INTERSIL

ICL7660

Monolithic MAXCMOS® Voltage Converter

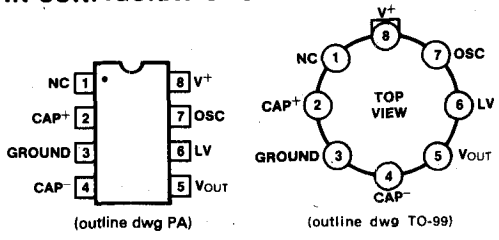
FEATURES

- **Simple Conversion of +5V Logic Supply to ±5V Supplies**
- **Simple Voltage Multiplication (V_{OUT} = (−) nV_{IN})**
- **99.9% Typical Open Circuit Voltage Conversion Efficiency**
- **98% Typical Power Efficiency**
- **Wide Operating Voltage Range 1.5V to 10.0V**
- **Easy to use - Requires only 2 External Non-Critical Passive Components**

APPLICATIONS

- On Board Negative Supply for up to 64 Dynamic RAMs.
- Localized μ-Processor (8080 type) Negative Supplies
- Inexpensive Negative Supplies
- Data Acquisition Systems

PIN CONFIGURATIONS



(outline dwg PA) (outline dwg TO-99)

ORDERING INFORMATION

PART NUMBER	TEMP. RANGE	PACKAGE
ICL7660CTY	-20° to +70°C	TO-99
ICL7660CPA	-20° to +70°C	8 PIN MINI DIP
ICL7660MTY	-55° to +125°C	TO-99
ICL7660/D		DICE

GENERAL DESCRIPTION

The Intersil ICL7660 is a monolithic MAXCMOS® power supply circuit which offers unique performance advantages over previously available devices. The ICL7660 performs the complete supply voltage conversion from positive to negative for an input range of +1.5V to +10.0V, resulting in complementary output voltages of −1.5 to −10.0V with the addition of only 2 non-critical external capacitors needed for the charge pump and charge reservoir functions. Note that an additional diode is required for V_{SUPPLY} >6.5V.

Contained on chip are a series DC power supply regulator, RC oscillator, voltage level translator, four output power MOS switches, and a unique logic element which senses the most negative voltage in the device and ensures that the output N-channel switches are not forward biased. This assures latch-up free operation.

The oscillator, when unloaded, oscillates at a nominal frequency of 10kHz for an input supply voltage of 5.0 volts. 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 (+3.5 to +10.0 volts), the LV pin is left floating to prevent device latchup.

Typical applications for the ICL7660 will be data acquisition and microprocessor based systems where there is a +5 volt supply available for the digital functions and an additional −5 volt supply is required for the analog functions. The ICL7660 is also ideally suited for providing low current, −5V body bias supply for dynamic RAMs.

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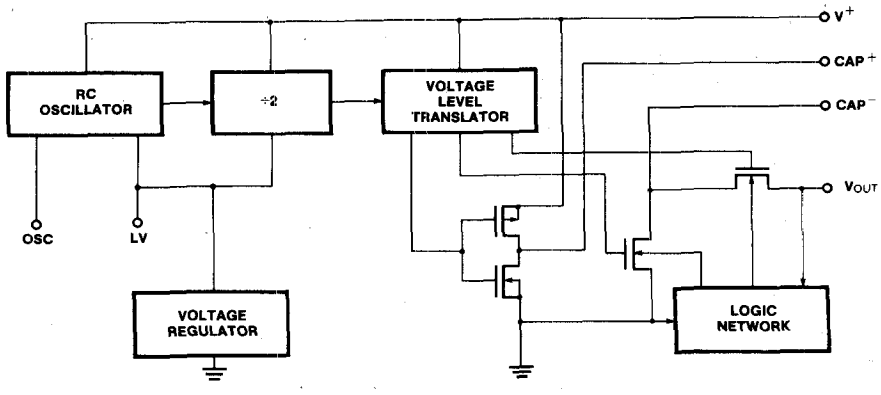
BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Supply Voltage 10.5V
Oscillator Input Voltage (Note 1) ..... −0.3V to (V^+ +0.3V) for V^+ < 5.5V
(V^+ −5.5V) to (V^+ +0.3V) for V^+ > 5.5V
−0.3V to (V^+ +0.3V) for V^+ < 3.5V
LV (Note 1) ..... No connection for V > 3.5V
Output Short Duration (V_{SUPPLY} ≤5.5V) ..... Continuous
Power Dissipation (Note 2)
ICL7660CTY 500mW
ICL7660CPA 300mW
ICL7660MTY 500mW

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

OPERATING CHARACTERISTICS

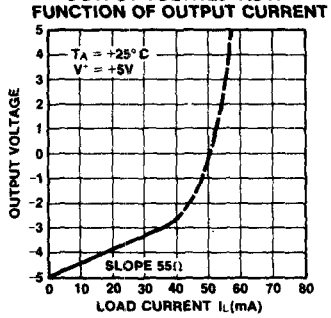
V^+ = 5V, T_A = 25°C, C_{OSC} = 0, Test Circuit Figure 1 (unless otherwise specified)

SYMBOL	PARAMETER	LIMITS MIN.	TYP.	MAX.	UNIT	TEST CONDITIONS
I^+	Supply Current		170	500	μA	R_L = ∞
V^+_{H1}	Supply Voltage Range - Hi (Dx out of circuit)	3.0		6.5	V	0°C ≤ T_A ≤ 70°C, R_L = 10kΩ, LV = No Connection
		3.0		5.0	V	−55°C ≤ T_A ≤ 125°C, R_L = 10kΩ, LV = Ground
V^+_{L1}	Supply Voltage Range - Lo (Dx out of circuit)	1.5		3.5	V	MIN ≤ T_A ≤ MAX, R_L = 10kΩ, LV = Ground
V^+_{H2}	Supply Voltage Range - Hi (Dx in circuit)	3.0		10.0	V	MIN ≤ T_A ≤ MAX, R_L = 10kΩ, LV = No Connection
V^+_{L2}	Supply Voltage Range - Lo (Dx in circuit)	1.5		3.5	V	MIN ≤ T_A ≤ MAX, R_L = 10kΩ, LV = Ground
R_{OUT}	Output Source Resistance		55	100	Ω	I_{OUT} = 20mA, T_A = 25°C
				120	Ω	I_{OUT} = 20mA, −20°C ≤ T_A ≤ +70°C
				150	Ω	I_{OUT} = 20mA, −55°C ≤ T_A ≤ +125°C
				300	Ω	V^+ = 2V, I_{OUT} = 3mA, LV = Ground, −20°C ≤ T_A ≤ +70°C
				400	Ω	V^+ = 2V, I_{OUT} = 3mA, LV = Ground, −55°C ≤ T_A ≤ +125°C, Dx in circuit
f_{OSC}	Oscillator Frequency		10		kHz	
P_{Ef}	Power Efficiency	95	98		%	R_L = 5kΩ
$V_{OUT\ Ef}$	Voltage Conversion Efficiency	97	99.9		%	R_L = ∞
Z_{OSC}	Oscillator Impedance		1.0		MΩ	V^+ = 2 Volts
			100		kΩ	V^+ = 5 Volts

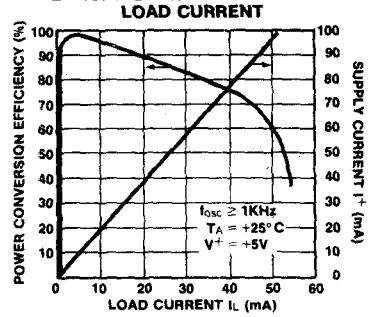
Notes: 1. Connecting any terminal to voltages greater than V^+ or less than GROUND may cause destructive latchup. It is recommended that no inputs from sources operating from external supplies be applied prior to "power up" of the ICL7660.
2. Derate linearly above 50°C by 5.5mW/°C.

TYPICAL PERFORMANCE CHARACTERISTICS

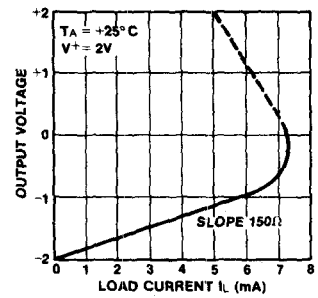
OUTPUT VOLTAGE AS A FUNCTION OF OUTPUT CURRENT



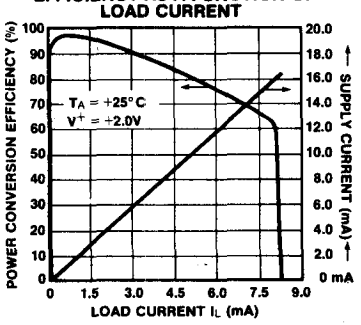
SUPPLY CURRENT & POWER CONVERSION EFFICIENCY AS A FUNCTION OF LOAD CURRENT



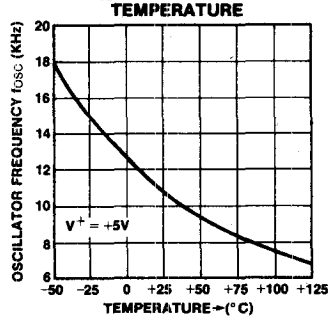
OUTPUT VOLTAGE AS A FUNCTION OF OUTPUT CURRENT



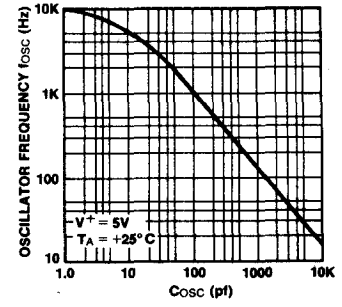
SUPPLY CURRENT POWER CONVERSION EFFICIENCY AS A FUNCTION OF LOAD CURRENT



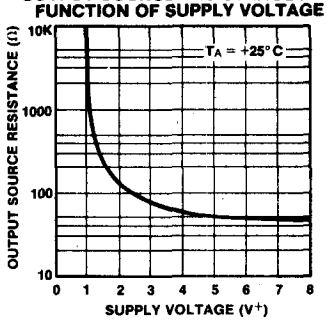
UNLOADED OSCILLATOR FREQUENCY AS A FUNCTION OF TEMPERATURE



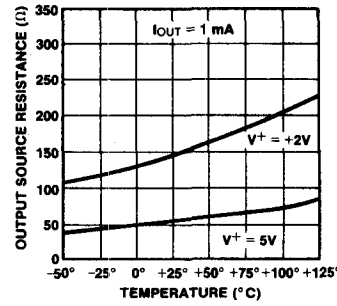
FREQUENCY OF OSCILLATION AS A FUNCTION OF EXTERNAL OSC. CAPACITANCE



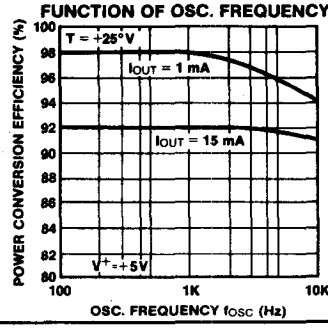
OUTPUT SOURCE RESISTANCE AS A FUNCTION OF SUPPLY VOLTAGE



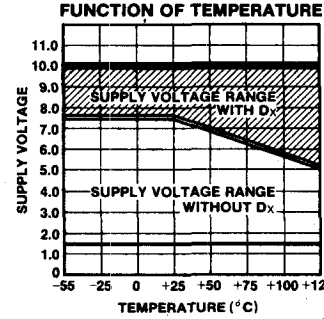
OUTPUT SOURCE RESISTANCE AS A FUNCTION OF TEMPERATURE

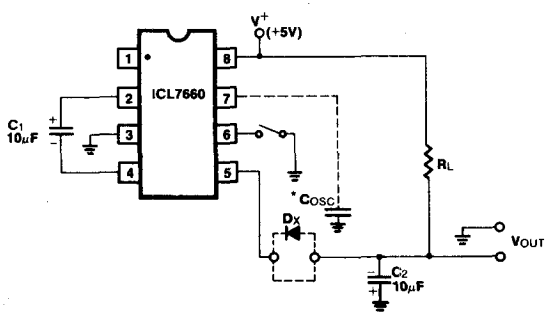


POWER CONVERSION EFFICIENCY AS A FUNCTION OF OSC. FREQUENCY



OPERATING VOLTAGE AS A FUNCTION OF TEMPERATURE





NOTES: 1. For large value of COSC (>1000pF) the values of C_1 and C_2 should be increased to 100μF.
2. DX is required for supply voltages greater than 6.5V @ −55° ≤ TA ≤ +70°C; refer to performance curves for additional information.

Figure 1: ICL7660 Test Circuit

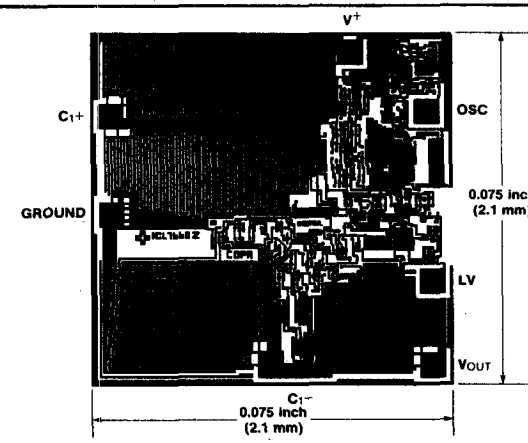


Figure 2: Chip Topography

CIRCUIT DESCRIPTION

The ICL7660 contains all the necessary circuitry to complete a voltage doubler, with the exception of 2 external capacitors which may be inexpensive 10μF polarized electrolytic capacitors. The mode of operation of the device may be best understood by considering Figure 3, which shows an idealized voltage doubler. 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 ICL7660 approaches this ideal situation more closely than existing non-mechanical circuits.

In the ICL7660, the 4 switches in Figure 3 are MOS power switches; S_1 is a P-channel device and S_2, S_3 & S_4 are N-channel devices. The main difficulty with this approach is that in integrating the switches, the substrates of S_3 & 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 startup, 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 latchup.

This problem is eliminated in the ICL7660 by a logic network which senses the output voltage (V_{OUT}) together with the level translators and switches the substrates or S_3 & S_4 to the correct level to maintain necessary reverse bias.

The voltage regulator portion of the ICL7660 is an integral part of the anti-latchup circuitry, however it's 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 3.5 volts the LV terminal must be left open to insure latchup proof operation, and prevent device damage.

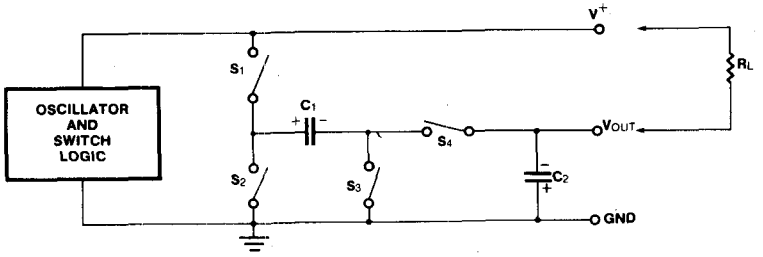


Figure 3: Idealized Voltage Doubler

THEORETICAL POWER EFFICIENCY CONSIDERATIONS

In theory a voltage multiplier can approach 100% efficiency if certain conditions are met:

A The drive circuitry consumes minimal power
B The output switches have extremely low ON resistance and virtually no offset.
C The impedances of the pump and reservoir capacitors are negligible at the pump frequency.

The ICL7660 approaches these conditions for negative voltage multiplication 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 Fig. 3) 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.

DO'S AND DON'TS

1 Do not exceed maximum supply voltages.
2 Do not connect LV terminal to GROUND for supply voltages greater than 3.5 volts.
3 Do not short circuit the output to V^+ supply for supply voltages above 5.5 volts for extended periods, however, transient conditions including startup are okay.
4 When using polarized capacitors, the + terminal of C_1 must be connected to pin 2 of the ICL7660 and the + terminal of C_2 must be connected to GROUND.
5 Add diode D_X as shown in Fig. 1 for hi-voltage, elevated temperature applications.

CONSIDERATIONS FOR HI VOLTAGE & ELEVATED TEMPERATURE

The ICL7660 will operate efficiently over its specified temperature range with only 2 external passive components (storage & pump capacitors), provided the operating supply voltage does not exceed 6.5 volts at +70°C and 5.0 volts at +125°C. Exceeding these maximums at the temperatures indicated may result in destructive latch-up of the ICL7660. (Ref: Graph "Operating Voltage Vs. Temperature")

Operation at supply voltages of up to 10.0 volts over the full temperature range without danger of latch-up can be achieved by adding a general purpose diode in series with the ICL7660 output, as shown by "D_X" in the circuit diagrams. The effect of this diode on overall circuit performance is the reduction of output voltage by one diode drop (approximately 0.6 volts).

TYPICAL APPLICATIONS

1. Simple Negative Voltage Converter

The majority of applications will undoubtedly utilize the ICL7660 for generation of negative supply voltages. Figure 4 shows typical connections to provide a negative supply where a positive supply is available. A similar scheme may be employed for supply voltages anywhere in the operating range of +1.5V to +10.0 volts, keeping in mind that pin 6 (LV) is tied to the supply negative (GND) only for supply voltages below 3.5 volts, and that diode D_X must be included for proper operation at higher voltages and/or elevated temperatures.

The output characteristics of the circuit in Figure 4 are those of a nearly ideal voltage source in series with 70 ohms. Thus for a load current of −10mA and a supply voltage of +5 volts, the output voltage will be −4.3 volts. The dynamic output impedance due to the capacitor impedances is $1/\omega C$ where

$$C = C_1 = C_2$$

giving $$\frac{1}{\omega C} = \frac{1}{2\pi f_{OSC} \times 10^{-5}} = 3 \text{ ohms}$$

for $C = 10\mu F$ and $f_{OSC} = 5kHz$ (1/2 of oscillator frequency)

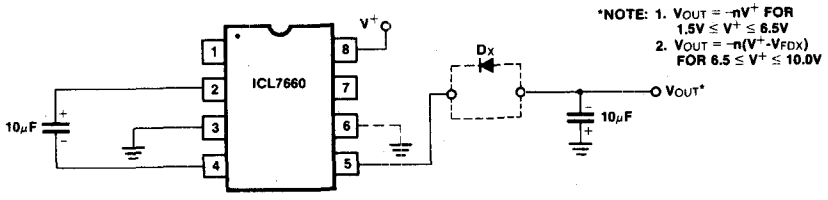


Figure 4: Simple Negative Converter

2. Paralleling Devices

Any number of ICL7660 voltage convertors 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

$$R_{OUT} = \frac{R_{OUT} \text{ (of ICL7660)}}{n \text{ (number of devices)}}$$

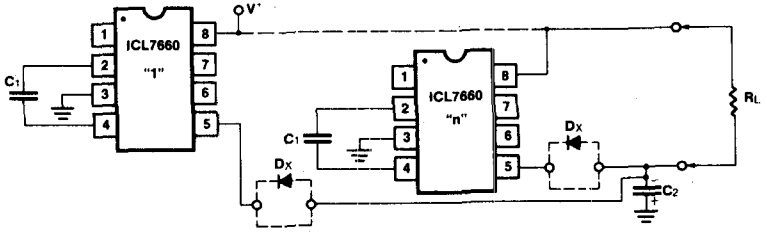


Figure 5: Paralleling Devices

3. Cascading Devices

The ICL7660 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 ICL7660 R_{OUT} values.

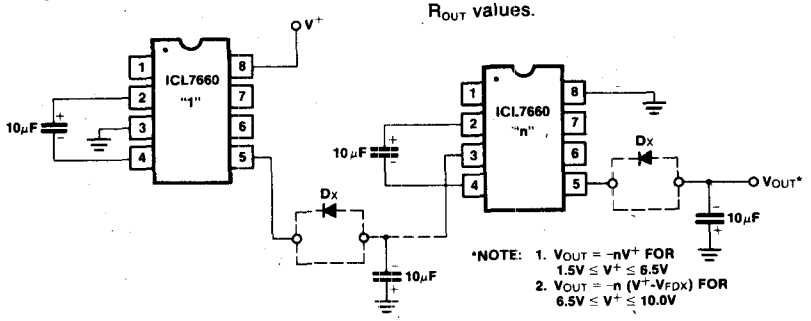


Figure 6: Cascading Devices for Increased Output Voltage

4. Changing the ICL7660 Oscillator 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 7. In order to prevent possible device latchup, a 1kΩ resistor must be used in series with the clock output. In the situation where the designer has generated the external clock frequency using TTL logic, the addition of a 10kΩ 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.

It is also possible to increase the conversion efficiency of the ICL7660 at low load levels by lowering the oscillator frequency. This reduces the switching losses, and is achieved by connecting an additional capacitor, C_{OSC}, as shown in Figure 8. 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 10μF to 100μF).

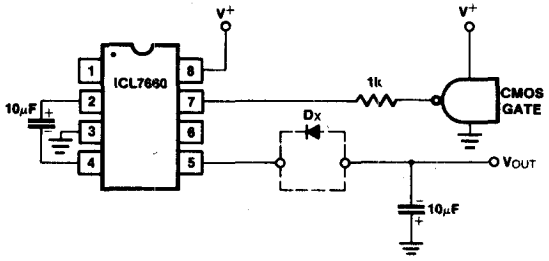


Figure 7: External Clocking

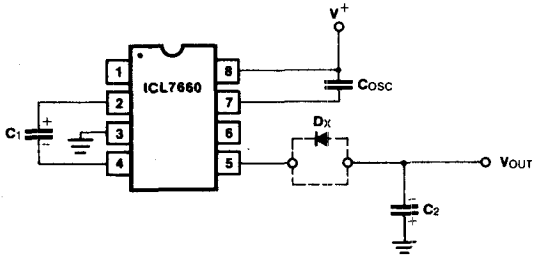


Figure 8: Lowering Oscillator Frequency

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5. Positive Voltage Multiplication

The ICL7660 may be employed to achieve positive voltage multiplication using the circuit shown in Figure 9. In this application, the pump inverter switches of the ICL7660 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 $V^+ = 5$ volts and an output current of 10mA it will be approximately 60 ohms.

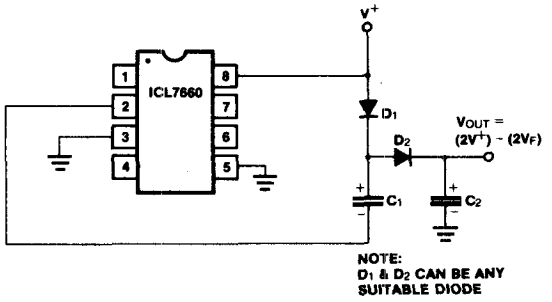

Figure 9: Positive Voltage Multiplier

6. Combined Negative Voltage Conversion and Positive Supply Multiplication

Figure 10 combines the functions shown in Figures 4 and 9 to provide negative voltage conversion and positive voltage multiplication simultaneously. This approach would be, for example, suitable for generating +9 volts and −5 volts from an existing +5 volt supply. In this instance capacitors C_1 and C_3 perform the pump and reservoir functions respectively for the generation of the negative voltage, while capacitors C_2 and C_4 are pump and reservoir respectively for the multiplied 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.

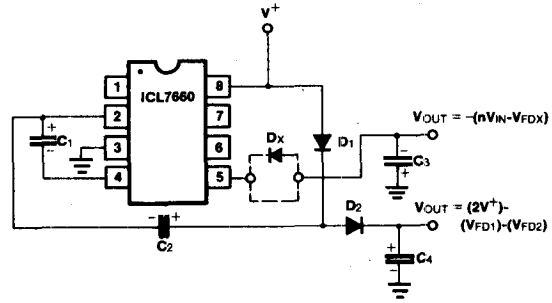

Figure 10: Combined Negative Converter and Positive Multiplier