and all of the other circuit layouts require either a split power plane or a separate power plane for the regulated voltage.

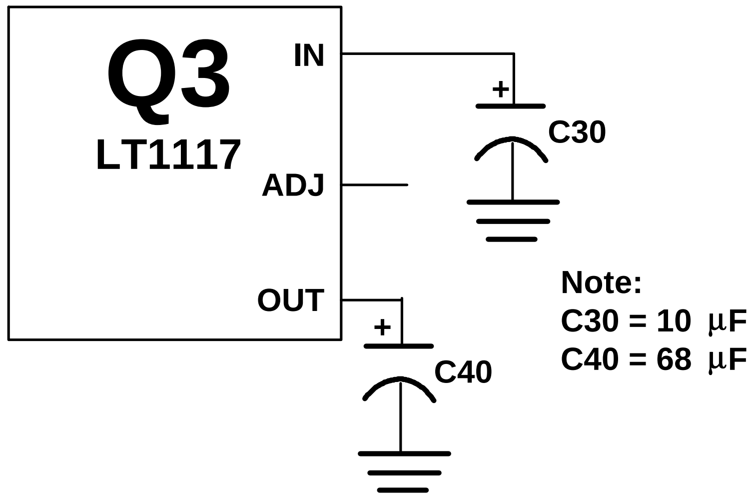


Figure 1. Standard 3.3 or 3.6 volt regulation

3.6 to 4.2 Volt Regulation

This second voltage range deals with the higher voltages needed for some triple clocked processors. The problem with this voltage range is at the higher voltages. Most linear regulators require a certain step-down voltage to insure proper biasing of the internal circuitry. Therefore, a circuit that requires 4.2 volts is at the upper limit of the regulation since a diode biasing voltage is approximately .6 volts. This factor combined with the tolerance of the input voltage 5V +/- .25V at 5% tolerance means that the step-down becomes 4.75 - .6 volts or 4.15 volts. Some of the manufacturers of these regulators have been able to reduce this step-down to .55 volts with a corresponding maximum output of 4.2 volts at 4.75 volts input. However, if the input voltage has a tolerance of only 10% or 4.5 volts minimum, then the maximum output voltage is 3.95 volts. Care must be taken to understand your target environment.

For this circuit example we used a Linear Technologies 1129 regulator, see figure 2. It is available in several package types and allows us to regulate from 4.2 to 3.6 volts assuming a 5% tolerance on the power supply. The output value is determined by two external resistors that setup a bias voltage to the regulator. The calculation for determining the output is shown in equation 6. This equation was taken from the manufacturer's data book.

$$V_{out} = 3.75V \times (1 + R2 \div R1) + (I_{adj \times R2}) \qquad (6)$$

where: $I_{adj} = 150nA\,at\ 25^{o}\mathrm{C}$

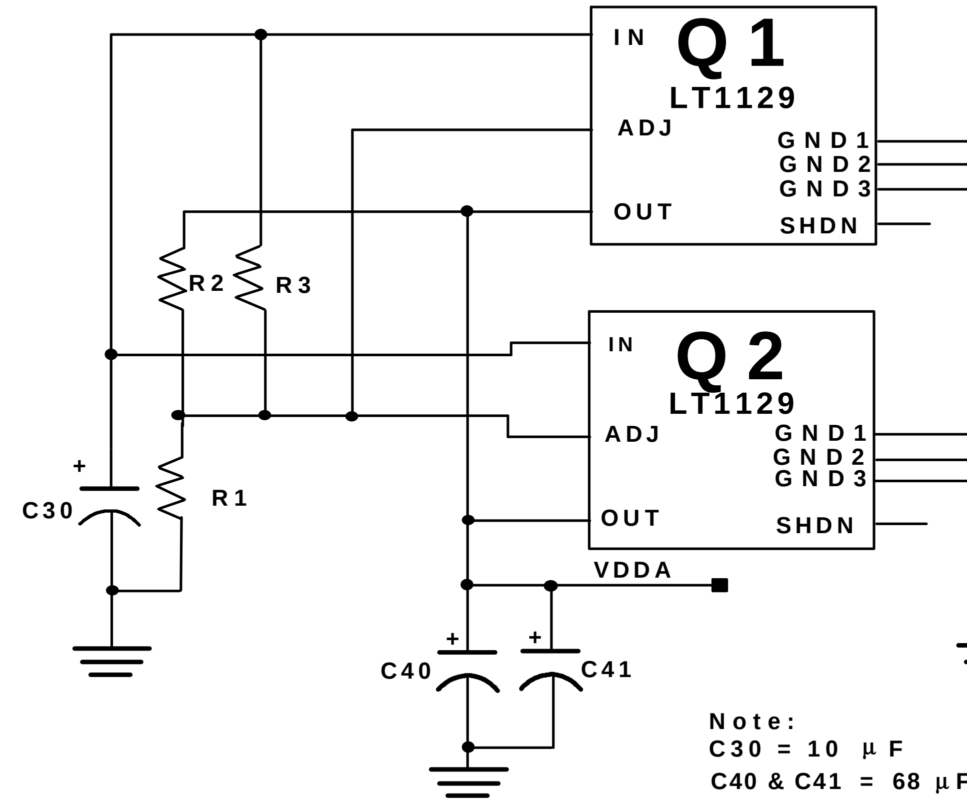


Figure 2: 3.6 to 4.2 volt regulation

For the case of V_{out} equal to 4.1 Volts, R1 = 3900 Ohms, R2 = 360 Ohms, and R3 is not present.

A second method for determining the output voltage with this circuit is to use feedback between the input and output rather than the output and ground. The equation then changes to:

$$V_{out} = V_{ref} \times (1 + R2/R3) - (R2/R3 \times V_{in}) \quad (7)$$

In the case of $V_{out}V_{out}$ equal to 3.6 Volts, R1 is not present, R2 = 100 Ohms, and R3 = 833 Ohms.

We use two voltage regulators to guarantee enough output current for the processor. Each 1129 regulator is capable of handling a load current of 700 mA, thus their combined load current is 1.4 amps. The 1129 is capable of ganging together and sharing the load. Note, some regulators are not capable of being ganged together. The designer must ascertain the abilities of the device chosen.

We elected to use an S8 or small SO style package. This allows us to implement the 1.4 Amp regulation circuit in a small area. The heat is dissipated by both the package and the printed circuit board through the ground and split power planes. The current and heat dissipation requirements account for the large vias to the power and ground planes, see figure 3.

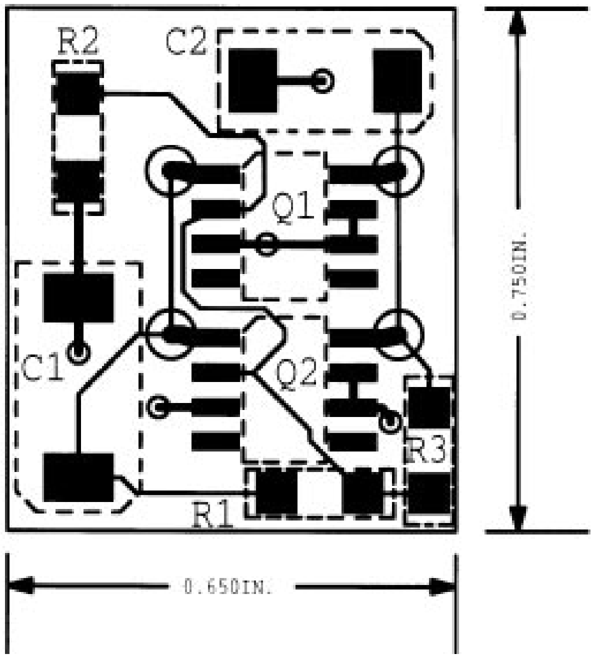


Figure 3: Circuit Layout for 3.6 to 4.2 Volt Regulator

3.3 to 4.2 Volt Regulation

For the final circuit we will combine the previous two sections and create a common schematic and layout that handles the entire range from 3.3 to 4.2 volt operation. This is accomplished by combining the schematics of figure 1 and figure 2. This combined schematic is shown in figure 4. The regulators Q1 and Q2 are used together unless a single regulator's output current of 700 mA is sufficient. Q3 can be either an adjustable LT1117 or a dedicated 3.3 or 3.6 volt regulator. All three regulators and all three resistors are never populated on the printed circuit board at the same time. Rather the output voltage required dictates which regulators and resistors are required. The equations for the circuit are the same as equations 6 and 7.

The layout for this combined circuit is shown as both a single, as well as, a double component layout. Surface mount technology is assumed and the minimum line width is 6 mils. In figure 5 the single component side layout is shown. Note that the LT1117 regulator is located horizontally across the layout using a SOT style package, see figure 6.

For the final layout we use a double component side approach, see figures 7A and 7B. This allows us to reduce the overall size of the component and routing area to .322 in^2. This layout shows the best approach to supplying lower voltages to the processor while minimizing the impact to the motherboard. Note, figure 7A is the top side and figure 7B is the bottom side turned over and mirrored.

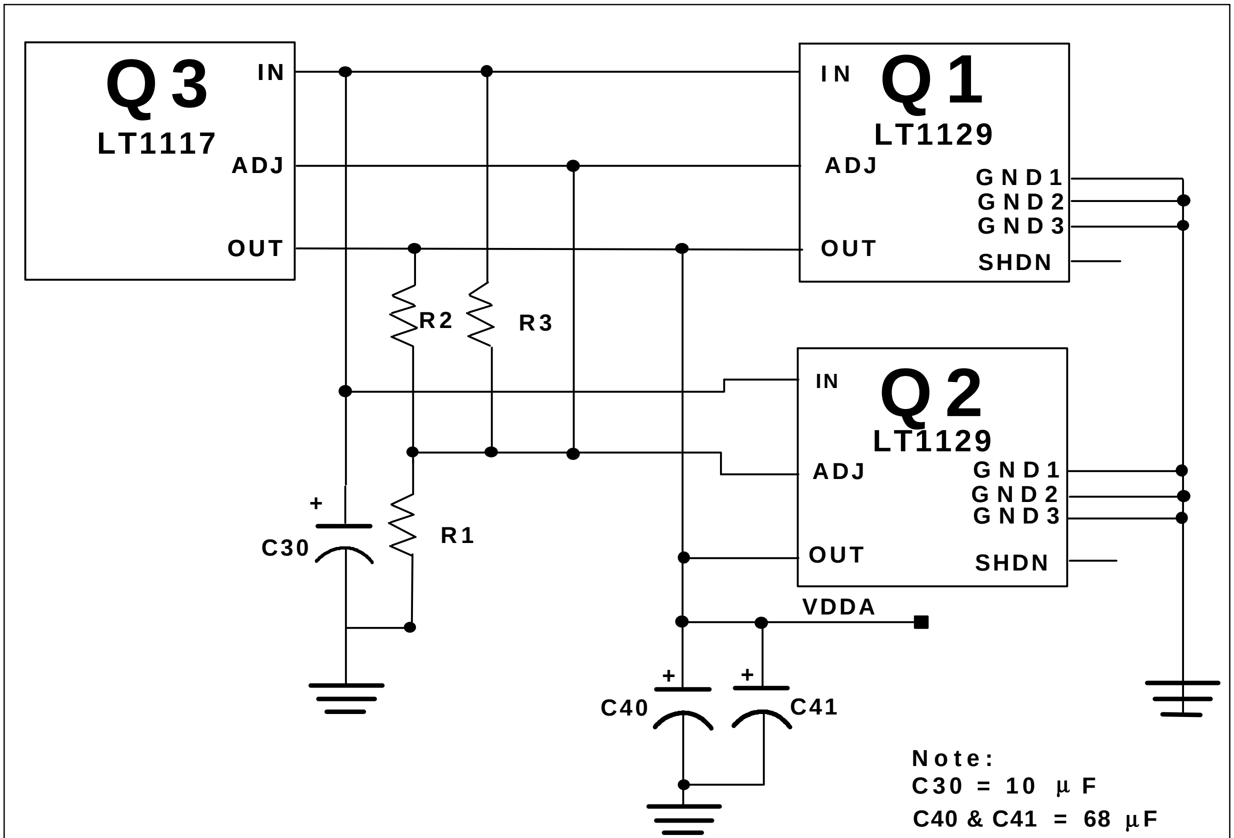


Figure 4: 3.3 to 4.2 volt regulation

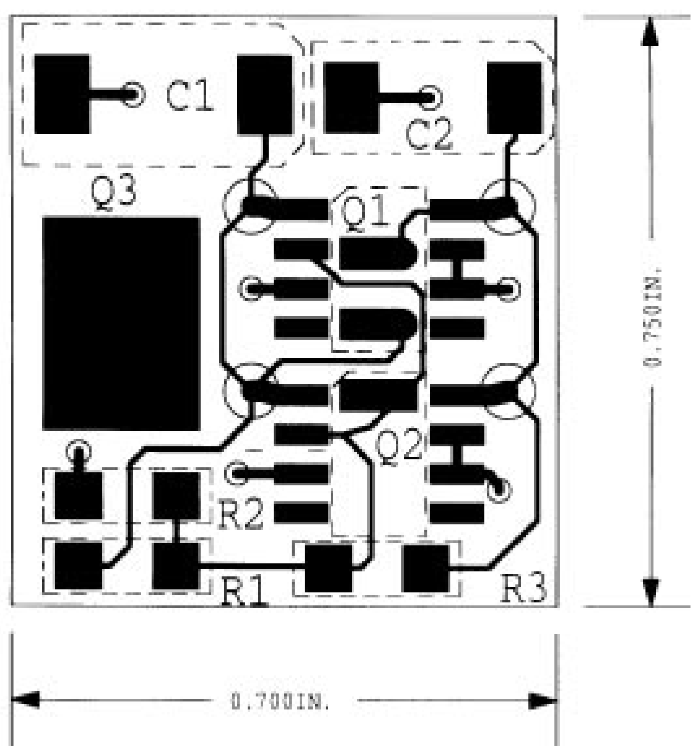


Figure 5: Circuit Layout for 3.3 to 4.2 Volt

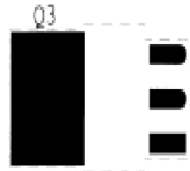
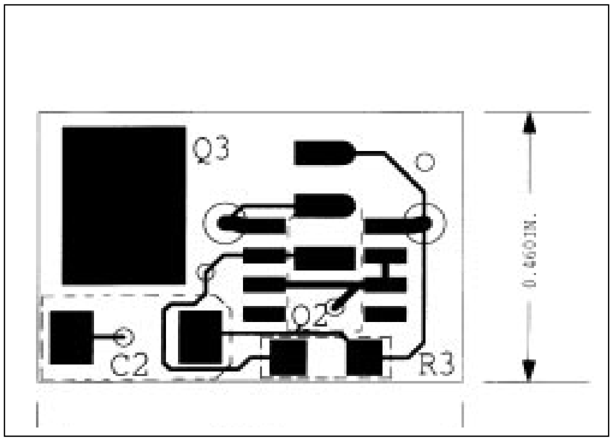
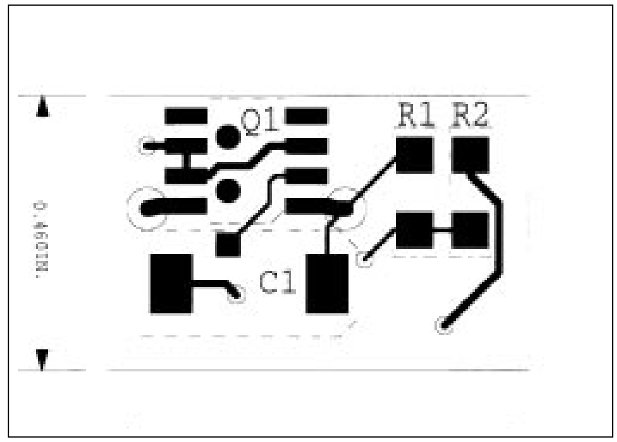


Figure 6: Layout of LT1117
Regulator in SOT Package





Figures 7A and 7B: Circuit Layout for 3.3 to 4.2 Volt Regulator Using Double Sided Design

Conclusion

This application note has shown some of the various circuits available in the linear regulation area that are capable of producing 3.3 to 4.2 volts from a input voltage of 5 volts. These circuits are shown as examples and are not guaranteed to work in any particular application and should not be used directly. The actual implementation of these circuits or variations of these circuits is left to the designer with the help of the manufacturers' data books. The designer should now realize that the requirement of an odd value such as 3.78 volts is not outside the normal bounds of design and is easily accomplished with a small board area and cost.

References

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