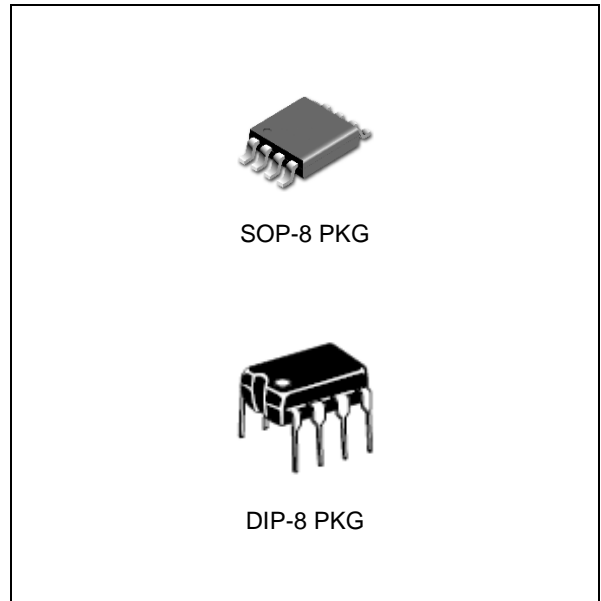


## FEATURES

- Simple Conversion of +5V Logic Supply  $\pm 5V$  Supplies
- Simple Voltage Multiplication ( $V_{OUT} = (-) nV_{IN}$ )
- Typical Open Circuit Voltage Conversion Efficiency 99.9%
- Typical Power Efficiency 98%
- Wide Operating Voltage Range: LM7660 1.5V to 10.0V
- Easy to Use: Requires Only 2 External Non-Critical Passive Components
- No External Diode Over-Full Temp. and Voltage Range
- Moisture Sensitivity Level 3

## APPLICATIONS

- On Board Negative Supply for Dynamic RAMs
- Localized  $\mu$ -Processor (8080 Type) Negative Supplies
- Inexpensive Negative Supplies
- Data Acquisition Systems



## ORDERING INFORMATION

| Device  | Package |
|---------|---------|
| LM7660D | SOP-8   |
| LM7660N | DIP-8   |

## DESCRIPTION

The LM7660 is a monolithic CMOS power supply circuit which offers unique performance advantages over previously available devices.

The LM7660 performs supply voltage conversions from positive to negative for an input range of +1.5V to +10.0V resulting in complementary output voltages of -1.5V to -10.0V. Only two noncritical external capacitors are needed for the charge pump and charge reservoir functions.

The LM7660 can also be connected to function as voltage doublers and will generate output voltages up to +18.6V with a +10V input. Contained on the chip are a series DC supply regulator, RC oscillator, voltage level translator, and four output power MOS switches.

A unique logic element senses the most negative voltage in the device and ensures that the output N-Channel switch source-substrate junctions are not forward biased. This assures latch-up free operation.

The oscillator, when unloaded, oscillates at a nominal frequency of 10 kHz for an input supply voltage of 5.0V.

This frequency can be lowered by the addition of an external capacitor to the "OSC" terminal, or the oscillator may be overdriven by an external clock.

The "LV" terminal may be tied to GROUND to bypass the internal series regulator and improve low voltage (LV) operation. At medium to high voltages (+3.5V to +10.0V for the LM7660), the LV pin is left floating to prevent device latch-up.

## ABSOLUTE MAXIMUM RATINGS

| CHARACTERISTIC                                   | SYMBOL    | VALUE  |
|--|-----------|--|
| Supply Voltage                                   | $V_+$     | +10.5V   |
| LV and OSC Input Voltage (Note 2)                | $V_I$     | -0.3V to $[(V_+ + 0.3V)$ for $V_+ < 5.5V$          |
|  |           | $(V_+ - 5.5V)$ to $[(V_+ + 0.3V)$ for $V_+ > 5.5V$ |
| Current into LV (Note 2)                         | $I_{LV}$  | 20 $\mu$ A for $V_+ > 3.5V$                        |
| Output Short Duration ( $V_{SUPPLY} \leq 5.5V$ ) | $V_{OUT}$ | Continuous   |
| Maximum Storage Temperature Range                | $T_{STG}$ | -65°C to 150°C                                     |
| Operating Ambient Temperature                    | $T_A$     | -20°C to 70°C                                      |

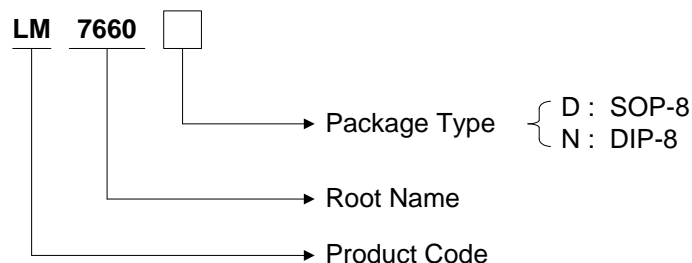
## THERMAL INFORMATION

| Thermal Resistance (Typical, Note 1) | $\theta_{JA}$ (°C/W) | $\theta_{JC}$ (°C/W) |
|--------------------------------------|----------------------|----------------------|
| PDIP Package                         | 150                  | N/A                  |
| SOP Package                          | 165                  | N/A                  |

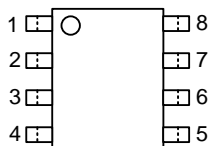
CAUTION: Stresses above those listed in “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

## ORDERING INFORMATION

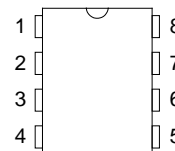
| Description                   | Package | Order No. | Supplied As | Status     |
|-------------------------------|---------|-----------|-------------|------------|
| Charge Pump Voltage Converter | SOP-8   | LM7660D   | Reel        | Contact Us |
| Charge Pump Voltage Converter | DIP-8   | LM7660N   | Tube        | Active     |



## PIN CONFIGURATION



SOP-8

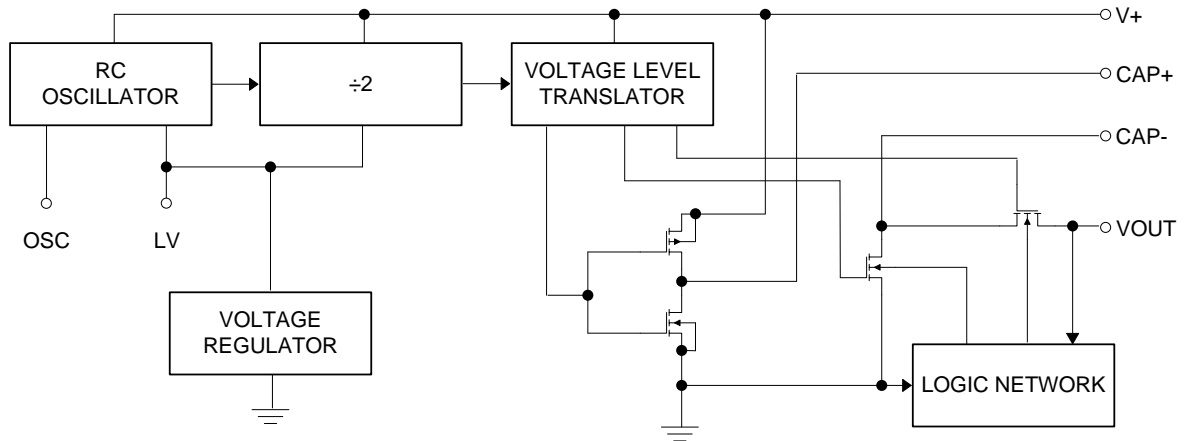


DIP-8

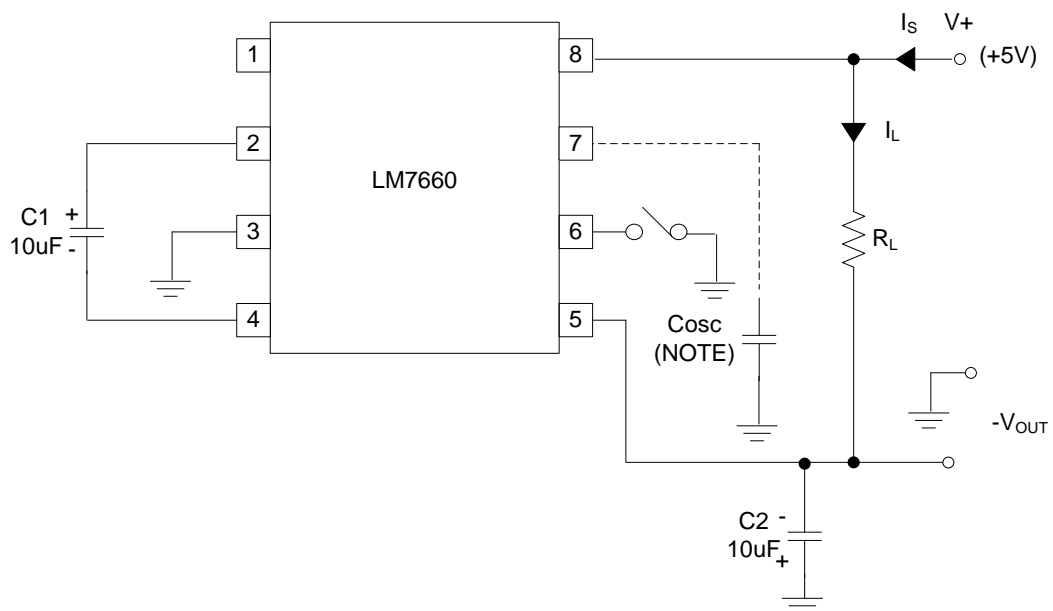
## PIN DESCRIPTION

| Pin No. | SOP-8 / DIP-8 PKG |                                    |
|---------|-------------------|------------------------------------|
|         | Name              | Function                           |
| 1       | N.C               | No Connection                      |
| 2       | CAP+              | Positive Capacitor                 |
| 3       | GND               | Ground                             |
| 4       | CAP-              | Negative Capacitor                 |
| 5       | VOUT              | Output Voltage                     |
| 6       | LV                | Improve Low Voltage (LV) Operation |
| 7       | OSC               | Oscillator Control Input           |
| 8       | V+                | Input Voltage                      |

## BLOCK DIAGRAM



## TEST CIRCUIT



Note: For large values of  $C_{osc}$  ( $>1000\text{pF}$ ) the values of  $C_1$  and  $C_2$  should be increased to  $100\mu\text{F}$ .

## ELECTRICAL CHARACTERISTICS

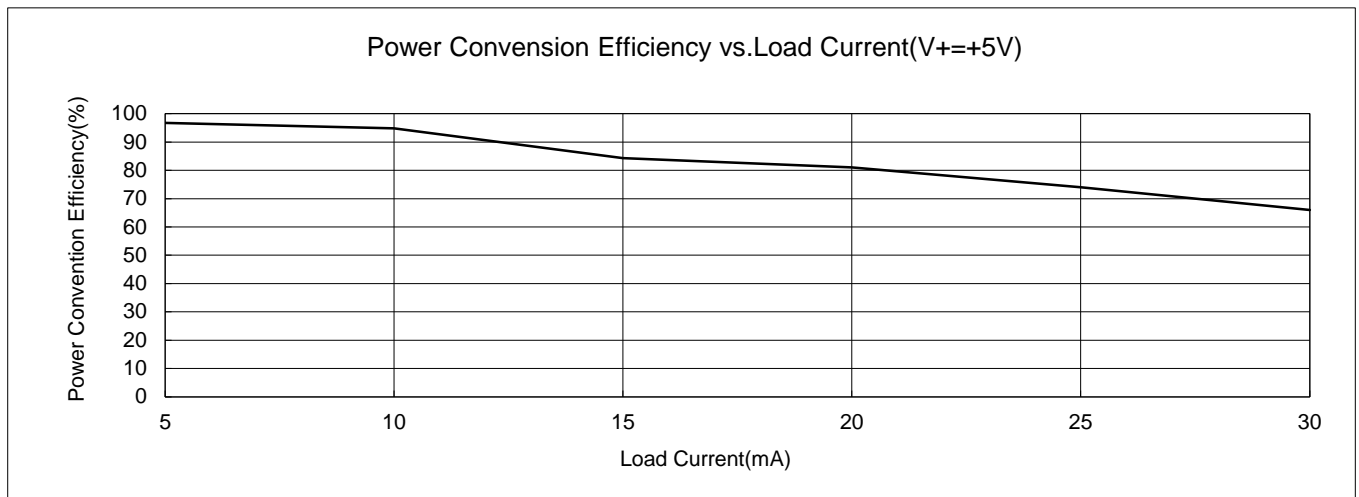
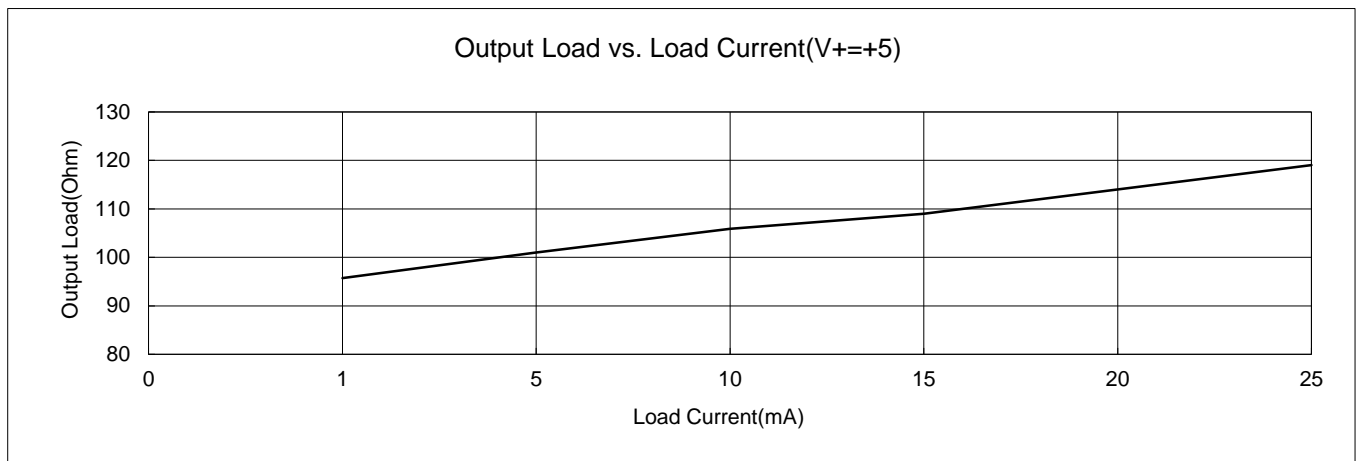
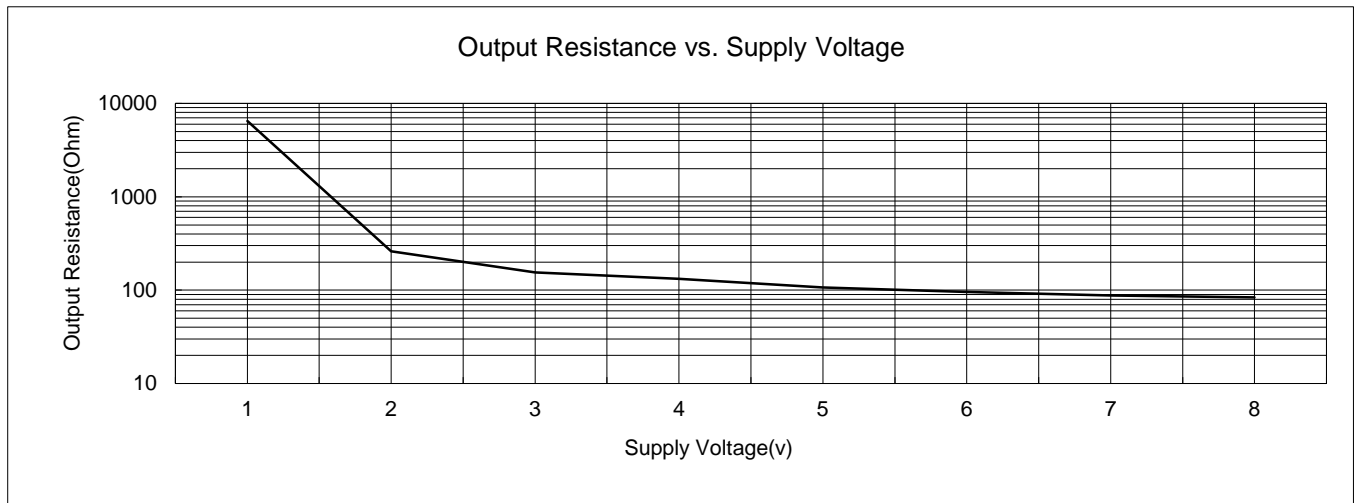
( $V_+ = 5V$ ,  $T_A = 25^\circ C$ ,  $C_{OSC} = 0$ , unless Otherwise Specified)

| SYMBOL        | PARAMETER                     | TEST CONDITIONS  | MIN. | TYP. | MAX. | UNIT     |
|---------------|-------------------------------|--|------|------|------|----------|
| $I_+$         | Supply Current                | $R_L = \infty$   | -    | 100  | 180  | $\mu A$  |
| $V_{L+}$      | Supply Voltage Range -Lo      | $Min \leq T_A \leq Max$ , $R_L = 10k\Omega$ , LV to GND  | 2.0  | -    | 3.5  | V        |
| $V_{H+}$      | Supply Voltage Range -Hi      | $Min \leq T_A \leq Max$ , $R_L = 10k\Omega$ , LV to Open | 3    | -    | -    | V        |
| $R_{OUT}$     | Output Source Resistance      | $I_{OUT} = 20mA$   | -    | 60   | 100  | $\Omega$ |
|               |                               | $V_+ = 2V$ , $I_{OUT} = 3mA$ , LV to GND                 | -    | -    | 300  | $\Omega$ |
|               |                               | $V_+ = 2V$ , $I_{OUT} = 3mA$ , LV to Open                | -    | -    | 400  | $\Omega$ |
| $F_{OSC}$     | Oscillator Frequency          |  | -    | 10   | -    | kHz      |
| $P_{EF}$      | Power Efficiency              | $R_L = 5k\Omega$   | 95   | 98   | -    | %        |
| $V_{OUT\ EF}$ | Voltage Conversion Efficiency | $R_L = \infty$   | 98   | 99.9 | -    | %        |

Note 1.  $\theta_{JA}$  is measured with the component mounted on an evaluation PC board in free air.

Note 2. Connecting any input terminal to voltages greater than  $V_+$  or less than GND may cause destructive latch-up. It is recommended that no inputs from sources operating from external supplies be applied prior to "power up" of the LM7660.

## TYPICAL PERFORMANCE CURVES



Note: These curves include in the supply current that current fed directly into the load  $R_L$  from the  $V_+$  (See Figure 11). Thus, approximately half the supply current goes directly to the positive side of the load, and the other half, through the LM7660, to the negative side of the load, ideally,  $V_{OUT}=2V_{IN}$ ,  $I_B=2I_L$ , so  $V_{IN} \times I_B = V_{OUT} \times I_L$

## APPLICATION INFORMATION

### Details Description

The LM7660 contains all the necessary circuitry to complete a negative voltage converter, with the exception of 2 external capacitors which may be inexpensive 10 $\mu$ F polarized electrolytic types. The mode of operation of the device may be best understood by considering Figure 12, which shows an idealized negative voltage converter. Capacitor  $C_1$  is charged to a voltage,  $V_+$ , for the half cycle when switches  $S_1$  and  $S_3$  are closed. (Note: Switches  $S_2$  and  $S_4$  are open during this half cycle.) During the second half-cycle of operation, switches  $S_2$  and  $S_4$  are closed, with  $S_1$  and  $S_3$  open, thereby shifting capacitor  $C_1$  negatively by  $V_+$  volts. Charge is then transferred from  $C_1$  to  $C_2$  such that the voltage on  $C_2$  is exactly  $V_+$ , assuming ideal switches and no load on  $C_2$ . The LM7660 approaches this ideal saturation more closely than existing non-mechanical circuits.

In the LM7660, the 4 switches of Figure 12 are MOS power switches;  $S_1$  is a P-Channel device and  $S_2$ ,  $S_3$  and  $S_4$  are N-Channel devices. The main difficulty with this approach is that in integrating the switches, the substrates of  $S_3$  and  $S_4$  must always remain reverse biased with respect to their sources, but not so much as to degrade their "ON" resistances. In addition, at circuit start-up, and under output short circuit conditions ( $V_{OUT} = V_+$ ), the output voltage must be sensed and the substrate bias adjusted accordingly. Failure to accomplish this would result in high power losses and probable device latch-up.

This problem is eliminated in the LM7660 by a logic network which senses the output voltage ( $V_{OUT}$ ) together with the level translators, and switches the substrates of  $S_3$  and  $S_4$  to the correct level to maintain necessary reverse bias. The voltage regulator portion of the LM7660 is an integral part of the anti-latch-up circuitry, however its inherent voltage drop can degrade operation at low voltages. Therefore, to improve low voltage operation the "LV" pin should be connected to GROUND, disabling the regulator. For supply voltages greater than 3.5V the LV terminal must be left open to insure latch-up proof operation, and prevent device damage.

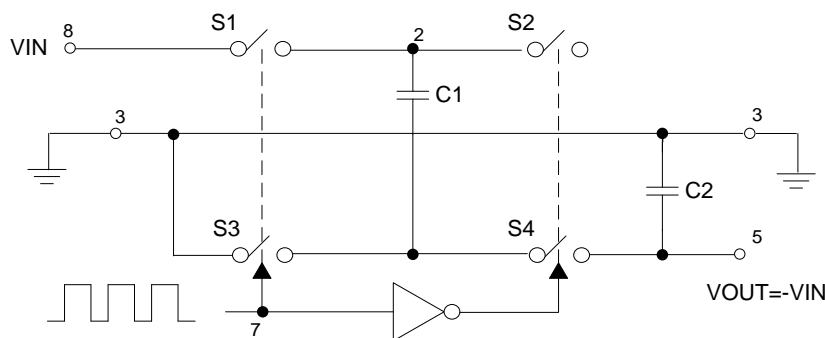


Figure 12. Idealized Negative Voltage Converter

### Theoretical Power Efficiency Considerations

In theory a voltage converter can approach 100% efficiency if certain conditions are met.

1. The driver circuitry consumes minimal power.
2. The output switches have extremely low ON resistance and virtually no offset.
3. The impedances of the pump and reservoir capacitors are negligible at the pump frequency.

The LM7660 approaches these conditions for negative voltage conversion if large values of  $C_1$  and  $C_2$  are used.

## Energy is Lost Only in the Transfer of Charge Between Capacitors if a Change in Voltage Occurs

The energy lost is defined by :  $E = 1/2 C_1 (V_1^2 - V_2^2)$

Where  $V_1$  and  $V_2$  are the voltages on  $C_1$  during the pump and transfer cycles. If the impedances of  $C_1$  and  $C_2$  are relatively high at the pump frequency (refer to Figure 12) compared to the value of  $R_L$ , there will be a substantial difference in the voltages  $V_1$  and  $V_2$ . Therefore it is not only desirable to make  $C_2$  as large as possible to eliminate output voltage ripple, but also to employ a correspondingly large value for  $C_1$  in order to achieve maximum efficiency of operation.

## DOs and DON'Ts

1. Do not exceed maximum supply voltages.
2. Do not connect LV terminal to GROUND for supply voltages greater than 3.5V.
3. Do not short circuit the output to V+ supply for supply voltages above 5.5V for extended periods, however, transient conditions including start-up are okay.
4. When using polarized capacitors, the + terminal of  $C_1$  must be connected to pin 2 of the LM7660 and the + terminal of  $C_2$  must be connected to GROUND.
5. If the voltage supply driving the LM7660 has a large source impedance ( $25\Omega - 30\Omega$ ), then a  $2.2\mu\text{F}$  capacitor from pin 8 to ground may be required to limit rate of rise of input voltage to less than  $2\text{V}/\mu\text{s}$ .
6. User should insure that the output (pin 5) does not go more positive than GND (pin 3). Device latch up will occur under these conditions. A 1N914 or similar diode placed in parallel with  $C_2$  will prevent the device from latching up under these conditions. (Anode pin 5, Cathode pin 3).

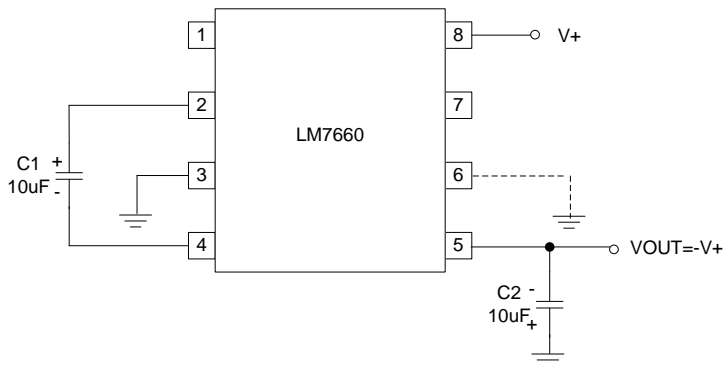


Figure 13A. Configuration

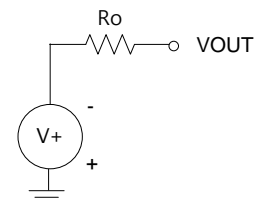


Figure 13B. Thevenin Equivalent

Figure 13. Simple Negative Converter



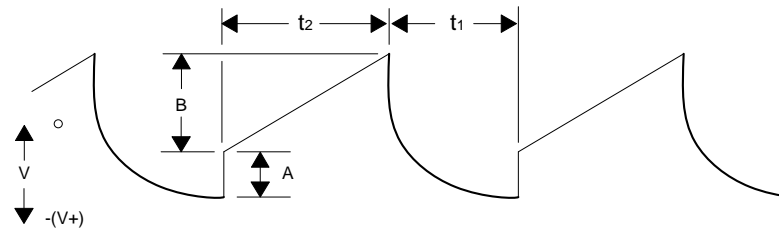


Figure 14. Output Ripple

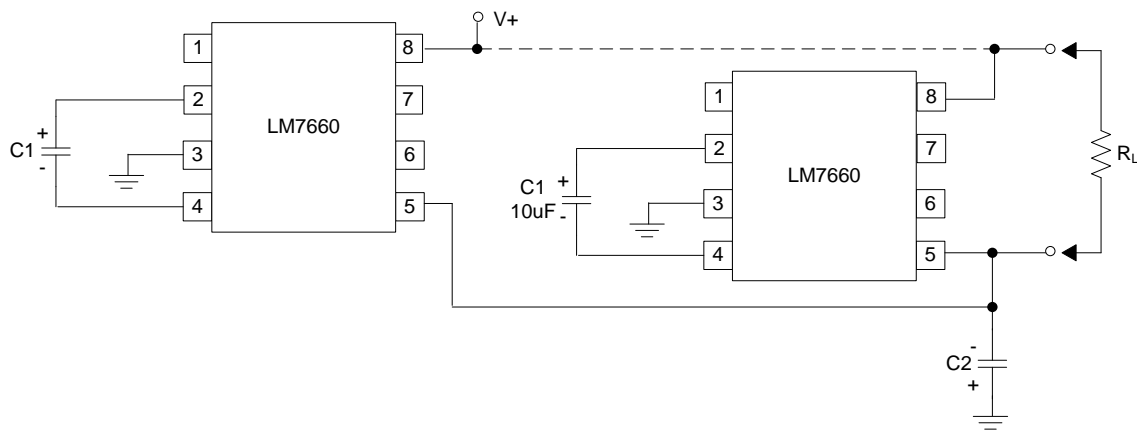


Figure 15. Paralleling Devices

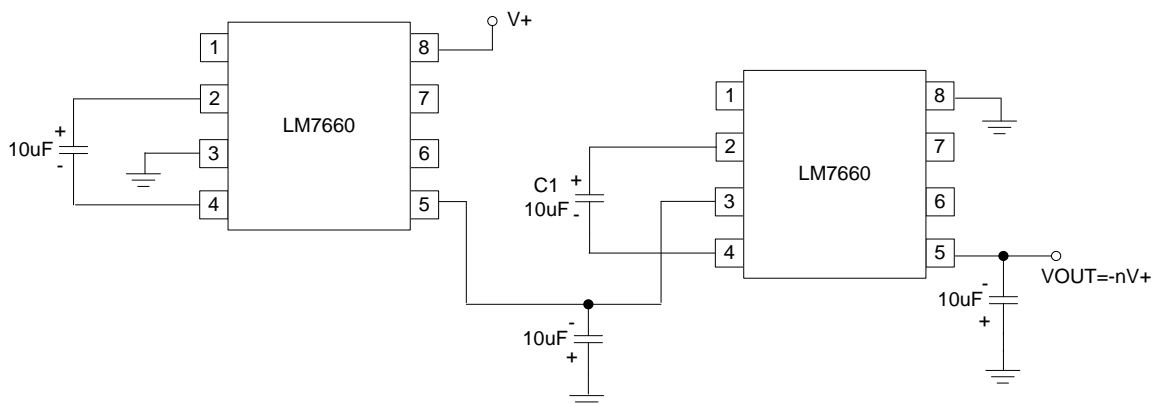


Figure 16. Cascading Devices for Increased Output Voltage

## Simple Negative Voltage Converter

The majority of applications will undoubtedly utilize the LM7660 for generation of negative supply voltages. Figure 13 shows typical connections to provide a negative supply negative (GND) for supply voltages below 3.5V.

The output characteristics of the circuit in Figure 13A can be approximated by an ideal voltage source in series with a resistance as shown in Figure 13B. The voltage source has a value of  $-V_+$ . The output impedance ( $R_O$ ) is a function of the ON resistance of the internal MOS switches (shown in Figure 12), the switching frequency, the value of  $C_1$  and  $C_2$ , and the ESR (equivalent series resistance) of  $C_1$  and  $C_2$ . A good first order approximation for  $R_O$  is:

$$R_O = 2(R_{SW1} + R_{SW3} + ESR_{C1}) + 2(R_{SW2} + R_{SW4} + ESR_{C1}) + 1/(f_{PUMP}) (C1) + ESR_{C2}$$

( $f_{PUMP} = f_{OSC}/2$ ,  $R_{SWX}$  = MOSFET switch resistance)

(Combining the four  $R_{SWX}$  terms as  $R_{SW}$ , we see that:

$$R_O = 2 (R_{SW}) + 1/(f_{PUMP}) (C1) + 4 (ESR_{C1}) + ESR_{C2}$$

$R_{sw}$ , the total switch resistance, is a function of supply voltage and temperature (See the Output Source Resistance graphs), typically 23Ω at 25°C and 5V. Careful selection of  $C_1$  and  $C_2$  will reduce the remaining terms, minimizing the output impedance. High value capacitors will reduce the  $1/(f_{PUMP} \cdot C_1)$  component, and low ESR capacitors will lower the ESR term. Increasing the oscillator frequency will reduce the  $1/(f_{PUMP} \cdot C_1)$  term, but may have the side effect of a net increase in output impedance when  $C_1 > 10\mu F$  and there is no longer enough time to fully charge the capacitors every cycle. In a typical application where  $f_{OSC} = 10kHz$  and  $C = C_1 = C_2 = 10\mu F$ :

$$R_O = 2 (23) + 1/(5 \cdot 10^3) (10^{-5}) + 4 (ESR_{C1}) + ESR_{C2}$$

$$R_O = 46 + 20 + 5 (ESR_C)$$

Since the ESRs of the capacitors are reflected in the output impedance multiplied by a factor of 5, a high value could potentially swamp out a low  $1/(f_{PUMP} \cdot C_1)$  term, rendering an increase in switching frequency or filter capacitance ineffective. Typical electrolytic capacitors may have ESRs as high as 10Ω.

## Output Ripple

ESR also affects the ripple voltage seen at the output. The total ripple is determined by 2 voltages, A and B, as shown in Figure 14. Segment A is the voltage drop across the ESR of  $C_2$  at the instant it goes from being charged by  $C_1$  (current flow into  $C_2$ ) to being discharged through the load (current flowing out of  $C_2$ ). The magnitude of this current change is  $2 \cdot I_{OUT}$ , hence the total drop is  $2 \cdot I_{OUT} \cdot eSR_{C2}V$ . Segment B is the voltage change across  $C_2$  during time  $t_2$ , the half of the cycle when  $C_2$  supplies current to the load. The drop at B is  $I_{OUT} \cdot t_2/C_2V$ . The peak-to-peak ripple voltage is the sum of these voltage drops:

$$VRIPPLE = [1/2 (f_{PUMP}) (C2) + 2 (ESR_{C2})] I_{OUT}$$

Again, a low ESR capacitor will result in a higher performance output.

## Paralleling Devices

Any number of LM7660 voltage converters may be paralleled to reduce output resistance. The reservoir capacitor,  $C_2$ , serves all devices while each device requires its own pump capacitor,  $C_1$ . The resultant output resistance would be approximately:

$$R_{OUT} = R_{OUT} \text{ (of LM7660)}/n \text{ (number of devices)}$$

## Cascading Devices

The LM7660 may be cascaded as shown to produce larger negative multiplication of the initial supply voltage. However, due to the finite efficiency of each device, the practical limit is 10 devices for light loads. The output voltage is defined by:

$$V_{OUT} = -n (V_{IN}),$$

Where  $n$  is an integer representing the number of devices cascaded. The resulting output resistance would be approximately the weighted sum of the individual LM7660  $R_{OUT}$  values.

## Changing the LM7660 Frequency

It may be desirable in some applications, due to noise or other considerations, to increase the oscillator frequency. This is achieved by overdriving the oscillator from an external clock, as shown in Figure 17. In order to prevent possible device latch-up, a  $1k\Omega$  resistor must be used in series with the clock output. In a situation where the designer has generated the external clock frequency using TTL logic, the addition of a  $10k\Omega$  pullup resistor to  $V+$  supply is required. Note that the pump frequency with external clocking, as with internal clocking, will be  $1/2$  of the clock frequency. Output transitions occur on the positive-going edge of the clock.

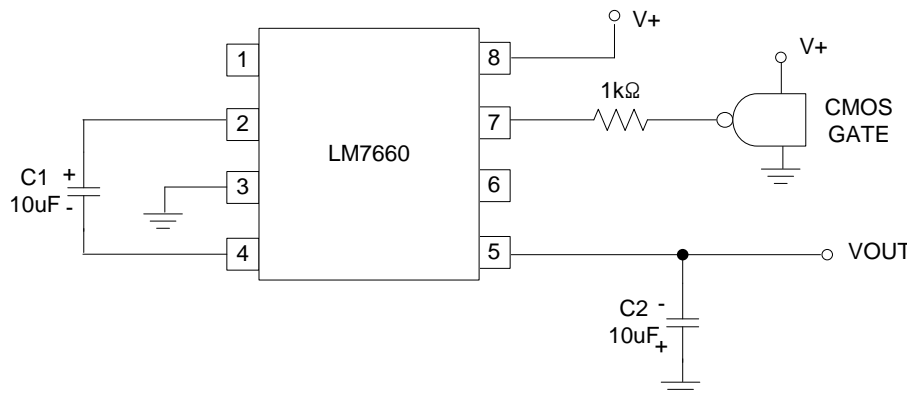


Figure 17. External Clocking

It is also possible to increase the conversion efficiency of the LM7660 at low load levels by lowering the oscillator frequency. This reduces the switching losses, and is shown in Figure 18. However, lowering the oscillator frequency will cause an undesirable increase in the impedance of the pump ( $C_1$ ) and reservoir ( $C_2$ ) capacitors; this is overcome by increasing the values of  $C_1$  and  $C_2$  by the same factor that the frequency has been reduced. For example, the addition of a  $100pF$  capacitor between pin 7 (OSC) and  $V+$  will lower the oscillator frequency to  $1kHz$  from its nominal frequency of  $10kHz$  (a multiple of 10), and thereby necessitate a corresponding increase in the value of  $C_1$  and  $C_2$  (from  $10\mu F$  to  $100\mu F$ ).

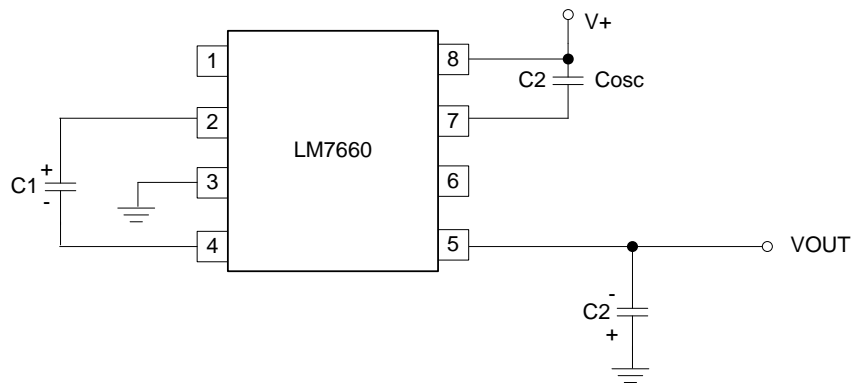


Figure 18. Lowering Oscillator Frequency

## Positive Voltage Doubling

The LM7660 may be employed to achieve positive voltage doubling using the circuit shown in Figure 19. In this application, the pump inverter switches of the LM7660 are used to charge  $C_1$  to a voltage level of  $V_+ - V_F$  (where  $V_+$  is the supply voltage and  $V_F$  is the forward voltage drop of diode  $D_1$ ). On the transfer cycle, the voltage on  $C_1$  plus the supply voltage ( $V_+$ ) is applied through diode  $D_2$  to capacitor  $C_2$ . The voltage thus created on  $C_2$  becomes  $(2V_+) - (2V_F)$  or twice the supply voltage minus the combined forward voltage drops of diodes  $D_1$  and  $D_2$ .

The source impedance of the output ( $V_{OUT}$ ) will depend on the output current, but for  $V_+ = 5V$  and an output current of 10mA it will be approximately  $60\Omega$ .

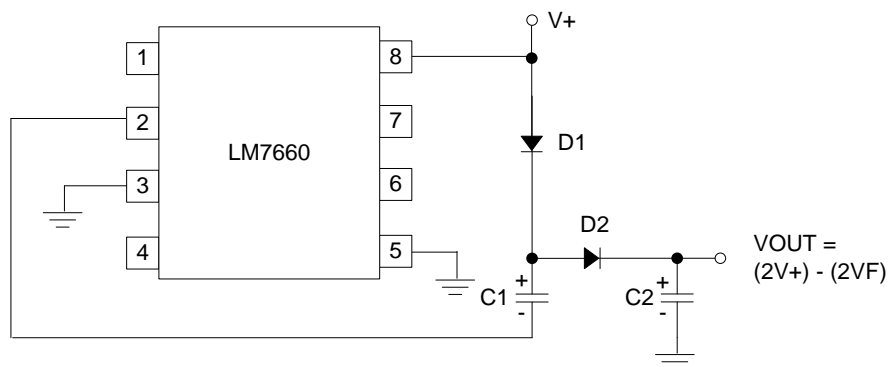


Figure 19. Positive Voltage Doubler

## Combined Negative Voltage Conversion and Positive Supply Doubling

Figure 20 combines the functions shown in Figures 13 and Figure 19 to provide negative voltage conversion and positive voltage doubling simultaneously. This approach would be, for example, suitable for generating +9V and 5V from an existing +5V supply. In this instance capacitors C<sub>1</sub> and C<sub>3</sub> perform the pump and reservoir functions respectively for the generation of the negative voltage, while capacitors C<sub>2</sub> and C<sub>4</sub> are pump and reservoir respectively for the doubled positive voltage. There is a penalty in this configuration which combines both functions, however, in that the source impedances of the generated supplies will be somewhat higher due to the finite impedance of the common charge pump driver at pin 2 of the device.

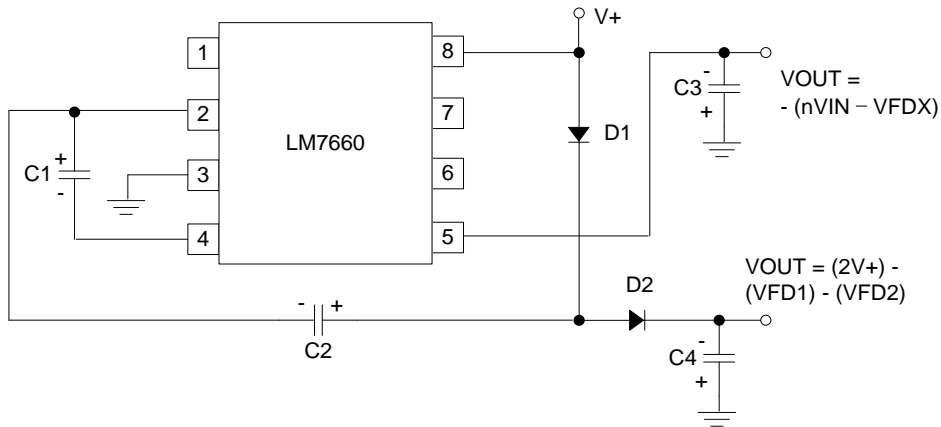


Figure 20. Combined Negative Voltage Converter and Positive Doubler

## Voltage Splitting

The bidirectional characteristics can also be used to split a higher supply in half, as shown in Figure 21. The combined load will be evenly shared between the two sides. Because the switches share the load in parallel, the output impedance is much lower than in the standard circuits, and higher currents can be drawn from the device.

By using this circuit, and then the circuit of Figure 16, +15V can be converted (via +7.5, and -7.5) to a nominal 15V, although with rather high series output resistance (~250Ω).

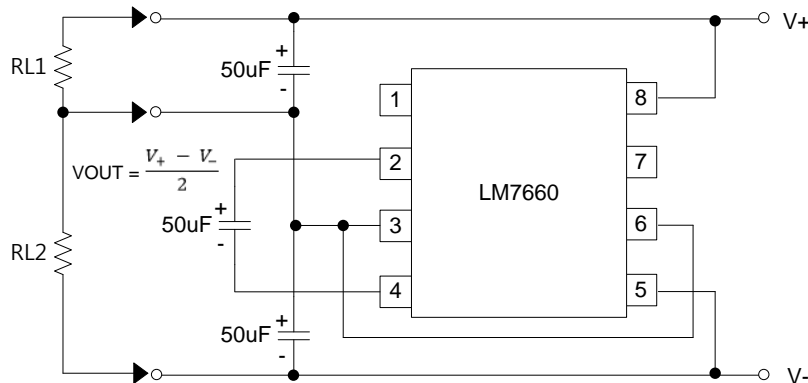


Figure 21. Splitting a Supply in Half



## REVISION NOTICE

The description in this datasheet is subject to change without any notice to describe its electrical characteristics properly.