

Chopper Stabilized Operational Amplifier

Features

- Low Input Offset Voltage: 0.7 μ V Typ
- Low Input Offset Voltage Drift: 0.05 μ V/ $^{\circ}$ C Max
- Low Input Bias Current: 10pA Max
- High Impedance Differential CMOS Inputs: 10¹² Ω
- High Open Loop Voltage Gain: 120dB Min.
- Low Input Noise Voltage: 2.0 μ Vp-p
- High Slew Rate: 2.5V/ μ sec.
- Low Power Operation: 20mW
- Output Clamp Speeds Recovery Time
- Compensated Internally for Stable Unity Gain Operation
- Direct Replacement for ICL7650
- Available in 8-Pin Plastic DIP and 14-Pin Plastic DIP Packages

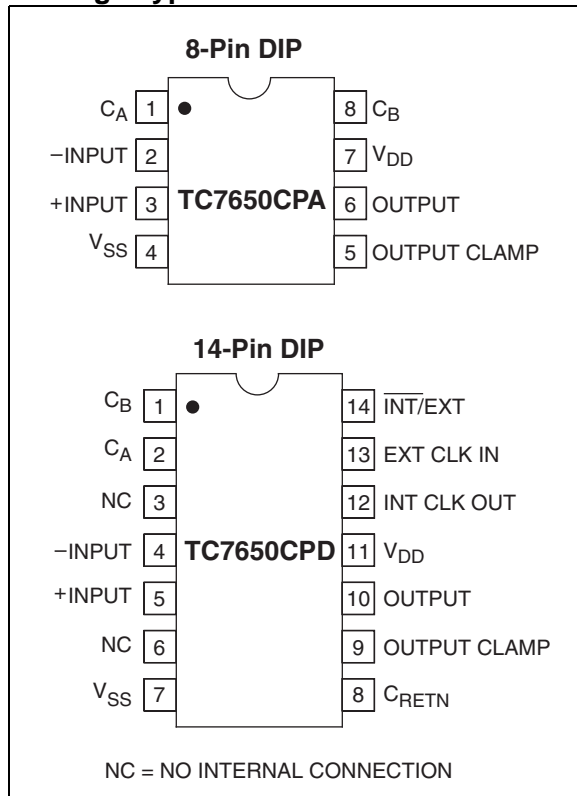
Applications

- Instrumentation
- Medical Instrumentation
- Embedded Control
- Temperature Sensor Amplifier
- Strain Gage Amplifier

Device Selection Table

Part Number	Package	Temperature Range	Max V _{OS}
TC7650CPA	8-Pin PDIP	0 $^{\circ}$ C to +70 $^{\circ}$ C	5 μ V
TC7650CPD	14-Pin PDIP	0 $^{\circ}$ C to +70 $^{\circ}$ C	5 μ V

Package Type



The TC7650 CMOS chopper stabilized operational amplifier practically removes offset voltage error terms from system error calculations. The $5\mu\text{V}$ maximum V_{OS} specification, for example, represents a 15 times improvement over the industry standard OP07E. The $50\text{nV}/^\circ\text{C}$ offset drift specification is over 25 times lower than the OP07E. The increased performance eliminates V_{OS} trim procedures, periodic potentiometer adjustment and the reliability problems caused by damaged trimmers.

Functional Block Diagram

The 14-pin dual-in-line package (DIP) has an external oscillator input to drive the nulling circuitry for optimum noise performance. Both the 8 and 14-pin DIPs have an output voltage clamp circuit to minimize overload recovery time.



1.0 ELECTRICAL CHARACTERISTICS

ABSOLUTE MAXIMUM RATINGS*

Total Supply Voltage (V_{DD} to V_{SS})	+18V
Input Voltage	($V_{DD} + 0.3V$) to ($V_{SS} - 0.3V$)
Storage Temperature Range	-65°C to +150°C
Voltage on Oscillator Control Pins	V_{DD} to V_{SS}
Duration of Output Short Circuit	Indefinite
Current Into Any Pin	10mA
While Operating (Note 3)	100μA
Package Power Dissipation ($T_A \leq 70^\circ\text{C}$)	
8-Pin Plastic DIP	730mW
14-Pin Plastic DIP	800mW
Operating Temperature Range	
C Device	0°C to +70°C

*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 operation sections of the specifications is not implied. Exposure to Absolute Maximum Rating conditions for extended periods may affect device reliability.

TC7652 ELECTRICAL SPECIFICATIONS

Electrical Characteristics: $V_{DD} = +5V$, $V_{SS} = -5V$, $C_A = C_B = 0.1\mu F$, $T_A = +25^\circ\text{C}$, unless otherwise indicated.						
Symbol	Parameter	Min.	Typ	Max	Units	Test Conditions
Input						
V_{OS}	Input Offset Voltage	—	± 0.7 ± 1.0	± 5 —	— μV	$T_A = +25^\circ\text{C}$ Over Operating Temp Range
$\Delta V_{OS}/\Delta T$	Input Offset Voltage Average Temperature Coefficient	—	0.01	0.05	μV/°C	Operating Temperature Range
	Offset Voltage vs. Time	—	100	—	nV/ month	
I_{BIAS}	Input Bias Current	—	1.5 35 100	10 150 400	pA pA pA	$T_A = +25^\circ\text{C}$ $0^\circ\text{C} \leq T_A \leq +70^\circ\text{C}$ $-25^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$
I_{OS}	Input Offset Current	—	0.5	—	pA	
e_{NP-P}	Input Noise Voltage	—	2	—	μV _{P-P}	$R_S = 100\Omega$, 0 to 10Hz
I_N	Input Noise Current	—	0.01	—	pA/√Hz	f = 10Hz
R_{IN}	Input Resistance	—	10^{12}	—	Ω	
CMVR	Common Mode Voltage Range	-5	-5.2 to +2	+1.6	V	
CMRR	Common Mode Rejection Ratio	120	130	—	dB	CMVR = -5V to +1.5V
Output						
A	Large Signal Voltage Gain	120	130	—	dB	$R_L = 10k\Omega$
V_{OUT}	Output Voltage Swing (Note 2)	± 4.7 —	± 4.85 ± 4.95	— —	v v	$R_L = 10k\Omega$ $R_L = 100k\Omega$
	Clamp ON Current	25	70	200	μA	$R_L = 100k\Omega$ (Note 1)
	Clamp OFF Current	—	1	—	pA	$-4V < V_{OUT} < +4V$ (Note 1)
Dynamic						
B_W	Unity Gain Bandwidth	—	2.0	—	MHz	Unity Gain (+1)
S_R	Slew Rate	—	2.5	—	V/μsec	$C_L = 50pF$, $R_L = 10k\Omega$
t_R	Rise Time	—	0.2	—	μsec	
	Overshoot	—	20	—	%	
f_{CH}	Internal Chopping Frequency	120	200	375	Hz	Pins 12–14 Open (DIP)
Supply						
V_{DD} , V_{SS}	Operating Supply Range	4.5	—	16	V	
I_S	Supply Current	—	2	3.5	mA	No Load
PSRR	Power Supply Rejection Ratio	120	130	—	dB	$V_S = \pm 3V$ to $\pm 8V$

- Note** 1: See "Output Clamp" discussion.
2: Output clamp not connected. See typical characteristics curves for output swing versus clamp current characteristics.
3: Limiting input current to 100μA is recommended to avoid latch-up problems.

2.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in Table 2-1.

TABLE 2-1: PIN FUNCTION TABLE

Pin Number		Symbol	Description
8-pin DIP	14-pin DIP		
1,8	2,1	C _A , C _B	Nulling capacitor pins
2	4	-INPUT	Inverting Input
3	5	+INPUT	Non-inverting Input
4	7	V _{SS}	Negative Power Supply
5	9	OUTPUT CLAMP	Output Voltage Clamp
6	10	OUTPUT	Output
7	11	V _{DD}	Positive Power Supply
—	3,6	NC	No internal connection
—	8	C _{RETN}	Capacitor current return pin
—	12	INT CLK OUT	Internal Clock Output
—	13	EXT CLK IN	External Clock Input
—	14	INT/EXT	Select Internal or External Clock

3.0 DETAILED DESCRIPTION

3.1 Theory of Operation

Figure 3-1 shows the major elements of the TC7650. There are two amplifiers (the main amplifier and the nulling amplifier), and both have offset null capability. The main amplifier is connected full-time from the input to the output. The nulling amplifier, under the control of the chopping frequency oscillator and clock circuit, alternately nulls itself and the main amplifier. Two external capacitors provide the required storage of the nulling potentials and the necessary nulling loop time constants. The nulling arrangement operates over the full common mode and power supply ranges, and is also independent of the output level, thus giving exceptionally high CMRR, PSRR and A_{VOL}.

Careful balancing of the input switches minimizes chopper frequency charge injection at the input terminals, and the feed forward type injection into the compensation capacitor that can cause output spikes in this type of circuit.

The circuit's offset voltage compensation is easily shown. With the nulling inputs shorted, a voltage almost identical to the nulling amplifier offset voltage is stored on C_A. The effective offset voltage at the null amplifier input is:

EQUATION 3-1:

$$V_{OSE} = \frac{1}{A_N + 1} V_{OSN}$$

After the nulling amplifier is zeroed, the main amplifier is zeroed; the A switches open and B switches close.

The output voltage equation is:

EQUATION 3-2:

$$V_{OUT} = A_M[V_{OSM} + (V^+ - V^-) + A_N(V^+ - V^-) + A_N V_{OSE}]$$

EQUATION 3-3:

$$V_{OUT} = A_M A_N \left[(V^+ - V^-) + \frac{V_{OSM} + V_{OSN}}{A_N} \right]$$

As desired, the device offset voltages are reduced by the high open loop gain of the nulling amplifier.

3.2 Output Stage/Loading

The output circuit is a high impedance stage (approximately 18kΩ). With loads less than this, the chopper amplifier behaves in some ways like a trans-conductance amplifier whose open-loop gain is proportional to load resistance. For example, the open loop gain will be 17dB lower with a 1kΩ load than with a 10kΩ load. If the amplifier is used strictly for DC, the lower gain is of little consequence, since the DC gain is typically greater than 120dB, even with a 1kΩ load. In wideband applications, the best frequency response will be achieved with a load resistor of 10kΩ or higher. This results in a smooth 6dB/octave response from 0.1Hz to 2MHz, with phase shifts of less than 10° in the transi-

tion region, where the main amplifier takes over from the null amplifier. The clock frequency sets the transition region.

3.3 Intermodulation

Previous chopper stabilized amplifiers have suffered from intermodulation effects between the chopper frequency and input signals. These arise because the finite AC gain of the amplifier results in a small AC signal at the input. This is seen by the zeroing circuit as an error signal, which is chopped and fed back, thus inject-

ing sum and difference frequencies, and causing disturbances to the gain and phase versus frequency characteristics near the chopping frequency. These effects are substantially reduced in the TC7650 by feeding the nulling circuit with a dynamic current corresponding to the compensation capacitor current in such a way as to cancel that portion of the input signal due to a finite AC gain. The intermodulation and gain/phase disturbances are held to very low values, and can generally be ignored.

FIGURE 3-1: TC7650 CONTAINS A NULLING AND MAIN AMPLIFIER. OFFSET CORRECTION VOLTAGES ARE STORED ON TWO EXTERNAL CAPACITORS.

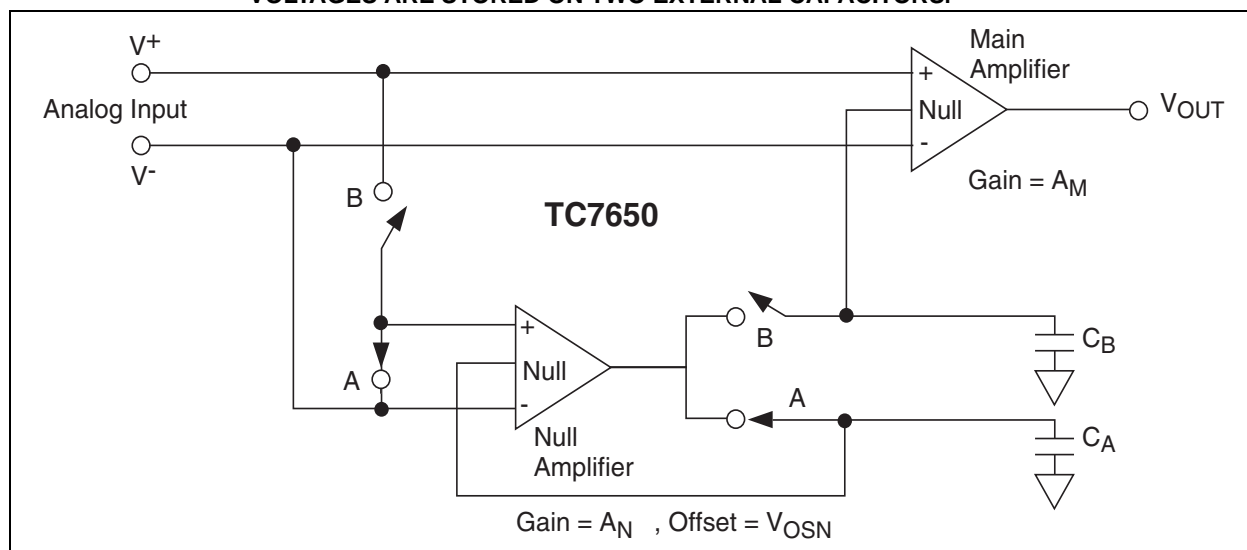
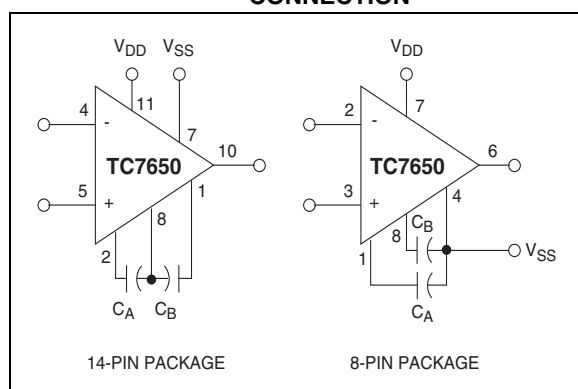


FIGURE 3-2: NULLING CAPACITOR CONNECTION



3.4 Nulling Capacitor Connection

The offset voltage correction capacitors are connected to C_A and C_B . The common capacitor connection is made to V_{SS} (Pin 4) on the 8-pin packages and to capacitor return (C_{RETN} , Pin 8) on the 14-pin packages. The common connection should be made through a separate PC trace or wire to avoid voltage drops. The capacitors outside foil, if possible, should be connected to C_{RETN} or V_{SS} .

3.5 Clock Operation

The internal oscillator is set for a 200Hz nominal chopping frequency on both the 8- and 14-pin DIPs. With the 14-pin DIP TC7650, the 200 Hz internal chopping frequency is available at the internal clock output (Pin 12). A 400Hz nominal signal will be present at the external clock input pin (Pin 13) with INT/EXT high or open. This is the internal clock signal before a divide-by-two operation.

The 14-pin DIP device can be driven by an external clock. The INT/EXT input (Pin 14) has an internal pull-up and may be left open for internal clock operation. If an external clock is used, INT/EXT must be tied to V_{SS} (Pin 7) to disable the internal clock. The external clock signal is applied to the external clock input (Pin 13).

The external clock amplitude should swing between V_{DD} and ground for power supplies up to $\pm 6V$ and between V^+ and $V^+ - 6V$ for higher supply voltages.

At low frequencies the external clock duty cycle is not critical, since an internal divide-by-two gives the desired 50% switching duty cycle. The offset storage correction capacitors are charged only when the external clock input is high. A 50% to 80% external clock

TC7650

positive duty cycle is desired for frequencies above 500Hz to ensure transients settle before the internal switches open.

The external clock input can also be used as a strobe input. If a strobe signal is connected at the external clock input so that it is LOW during the time an overload signal is applied, neither capacitor will be charged. The leakage currents at the capacitors pins are very low. At 25°C a typical TC7650 will drift less than 10μV/sec.

3.6 Output Clamp

Chopper-stabilized systems can show long recovery times from overloads. If the output is driven to either supply rail, output saturation occurs. The inputs are no longer held at a "virtual ground." The V_{OS} null circuit treats the differential signal as an offset and tries to correct it by charging the external capacitors. The nulling circuit also saturates. Once the input signal returns to normal, the response time is lengthened by the long recovery time of the nulling amplifier and external capacitors.

Through an external clamp connection, the TC7650 eliminates the overload recovery problem by reducing the feedback network gain before the output voltage reaches either supply rail.

FIGURE 3-3: INTERNAL CLAMP CIRCUIT

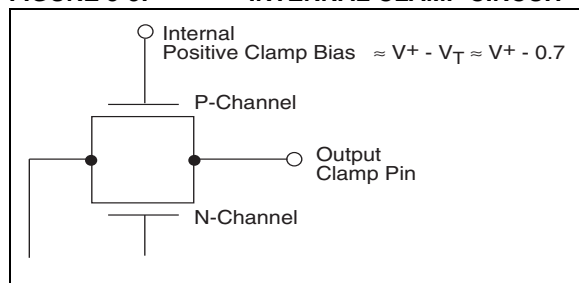


FIGURE 3-4: NON-INVERTING AMPLIFIER WITH OPTIONAL CLAMP

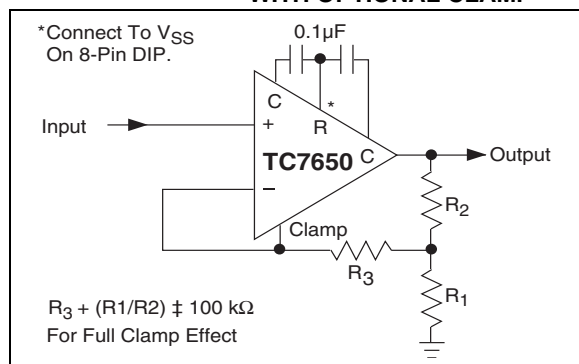
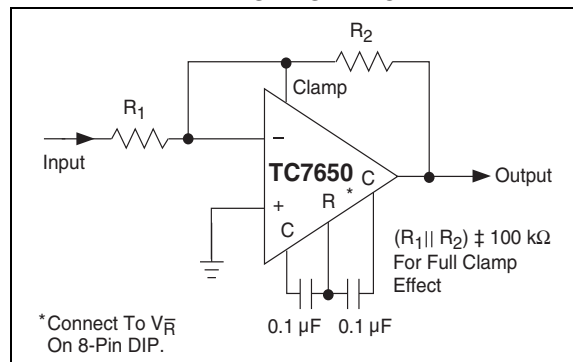


FIGURE 3-5: INVERTING AMPLIFIER WITH OPTIONAL CLAMP



The output clamp circuit is shown in Figure 3-3, with typical inverting and non-inverting circuit connections shown in Figures 3-4 and 3-5. Output voltage versus clamp circuit current characteristics are shown in the typical operating curves. For the clamp to be fully effective, the impedance across the clamp output should be greater than 100kΩ.

3.7 Latch-Up Avoidance

Junction-isolated CMOS circuits inherently include a parasitic 4-layer (p-n-p-n) structure which has characteristics similar to an SCR. Under certain circumstances this junction may be triggered into a low-impedance state, resulting in excessive supply current. To avoid this condition, no voltage greater than 0.3V beyond the supply rails should be applied to any pin. In general, the amplifier supplies must be established either at the same time or before any input signals are applied. If this is not possible, the drive circuits must limit input current flow to under 0.1mA to avoid latch-up.

3.8 Thermoelectric Potentials

Precision DC measurements are ultimately limited by thermoelectric potentials developed in thermocouple junctions of dissimilar metals, alloys, silicon, etc. Unless all junctions are at the same temperature, thermoelectric voltages, typically around 0.1μV/°C, but up to tens of μV/°C for some materials, will be generated. In order to realize the benefits extremely-low offset voltages provide, it is essential to take special precautions to avoid temperature gradients. All components should be enclosed to eliminate air movement, especially those caused by power dissipating elements in the system. Low thermoelectric co-efficient connections should be used where possible and power supply voltages and power dissipation should be kept to a minimum. High impedance loads are preferable, and separation from surrounding heat dissipating elements is advised.

3.9 Pin Compatibility

On the 8-pin mini-DIP TC7650, the external null storage capacitors are connected to pins 1 and 8. On most other operational amplifiers these are left open or are used for offset potentiometer or compensation capacitor connections.

For OP05 and OP07 operational amplifiers, the replacement of the offset null potentiometer between pins 1 and 8 by two capacitors from the pins to V_{SS} will convert the OP05/07 pin configurations for TC7650 operation. For LM108 devices, the compensation capacitor is replaced by the external nulling capacitors. The LM101/748/709 pinouts are modified similarly by removing any circuit connections to Pin 5. On the TC7650, Pin 5 is the output clamp connection.

Other operational amplifiers may use this pin as an offset or compensation point.

The minor modifications needed to retrofit a TC7650 into existing sockets operating at reduced power supply voltages make prototyping and circuit verification straightforward.

3.10 Input Guarding

High impedance, low leakage CMOS inputs allow the TC7650 to make measurements of high-impedance sources. Stray leakage paths can increase input currents and decrease input resistance unless inputs are guarded. A guard is a conductive PC trace surrounding the input terminals. The ring connects to a low impedance point at the same potential as the inputs. Stray leakages are absorbed by the low impedance ring. The equal potential between ring and inputs prevents input leakage currents. Typical guard connections are shown in Figure 3-6.

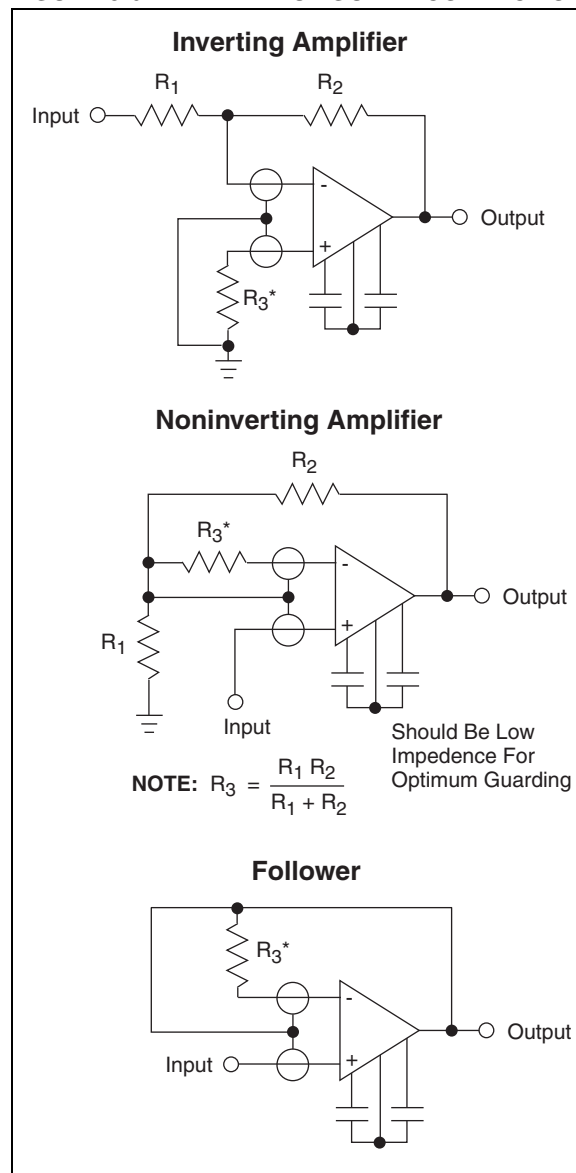
The 14-pin DIP configuration has been specifically designed to ease input guarding. The pins adjacent to the inputs are unused.

In applications requiring low leakage currents, boards should be cleaned thoroughly and blown dry after soldering. Protective coatings will prevent future board contamination.

3.11 Component Selection

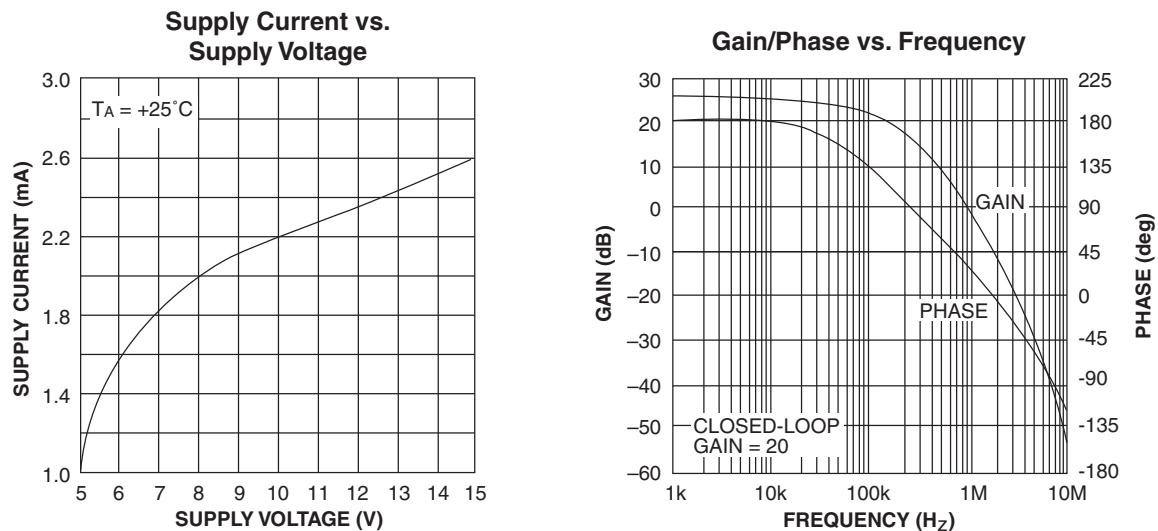
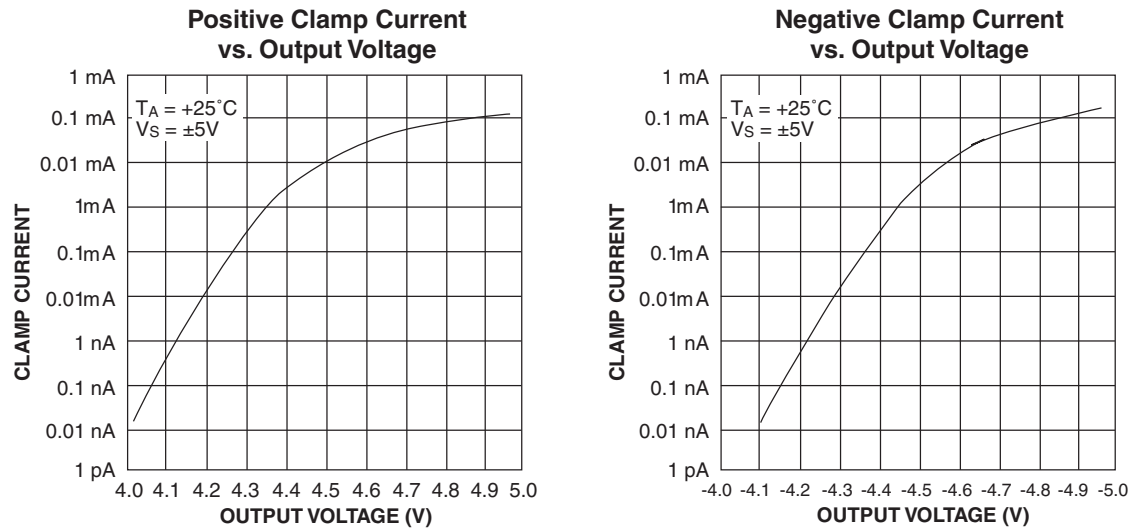
The two required capacitors, C_A and C_B , have optimum values, depending on the clock or chopping frequency. For the preset internal clock, the correct value is $0.1\mu\text{F}$. To maintain the same relationship between the chopping frequency and the nulling time constant, the capacitor values should be scaled in proportion to the external clock, if used. High quality film type capacitors (such as Mylar) are preferred; ceramic or other lower grade capacitors may be suitable in some applications. For fast settling on initial turn-on, low dielectric absorption capacitors (such as polypropylene) should be used. With ceramic capacitors, several seconds may be required to settle to $1\mu\text{V}$.

FIGURE 3-6: INPUT GUARD CONNECTION



4.0 TYPICAL CHARACTERISTICS

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.



6.0 REVISION HISTORY

Revision C (December 2012)

Added a note to each package outline drawing.

SALES AND SUPPORT

Data Sheets

Products supported by a preliminary Data Sheet may have an errata sheet describing minor operational differences and recommended workarounds. To determine if an errata sheet exists for a particular device, please contact one of the following:

1. Your local Microchip sales office
2. The Microchip Worldwide Site (www.microchip.com)

Please specify which device, revision of silicon and Data Sheet (include Literature #) you are using.

New Customer Notification System

Register on our web site (www.microchip.com/cn) to receive the most current information on our products.

TC7650

NOTES:

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILITY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, dsPIC, FlashFlex, KEELOQ, KEELOQ logo, MPLAB, PIC, PICmicro, PICSTART, PIC³² logo, rPIC, SST, SST Logo, SuperFlash and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, Hampshire, HI-TECH C, Linear Active Thermistor, MTP, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.


Analog-for-the-Digital Age, Application Maestro, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, dsPICworks, dsSPEAK, ECAN, ECONOMONITOR, FanSense, HI-TIDE, In-Circuit Serial Programming, ICSP, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, mTouch, Omniscent Code Generation, PICC, PICC-18, PICDEM, PICDEM.net, PICkit, PICtail, REAL ICE, rLAB, Select Mode, SQL, Serial Quad I/O, Total Endurance, TSHARC, UniWinDriver, WiperLock, ZENA and Z-Scale are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

GestIC and ULPP are registered trademarks of Microchip Technology Germany II GmbH & Co. & KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

© 2001-2012, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

 Printed on recycled paper.

ISBN: 9781620768402

QUALITY MANAGEMENT SYSTEM
CERTIFIED BY DNV
== ISO/TS 16949 ==

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
<http://www.microchip.com/support>
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

Santa Clara
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

Toronto
Mississauga, Ontario,
Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Chongqing
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

China - Hangzhou
Tel: 86-571-2819-3187
Fax: 86-571-2819-3189

China - Hong Kong SAR
Tel: 852-2943-5100
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8864-2200
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Osaka
Tel: 81-6-6152-7160
Fax: 81-6-6152-9310

Japan - Tokyo
Tel: 81-3-6880-3770
Fax: 81-3-6880-3771

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-5778-366
Fax: 886-3-5770-955

Taiwan - Kaohsiung
Tel: 886-7-213-7828
Fax: 886-7-330-9305

Taiwan - Taipei
Tel: 886-2-2508-8600
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

UK - Wokingham
Tel: 44-118-921-5869
Fax: 44-118-921-5820