NJR CORPORATION

198 Stauffer Blvd., San Jose, CA 94125 Tel: (408) 995-6200 Fax: (408) 938-5580

Product Note

NJM2360 Provides Modern, Low Parts-Count Solution to DC-DC Voltage Conversion

Introduction

The NJRC NJM2360 DC to DC converter is a bipolar device which contains all of the active circuitry required to perform step-up, step-down, or inverting operations with a minimum number of external parts. The inclusion of an on-board, high current output switch allows the device to supply current of up to 1.5 amperes without the use of an external switching transistor. The NJM2360 utilizes switching power supply technology to provide a large range of output voltages both positive and negative. The wide range of input voltages and high current capabilities make the NJM2360 ideal for applications requiring multiple voltages from a single voltage supply such as hard disk drives or any environment utilizing mixed-voltage components .

Linear vs. Switching Power Supplies

In order to understand how the NJM2360 operates, and to understand the advantages of this type of circuitry, a comparison of linear and switching power supply technologies will be useful.

The Series Pass Regulator

The requirement for regulated power supplies is mostly a product of the solid state era. Before transistors and integrated circuits, only precision medical and critical measuring equipment needed regulated supplies. In cases where regulation was required, it was what we now call linear regulation consisting of either shunt-type regulators or series-pass regulators. As solid state equipment proliferated, the series pass regulator became the circuit of choice, and is still the most cost-effective solution to the requirement for low current regulated supplies in consumer level analog and digital equipment.

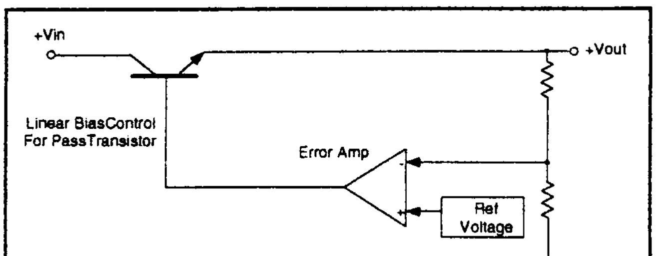


Figure 1. Showing A Typical Linear Regulator Circuit

In a series pass regulator, filtered DC is fed through a series pass transistor where a sample of the output is fed back to control the conductivity of the pass transistor to regulate the voltage as shown in figure 1.

The output sample is generally fed into an error amplifier along with a reference voltage which can be formed with either a resistor network or, more commonly, a zener diode. The output of this comparator is used to bias the pass transistor and control the output. If the sampled output voltage falls below the reference, the comparator biases the pass transistor to conduct more, allowing the output voltage to increase. When the output increases more than a few percent above the desired voltage, the fed-back sample exceeds the level of the reference at the comparator, and this reduces the bias on the pass transistor, causing it to conduct less. Between Von and Vsat, the pass transistor acts like a potentiometer turning the voltage at the output up or down, in response to the load to keep it within a fairly narrow margin. Easy and fairly inexpensive to implement, the series pass regulator is used in many analog circuits today. The main drawback of this type of circuit is that it wastes power by dissipating it as heat in the pass transistor which is operating in its linear range all of the time. The maximum efficiency of a series pass regulator is usually less than 50 per cent and the size of the 50/60 Hz components make the supplies large and heavy, especially if they are to provide high output current.

Switching Regulator Technology

To regulate the voltage in a switching power supply, the output is sampled and compared to a reference, just as in a traditional series pass regulator. but here, the similarity stops. In a switching regulator, the output of the error amp controls a pulse-width modulation circuit which is used to control the duty cycle, or time-on to time-off relationship of the pass transistor as seen in figure 2. If the pass transistor is off more than

NJR CORPORATION

198 Stauffer Blvd., San Jose, CA 94125 Tel: (408) 995-6200 Fax: (408) 938-5580

it is on, the voltage at the output drops, if the transistor is on more than off, the output voltage increases. Since the pass transistor in a switching regulator circuit is either totally off or totally saturated (ON), very little power is actually dissipated by the pass transistor as heat.
The main advantageof this type of regulator circuit is the low power dissipation of the regulator components. Compact, high-efficiency (75% and more), high current supplies are possible using this technique and this advantage often justifies the higher cost incurred by the more complex design. The major disadvantage of switching power supplies, other than the increased complexity of the design, is the high RFI/EMI levels generated.

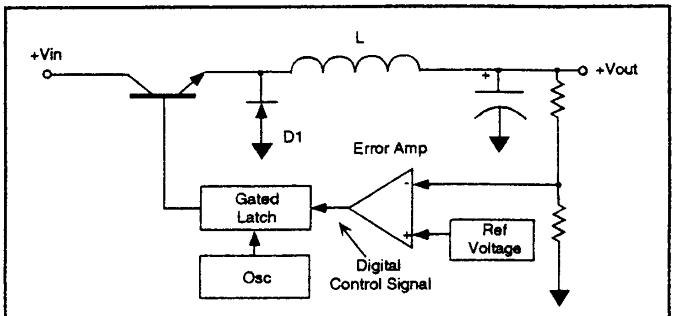


Figure 2. Shows Typical Switching Regulator Circuit

The NJM2360 DC to DC Converter

Internal Operation of the NJM2360

The NJM2360 uses switching regulator technology to facilitate step-up, step-down, and inverting DC voltage conversion operations.
The device consists of several internal circuits: a 1.25V temperature compensated band-gap DC reference source, a comparator, a duty cycle controlled oscillator with a current limiting input, and a high-current output switch.

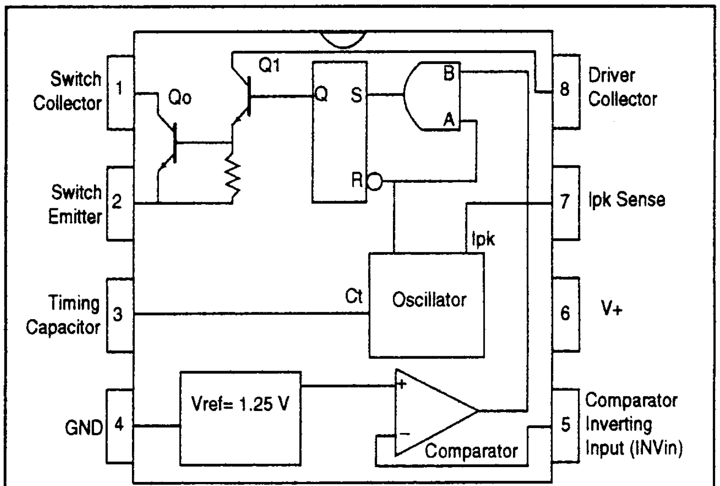


Figure 3. Block Diagram Of NJRC NJM2360

The heart of the NJM2360 is the duty cycle controlled oscillator. It is composed of a current source/sink which charges and discharges a customer supplied external capacitor Ct between an upper and lower preset threshold. Typical charge and discharge currents are 33uA and 200uA respectively yielding a charge-to-discharge ratio of approximately 6 to 1. This makes the ramp-up time of the resultant triangular oscillator waveform six times longer than the ramp-down time as shown in Figure 4. The upper threshold is the same as the reference voltage; in this case, 1.25 volts. The actual frequency of the oscillator is set by the external capacitor **Ct** and it runs continuously. Referring to the block diagram of the NJM2360, Figure 3, we see that the oscillator output is tied to one side of an AND gate. It is also tied to the reset of an RS flip-flop being used as a latch. When the oscillator is ramping-up, a '1' is output to the 'A' input of the AND gate. If the input to the comparator is below the level of the reference voltage, a '1' is also applied to the 'B' input of the AND gate. This results in a '1' being applied to the 'S' input of the latch, which turns the Darlington pair comprising the output switch (Qo) ON. It should be noted here, that the comparator can only turn the output switch ON. It cannot turn the switch OFF when the comparator input exceeds the reference voltage forcing the 'B' input of the AND gate low. The latch can only be reset (thus turning the output switch OFF) when the output of the oscillator circuit goes low, and resets the latch through the /R input (see block diagram, Figure 3). Consequently, when the **INVin** input to the comparator exceeds **Vref**, the output switch does not shut down instantaneously. It requires that the oscillator start to discharge **Ct** to issue a reset to the latch, turning the output switch OFF. The output switch will then remain OFF until the input to **INVin** falls below **Vref** again.
The NJM2360 has an overcurrent protection circuit built in. It works through the **Ipk Sense** input (pin 7). In the external circuitry, pin 6 is connected to Vin (supply voltage). Pin 7 is also connected to Vin across **Rsc**, a small current sensing resistor. This resistor is in series with the output of the DC-to-DC converter. When the voltage drop across **Rsc** exceeds 300mV, the **Ipk Sense** detects this and the oscillator immediately goes to **Vref** irrespective of where it is in the ramp-up cycle. This causes the oscillator output to go low, invoking the /R pin on the latch. When the latch is reset in this manner, Qo is turned OFF, and remains off as long as the overcurrent condition exists. When the voltage drop across **Rsc** again falls below 300 mV, normal oscillator operation resumes and the switch again responds to the comparator output.

198 Stauffer Blvd., San Jose, CA 94125 Tel: (408) 995-6200 Fax: (408) 938-5580

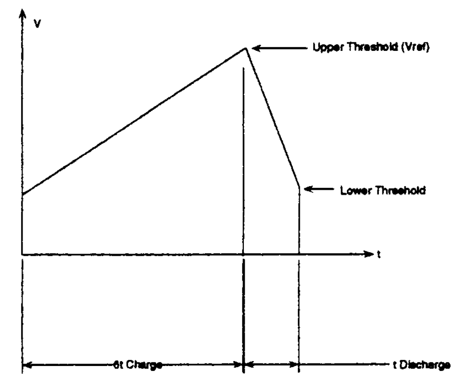


Figure 4. Showing Oscillator Waveform And Threshold Voltage

Step-Down Switching Regulator Circuit

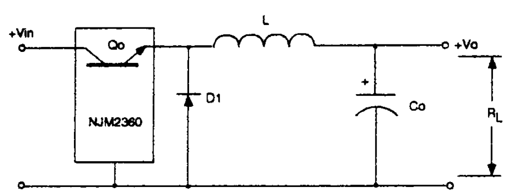


Figure 5. Showing concept of Step-Down DC/DC Converter using NJM2360

One of the three basic functions of the NJM2360 is a step-down regulator. In this application, the output transistor provides a variable duty-cycle square wave to a simple LC filter which averages the square wave resulting in a DC voltage which can be set to any voltage *less* than the input voltage by controlling the duty cycle of Qo. Therefore, we see that:

$Vout = Vin\{t_{on}/(t_{on}+t_{off})\}$

Step-up Switching Regulator Circuit

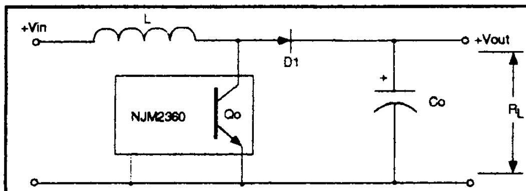


Figure 6. Showing concept of Step-Up DC/DC Converter using NJM2360

The second basic function of the NJM2360 is that of a step-up switching regulator. In this circuit, energy is stored in an inductor which is in series with Vin. Qo is across the output of the inductor to ground. When Qo turns OFF, the field of the inductor collapses inducing a current in series with Vin to the filter capacitor and load. This configuration allows Vout to be set to any voltage greater than Vin according to the following relationship:

$Vout = Vin(t_{on}/t_{off}) + Vin$ or **$Vout = Vin(t_{on}/t_{off} + 1)$**

Voltage Inverter

The third basic configuration for the NJM2360 is a voltage inverter which will produce a negative switching-regulated voltage from a positive Vin. In this circuit, Qo is wired in series with Vin as a pass transistor. The inductor L is wired to the emitter of Qo and to the return. A commutating diode, D1 is between the Qo emitter and Vout, and between D1 and -Vout is the negative end of the filter capacitor.

While Qo is ON, energy is stored in the inductor, and when Qo is OFF, the inductor field collapses inducing a current to the output filter capacitor. In this configuration, voltage is derived *only* from the collapsing field of the inductor. This design allows the output voltage to be set at any value within the NJM2360's specification range. The voltage may be less than, greater than, or equal to Vin and is controlled by the following relationship:

$Vout = Vin(t_{on}/t_{off})$

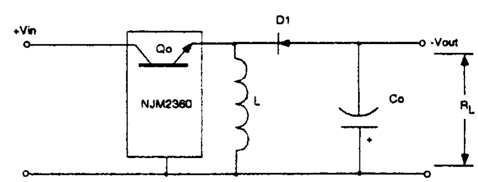


Figure 7. Showing concept of Inverter DC/DC Converter using NJM2360

NJM2360 Applications Examples

Now that we have examined the NJM2360 and discussed how it functions, we shall now look at three actual circuits, one for each of the conceptual examples shown above. We have included the math required to derive the actual parts values for each example. All the user need do to utilize these circuits is to plug in his or her requirements into the equations. The Co value is, in practicality, figured to be 3X the calculated value to compensate for internal resistance. Likewise, the calculated L value is multiplied by 1.3 to account for energy loss. Diode D1 must be a Schottky Boundry Diode (SBD). Please pick this diode for your application's current requirements.

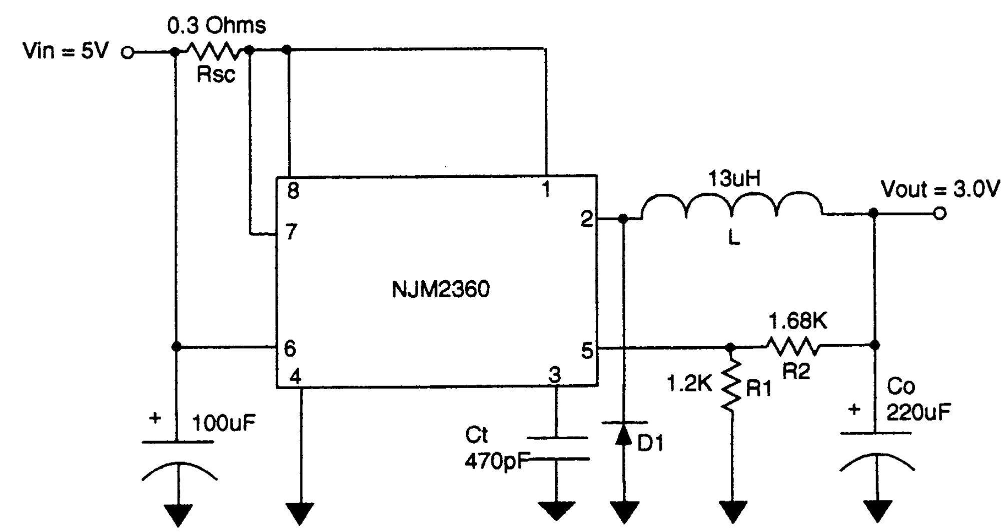
198 Stauffer Blvd., San Jose, CA 94125 Tel: (408) 995-6200 Fax: (408) 938-5580

Step-Down

The step-down example assumes a 5 volt input, a 3 volt output, and an oscillator frequency of 80 KHz nominal. This is a perfect circuit for use on boards utilizing mixed 5 and 3 volt components.

Vout = 3 V
Iout = 500 mA
fmin = 80 kHz
Vin(min) = 5 V - 5% or 4.75 V
Vripple(p-p) = 25 mVp-p

1) ton/toff = (Vout + Vf) / (Vin(min) - Vsat - Vout) = (3 + 0.8) / (4.75 - 0.8 - 3) = 4.00
2) ton(max)+ toff = 1 / fmin = 1 / (80 x 10-3) = 12.5 usec
3) toff = 12.5 / (4.00 +1) = 2.5 usec
   ton(max) = 12.5 - 2.5 = 10.0 usec
4) **Ct** = (4.0 x 10-5) ton(max) = (4.0 x 10-5) (10 x 10-6) = 400 pF **USE 470 pF**
5) Ipk(switch) = 2 x Iout = 2 (500 x 10-3) = 1 A
6) **L**(min) = ton(max) (Vin(min) - Vsat - Vout) / Ipk(switch) = (10 x (4.75 - 0.8 - 3) / 1 = 9.5 uH
   USE 13 uH
7) **Rsc** = Vpk(switch) / Ipk(switch) = 0.3 / 1 = **0.3 Ohm**
8) **Co** = Ipk(switch) (ton(max) + toff) / (8 x Vripple(p-p)) = 1 (12.5 x 10-6) / (8 x 25 x 10-3) = 62.5 uF
   USE 220 uF
9) Vout = 1.25 (R2 / R3 + 1)If **R1 = 1.2 k** is selected, **R2** = (Vout / 1.25 - 1) x R3 = (3 / 1.25 - 1) x (1.2 x 103) = 1.68 k
USE 1.8 K



Application Example for Above Equations

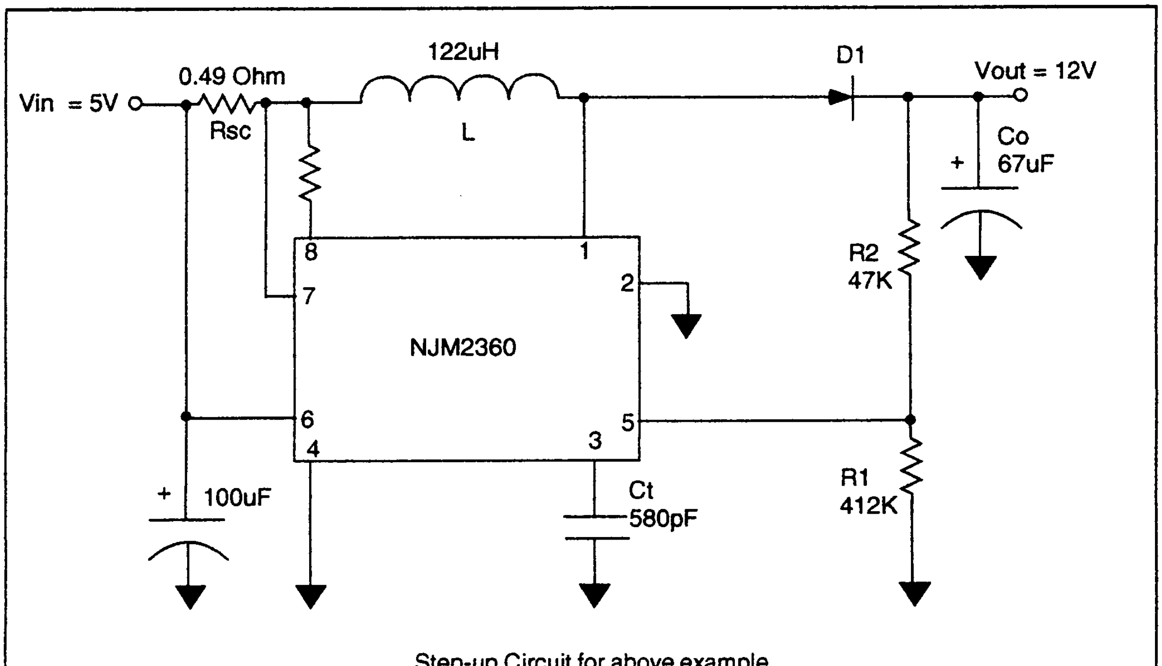
198 Stauffer Blvd., San Jose, CA 94125 Tel: (408) 995-6200 Fax: (408) 938-5580

Step-Up

This step-up example assumes an output of 12 volts from a 5 volt input at a nominal oscillator frequency of 50KHz.

Vout = 12 V
Iout = 100 mA
fmin = 50 kHz
Vin(min) = 5 V - 5% or 4.75 V
Vripple(p-p) = 5% or 60 mVp-p

1) ton/toff = (Vout + Vf - Vin(min)) / (Vin(min) - Vsat) = (12 + 0.8 - 4.75) / (4.75 - 0.8) = 2.04
2) ton(max) + toff = 1 / fmin = 1 / (50 x 10-3) = 20.0 usec
3) toff = 20 / (2.04 +1) = 6.58 usec
ton(max) = 20.0 - 6.58 = 13.42 usec
4) **Ct** = (4.0 x 10-5) ton(max) = (4.0 x 10-5) (13.42 x 10-6) = 537 pF **USE 580 pF**
5) Ipk(switch) = 2 x Iout (ton/toff + 1) = 2 (100 x 10-3) (2.04 + 1) = 608 mA
6) **L(min)** = ton (Vin(min) - Vsat) / Ipk(switch) = (13.42 x 10-6) (4.75 - 0.8) / 0.608 = 87 uH
USE 122 uH
7) **Rsc** = Vpk(switch) / Ipk(switch) = 0.3 / 0.608 = 0.49 Ohm
8) **Co** = ton (Iout) / Vripple(p-p) @ (13.42 x 10-6) (0.1) / (0.06) @ 22.4 uF **USE 67 uF**
9) Vout = 1.25 (R2 / R3 + 1)
If **R2 = 46 k** is selected, **R1** = (Vout / 1.25 - 1) x R2 = (12 / 1.25 - 1) x (46 x 103) = 395.6 k **USE 410K**
10) Ib = Ipk(switch) / Bf = 0.608 / 20 = 34 mA
The current driving the internal 170 Ohm base-emitter resistor is:
I 170Ohms = Vbe(switch) / 170 = 4.12 mA
Rdriver = (Vin - Vsat(driver) - Vrsc) / (Ib + I 170 Ohms) = (4.75 - 0.3 - 0.2) / {(34 x 10-3) + (4.1 x 10-3)} = 112 Ohms **USE 150 Ohms**



Step-up Circuit for above example

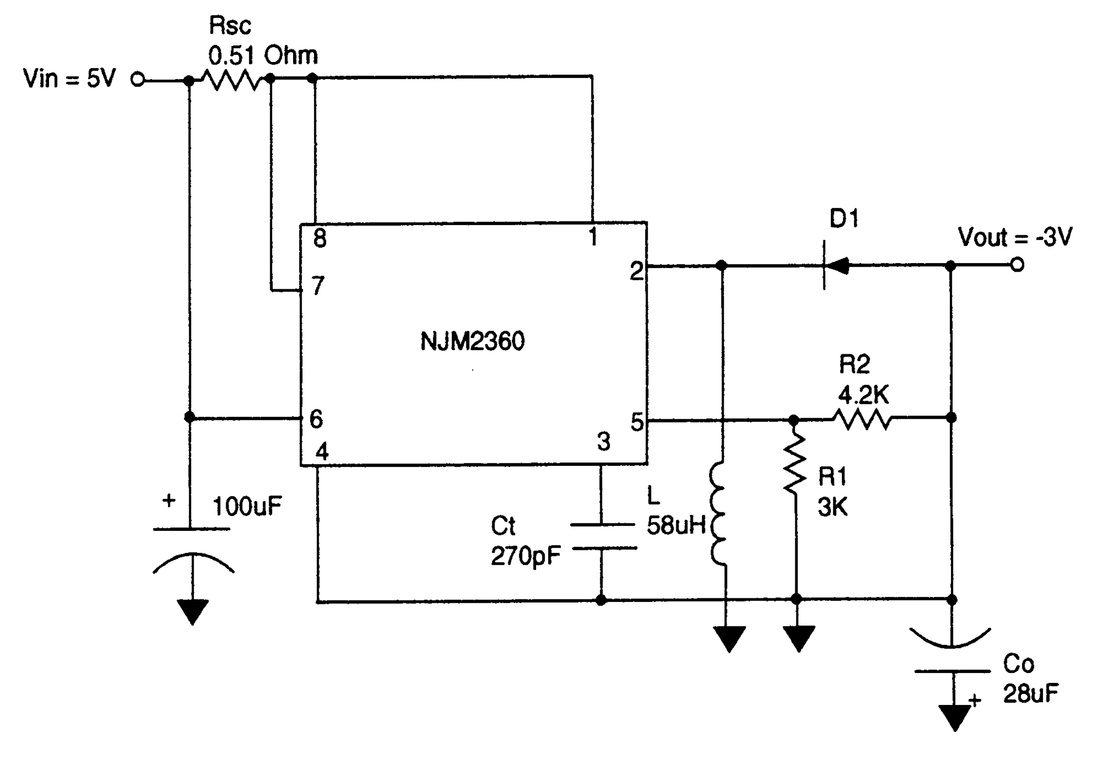
198 Stauffer Blvd., San Jose, CA 94125 **Tel: (408) 995-6200 Fax: (408) 938-5580**

Voltage Inverter

Since the inductor acts as the energy storage in this example, the output voltage depends solely on its value. The output voltage can, therefore, be set to a value that is less or greater than the input voltage. The voltage across the inductor during ton is {Vin - Vsat} and for toff is given by {|Vout|+ Vf}. Their ratio is thus defined as: ton/toff = (|Vout| + Vf) / (Vin - Vsat).

Vout = -3 V
Iout = 150 mA
fmin = 80 kHz
Vin(min) = 5 V - 5% or 4.75 V
Vripple(p-p) = 100 mVp-p

1) ton/toff = (|Vout| + Vf) / (Vin(min) - Vsat) = (3 + 0.8) / (4.75 - 0.8) = 0.96
2) ton(max) + toff = 1 / fmin = 1 / (80 x 10-3) = 12.5 usec
3) toff = 12.5 / (0.96 +1) = 6.37 usec
ton(max) = 12.5 - 6.37 = 6.12 usec
4) **Ct** = (4.0 x 10-5) ton(max) = (4.0 x 10-5) (6.12 x 10-6) = 245 pF **USE 270 pF**
5) Ipk(switch) = 2 x Iout (ton/toff + 1) = 2 (150 x 10-3) (0.96 + 1) = 588 mA
6) **L(min)** = ton (Vin(min) - Vsat) / Ipk(switch) = (6.12 x 10-6) (4.75 - 0.8) / 0.588 = 41.1 uH
USE 58 uH
7) **Rsc** = Vpk(switch) / Ipk(switch) = 0.3 / 0.588 = **0.51 Ohm**
8) **Co** = ton (Iout) / Vripple(p-p) = (6.12 x 10-6) (0.15) / (0.1) = 9.18 uF: **USE 33 uF**
9) |Vout| = 1.25 (R2 / R3 + 1)
If **R1 = 3 k** is selected, **R2** = (|Vout| / 1.25 - 1) x R3 = (3 / 1.25 - 1) x (3 x 103) = **4.2 k**



Inverter Circuit for Equations Given Above