MAXIM

1992 APPLICATIONS AND PRODUCT HIGHLIGHTS

Featuring:

- Flash EPROM Programmer Plus Adjustable LCD Supply
- Full-Function Portable Power Management
- Remotely-Powered Sensor Amp Using 1µA Op Amp
- Video, Power, and Channel Select Signals on a Single Coax
- Two Complete PC RS-232 Ports – One Chip
- DSP System Anti-Aliasing Using Continuous Active Filters
- Fault-Protected 8-Channel 18-Bit Dynamic Range A/D Circuit

. . . AND 40 MORE!

1992 ANALOG DESIGN GUIDE SERIES
Book 2

TABLE OF CONTENTS

COMPANY BRIEF:

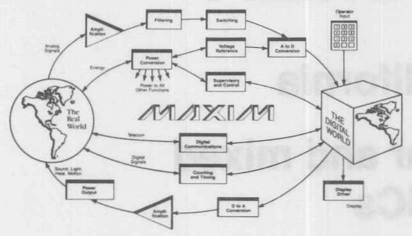
Corporate Office:	**Sunnyvale, California**
Markets:	**Precision linear and mixed analog-digital ICs**
Products:	**433 analog ICs including 220 proprietary products 90%CMOS based**
Sales:	**$19.6 million quarter ending 6/30/91**
Employees:	**505**
Profitable:	**Last 21 consecutive quarters**

MAXIM

MAXIM'S CLASS 10 WAFER FAB

- Reduces process development time
- Improves time to market for new products
- Capable of 1.2µ BiCMOS technology
- Foundries remain as major source of wafers
- Yield improvements reduce manufacturing costs and pricing
- Linear and mixed-signal process capability unsurpassed

MAXIM

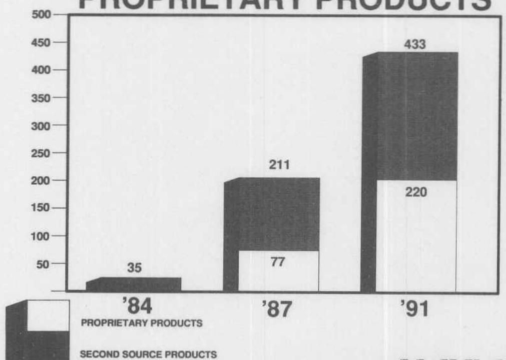


MAXIM

MAXIM HAS INTRODUCED MORE NEW PRODUCTS IN THE LAST 8 YEARS THAN ANY OTHER ANALOG COMPANY

MAXIM

GROWTH OF MAXIM PROPRIETARY PRODUCTS



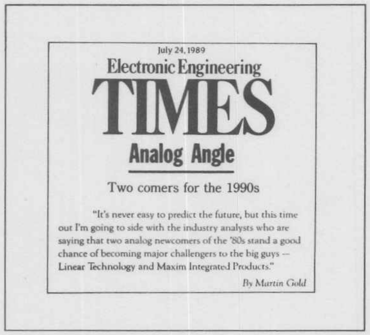
MAXIM

1990 EE TIMES SEMICONDUCTOR BRAND PREFERENCE STUDY

Top Technological Innovators

1. Intel
2. Motorola
3. Texas Instruments
4. AMD
5. Cypress
6. National Semiconductor
7. IDT
8. MAXIM

MAXIM


July 24, 1989

Electronic Engineering

TIMES

Analog Angle

Two comers for the 1990s

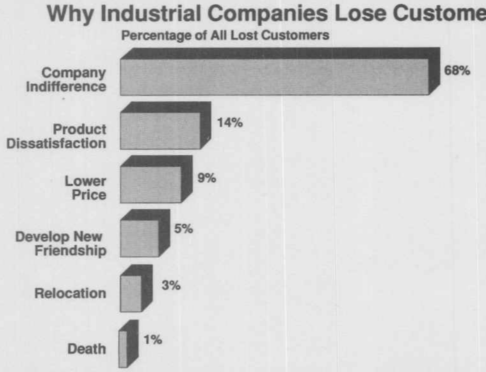
"It's never easy to predict the future, but this time out I'm going to side with the industry analysts who are saying that two analog newcomers of the '80s stand a good chance of becoming major challengers to the big guys — Linear Technology and Maxim Integrated Products."

By Martin Gold

MAXIM

THE VALUE OF CUSTOMER SATISFACTION

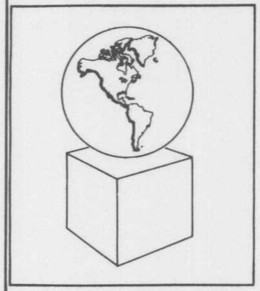
Why Industrial Companies Lose Customers



Source: The McKinsey Quarterly, Winter, 1990

MAXIM

MAXIM CHOSEN AS NICHE MARKET IC SUPPLIER OF THE YEAR FOR 1991



- DataQuest survey of purchasing management at top 250 electronics companies worldwide

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DataQuest Inc.
Presents to
MAXIM

Semiconductor Supplier of the Year Award, 1991
for
Excellence in Customer Service, Quality, Price, Delivery and Technical Support.

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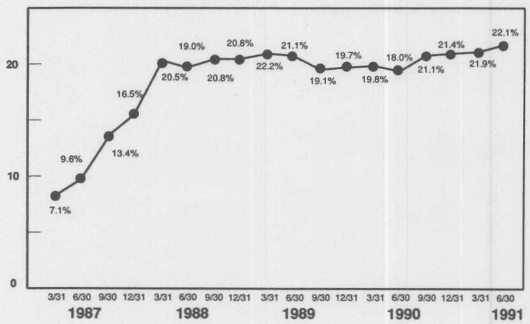
SIGNIFICANT 1990 SALES IN ALL WORLDWIDE MARKETS

- 43% United States
- 31% Europe
- 26% Japan / ROW

MAXIM

GROWTH IN OPERATING PROFIT MARGIN



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MAXIM RATED 67th OF THE BEST 100 SMALL GROWTH COMPANIES

BusinessWeek Magazine
05/27/91

MAXIM

The 200 Best Small Companies in America

What it takes to be the best

Almost 4,300 public U.S. corporations meet our definition of small—latest 12-month sales between $5 million and $350 million—but our stringent growth and quality requirements eliminated most of these contenders. We used a five-year time interval to test for consistency of earnings and sales growth.

The 200 Best Small Companies in America

Rank this year	Rank last year	Company/business	Return on equity 5-year average	Return on equity latest 12 mos	5-year EPS growth rate	Latest 12 mos sales (millions)	Latest 12 mos profits (millions)	Debt/equity	Quick ratio[1]	Recent stock price	Market value (mil)	Latest 12 mos EPS	Latest 12 mos P/E	Est 1990 EPS
157	*	**Maxim Integrated Prods** integrated circuits	13.9	20.2	125	56.0	7.6	13	1.26	8	97.4	0.58	14.0	0.79[3]

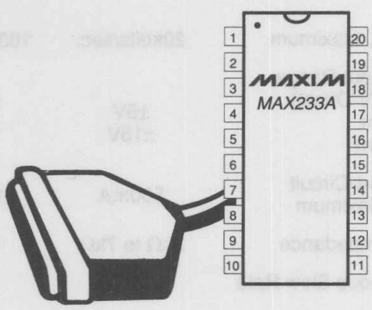
NOVEMBER 12, 1990

MAXIM

INTERFACE

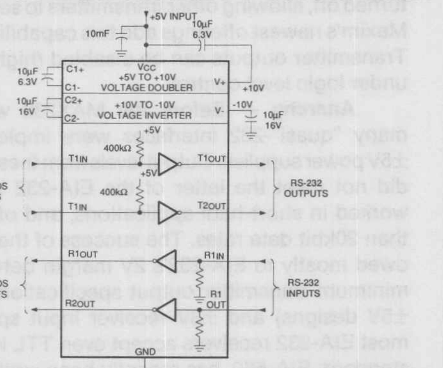
- **Increased Data Rate**
- **Low Power RS-232**
- **Simplify Cabling**
- **Multiple Serial Ports**
- **Isolation**

A COMPLETE DTE INTERFACE



MAXIM

WHY IC'S SPECIFICALLY FOR RS-232?



MAXIM

The RS-232 (as well as EIA-232 and V.28) standards, and the ICs designed to meet them, were created to provide a reliable low cost method for serial communication. Most 232 specs are targeted toward providing the necessary timing and voltage levels to drive "cheap" cables which have significant loss. Transmitters in Maxim's EIA-232 products take TTL or CMOS inputs and translate them to ±9V levels. This is done while running from only a +5V supply because patented charge pump circuitry generates the required supplies on-chip. Receivers convert RS-232 levels (between ±5V and ±15V) to those compatible with TTL or CMOS logic.

COMPARISON OF INTERFACE STANDARDS

	EIA-232E	EIA-423A	EIA-422A	RS-485	EIA-562
Mode of Operation	Single Ended	Single Ended	Differential	Differential	Single Ended
Allowed # of Tx and Rx per Data Line	1 Tx, 1 Rx	1 Tx, 1 Rx	1 Tx, 10 Rx	32 Tx, 32 Rx	1 Tx, 1 Rx
Cable Length, Maximum	C ≤ 2500pF	4kft	4kft	4kft	C ≤ 2500pF for ≤ 20kbits/sec C ≤ 1000pF for > 20kbits/sec
Data Rate, Maximum	20kbits/sec.	100kbits/sec.	10Mbits/sec.	10Mbits/sec.	64kbits/sec
Driver Output Range, Loaded (0V Offset): Minimum Maximum	±5V ±15V	±3.6V ±5.4V	±2V ±5V	±1.5V ±5V	±3.7V ±13.2V
Driver Short-Circuit Current, Maximum	500mA	150mA	150mA	250mA	60mA
TX Load Impedance	3kΩ to 7kΩ	450Ω	100Ω	54W	3kΩ to 7kΩ
Instantaneous Slew Rate	< 30V/µs	—	—	—	< 30V/µs
Rx Input Sensitivity	±3V	±200mV	±200mV	±200mV	±3V
Rx Input Resistance, Minimum	3kΩ to 7kΩ	4kΩ	4kΩ	12kΩ	3kΩ to 7kΩ
Rx Input Range	±25V	±12V	±7V	-7V to +12V	±25V

MAXIM

RS-232 (now EIA-232E) and V.28 dominate the serial interface world, but not without yielding to a few other interface standards when the application dictates. Previous reasons for choosing other interfaces are:

Speed — EIA232 defines only 20kbits/sec. However, many users routinely push this to 100kbits. Maxim's new RS232 devices guarantee 116kbits/sec

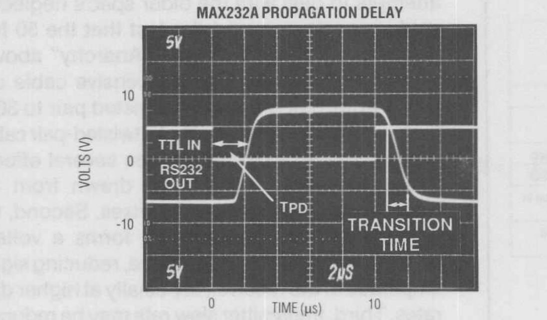
Supply Requirements — EIA-232 used to need three power supplies: +5V and ±12V, while other standards allowed more convenient ±5V or +5V supplies. The MAX232 and its offspring changed that by requiring only +5V to power any EIA-232 interface.

New 232 devices have cut supply current as well by either reducing operating current (MAX220), or by providing shutdown capability (several products). To further cut power, transmitter outputs turn off in shutdown so that line terminators cannot continue to draw current.

Shared Outputs — EIA-232, as written, does not acknowledge applications where more than one transmitter is connected to a line. Devices for other standards, designed for use in networks, have outputs which can be turned off, allowing other transmitters to send. Several of Maxim's newest offerings add this capability to EIA-232. Transmitter outputs can be disabled (high impedance) under logic level control

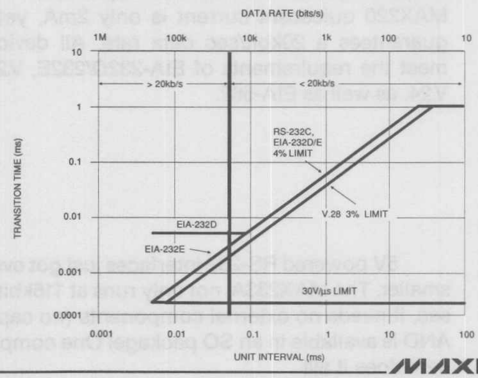
Anarchy — Before the MAX232 was invented, many "quasi"-232 interfaces were implemented with ±5V power supplies. Output levels from these transmitters did not meet the letter of the EIA-232 law, but they worked in short-haul applications, and often at higher than 20kbit data rates. The success of these designs is owed mostly to EIA-232's 2V margin between its ±5V minimum transmitter output specification (not met by ±5V designs) and ±3V receiver input spec (Actually, most EIA-232 receivers accept even TTL levels). A new standard, EIA-562, has recently been written, belatedly giving amnesty to "connectivity objectors". Consequently, EIA-562 is very similar to 232 except for driver output levels and data rate.

TRANSITION TIME AND PROP. DELAY



The EIA-232 and V.28 standards are nearly identical. The only significant differences relate to "transition time"; the time that outputs may take to swing from +3V to -3V, and vice versa. These limits are plotted in the graph for the EIA-232D, EIA-232E, and V.28 specs. The maximum allowed transition time is a function of data rate (expressed here as "unit interval" which equals 1/data rate). The minimum allowed transition time, 0.2µs, is set by all specs' 30V/µs max slew rate limit, which limits radiated noise. As the graph shows, V.28 requires slightly faster transitions than EIA-232, and EIA-232E maintains 232D's 4% limit at higher data rates. The portions of the graph beyond 20kbits/sec are extrapolations of the existing specs. Many of Maxim's newest EIA-232 drivers meet all standards out to 116kbits/sec.

TRANSITION TIME vs. DATA RATE



TRANSITION TIME vs. DATA RATE

	DATA RATE	UNIT INTERVAL (U.I.)	TRANSITION TIME
EIA-232E	≤ 40b/s	≥ 25ms	1ms
	40b/s to 8kb/s	25ms to 125µs	4% of U.I.
	> 8kb/s	< 125µs	4% (5µs, 232D)
V.28	≤ 30b/s	≥ 33ms	1ms
	> 30b/s	< 33ms	3% of U.I.

Part	Guaranteed kb/sec	External Caps (μF)	Supply Current (mA) max	Shutdown & Three-State	Features
MAX220	20	4.7/10	2	NO	Lowest Power
MAX222	116	0.1	10	YES	MAX232A + 10μA Shutdown Mode
MAX232A	116	0.1	10	NO	Guaranteed 116kbits/sec
MAX233A	116	NONE	10	NO	No ext. caps, avail. in SO
MAX242	116	0.1	10	YES	MAX222 + Receivers on in Shutdown
MAX243	116	0.1	10	NO	Same cable for 2 wire/4 wire—No Jumpers

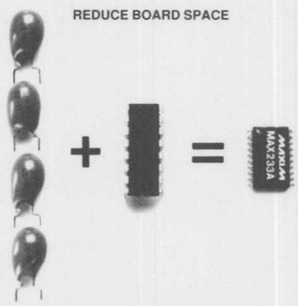
MAXIM

cable capacitance, and the fact that the 50 foot limit was often ignored (see "Anarchy" above). The capacitance/foot of inexpensive cable can range from 12pF for a single twisted pair to 30pF for low-noise, shielded, multiple-twisted-pair cable.

Increased capacitance has several effects. First, more output current is drawn from the transmitter, so supply current rises. Second, the transmitter output impedance forms a voltage divider with the cable impedance, reducing signal amplitude at the receiver, especially at higher data rates. Third, transmitter slew rate may be reduced, increasing transition time and limiting data rate.

The MAX222/232A/233A/242/243 are the only +5V powered EIA-232 transceivers to guarantee a 116kbit/sec data rate (200kb/sec typ) with full 2500pF/3kΩ loads. They use only 0.1μF charge-pump capacitors, except for the MAX233A, which requires no external capacitors. The MAX220 quiescent current is only 2mA, yet it guarantees a 20kbit/sec data rate. All devices meet the requirements of EIA-232D/232E, V.28/V.24, as well as EIA-562.

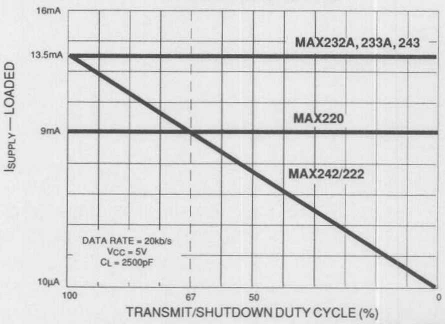
INTERNAL CAPS IN SO PACKAGE! MAX233A



MAXIM

5V powered RS-232 interfaces just got even smaller. The MAX233A not only runs at 116kbits/sec, it needs no external components (no caps) AND is available in an SO package! One component does it all!

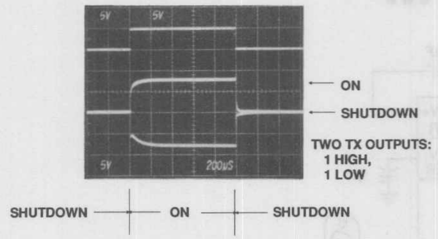
SAVE POWER WITH NEW RS-232 PRODUCTS



MAXIM

Minimum power consumption is frequent goal in many designs with serial interfaces. The graph illustrates two ways that supply can be cut. The MAX220 has the lowest supply current of any +5V powered EIA-232 transceiver. But, the MAX222 and MAX242 can sometimes beat it using their shutdown capability. If turned off for 33% of the time or more, the MAX222/242 uses less average supply current when typical loads are driven (5kΩ/2500pF, data rate has negligible effect) Although the MAX220 needs only 2mA quiescent current, 9mA is typically drawn from the +5V supply when loads are connected to both transmitters. The MAX222/242 shutdown current is less than 10μA, the lowest in the industry. Also since transmitter outputs become high impedances in shutdown, no current flows to the 3kΩ-7kΩ receiver termination resistors.

THREE-STATE MAX222, MAX242

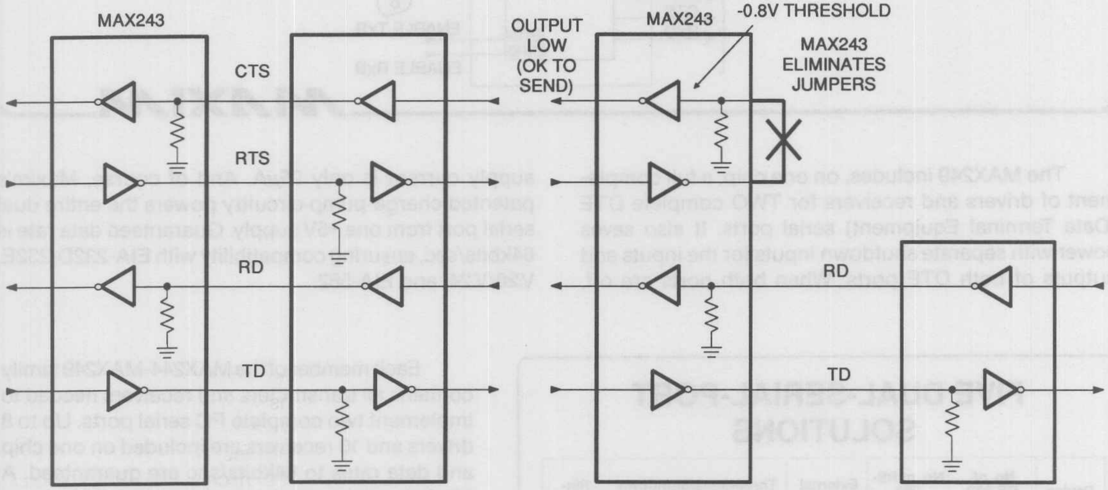


transmitter outputs are shown going to opposite EIA-232 levels (one transmitter input is high, the other is low). Note that during the transition in and out of shutdown, the transmitter outputs are well behaved, with no ringing.

MAX243 SIMPLIFIES CABLING

4-WIRE (CTS/RTS)

2-WIRE (X-ON/X-OFF)

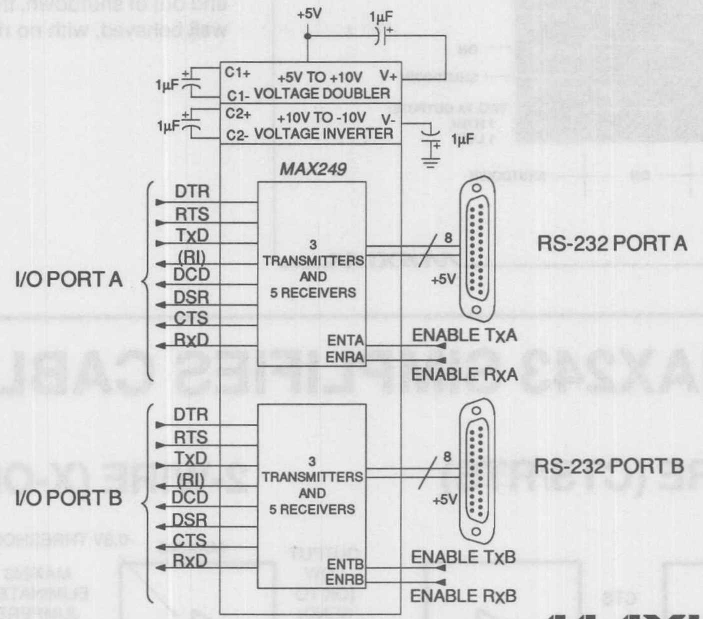


Switch between Xon/Xoff and CTS/RTS flow control without changing cables with the MAX243

The MAX243 lets you swap between 2-wire (Xon/Xoff) and 4-wire (CTS/RTS or DTR/DTS) interfaces without changing cables or adding jumpers. Because one of the two receiver-input thresholds is negative (−0.8V) instead of positive (+1.4V), CTS/RTS flow-control lines can float without interrupting communications.

The receiver output goes high only if its input is actively driven negative. If the input is floating or not driven, the output defaults to the low "OK to send" state. In normal applications, the negative-threshold receiver connects to the flow-control line and the 1.4V threshold receiver connects to the data line. The MAX243 operates with space-saving 0.1μF external charge-pump capacitors, and is guaranteed for data rates up to 116kbits/sec.

TWO SERIAL PORTS—ONE CHIP



MAXIM

The MAX249 includes, on one chip, a full complement of drivers and receivers for TWO complete DTE (Data Terminal Equipment) serial ports. It also saves power with separate shutdown inputs for the inputs and outputs of both DTE ports. When both ports are off, supply current is only 25μA. And of course, Maxim's patented charge-pump circuitry powers the entire dual serial port from one +5V supply. Guaranteed data rate is 64kbits/sec, ensuring compatibility with EIA-232D/232E, V.28/V.24, and EIA-562.

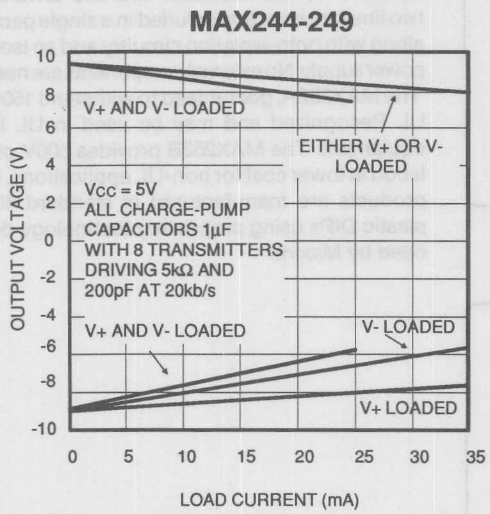
FIVE DUAL-SERIAL-PORT SOLUTIONS

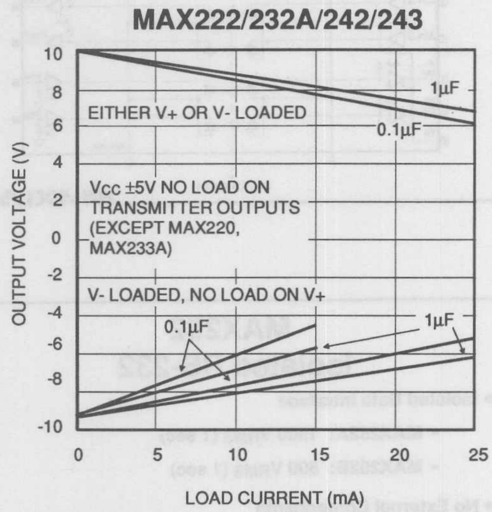
Device	No. of RS-232 Drivers	No. of RS-232 Receivers	External Capacitors	Three-State/Shutdown Control Pins	Pin-Package
MAX244	8	10	1µF	None	44 PLCC
MAX245	8	10	None	Separate Transmitter and Receiver Controls	40 PDIP
MAX246	8	10	None	Separate Port A and Port B Controls	40 PDIP
MAX247	8	9	None	4 Control Inputs	40 PDIP
MAX248	8	8	1µF	4 Control Inputs	44 PLCC
MAX249	6	10	1µF	4 Control Inputs	44 PLCC

MAXIM

Each member of the MAX244-MAX249 family contains all transmitters and receivers needed to implement two complete PC serial ports. Up to 8 drivers and 10 receivers are included on one chip and data rates to 64kbits/sec are guaranteed. A 25μA shutdown mode may be activated by one or more control inputs to cut current consumption. As shown in the table, various control arrangements are available. These include separate control of each serial port, separate control of transmitters and receivers, and "always active" receivers which remain on during shutdown. Only the MAX244 does not include control functions. As always, only a single +5V supply is required, and three parts (MAX245/246/247) include internal charge-pump capacitors, completely eliminating external components.

"STEALING" POWER FROM V+, V- UP TO 35mA!





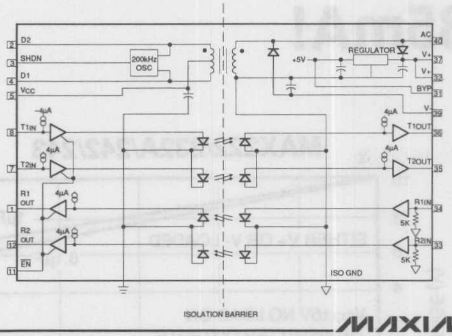
From time to time a design may require + and – supplies to power circuitry in addition to that used in serial communications. If ±9V is sufficient and current requirements are light, the internal charge pump supplies of the MAX2XX series may suffice. The two graphs plot output voltage vs. load current for a number of products. In both graphs, output current is measured with all transmitters loaded (5kΩ and 2500pF) so that the current shown is supplied while the interface is powered. For example, the MAX244-249 supplies ±8V at 10mA (from V+ and V–) while also powering 2 complete PC serial ports. Of course if transmitters are disabled by one of the control inputs, then more current may be supplied to other loads.

ISOLATED RS-232

MAX252A: 1500V ISOLATION (UL)

MAX252B: 500V ISOLATION

In many serial interfaces, line isolation is sometimes included to protect the network against "unorthodox" connections. However, isolation does more than provide fault protection: When RS-232 lines join computers and terminals in separate buildings, for example, ground differences and ground-current noise can be severe if earth-ground connections are at different potentials. In severe cases this difference may be enough to damage equipment, but even a small ground difference (5 or 10V) can generate enough noise to interrupt data. Isolation effectively eliminates these problems. In industrial environments, a UL-rated isolation barrier, rated for 1500V or more, may be necessary.



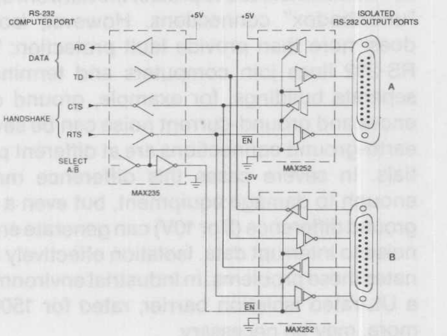
supplies power across the isolation barrier while the opto-couplers transmit data. UL specifications are used in the U.S., whereas the German standard, VDE, is popular in Europe.

The MAX252 offers a complete, electrically isolated, RS-232 interface. Two line drivers and two line receivers are included in a single package along with opto-isolation circuitry and an isolated power supply. No external components are needed. The MAX252A, guaranteed to withstand 1500V, is UL Recognized and may be used in UL listed equipment. The MAX252B provides 500V of isolation at lower cost for non-UL applications. Both products are manufactured in standard 40-pin plastic DIPs using proprietary technology developed by Maxim.

MAX252
Isolated RS-232

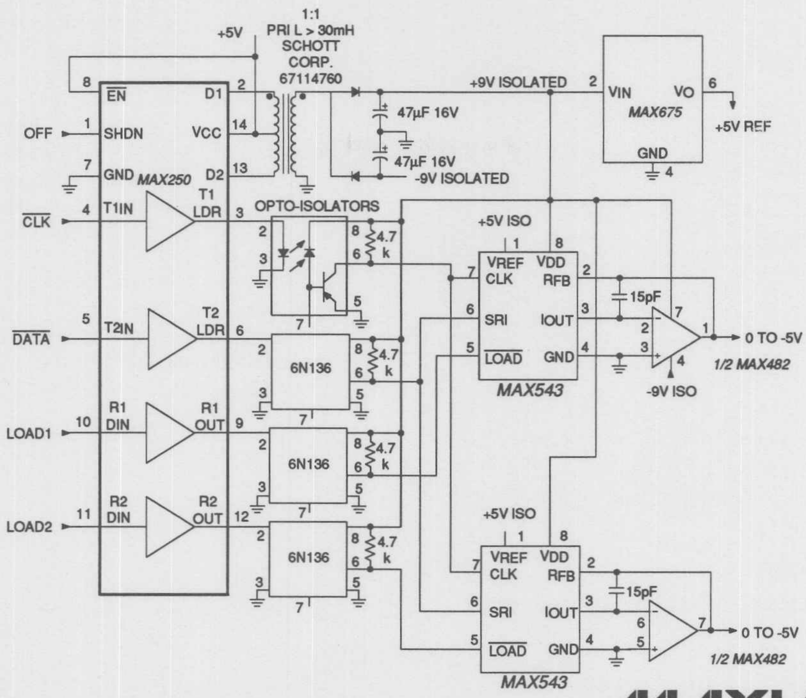
- **Isolated Data Interface**
  - **- MAX252A: 1500 V_{RMS} (1 sec)**
  - **- MAX252B: 500 V_{RMS} (1 sec)**
- **No External Components**
- **9600 bits/sec Guranteed (19.2kb/s typ)**
- **Single +5V Supply**
- **10µA Low Power Shutdown**
- **UL Recognized: MAX252A**

FULLY ISOLATED DATA MUX



This fully isolated RS-232 multiplexer allows a single RS-232 computer port, powered from 5V, to drive one of two separate remotely located peripherals, typically a data acquisition "satellite" and a remote printer. Isolation is useful here because both devices are likely to have ground potentials different from that of the computer. Also, the connection isolates the peripherals from each other as well as the computer. The MAX235 takes RS-232 data and handshake lines and a "Select A/B" output from the computer and converts them to logic levels. These are passed along to both MAX252 isolated transceivers. The RTS line controls which port is selected.

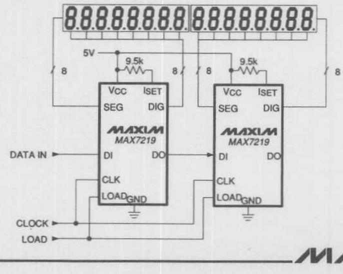
MAX250 DRIVES ISOLATED DACS



The two chips that operate the isolated and un-isolated sides of the MAX252 are also available as individual ICs: The MAX250 and MAX251. The MAX250 contains two LED drivers, two LED receivers, and transformer drive circuitry, making it useful for a number of isolated applications not involving RS-232. In this example, two MAX543 serial-input 12-bit DACs receive power and data from the MAX250. Clock and data lines are shared by both DACs but separate LOAD1 and LOAD2 inputs latch the data in. The MAX250 also has a shutdown input (SHDN) that powers down the circuit and cuts supply current to less than 10μA. Note that the two MAX250 receivers are used here as transmitters; this is permissible because the MAX250 receivers were designed to be used as transmitters also, just as the transmitters can be used as receivers.

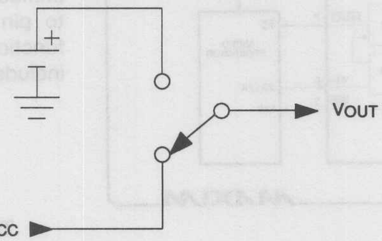
NEW 8-DIGIT LED DRIVER

- **Fast Serial μP Interface**
- **24 Pin Narrow DIP, SO Packages**
- **Digital Brightness Control**



The MAX7219 makes simple work of driving LED displays and arrays. One resistor sets the maximum current for all segments while a fast (up to 10MHz) cascadable serial interface loads data directly from nearly any microprocessor. The serial link also cuts pins, making the MAX7219 the smallest 8-digit driver available (especially in SO). Other features include digital brightness (via the serial interface) and selectable decode and no-decode modes. Any combination of 7-segment digits, annunciators, and individual LEDs can be driven with no hardware changes. In the diagram, two MAX7219s drive 16 digits from a single 5V supply while being addressed via one three-wire serial link.

μP SUPERVISORS



Battery Switchover Functions

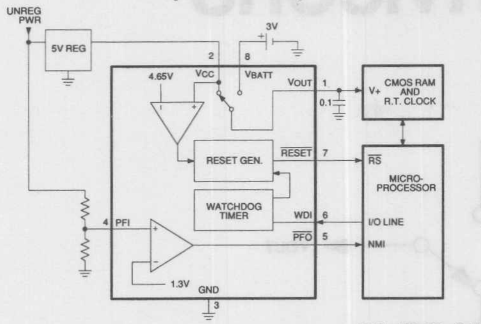
New Features

Backup Tips

What is a "microprocessor supervisor"? The term misleads because in most such circuits (or ICs) more circuitry is devoted to monitoring the microprocessor (μP) ENVIRONMENT than the μP itself. Supervisory circuits essentially perform the "messy" analog monitoring and housekeeping functions required to keep "smart" systems from doing stupid things when external conditions are less than ideal. Some of these functions are shown in the block diagram of a basic supervisor (MAX690).

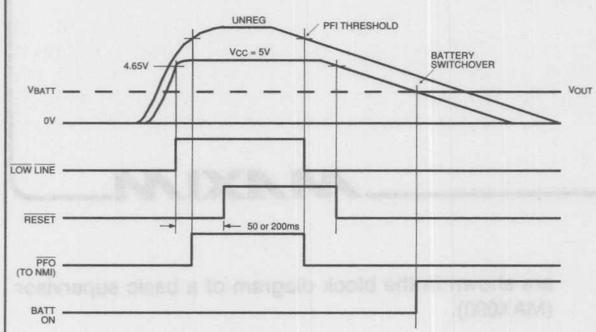
Power-On Reset
Low-Voltage Reset — monitors V_{CC}
Power Fail Early Warning — via resistors at PFI
Backup Battery Switchover
Watchdog Timer — monitors WDI, activates Reset

SUPERVISOR FUNCTIONS (MAX690)



A typical supervisor (MAX690) has plenty to do during both power-up and power-down. The timing diagram shows all basic MAX690 functions except watchdog. Note that $\overline{\text{RESET}}$ falls immediately when V_{CC} falls, but waits (50 or 200ms, depending on the device) before returning high when V_{CC} rises, to give all system components time to "wake up". $\overline{\text{LOW LINE}}$ rises and falls immediately but is not included on all devices due to pin limitations. These are the most basic functions, however a large number of others are included on new products to be discussed.

POWER-UP, -DOWN SEQUENCE



The following list summarizes how a typical μP supervisor behaves under various conditions during power-up:

1. **No power** — μP is reset, CMOS RAM and real-time clock (RTC) are write-protected and battery powered, other circuits are reset and shut down.
2. **V_{CC} rises** above the battery voltage — supervisor switches RAM and RTC to the main supply.
3. **V_{CC} rises** above the threshold voltage — Reset timer starts, and write protection is removed.
4. **50ms (or 200ms) after** V_{CC} rises — μP leaves reset mode, watchdog timer starts, μP starts its initialization routine.

During power-down:

1. **Power failure** detected via PFI input — μP receives non-maskable interrupt and begins orderly shutdown. V_{CC} is momentarily sustained by the power supply output capacitance.
2. **V_{CC} falls** below the supervisor's threshold voltage — The μP is reset, and write-protection is activated.
3. **V_{CC} falls** to the battery voltage — The supervisor switches the RAM and the RTC to backup battery power, and enters a low current standby mode.

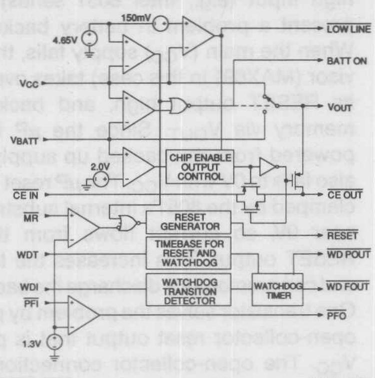
MAX790 IMPROVEMENTS

	MAX790	MAX690
SUPPLY CURRENT	70µA	2mA
BACKUP OUTPUT CURRENT	25mA	1mA
OPERATING OUTPUT CURRENT	250mA	50mA
$\overline{\text{RESET}}$ VALID TO:	1.5V	2V

* MAX790 is Pin Compatible with MAX690

The MAX790 provides major improvements to the MAX690 in several key areas as noted in the table. The MAX790 is pin compatible with the MAX690 and is designed as a premium version for applications needing more output current from the switchover circuitry, tighter threshold tolerances, and/or lower supply current.

MAX791



MAXIM

The MAX791 is Maxim's most advanced supervisor product. As can be seen from the block diagram and the following list, the MAX791 contains all MAX790 improvements listed above, plus additional features not found in any other single-chip solution:

Power-On Reset
Low-Voltage Reset — V_{CC} is monitored
Two Stage Power Fail Warning — $\overline{\text{LOW LINE}}$ falls when V_{CC} is 150mV above the reset threshold
Backup Battery Switchover — V_{OUT} connects to V_{BATT} when V_{CC} falls
Backup Battery Monitor — see below
"Battery On" Indicator — BATT ON high during backup
Separate Watchdog and Reset Outputs
Adjustable Watchdog Timer
Manual Reset Input
Memory Chip Enable Gating — $\overline{\text{CE}}$ path to memory is inhibited during a Reset
Memory Write Cycle Completion — last $\overline{\text{WR}}$ completes before a Reset
Additional Voltage Monitor — at PFI and PFO

The MAX791 is not compatible with the MAX691 (but it's close). It provides improved performance for the MAX691, 693, 695, 696, and 697. The MAX691A is pin compatible with the MAX691 and provides MAX791-like performance.

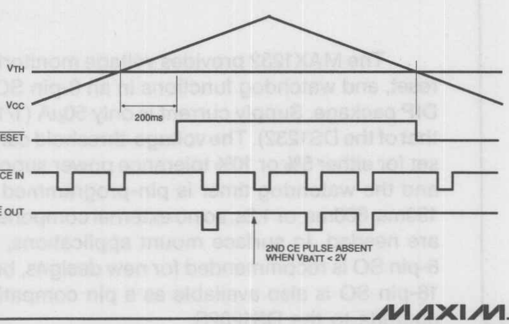
MAX791 ADDITIONAL FEATURES

All Features of MAX790 Plus:

- **Two-Stage Power Fail Warning**
- **Separate Watchdog and Reset**
- **Manual Reset Input**
- **Memory Write Cycle Completion**
- **Backup Battery Monitor**

MAXIM

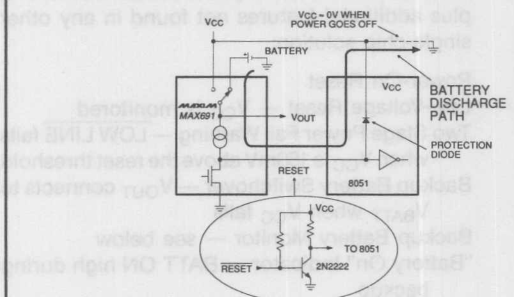
MAX791 MONITORS BACK-UP BATTERY STATUS



MAXIM

In addition to monitoring all aspects of the input supply, the MAX791 also keeps tabs on the backup battery: Each time a Reset ends, the battery is checked. If it is less than 2V, the 2nd write operation to memory after Reset releases is inhibited by the $\overline{\text{CE}}$ gating path. The processor can detect this by loading different data to a memory location on two successive writes, immediately after coming out of Reset. The processor then reads the memory location. The contents will disclose whether the second write was inhibited, and whether the backup battery is discharged.

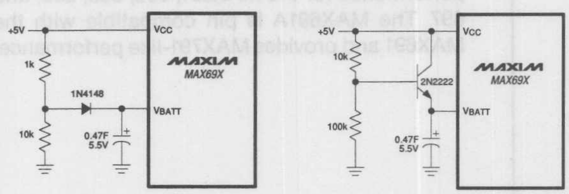
ELIMINATING HIDDEN DISCHARGE PATHS



MAXIM

Microprocessors that are reset by a logic-high input (e.g., Intel 8051 series) sometimes present a problem in battery backed systems. When the main (V_{CC}) supply falls, the μP supervisor (MAX691 in this case) takes over by pulling its RESET output high, and backing up the memory via V_{OUT}. Since the μP itself is not powered from the backed up supply, its supply also falls to 0V with V_{CC}. The μP reset input is then clamped by the 8051's internal substrate diode to near 0V, so current flows from the MAX691 RESET output. This increases the load current and can prematurely discharge the backup battery. One transistor solves the problem by providing an open-collector reset output that is pulled up to V_{CC}. The open-collector connection inverts so the base must be driven from $\overline{\text{RESET}}$ to maintain the correct polarity at the 8051.

USING BACKUP CAPS WITH 690 FAMILY

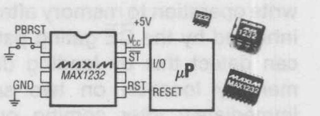


MAXIM

High value capacitors can supplant lithium or NiCd batteries as backup voltage sources in applications requiring relatively short backup times. With microamp-level backup load currents, a 0.47 Farad "Supercap" (a.k.a "Maxcap") can keep memory powered for several days. However, one caution is necessary to ensure that these applications do not generate false reset outputs or switch prematurely to the backed up state.

Most backup switchover circuits decide between powered operation and backup by comparing the main power supply voltage to the backup supply. The highest supply determines the status of the system. If the backup capacitor charges from V_{CC} through a resistor, it will charge all the way to V_{CC}. If V_{CC} falls by only a small amount (due to line variations) a false reset may be triggered. This is prevented by one of the accompanying circuits which charge the battery to a voltage less than V_{CC}. The left hand circuit is slightly simpler but requires low resistor values (which continually load V_{CC}) to quickly charge the capacitor. If the diode is replaced by a transistor, both light supply loading and quick charging can be achieved.

WATCHDOG AND RESET IN 8-PIN SO MAX1232

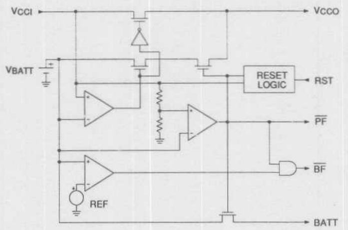


- 1/10th Current of DS1232 - 200μA Max.
- 1/3 Size of DS1232 - 8-Pin SO
- No External Components
- 5%/10% Tolerance Pin-Selectable

MAXIM

The MAX1232 provides voltage monitoring, reset, and watchdog functions in an 8-pin SO or DIP package. Supply current is only 50μA (1/10th that of the DS1232). The voltage-threshold can be set for either 5% or 10% tolerance power supplies and the watchdog timer is pin-programmed for 150ms, 600ms, or 1.2s, so no external components are needed. In surface mount applications, the 8-pin SO is recommended for new designs, but a 16-pin SO is also available as a pin compatible upgrade to the DS1232S.

COMPLETE ONE-CHIP BATTERY MANAGEMENT MAX1259

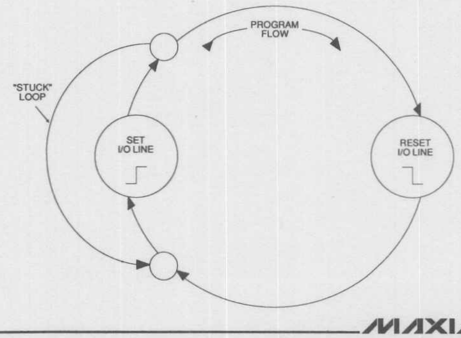


The MAX1259 provides complete management and control for battery backed-up systems. It switches to the backup battery when primary power is interrupted and Power Fail ($\overline{PF}$) and Battery Fail ($\overline{BF}$) outputs indicate power and battery status. A "storage" feature allows the backup battery to be completely disconnected by pulsing RST high when power is applied. Then when power is removed, the battery is not switched on. This prevents battery discharge when the completed circuit is stored or shipped. The MAX1259 is pin compatible with the DS1259, but operates on 1/3 the supply current.

MAX1259 FEATURES

- **70% Less Power Consumption Than DS1259**
- **25% More Output Current Than DS1259**
- **Switches to Backup Battery if Power Fails**
- **Battery Monitor Indicates Low Battery**
- **Power-Fail Output**
- **Consumes Less than 100nA of Battery Current**

WATCHDOG SOFTWARE TIP
"MAXIM KNOWS SOFTWARE?"

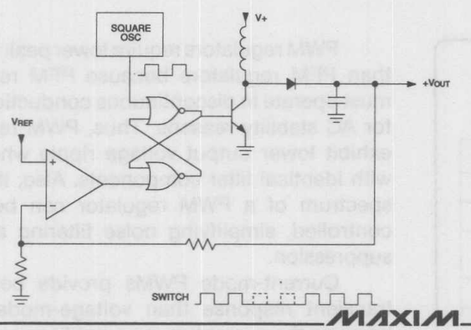


(No, we haven't been purchased by one of those newly-formed software conglomerates.) A way to help a watchdog timer keep closer tabs on software execution involves setting and resetting the watchdog input at opposite ends of program flow, rather than at one point. If the watchdog input goes high and low at the same point then a small "stuck" loop might still include that point and keep the watchdog from timing out. By separating the high and low transitions, far fewer bugs go undetected.

POWER APPLICATIONS

- **Simpler DC-DC Converters**
- **Current Mode PWM**
- **Flash EPROM Power**
- **Surface Mount Circuits**
- **Portable Power Management**

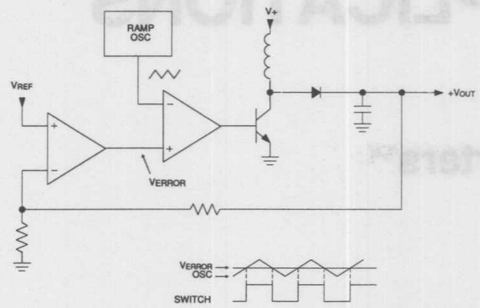
CLOCKED-PFM (PULSE-SKIPPING) REGULATOR



Clocked-PFM, voltage-mode-PWM, and current-mode-PWM DC-DC converter control schemes are commonly used in low-power designs.

Clocked-PFM regulators, also called burp-mode, gated-oscillator, or pulse-skipping regulators, offer ultra-low quiescent supply current and are often used in battery-powered circuits. In creased low-frequency, subharmonic noise is the tradeoff for realizing micropower operation.

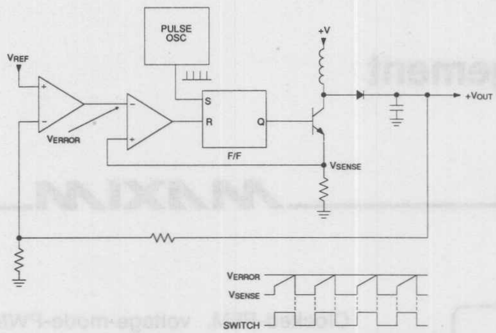
VOLTAGE-MODE PWM



There are two big advantages of PWM control schemes: They exhibit less low-frequency, difficult-to-filter noise than PFM types, and they can reduce the stress on the switching components by operating in continuous conduction mode.

Traditional voltage-mode PWMs are simple but difficult to compen sate for ac stability. The newer current-mode types are easier to stabilize because they exhibit one less pole in their loop response characteristic.

CURRENT-MODE PWM



A cycle of operation of a current-mode regulator begins when the pulse oscillator sets the flip-flop and turns on the switch transistor. The inductor current then ramps up at a rate determined by the input voltage and the inductor value, until the inductor current reaches a threshold set by the sense resistor and V_{ERROR} voltage. Now, the flip-flop resets and the switch transistor is turned off, allowing the inductor to fly up and deliver a pulse of energy to the output.

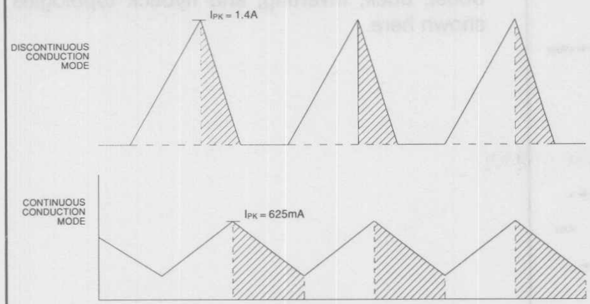
COMPARISON OF REGULATOR CONTROL SCHEMES

	PFM	Voltage PWM	Current PWM
Ripple Voltage	Moderate	Low	Low
Ripple Frequency	Varies (see text)	Fixed	Fixed
Efficiency	Higher at Light Loads		
Quiescent Current	Low	Moderate	Moderate
Transient Response	Average	Below Average	Above Average
Ease of Compensation	Unimportant	More Difficult	Less Difficult
Size Miniaturization	Larger Inductors & Capacitors	Good	Good

PWM regulators require lower peak currents than PFM regulators because PFM regulators must operate in discontinuous conduction mode for AC stability reasons. Thus, PWM regulators exhibit lower output voltage ripple when used with identical filter components. Also, the noise spectrum of a PWM regulator can be tightly controlled, simplifying noise filtering and EMI suppression.

Current-mode PWMs provide better line transient response than voltage-mode PWMs because the current-sense amplifier corrects for input voltage changes within one cycle. A step change in input voltage causes a change in inductor current immediately detected by the current sense amplifier, which then resets the flip/flop and turns off the power transistor. This action minimizes output overshoot.

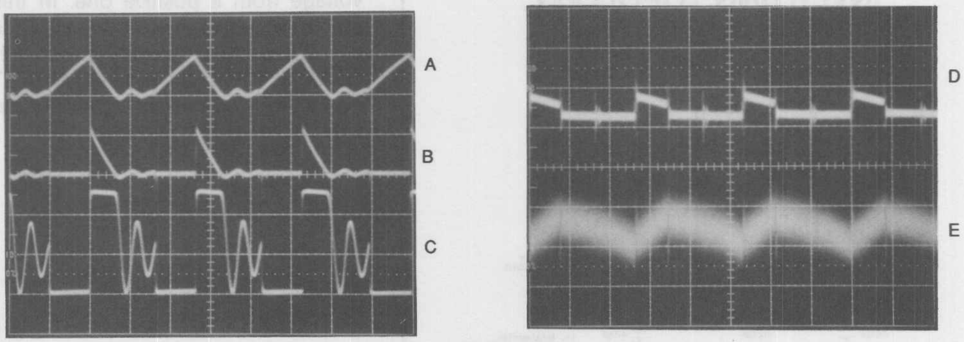
CONTINUOUS vs. DISCONTINUOUS CONDUCTION PEAK CURRENTS



BOOST CONVERTERS: 2 CELL (2V) TO +12V AT 60mA LOAD

Continuous-conduction mode refers to circuits where current flows in the inductor throughout each switching cycle. Continuous-conduction mode occurs in circuits which have a relatively high inductor value and a high maximum duty cycle limit, higher than the amount of duty cycle predetermined by the output/input voltage ratio. In other words, the ON- and OFF-times, along with the rate-of-change of inductor current, determine whether or not the inductor current returns to zero at some point during the cycle. Most pulse-skipping PFM regulators have a relatively low maximum duty cycle limit (such as 50%) in order to ensure discontinuous-mode operation and enhance AC stability.

SWITCHING REGULATOR NOISE SOURCES



A = Inductor Current, 100mA/Div
B = Rectifier Current, 100mA/Div
C = Lx Switch Voltage, 5V/Div
D = Output Ripple, 50mV/Div
E = Output Ripple, 1mV/Div (with optional Pi filter)

Horizontal = 2µs/Div

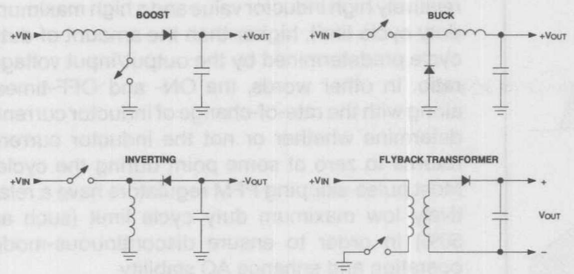
Waveforms A,B, and C show operation in the discontinuous conduction mode. Note that when the inductor current has been depleted, the LX voltage rings around the level of the input supply voltage. This is caused by the tank circuit formed by the inductor and the stray capacitances of the inductor windings, the diode, and the power MOSFET within the regulator.

Waveforms D and E show output noise in a simple step-up PWM regulator; this noise takes several forms:

1. The most significant noise mechanism is the IR drop through the output filter capacitor's ESR (equivalent series resistance), which is caused by large current pulses from the inductor.
2. Switching noise in the form of short spikes riding on the DC waveform has several sources: the filter capacitor's equivalent series inductance (ESL), current spikes in the ground trace, rectifier switching transients, and extraneous EMI picked up by the oscilloscope's ground lead.
3. The RC discharge of the filter capacitor to the load resistor, often undetectable, is seldom significant for converters operating above 20kHz.

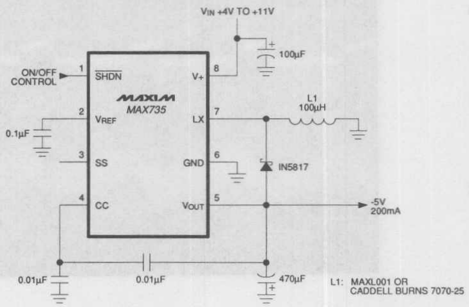
An inductor in series with the output voltage is effective in eliminating switching spikes, even if the "inductor" is only a long PC trace terminated with a ceramic capacitor. To eliminate the output ripple's lower-frequency fundamental component as well, you must set the natural frequency of this LC output filter lower than the switching frequency (at least 10 times lower, preferably).

DC-DC TOPOLOGIES



Voltage-mode and current-mode PWMs, as well as PFM regulators, can all be used with a variety of switching topologies, such as the simple boost, buck, inverting, and flyback topologies shown here.

INVERTING TOPOLOGY: NEGATIVE OUTPUT



The inverting topology generates a negative voltage from a positive one. In this circuit, a MAX739 current-mode PWM regulator provides all of the active circuitry needed, including a "sense-FET" P-channel power MOSFET. Switching frequency is a relatively high 165kHz, allowing for small external components.

INVERTER COMPARISON

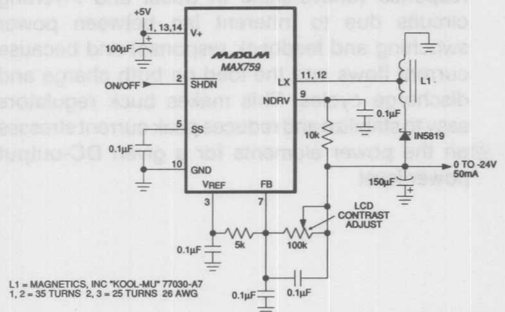
	MAX635	MAX735*	MAX739*
Control Scheme	PFM	PWM	PWM
Output Voltage	-5V/Adjustable	-5V	-5V
Output Current (5V In)	20mA	200mA	300mA
Supply Current (Typ.)	80µA	2mA	2mA
Supply Range	2.6V to 16.5V	4V to 11V	4V to 16.5V
Shutdown Current (Typ.)	N/A	1µA	1µA
Process Technology	5 micron	3 micron	5 micron
SOIC Package	8-lead 0.15"	8-lead 0.15"	16-lead 0.3"

* Adjustable Version Available

This comparison of inverting (negative output) switching regulators highlights the practical differences between PFM and PWM control schemes. The PFM type (MAX635) provides only low output power levels but has very low quiescent supply current, while the PWMs operate in continuous-conduction mode and draw more supply current under no-load conditions.

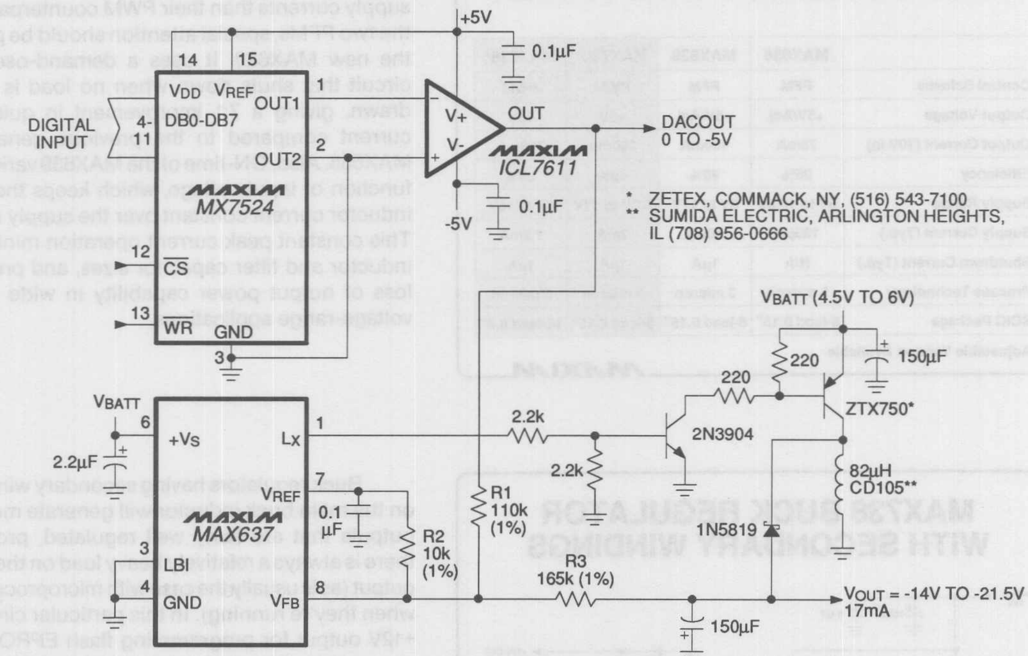
The MAX739 can be bootstrapped by connecting it's NDRV pin to a negative voltage. Bootstrapping increases the drive voltage to the P-channel MOSFET, reduces it's ON-resistance and increases the load capability from 200mA to 300mA. This increase in output and efficiency is not free; maximum input voltage is decreased from +16.5V to +11V.

ADJUSTABLE LCD SUPPLY WITH AUTOTRANSFORMER



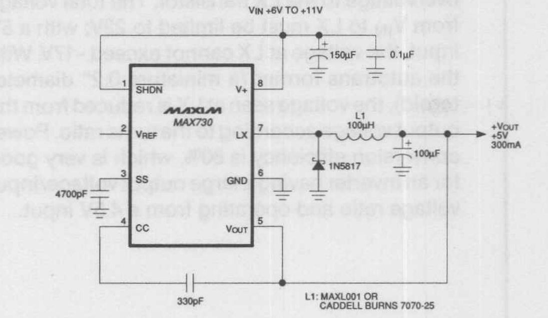
This circuit provides a variable output voltage to adjust the contrast of a liquid-crystal display. An autotransformer steps up the output to prevent overvoltage to the LX transistor. The total voltage from V_{IN} to LX must be limited to 22V; with a 5V input, the voltage at LX cannot exceed −17V. With the autotrans former (a miniature 0.2″ diameter toroid), the voltage seen at LX is reduced from the output voltage according to the turns ratio. Power conversion efficiency is 80%, which is very good for an inverter having a large output voltage/input voltage ratio and operating from a 4.5V input.

LCD SUPPLY WITH DIGITAL ADJUST



If the expense of acquiring a customized autotransformer is too high, this low-cost pulse-skipping circuit can be used instead of the previous circuit in order to generate an adjustable voltage for LCDs. In this case, the relatively high output voltage is accommodated via an external switch transistor having 40V BV_{CEO} specifications. A simple D/A scheme adjusts the output for contrast control and temperature compensation of the LCD.

BUCK TOPOLOGY: VOUT < VIN



Buck regulators are more designer-friendly than the other two basic topologies because they lack a certain right-half-plane zero in the loop response (unavoidable in boost and inverting circuits due to inherent lag between power switching and feedback response) and because current flows into the load on both charge and discharge cycles. This makes buck regulators easy to stabilize and reduces peak current stresses on the power elements for a given DC-output power level.

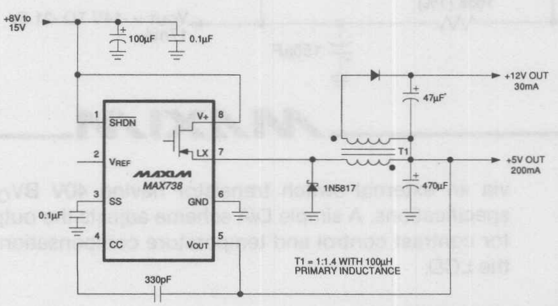
BUCK REGULATOR COMPARISON

	MAX638	MAX639	MAX730*	MAX738*
Control Scheme	PFM	PFM	PWM	PWM
Output Voltage	+5V/Adj	+5V/Adj	+5V	+5V
Output Current (10V In)	75mA	150mA	300mA	750mA
Efficiency	85%	90%	89%	89%
Supply Range	6V to 16.5V	6V to 11V	5.2V to 11V	6V to 16V
Supply Current (Typ.)	135µA	20µA	2mA	1.6mA
Shutdown Current (Typ.)	N/A	1µA	1µA	1µA
Process Technology	5 micron	3 micron	3 micron	5 micron
SOIC Package	8-lead 0.15"	8-lead 0.15"	8-lead 0.15"	16-lead 0.3"

* Adjustable Version Available

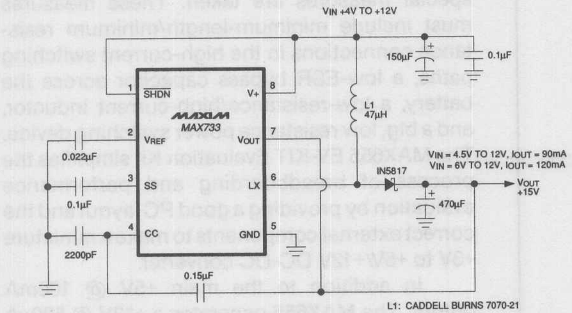
Again, the pulse-skipping regulators have lower output power and much lower quiescent supply currents than their PWM counterparts. Of the two PFMs, special attention should be paid to the new MAX639. It uses a demand-oscillator circuit that shuts down when no load is being drawn, giving a 7:1 improvement in quiescent current compared to the previous generation MAX638. Also, ON-time of the MAX639 varies as a function of input voltage, which keeps the peak inductor current constant over the supply range. This constant peak current operation minimizes inductor and filter capacitor sizes, and prevents loss of output power capability in wide input-voltage-range applications.

MAX738 BUCK REGULATOR WITH SECONDARY WINDINGS



Buck regulators having secondary windings on the main buck inductor will generate multiple outputs that are fairly well regulated, provided there is always a relatively heavy load on the main output (as is usually the case with microprocessors when they're running). In this particular circuit, a +12V output for programming flash EPROMS is generated with help from the series-aiding connection of the +5V output and the secondary winding.

BOOST TOPOLOGY: VOUT > VIN



Peak currents in the classic boost topology are slightly lower compared to those in an inverter with the same output power level, because the boost converter faces a lower energy "hill" (step-up ratio). The boost configuration also allows a ground-referenced N-channel rather than P-channel MOSFET as the power switching transistor, providing 1/3 the ON-resistance in a transistor of the same size.

Like the other new PWMs, the MAX732 benefits from "sense-FET" technology, internal undervoltage lockout, cycle-by-cycle over-current limiting, and programmable soft-start.

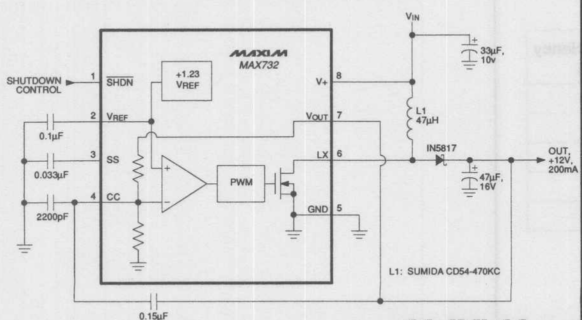
BOOST REGULATOR COMPARISON

	MAX632/3	MAX732*	MAX733*
Control Scheme	PFM	PWM	PWM
Output Voltage	+12V, Adj/ +15V, Adj	+12V	+15V
Output Current (5V Input)	25mA/15mA	150mA	100mA
Supply Range	2V to 16.5V	4V to 9V	4V to 12V
Supply Current (Typ.)	500µA/750µA	1.6mA	1.6mA
Shutdown Current (Typ.)	N/A	1µA	1µA

* Adjustable Version Available

Moderately high supply current (on the order of 1mA or 2mA) is the main disadvantage of PWM regulators when compared to micropower PFM regulators. This disadvantage is minimized via a system-controlled low-current shutdown mode provided on most of the new PWM regulators.

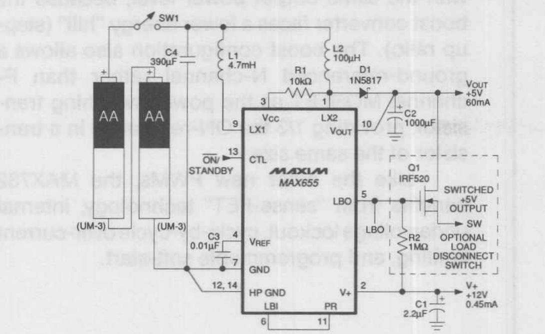
MAX732 FLASH EPROM PROGRAMMER



The MAX732 current-mode PWM regulator makes a good flash EPROM programmer because it has a logic-compatible shutdown control and can be made into a highly-dense SMT supply capable of programming four flash devices simultaneously. These waveforms show discontinuous conduction mode; however, when heavily loaded, the MAX732 operates in continuous conduction mode, where the inductor current never returns to zero.

Note that when the inductor current has been depleted, the LX voltage rings around the level of the input supply voltage. This is caused by the tank circuit formed by the 50µH inductor and the stray capacitances of the inductor windings, the diode, and the power MOSFET within the MAX732.

2 AA BATTERIES TO +5V/60mA

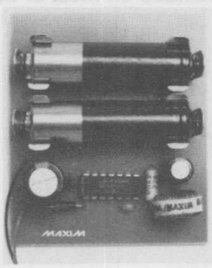


Converting low voltages (such as 1.8V, the end-of-life voltage for two alkaline cells in series) into higher voltages, is difficult to do unless special measures are taken. These measures must include minimum-length/minimum resistance connections in the high-current switching paths, a low-ESR bypass capacitor across the battery, a low-resistance/high-current inductor, and a big, low resistance power switching device. The MAX655 EV-KIT Evaluation Kit simplifies the process of breadboarding and performance evaluation by providing a good PC layout and the correct external components to make a miniature +3V to +5V/+12V DC-DC converter.

In addition to the main +5V @ 100mA output, The MAX655 generates a +12V @ 500µA high-side supply for load-switching applications. In this particular circuit, the low battery detector is being used as a level translator for high-side load switching. Standby current is 80µA (with the +5V output still alive and regulating) and efficiency is 82%.

STEP-UP +5V FROM ONE OR TWO CELLS

1.15V Start-Up and 40µA Standby Mode

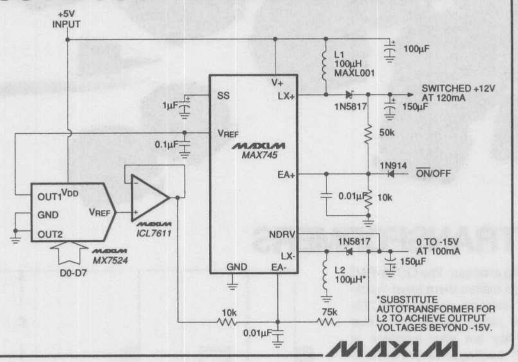


The MAX655 is one of a series of Maxim DC-DC converter ICs that operate from low input voltages. The MAX654, MAX656, and MAX657 are optimized for single-cell input, while the MAX655 and MAX658 operate from two series alkaline or NiCd cells, or one +3V lithium cell.

LOW VOLTAGE STEP-UP DC-DC CONVERTERS

Part	Typ Input Range (V)	Out (V)	Power Switch	Output (mA)	Typ Efficiency (%)
MAX654	1.0 - 1.6	5	Internal	50	75
MAX655	2.0 - 3.2	5	Internal	80	83
MAX656	1.0 - 1.6	5	Ext MOSFET	200	85
MAX657	1.0 - 1.6	3	Internal	70	70
MAX658	2.0 - 3.2	5	Ext MOSFET	300	88

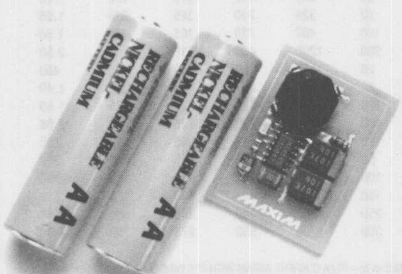
FLASH EPROM PROGRAMMER PLUS ADJUSTABLE LCD SUPPLY



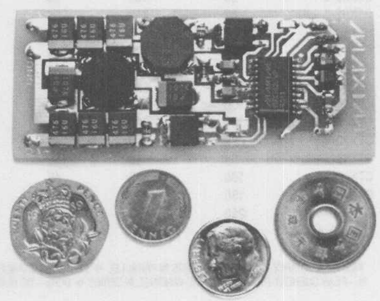
The MAX745, an adjustable version of the MAX743, generates both positive and negative boosted outputs from a +5V input supply. This particular circuit is configured for small microprocessor systems, and contains a DAC to adjust the negative voltage for LCD contrast control. Also shown is a method for switching on and off the +12V output to program flash EPROMs. The output turns off when the feedback input is forced high by a CMOS logic level through a small-signal diode. Like Maxim's other new PWM regulators, this circuit operates at a high switching frequency (200kHz for the MAX743), allowing a miniaturized SMT version of the circuit to fit in a 1.7″ × 0.7″ × 0.2″ space (18 Watts per cubic inch!).

COMPACT POWER SUPPLIES USING HIGH-ENERGY SMT INDUCTORS

2 AA to 5V at 60mA
MAX655



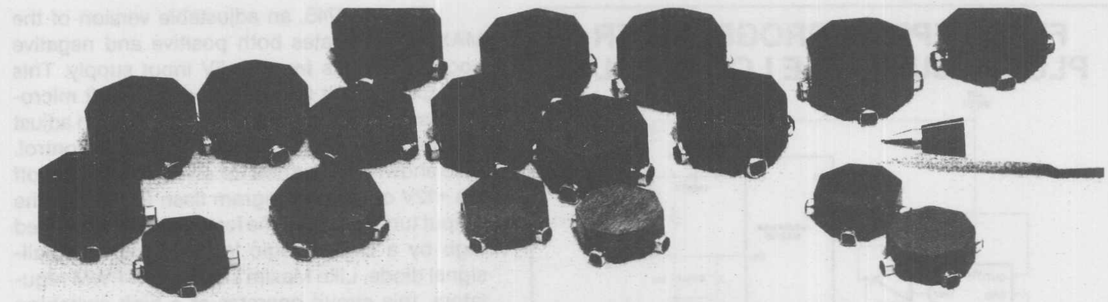
5V to ±15V at 750mA
MAX742



MAXIM

Although surface-mount circuits can be painful to prototype, and power SMT inductors can be difficult to find if you don't know where to look, SMT is wonderful once you get the circuit going. Parasitic wiring inductances that previously thrashed quiet analog sections with huge switching spikes are gone. Stray capacitances that previously sapped efficiency disappear. High power levels can be combined with clean, low-noise operation. Try it, you'll like it.

The through-hole equivalent of this MAX742 10W, dual-output power supply measures 4″ × 3″ × 1″. This surface mount version is only 2.5″ × 1.2″ × 0.3″, and offers better efficiency with less switching noise at the output.

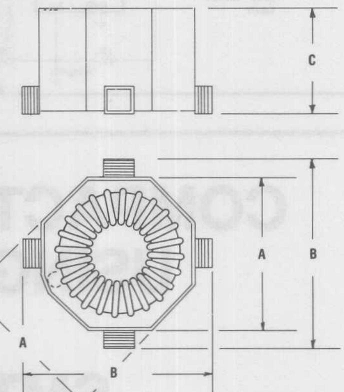


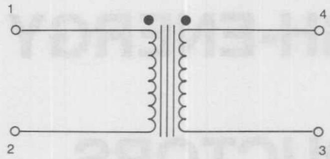
SMT POWER INDUCTOR/TRANSFORMERS

OCTA-PACs are SMT devices that can individually be used in multiple engineering applications depending on how the user wires them. When used as inductors, they can provide low inductance with high current or high inductance with low current capabilities. When wired as a 1:1 transformer, they provide electrical isolation and can provide an extremely wide voltage transformation range when configured in the flyback topology.

OCTA-PACs are also designed to make it easy to use them in any SMT sub-assembly manufacturing process. The OCTA-PAC physical package makes them ideal "pick-and-placeable" devices, and each OCTA-PAC's pin #1 is plainly marked for clear identification. They are also available in "Tape and Reel" packages to further facilitate their use.

OCTA-PACs are built using materials that are thoroughly resistant to high temperatures. This further ensures their functional integrity even if they go through infra-red reflow during sub-assembly manufacture.





COILTRONICS PART NUMBER	INDUCTANCE μH	CURRENT ADC	ENERGY μj	A	B (All in inches)	C MAX	INDp μH	INDs μH	Ip ADC	Is ADC	DCRp OHMS	DCRs OHMS
CTX20-1	20	1.15	13	.350	.450	.165	20	80	1.15	.575	.175	.700
CTX50-1	50	.730	13	.350	.450	.165	50	200	.730	.365	.300	1.20
CTX100-1	100	.510	13	.350	.450	.165	100	400	.510	.255	.375	1.50
CTX200-1	200	.360	13	.350	.450	.165	200	800	.360	.180	.700	2.80
CTX20-2	20	1.60	26	.350	.450	.235	20	80	1.60	.800	.103	.412
CTX50-2	50	1.02	26	.350	.450	.235	50	200	1.02	.510	.180	.720
CTX82-2	82	.730	26	.350	.450	.235	82	328	.730	.365	.320	1.28
CTX100-2	100	.730	26	.350	.450	.235	100	400	.730	.365	.375	1.50
CTX300-2	300	.420	26	.350	.450	.235	300	1200	.420	.210	.625	2.50
CTX20-3	20	1.50	23	.450	.550	.180	20	80	1.50	.750	.100	.400
CTX50-3	50	.950	23	.450	.550	.180	50	200	.950	.475	.350	1.40
CTX100-3	100	.670	23	.450	.550	.180	100	400	.670	.335	.375	1.50
CTX300-3	300	.390	23	.450	.550	.180	300	1200	.390	.195	.720	2.88
CTX20-4	20	2.10	45	.450	.550	.250	20	80	2.10	1.05	.050	.200
CTX50-4	50	1.35	45	.450	.550	.250	50	200	1.35	.675	.090	.360
CTX100-4	100	.950	45	.450	.550	.250	100	400	.950	.475	.175	.700
CTX150-4	150	.720	45	.450	.550	.250	150	600	.720	.360	.175	.700
CTX250-4	250	.600	45	.450	.550	.250	250	1000	.600	.300	.600	2.40
CTX300-4	300	.550	45	.450	.550	.250	300	1200	.550	.275	.750	3.00

INDp—INDUCTANCE WITH THE WINDINGS IN PARALLEL ❖ INDs—INDUCTANCE WITH THE WINDINGS IN SERIES ❖ Ip—PEAK CURRENT RATING WITH THE WINDINGS IN PARALLEL ❖ Is—PEAK CURRENT RATING WITH THE WINDINGS IN SERIES ❖ DCRp—DC RESISTANCE WITH THE WINDINGS IN PARALLEL ❖ DCRs—DC RESISTANCE WITH THE WINDINGS IN SERIES

COILTRONICS

INTERNATIONAL

984 S.W. 13th Court • Pompano Beach, Florida 33069 • Telephone: (305) 781-8900 • FAX: (305) 782-4163

Coiltronics' new CTX-series power SMT inductors appear in the previous MAX655 and MAX742 SMT-board photos. They can optionally be used as 1:1 transformers for applications needing high energy storage, such as flyback circuits. These encapsulated SMT toroids feature an excellent new low-loss powdered-iron core material from Magnetics Inc, called Kool-Mu.

NEW PRODUCTS 新 製 品

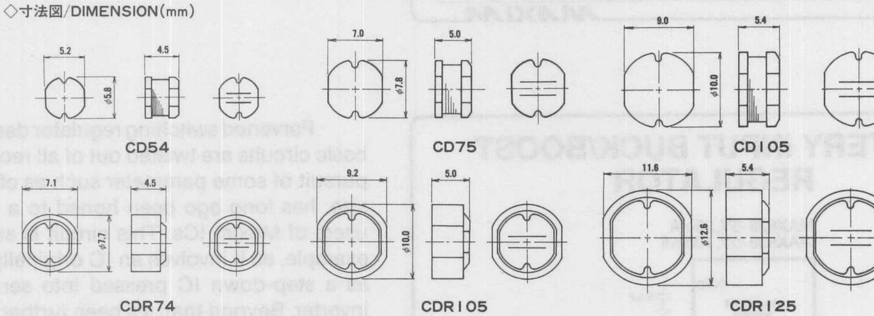
SMD POWER INDUCTORS 面実装パワーインダクタ

概 要 OUTLINE

電極付リードレス面実装パワーインダクタです。リング付シールドタイプもあります。
Lead-less, surface mount type power inductors, also magnetic shielding type.

CD54 CDR74 CD75 CDR105 CD105 CDR125

◇寸法図/DIMENSION(mm)



◇特 徴

1. コアに直接電極を設け、取り付け基板面積が省スペースで高密度実装が可能です。
2. 面実装が可能で、クロロセン(トリクロルエタン)洗浄が可能です。
3. 定格電流が大きい。直流抵抗が小さい。
4. 小型低背です。
5. キャリアテープでの納入が可能です。

◇FEATURES

1. Put the electrode with ferrite core directly, a small surface area allow a high mounting density.
2. These can be reflow soldering, flux rinsing with chlorothen or trichloroethane.
3. Large permissible DC current. Low DC resistor.
4. Compact and thin type.
5. Supply in a form of embossed tape carring.

◇用 途

DC/DCコンバータ入出力平滑用チョークコイル及びチョッパーコイル

1. カメラ一体型ビデオ電源
2. OA機器電源
3. 液晶TV電源
4. ノート型ワープロ・パソコン電源

◇USES

For the output input smoothing circuit of DC/DC converter chork coils and chopper coil.

1. Power supply for Camecorder.
2. Power supply for OA equipment.
3. Power supply for LCD TV.
4. Power supply for Note type word prossecer and personal computer.

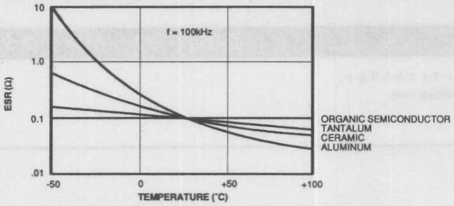
◇仕 様/SPECIFICATIONS

		CD54	CDR74	CD75	CDR105	CD105	CDR125
22μH	許容電流 Permissible DC current	1.11 A	1.11 A	1.50 A	1.71 A	2.13 A	2.20 A
	直流抵抗 Rdc (Max.)	0.18 Ω	0.12 Ω	0.11 Ω	0.09 Ω	0.07 Ω	0.07 Ω
100μH	許容電流 Permissible DC current	0.52 A	0.52 A	0.72 A	0.80 A	1.00 A	1.05 A
	直流抵抗 Rdc (Max.)	0.63 Ω	0.51 Ω	0.43 Ω	0.35 Ω	0.32 Ω	0.25 Ω
220μH	許容電流 Permissible DC current	0.35 A	0.35 A	0.49 A	0.54 A	0.67 A	0.70 A
	直流抵抗 Rdc (Max.)	1.50 Ω	0.98 Ω	0.96 Ω	0.69 Ω	0.71 Ω	0.62 Ω
インダクタンス範囲 Inductance range		10~220μH	10~270μH	10~470μH	10~470μH	10~820μH	10~820μH

スミダ電機株式会社 — 5 —

Sumida Electric makes a line of ferrite-core power SMT and through-hole inductors that include a broad range of values and peak current storage ratings. Compared to Coiltronics, the Sumida parts are less expensive and smaller, and available in a broader range of current ratings. The Coiltronics parts are slightly quieter, more versatile, and easily inspected for solder joint integrity.

EQUIVALENT SERIES RESISTANCE



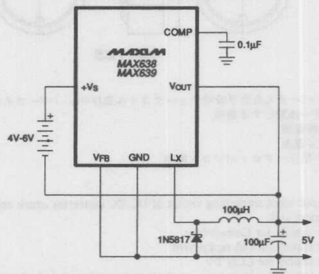
REPRESENTATIVE MANUFACTURERS

TYPE	MANUFACTURER	MODEL	TYPICAL VALUE FOR 0.1Ω ESR
Organic Semiconductor	Sanyo	OS-CON	47µF @ 16V
Solid Tantalum	Matsuo	Type 221	33µF @ 16V
Multilayer Ceramic	Murata-Erie	GR250	1µF @ 16V
Aluminum Electrolytic	Nichicon	PL Series	330µF @ 16V

Low equivalent series resistance (ESR) is the most important criteria for selecting an input or output filter capacitor for a high-frequency switching regulator. Not only is the output voltage ripple directly proportional to ESR, but ESR also creates a zero in the loop response that tends to destroy feedback loop stability. Take care with circuits using aluminum electrolytic types; they should be thoroughly checked for noise and AC stability at the lowest ambient operating temperature.

BATTERY INPUT BUCK/BOOST REGULATOR

MAX638-5V, 25mA
MAX639-5V, 100mA

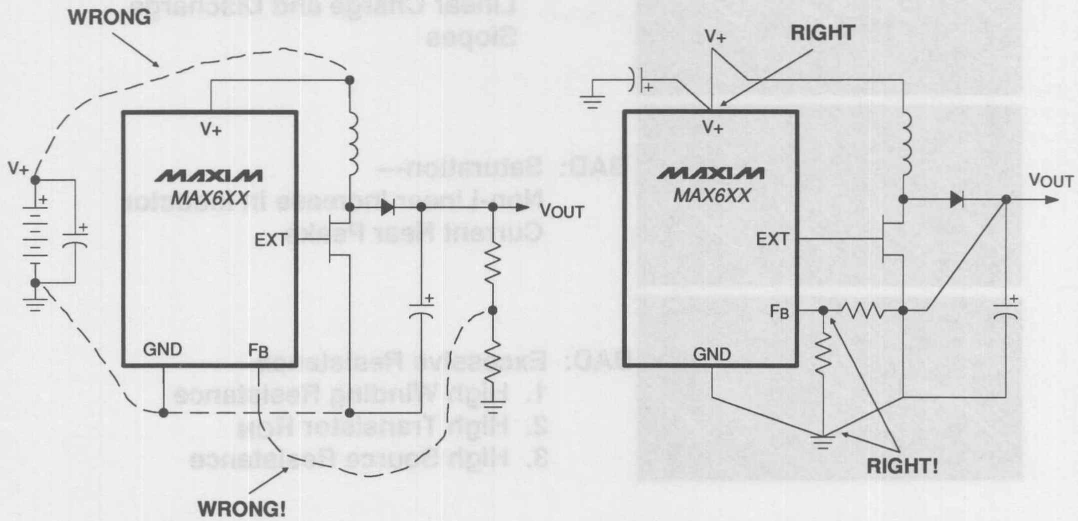


Perverted switching regulator design, where basic circuits are twisted out of all recognition in pursuit of some parameter such as efficiency or size, has long ago been honed to a fine art by users of Maxim ICs. This circuit is an excellent example, as it involves an IC originally designed as a step-down IC pressed into service as an inverter. Beyond that, it's been further twisted by rearranging the grounds such that it is, in effect, a positive-output circuit again.

Converting an input voltage that can range above and below the desired output voltage is the problem which this circuit solves. Normally, such a circuit must provide both step up and step down action. However, if the input ground can be floated, as is often the case with a battery, an inverter can be used instead of a transformer or a complicated and lossy step-up/down circuit, by fixing the most negative output voltage at ground. This trick works with any inverter (such as the MAX735).

DC-DC "GOTCHAS"

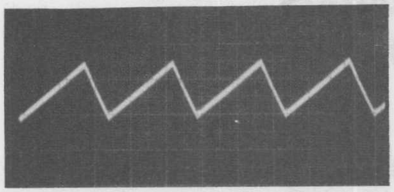
- **High Current Grounds**
- **Feedback Nodes**



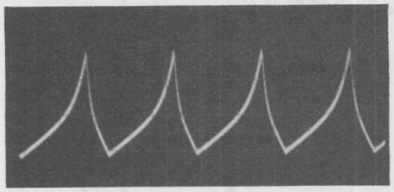
Even though low-power switching regulator ICs are generally easy to use, some attention must be paid to PC layout and routing, especially at higher power levels (>1 Watt) or when using the newer high-speed PWM devices. These recommendations are in order of priority:

1. Trace out the high-current paths and absolutely minimize their lengths, especially in the ground trace.
2. Use a "star" ground, with all grounds brought to one point.
3. Place an input filter capacitor physically close to the IC.
4. Minimize stray capacitance at the feedback (FB) pin.
5. Compensation capacitors and reference bypass capacitors must be returned to quiet, well-filtered points (such as an analog ground pin).

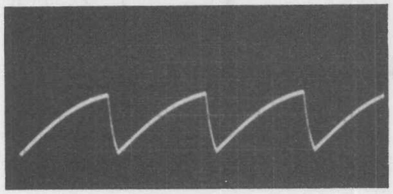
GOOD/BAD INDUCTOR CURRENT WAVEFORMS



**GOOD: Normal Operation—
Linear Charge and Discharge Slopes**



**BAD: Saturation—
Non-Linear Increase in Inductor Current Near Peaks**



BAD: Excessive Resistance—

1. **High Winding Resistance**
2. **High Transistor R_{ON}**
3. **High Source Resistance**

MAXIM

The most common problems in a DC-DC breadboard involve inductors, and most inductor problems can be traced to inadequate saturation (peak current) ratings or excessive DC resistance. If the inductor saturates, it's current rises exponentially with time. If there is excessive resistance, a distinct LR characteristic is seen. If the waveform takes small but strange bends, it may be doing both.

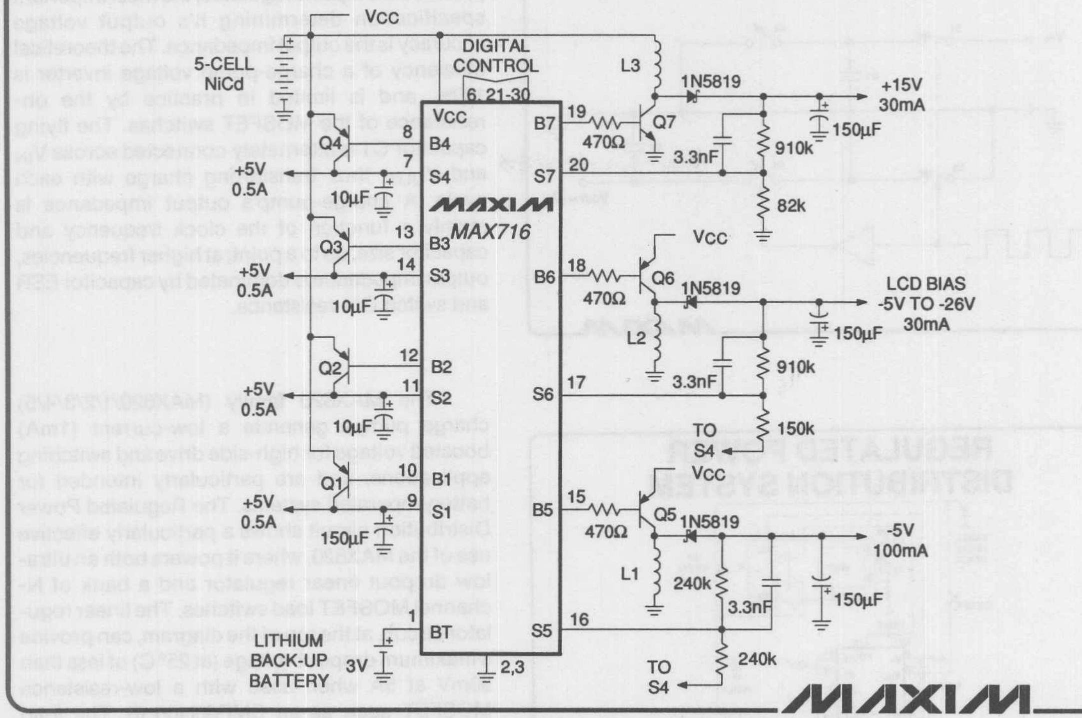
GOALS OF PORTABLE POWER MANAGEMENT

- **Long Battery Life**
  - **High Efficiency**
  - **Minimum Size**
  - **Low Operating/Quiescent Current**
  - **Load Management**
  - **Multi-Output**
  - **Digital Control**

MAXIM

The advent of portable "notebook" and smaller size computers is focusing an entire industry on the advantages of load reduction, power management, and efficiency in power supply circuitry. Now that these characteristics drive features that are "sold" to end users (product size and weight, and battery life), incentives have never been stronger for better, smaller, power supplies. Maxim's leads the industry in this technology.

FULL FUNCTION PORTABLE POWER



The MAX714/715/716 are highly integrated energy management ICs for 5-cell and 6-cell battery-operated microprocessor systems. These ICs combine multiple regulated outputs with microprocessor-supervisory functions optimized for battery-powered supplies. One of the three switching regulators has a negative output controlled by a 5-bit on-board D/A converter, for LCD contrast adjustment.

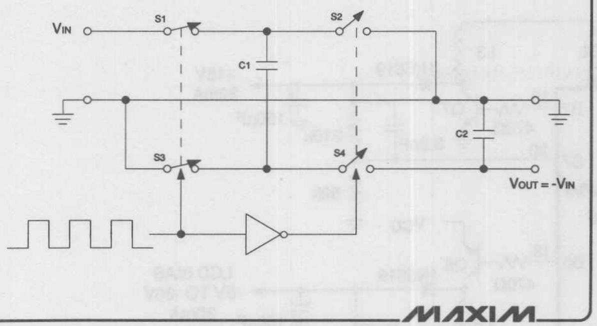
MAX714/715/716

- **Four Low-Dropout Regulators**
- **Adjustable DC-DC for LCD**
- **DC-DC Boost Converter**
- **DC-DC Inverter**
- **Backup Battery Switchover**
- **20µA Standby Mode**
- **Full Digital Control**
- **RESET and Low V Warning Outputs**

MAXIM

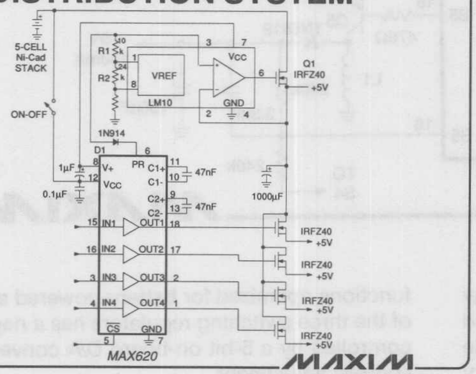
The MAX716 includes all the features listed here, and is supplied in 28-pin DIP and wide SO packages. The MAX715, in 24-pin DIP and CERDIP packages, eliminates one linear regulator output. The MAX714, in 16-pin packages, includes two linear regulators and one DC-DC converter.

CHARGE PUMP OPERATION



A charge pump is normally used as a DC-DC inverter (+V_{IN} to -V_{OUT}), but can also work as a voltage doubler. The output is not regulated, so, provided the input is regulated, the most important specification determining it's output voltage accuracy is the output impedance. The theoretical efficiency of a charge-pump voltage inverter is 100%, and is limited in practice by the on-resistance of the MOSFET switches. The flying capacitor C1 is alternately connected across V_{IN} and V_{OUT}, thus transferring charge with each cycle. A charge-pump's output impedance is mainly a function of the clock frequency and capacitor size, up to a point; at higher frequencies, output impedance is dominated by capacitor ESR and switch ON-resistance.

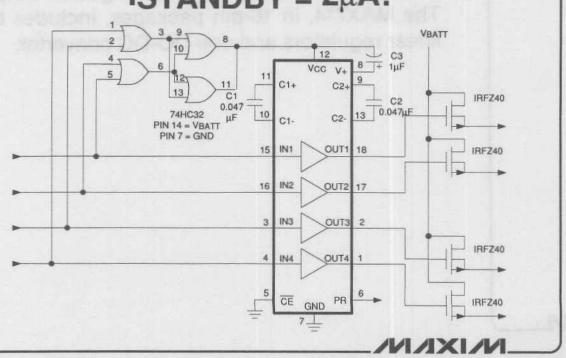
REGULATED POWER DISTRIBUTION SYSTEM



The MAX620 family (MAX620/1/2/3/4/5) charge pumps generate a low-current (1mA) boosted voltage for high-side drive and switching applications, and are particularly intended for battery-operated systems. The Regulated Power Distribution circuit shows a particularly effective use of the MAX620, where it powers both an ultra-low dropout linear regulator and a bank of N-channel MOSFET load switches. The linear regulator circuit, at the top of the diagram, can provide a maximum dropout voltage (at 25° C) of less than 90mV at 5A when used with a low-resistance MOSFET such as an SMP60N06-18. The load switches are driven by the high-side voltage, which is regulated at +11V above the supply voltage, via the four on-board latched level translators.

One of the nice features of this circuit is it goes into dropout gracefully, without drawing excessive current. If this circuit had used a bipolar PNP transistor in place of the Q1 MOSFET, excessive base current would be drawn when in dropout. In this circuit, the MOSFET is simply a closed switch when in dropout, thus still powering the load with extremely good efficiency until the battery is completely dead.

LOWEST STANDBY POWER ISTANDBY = 2µA!



This battery-management circuit controls four loads via low ON-resistance N-channel MOSFETs. N-channel MOSFETs are preferable to P-channels or PNPs for high load currents, as the don't leak away base current and are about 1/3 the cost and size of equivalent P-channel devices. The trick in this circuit is that if all four switches are programmed off, the power supply input to the MAX620 is disconnected, and the standby supply drain is reduced to 2μA.

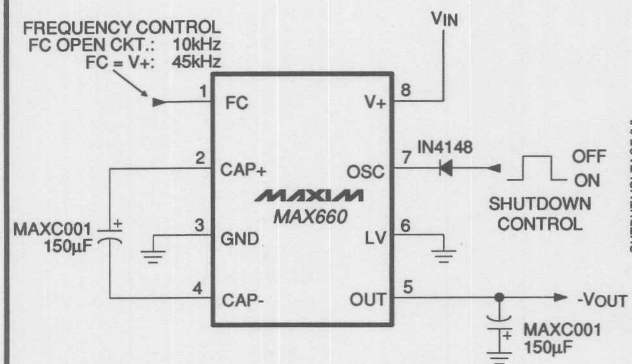
HIGH-SIDE DRIVER FAMILY

- **No Inductors**
- **Regulated Output = V_{CC} +11V**
- **Full Digital Control**
- **Wide Supply Range: V_{CC} = +4.5V to +16.5V**

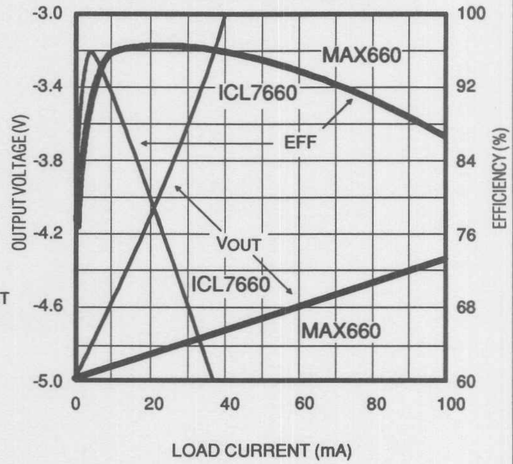
	MAX620	MAX621	MAX622	MAX623	MAX625
	High Side Power and FET Drivers		High-Side Power Supply		Internal 0.2Ω MOSFETS
Outputs	4	4	1	1	4
Pump Caps	3	Internal	3	Internal	Internal
Package	18-P DIP, SO	18-P DIP	8-P DIP	18-P DIP	24-P DIP

All of the members of this family of high-side supply ICs contain a basic power supply that generates a supply voltage 11V above the input voltage. Some members are hybrids that require no external charge pump capacitors, and others have on-board level translators. The Cadillac device, the MAX625, also contains four 0.2Ω power MOSFET switches within the IC package.

MAX660 CHARGE PUMP WITH SHUTDOWN

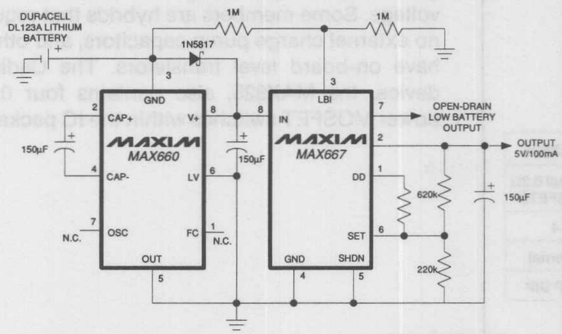


OUTPUT VOLTAGE AND EFFICIENCY vs. LOAD CURRENT, V+ = 5V



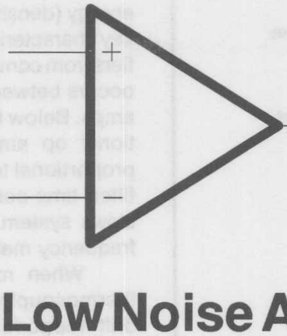
The MAX660, big brother to the popular ICL7660 charge-pump IC, is shown here as a voltage inverter, creating a negative voltage of approximately equal magnitude to the input voltage. Although the MAX660 has no feedback mechanism, and so is unregulated, it can generate a stiff, accurate supply when operated from a regulated input. An output current of 100mA results in a voltage loss of typically only 0.65V; the drop at 10mA is less than 100mV. The FC input selects a 10kHz or 45kHz oscillator frequency. This diagram shows an optional shutdown circuit that disables the internal oscillator, reducing the supply current to less than 1µA.

3V BATTERY TO +5V NO INDUCTORS



This inductor-less DC-DC converter generates a regulated +5V at up to 100mA from a single lithium cell. When powered by a DL123A (smaller than an AA cell), it will provide 40mA of load current for 12 hours or more. The MAX660 in doubler configuration steps up the battery voltage to +6V, which is then regulated down to +5V by the MAX667. The surface-mount version of this circuit occupies only 1/2 sq. in. of PC board area, because it uses capacitors for energy storage instead of inductors. The circuit capitalizes on the low dropout voltage of the MAX667 (typically <100mV at 150mA) and the 100mA load capability and 95% efficiency of the MAX660.

PRECISION OP-AMPS

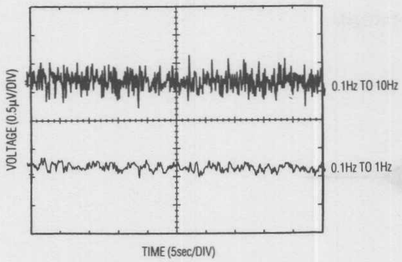


New Low Noise Amps
Micropower Applications
Single Supply Applications
Breaking 10MHz/mA

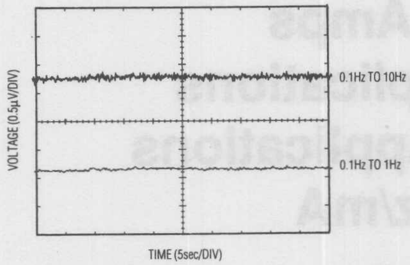
MAXIM

LOW 1/f NOISE USING SWITCHING TECHNIQUES

TLC2654 Noise in 10Hz and 1Hz Bandwidth

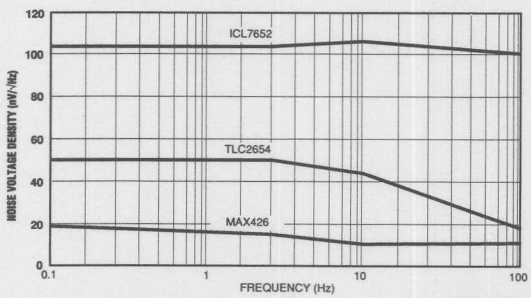


MAX425/MAX426 Noise in 10Hz and 1Hz Bandwidth



MAXIM

LOW 1/f NOISE USING SWITCHING TECHNIQUES



MAXIM

Low-noise amplifiers are of two types: those exhibiting low noise at DC and low frequencies, and those that exhibit low wide band noise. The latter type (which covers the majority of low-noise amplifiers) finds applications in audio, video and other dynamic measurement and high-frequency systems.

The "1/f corner frequency", where noise energy (density) vs. frequency changes slope, is a key characteristic separating DC optimized amplifiers from conventional types. This corner typically occurs between 10Hz and 1000Hz for typical op amps. Below the 1/f corner, the noise of conventional op amps increases at a rate inversely proportional to frequency. 1/f noise requires long filter time-constants to reduce. This severely slows system response, making low-level low-frequency measurements difficult.

When measuring low level signals from thermocouples, RTDs, and strain gauges, stable drift-free performance over long periods is needed. In these applications, a switched amplifier such as the MAX425/426 provides superior performance to low noise bipolar amplifiers (such as the LT1028: available from Maxim) as well as the previous "best" chopper stabilized amplifiers (ICL7652, TLC2654). A major reason for this advantage is that the amplifier's switching architecture effectively eliminates the noise rise below the 1/f corner while also virtually eliminating drift.

The MAX425 "Super Amp" is the industry's lowest noise CMOS op amp. In addition to negligible current noise, voltage noise is below $100nV_{p-p}$ in a 1Hz bandwidth. When optimizing low noise and low drift is critical, especially over wide temperature swings (V_{OS} is typically 200nV at +200°C!), the MAX425 is the best monolithic amplifier available, bipolar or CMOS.

IS 1/f NOISE INFINITE AT DC?

$$V_n = \sqrt{K \ln \frac{f_H}{f_L}}$$

$$V_{nA}\ (0.1\text{Hz to }10\text{Hz}) = \sqrt{K \ln \frac{10}{0.1}}$$

$$V_{nB}\ (10^{-18}\text{Hz to }10\text{Hz}) = \sqrt{K \ln \frac{10}{10^{-18}}}$$

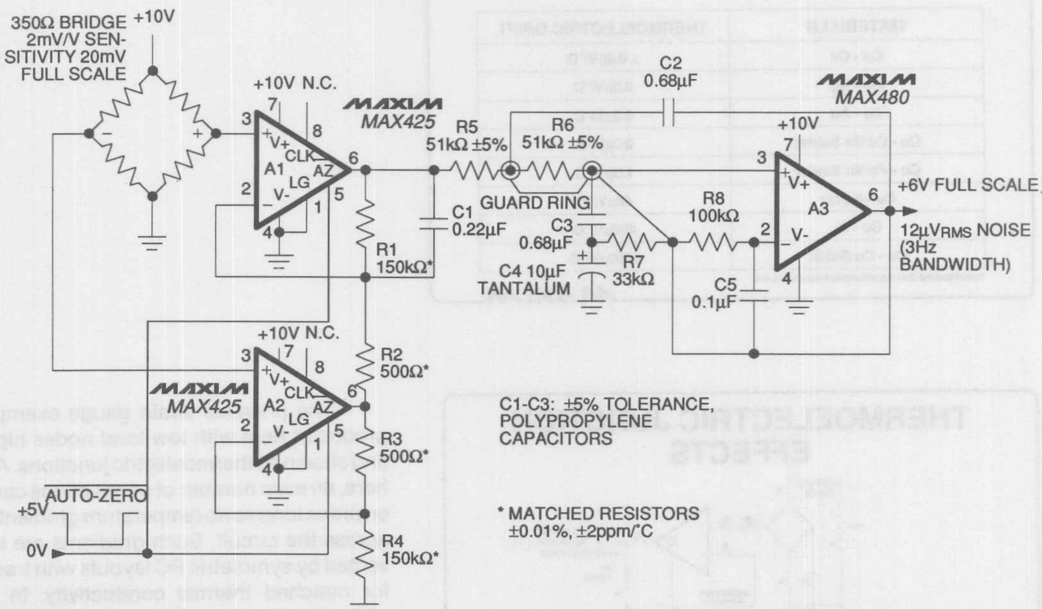
$\frac{1}{\text{Age Of The Universe}}$

$$\frac{V_{nB}}{V_{nA}} = \frac{\sqrt{K \ln 10^{19}}}{\sqrt{K \ln 10^{2}}} = 3.08!!$$

∴ If you wait forever, the noise is only 3 times more.

What does "1/f" say about noise at very low frequencies, like DC? Does noise reach infinity as f approaches 0? Not quite, as the equations for V_n show. The ratio between noise in a 0.1Hz to 10Hz band and a 10^{-18}Hz to 10Hz band is compared. 10^{-18}Hz is chosen as the reciprocal of the age of the universe, i.e. 1/forever. As can be seen the noise in the "forever" band is only 3.08 times large, and is not infinite.

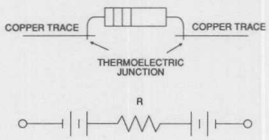
STRAIN GAUGE AMP



In addition to excellent noise and drift performance, the MAX425 and MAX426 feature a unique, controllable auto-zero input. This further reduces noise by allowing the amp to be nulled at convenient times so that switch circuitry can be turned off when measurements are made. In the circuit, two MAX425s (A1, A2) amplify the differential 20mV full-scale output of a strain-gauge bridge. This signal is then filtered and buffered by A3 (MAX480). The filter's 3Hz bandwidth limits output noise to around 12μV$_{RMS}$ (40nV$_{RMS}$ referred to the input). This translates to a signal-to-noise ratio of 114dB which allows stable measurements to within a few parts per million.

COMPARE

MAX425's 0.005µV/°C V_{OS} Drift to A Thermoelectric Junction Drift of 1.3µV/°C

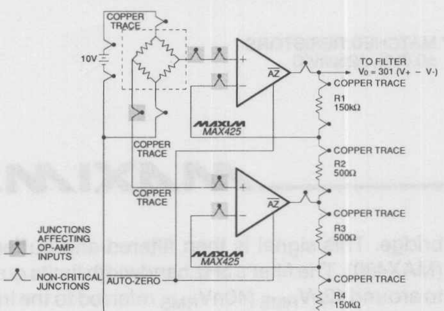


THERMOELECTRIC POTENTIALS FOR JUNCTIONS OF COMMON MATERIALS WITH COPPER

MATERIALS	THERMOELECTRIC DRIFT
Cu - Cu	≤ 0.2µV/°C
Cu - Ag	0.3µV/°C
Cu - Au	0.3µV/°C
Cu - Cd/Sn Solder	0.3µV/°C
Cu - Pb/Sn Solder	1.3µV/°C
Cu - Kovar	40µV/°C
Cu - Si	400µV/°C
Cu - Cu Oxide	1400µV/°C

Table Provided Courtesy of Keithley Instruments, Inc.

THERMOELECTRIC JUNCTION EFFECTS



Compare: MAX425 Drift To Thermoelectric Junction

Unfortunately, error free op-amps alone do not ensure error free measurements. When amplifying low level signals, the effects of thermoelectric junctions in the associated connections may appear as amplifier offset error and drift when in fact they are external. When two different metals (e.g., a copper trace and solder) contact, a voltage, which changes significantly with temperature, is generated by the resulting junction. In most two-lead devices, if both ends are at the same temperature, equal but opposite thermoelectric voltages cancel without generating error. This however can't always be assumed.

The most effective ways to eliminate thermoelectric errors is to 1) eliminate thermal gradients near sensitive circuitry, and 2) maintain an even number of junctions in low level circuit paths.

The previous strain gauge example is reproduced here with low level nodes highlighted and shown as thermoelectric junctions. As shown here, an even number of connections cancels the errors as long as no temperature gradients appear across the circuit. Such gradients are best prevented by symmetric PC layouts with traces sized for matched thermal conductivity. In extreme cases the circuitry can be insulated from external heat sources and drafts as well.

LOW CURRENT PRECISION OP AMPS

	Low Noise & Ultra-Low Drift MAX425/426	Precision Low Voltage Micropower MAX480	Chopper Stabilized No External Caps MAX432
Input Offset (µV max)	5	70	5
Drift (µV/°C)	0.005	0.3	0.05
Supply Current (mA)	1.2	0.014	0.3
Supply Range (V)	4.75 to 15.75	1.6 to 36	±2.5 to ±16.5
Input Range (V)	V- + 1 to V+ - 2	V- to V+ - 1.5	V- to V+ - 3
Output Range (V)	Rail-to-Rail	100µV to V+ - 1	Rail-to-Rail
0.1 to 10Hz Voltage Noise (µVp-p)	0.25	3	1.2
10Hz Current Noise Density (pA/√Hz)	Negligible	2	0.01

Maxim has introduced several advanced state-of-the-art op-amp designs that deal with difficult analog design problems, particularly those aggravated by shrinking supply voltages and supply current budgets.

MAX425/426 — Unsurpassed combination of low offset, drift, and noise

MAX480 — Low voltage operation, 14μA supply current, 70μV offset

MAX432 — 300μA supply current with 50nV/°C max drift

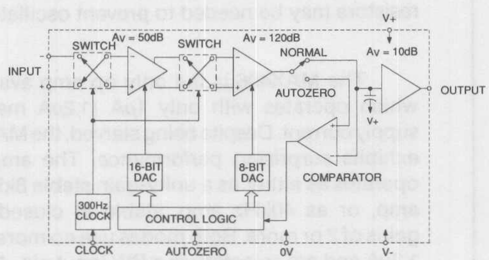
LT1028 — Lowest wide band noise — 1nV/$\sqrt{Hz}$

MAX412 — Lowest noise dual — 2nV/$\sqrt{Hz}$, Low voltage operation

MODERATE CURRENT PRECISION OP AMPS

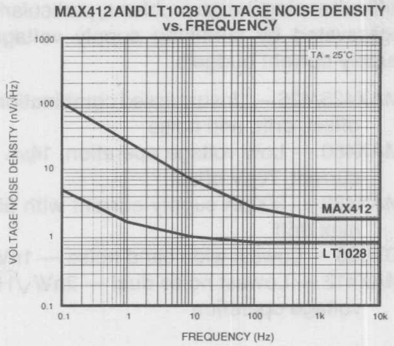
	Lowest Voltage Noise LT1028	Low Voltage Low Noise Dual MAX412
Input Offset (µV max)	40	250
Drift (µV/°C)	0.2	1
Supply Current (mA)	7.4	2.5/Amplifier
Supply Range (V)	±4.5 to ±18	±2.4 to ±5.25
Input Range (V)	V- + 2.8 to V+ - 2.8	V- + 1.2 to V+ - 1.3
Output Range (V)	V- + 0.7 to V+ - 0.7	V- + 1.2 to V+ - 1.3
0.1 to 10Hz Voltage Noise (µVp-p)	0.035	0.16
10Hz Voltage Noise Density (nv/√Hz)	1	7
10Hz Current Noise Density (pA/√Hz)	4.7	2.6
Slew Rate (v/µS)	15	4.5
GBW (MHz)	75	28

MAX425/426



The MAX425/426 unique precision amplifier design employs two independent error-correction schemes. A switching input amplifier eliminates V_{OS} and minimizes 1/f noise, and digital auto-zeroing corrects all internal amplifier stage offsets to remove common-mode errors and clock ripple. The block diagram shows the basic architecture. The amplifier can be set to use both, one, or none of these correction techniques.

MAXIM's LOW NOISE LEADERS



MAXIM

In addition to the MAX425/MAX426 combination of low drift and noise, two general purpose wide band low noise amplifiers also lead the industry: The LT1028 (supplied by Maxim) provides the lowest noise voltage presently available in a monolithic op amp. As seen in the plots at left, the MAX412 dual op amp comes very close to the LT1028 on noise, but uses nearly three times less supply current, provides superior performance at low supply voltages, and best of all: includes two amplifiers in one 8-pin package.

OP AMPS IN SINGLE-SUPPLY SYSTEMS

- Dynamic Range
  - Output Voltage Swing
  - Noise, Offset, and Drift
  - Input Range Includes Ground
- Ground Quality Important
  - Signal and Power Ground Shared
- Battery-Powered Systems
  - Low Supply Current
  - Stability with C_{LOAD}
  - Power Supply Rejection

MAXIM

When choosing amplifiers for single-supply systems, input voltage range and output voltage swing are often the first consideration. Input range and output swing near ground ensure that low-level signals near zero volts are not "lost". In addition, outputs that swing near the positive supply maximize signal range — a greater concern in 5V powered systems than those powered from 12V or ±15V. Amplifier noise, offset, and drift are also more troublesome in low-voltage single-supply systems because, in addition to voltage-swing limits, they constrain dynamic range.

Noise and grounding problems also become more pressing as the supply voltage and signal ranges decrease. PC board ground quality is more important when there is only one supply because signal ground and power return are the same, unlike split-supply analog circuits where most supply current flows from V+ to V– and not to ground.

Operating current is often an important criterion in single supply systems, because they are often battery-powered. Many systems operate with unregulated battery power so supply rejection may also be a concern. Another feature often sacrificed in low-current amplifiers is the ability to remain stable while driving capacitive loads. In these cases extra compensation or output isolation resistors may be needed to prevent oscillation.

ULTRA-LOW-POWER CMOS OP AMP

MAX406

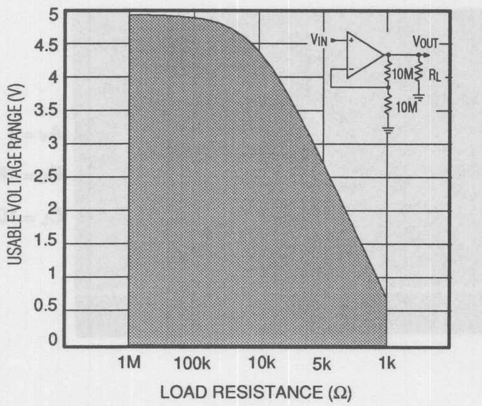
- 1.2µA MAX Supply Current
- +2.5V to +10V Supply Range
- High-Speed Mode–40kHz B.W, $A_{VMIN} = 2$
- Unity-Gain Stable Mode–8kHz B.W
- 0.5mV MAX Offset Voltage
- 20pA MAX Input Bias Current at 70°C

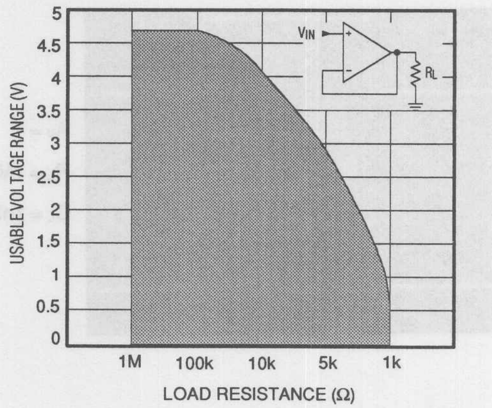
MAXIM

The MAX406 is the only op amp available which operates with only 1µA (1.2µA max) of supply current. Despite being starved, the MAX406 exhibits surprising performance. The amplifier operates as either as a unity-gain stable 8kHz op amp, or as 40kHz amp, stable at closed-loop gains of 2 or more. Both modes use no more than 1.2µA and are selected via a BW input pin. A dual unity-gain stable version, the MAX407 is also available.

USABLE OUTPUT RANGE
MAX406

- **Input/Output Range Includes Ground**
- **Wide Output**



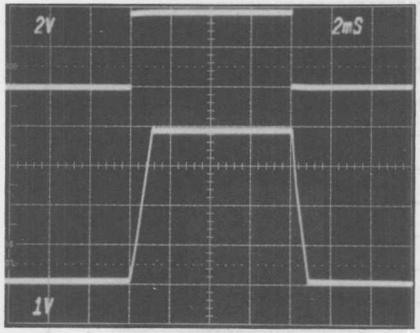


When analog circuitry must operate at low power and/or from reduced voltage (batteries), operating signal range becomes important. With limited dynamics, every means to increase signal range is employed. If a battery supply is unregulated, signal range falls with battery voltage. In a single-supply system, where ground is the most negative point, how the amplifier handles signals near zero is particularly important.

The graph plots the MAX406's TRUE operating signal range for a range of grounded load resistances. For the purposes of the graph, operating signal range is defined as the point where the output error exceeds 0.5mV. The plot is shown for a unity gain buffer and a non-inverting gain of 2. As the graph shows, the MAX406 works well with a single 5V supply. Input range includes ground and output swing is rail-to-rail unloaded and is a function of load resistance as shown.

• Stable For Cap. Loads Beyond 10nF

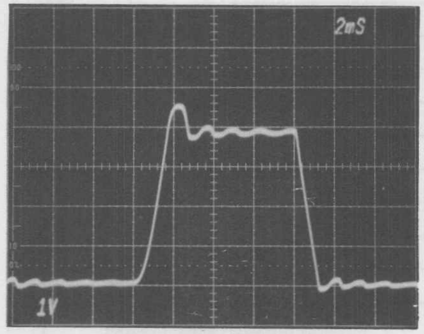
MAX406



$A_V = 1$

$R_L = 1M\Omega$

$C_L = 1nF$



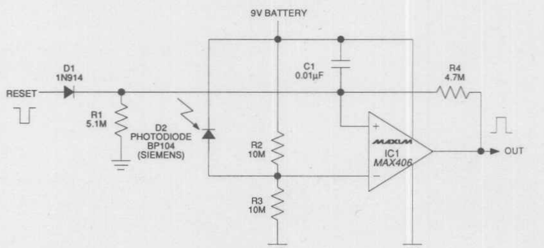
$A_V = 1$

$R_L = 1M\Omega$

$C_L = 10nF$

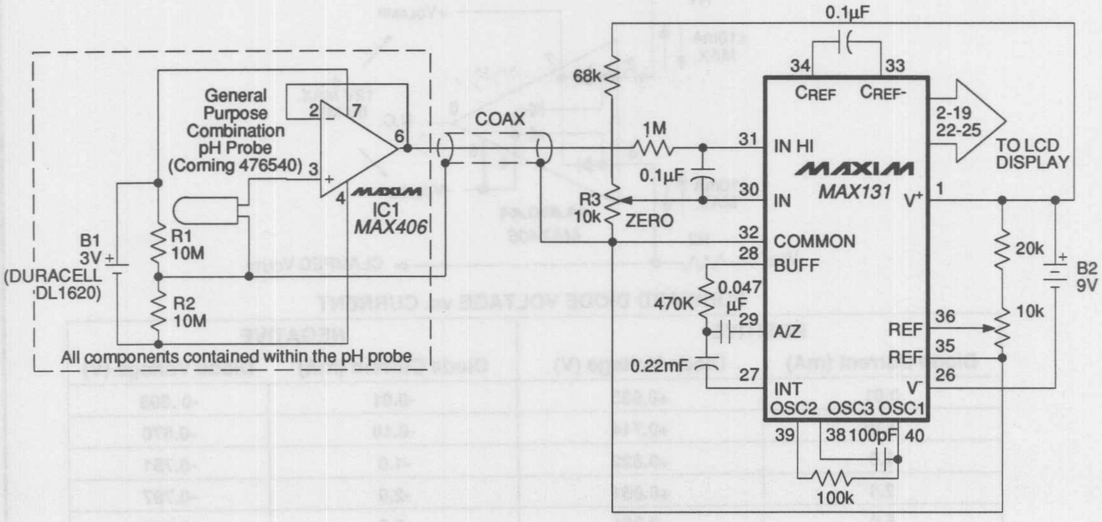
For a low (or micro-) power amplifier to do its job, it must be able to deal with real-world load conditions. This includes capacitive loads, which are often a notorious problem for low power output stages. A large part of the benefit of a low power amp is lost if a buffer must then be added. The behavior of the MAX406 under heavy capacitive loading is shown in the photos at left. Connected as a unity-gain buffer, the op amp shows no signs of ringing into a 1nF load and only a small amount when driving 10nF.

BATTERY POWERED ALARM CIRCUIT OPERATES FOR YEARS



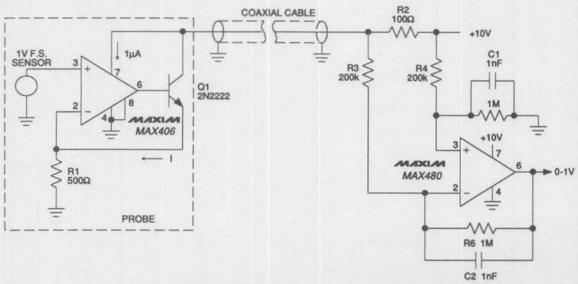
This light-detector alarm takes full advantage of the MAX406's 1μA quiescent current. The entire circuit draws 1.5μA; at this load, a 9V alkaline battery can supply 200mA-hours, which translates to a 15 year life. Of course, the shelf life of the battery most likely will end before this time. This circuit output latches high when light is detected. If the sensor is exposed, the output remains on until it is reset. The MAX406 operates as a comparator and as a latch by adding hysteresis externally via R4. If reconfigured to trigger, and latch, on darkness instead of light, this circuit may help solve an age-old engineering puzzle: Does the refrigerator light really does turn off when the door is closed?

LOW-COST CABLE



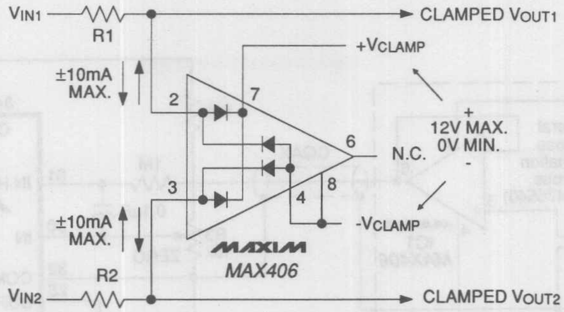
Besides using very little supply current, the MAX406 also demands low current at its input pins. Input bias current is guaranteed to be less than 20pA over temperature, and is typically below 0.1pA at 25°C. These characteristics are ideal for buffering pH probes and a variety of other high output-impedance chemical sensors. The circuit at left eliminates expensive low leakage cables that often connect pH probes to meters. A MAX406 and a Lithium battery are included in the probe housing. A conventional low-cost coax cable carries the buffered pH signal to the MAX131 A-to-D converter. Battery life depends on the DC loading of the amplifier output, which is only the MAX131 input current and cable leakage. In most cases battery life exceeds the functional life of the probe itself.

REMOTELY-POWERED SENSOR AMP



A simple two-wire current transmitter uses no power at its transmitting end except that from the transmitted signal itself. At the transmitter, a 0V to 1V input input drives a MAX406 and NPN transistor connected as a voltage controlled current sink. Although the MAX406's supply current is taken from the signal, negligible error (1μA out of 2mA) is added. The 0mA to 2mA output is sent through a coax cable to the receiver, where a MAX480 looks differentially across a sense resistor (R2). The MAX480 then reconstructs a ground referenced 0V to 1V signal.

MAX406 AS DUAL LOW-LEAKAGE CLAMP



FORWARD DIODE VOLTAGE vs. CURRENT

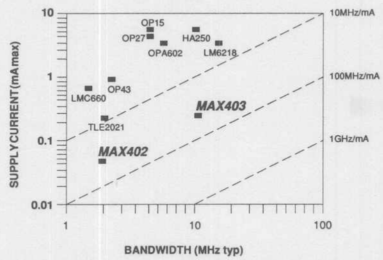
POSITIVE		NEGATIVE	
Diode Current (mA)	**Diode Voltage (V)**	**Diode Current (mA)**	**Diode Voltage (V)**
0.01	+0.635	-0.01	-0 .608
0.10	+0.714	-0.10	-0.670
1.0	+0.822	-1.0	-0.751
2.0	+0.861	-2.0	-0.787
5.0	+0.921	-5.0	-0.858
10.0	+0.980	-10.0	-0.931

MAXIM

To keep input leakage to a minimum, internal protection diodes at the MAX406 + and - inputs are kept small. This makes them ideal for use in a very unusual, but effective application: as a dual low-leakage clamp. Two signals may be clamped by tying each to an op amp input. The MAX406's + and - supply pins set the clamp limits.

Typically, MAX406 leakage is only 100fA at 25°C. This is superior to most discrete low leakage diodes. At high temperatures, guaranteed leakage is 20pA @ 70°C, 50pA @ 85°C, and 1nA @ 125°C. Limitations of this circuit are that current into the two input pins must be limited by R1 and R2 to 10mA, and the voltage between the + and - supply pins must not exceed 12V.

MAX402/403 BREAK 10MHz/mA BARRIER

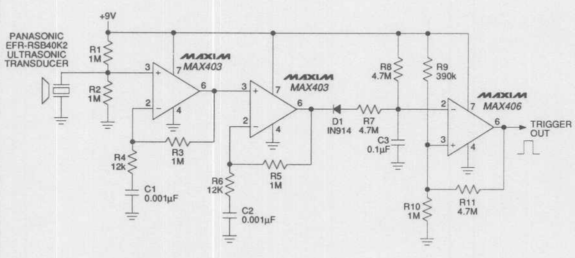


The new MAX402 and MAX403 provide the best speed and power combination in the industry, guaranteeing a 2MHz bandwidth at a 75μA supply current for the MAX402, and 10MHz at 375μA for the MAX403. The supply current vs. bandwidth plot shows how these amplifiers soundly break the "10MHz per mA" barrier, previously unchallenged by any existing high speed op amps (trumpet fanfare here).

HIGH-SPEED, MICRO-POWER OP AMPS

	MAX402	MAX403
Slew Rate	5V/µs Min.	25V/µs Min.
Operating Supply Voltage	±3 to ±5V	±3V to ±5V
Supply Current	75µA Max.	375µA Max.
GBW	2MHz (1.4 Min.)	10MHz (7 Min.)
Input Bias Current	±5nA Max.	±25nA Max.
Input Offset Voltage	2mV Max.	2mV Max.

ULTRASONIC RECEIVER



A low power ultrasonic receiver built around MAX403s can operate for several weeks on a 9V battery. The receiver must have high gain at ultrasonic frequencies in order to detect faint reflections from a separate ultrasonic source (not shown). To prevent false triggering, the 40kHz received signal passes through R7 to charge C3 after being rectified by D1. The rectified signal is detected by a MAX406 op amp connected as a comparator, chosen because of its 1μA supply current and rail-to-rail output swing.

VIDEO/HIGH-SPEED

SOLUTIONS TO HIGH-SPEED PROBLEMS

VIDEO MUX BUFFERS

CLOCKED ECL COMPARATORS

MAXIM

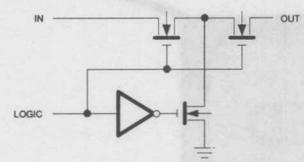
OPTIMIZING HIGH-SPEED PERFORMANCE

PROBLEM	SOLUTION
Feedthrough	"T" Network Switches and Multiplexers
PC Trace Capacitance – Crosstalk	Alternating Pin Placement (MAX453-MAX456)
PC Trace Capacitance–Reduced Bandwidth	"Active Guard" Pinout (MAX405)
Gain Variation with Load	Precision Buffer (MAX405)
Comparator Oscillation	Separate Input and Output Supplies (MAX900-903)
	Clocked Output (MAX905/MAX906)

MAXIM

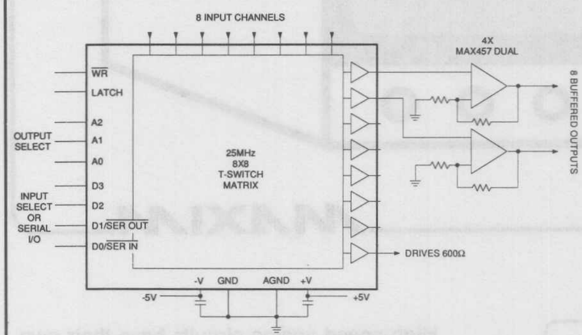
High-speed analog circuits have their own "special" set of problems, most of which only thorough engineering and experience can avoid. Even the "latest and greatest" high speed ICs are no less vulnerable without attention to the realities of high speed design. Maxim's newest high speed products focus on achievable results in end products, not just "laboratory results". The practical issues for optimizing high speed performance outlined in the table are covered in this chapter.

VIDEO "T" SWITCH



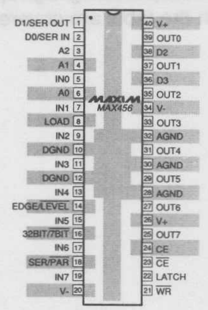
A "T" switch configuration reduces crosstalk in a number of Maxim video products. The "T" switch has lower effective feedthrough capacitance and, therefore, higher off isolation and inter-channel isolation than a single switch. When the network is "on", two series FETs between the input and the output turn on. In the off state, these devices turn off, and the junction between them is shunted to ground via a third N-channel FET. This shunts to ground any AC signal coupled through the input FET's drain-to-source capacitance. The MAX456 (8x8 crosspoint) achieves 80dB off isolation at 5Mhz using this technique.

MAX456 8X8 CROSSPOINT



The MAX456 contains a 30Mhz 8 × 8 "T-switch" matrix arranged for 8 input and 8 output channels. Each output drives 400Ω and 20pF to 1.2V. Switch programming data is loaded into the MAX456 one of two ways: as a 7-bit parallel word, or as a 32-bit serial stream. Each of the 8 output channels may be connected to any one input channel. The MAX456 outputs are also conveniently pinned out to drive MAX457 dual amplifiers so that 75Ω loads can be driven with minimum components.

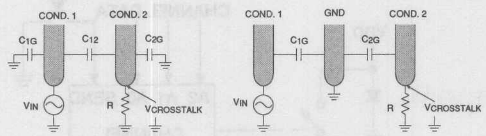
IC PIN ASSIGNMENT REDUCES PARASITIC EFFECTS



At high frequencies (1MHz and up), even the capacitance between adjacent IC pins IC can cause crosstalk. To reduce this, the MAX456 input pins are separated by a pin connected either to ground, a power supply voltage, or a stationary logic level. Each of these pins (and the connected traces) acts as a guard between inputs, reducing coupling capacitance and crosstalk. MAX456 outputs are also arranged using this alternating pin placement.

REDUCING CROSSTALK

PARALLEL CONDUCTORS   GUARD TRACE



Crosstalk occurs between printed circuit traces and IC pins when the coupling capacitance becomes significant compared to the terminating impedance of the "receiving" trace. In the example, crosstalk amplitude is a function of the signal amplitude on Conductor 1, the coupling capacitance C_{12}, and the impedance (resistance and parallel capacitance) at Conductor 2.

Adding a guard trace as shown greatly reduces C_{12}, which in turn reduces the crosstalk. In practice, the guard lowers crosstalk by about 20dB. The pin arrangement of the MAX456 as well as the MAX453/454/455 facilitates guarding by not placing signal-carrying pins next to each other.

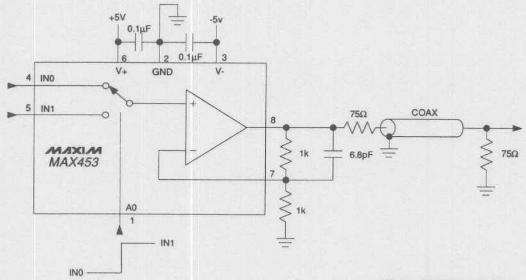
MAX453/4/5 VIDEO MUX/AMPLIFIERS

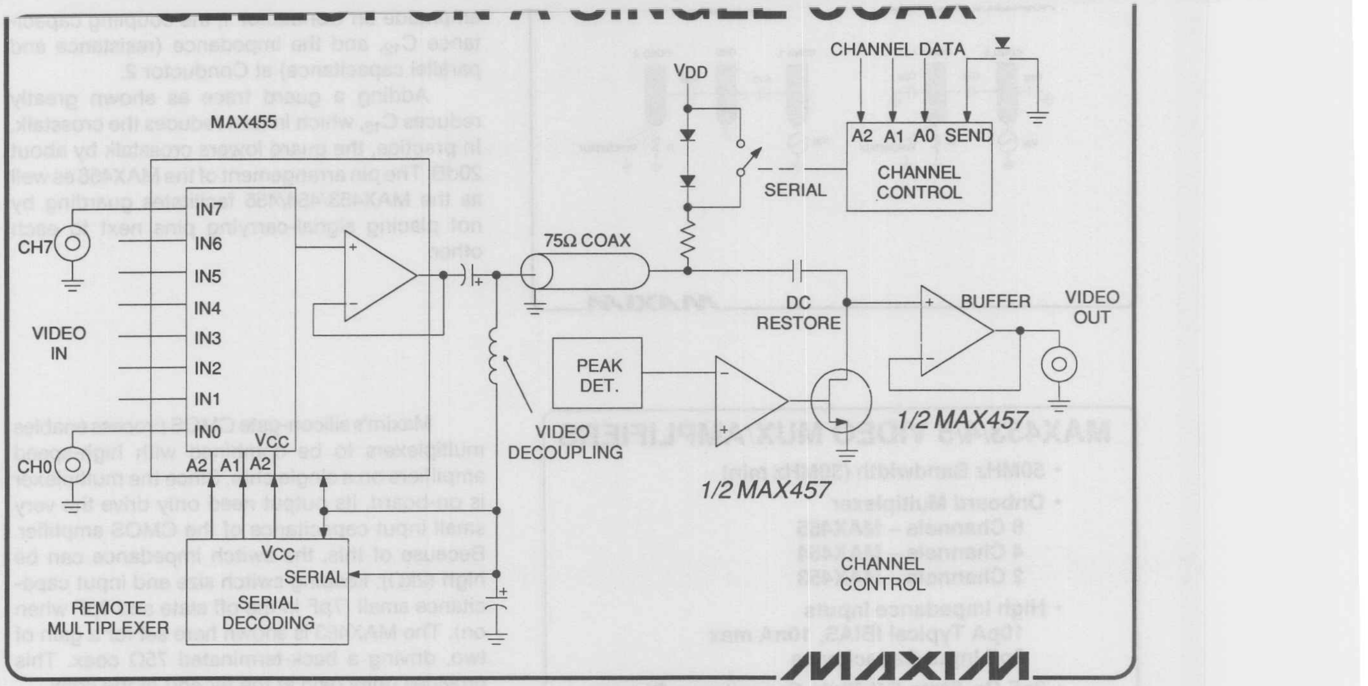
- 50MHz Bandwidth (30MHz min)
- Onboard Multiplexer
  - 8 Channels – MAX455
  - 4 Channels – MAX454
  - 2 Channels – MAX453
- High Impedance Inputs
  - 10pA Typical IBIAS, 10nA max
  - 9pF Input Capacitance
- 2pF On-State-Off-State Capacitance Change
- Drives 75Ω Coax ±1V
- Unity Gain Stable
  - No External Compensation Needed

Maxim's silicon-gate CMOS process enables multiplexers to be combined with high-speed amplifiers on a single chip. Since the multiplexer is on-board, its output need only drive the very small input capacitance of the CMOS amplifier. Because of this, the switch impedance can be high (2kΩ), keeping switch size and input capacitance small (7pF in the off state and 9pF when on). The MAX453 is shown here set for a gain of two, driving a back-terminated 75Ω coax. This provides unity gain at the far end of the coax.

8-PIN VIDEO MUX/BUFFER

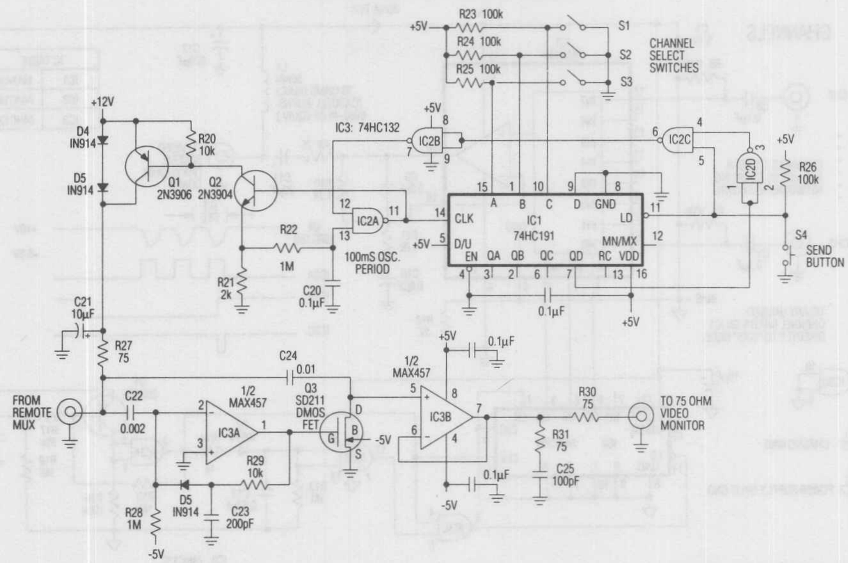
- 30MHz Bandwidth
- -60dB Crosstalk @ 4MHz





In this video system, a single coaxial cable carries power to the remote location, selects one of eight video channels, and returns the selected signal. The system can choose one of several remote surveillance-camera signals, for example, and display the picture on a monitor near the channel select box.

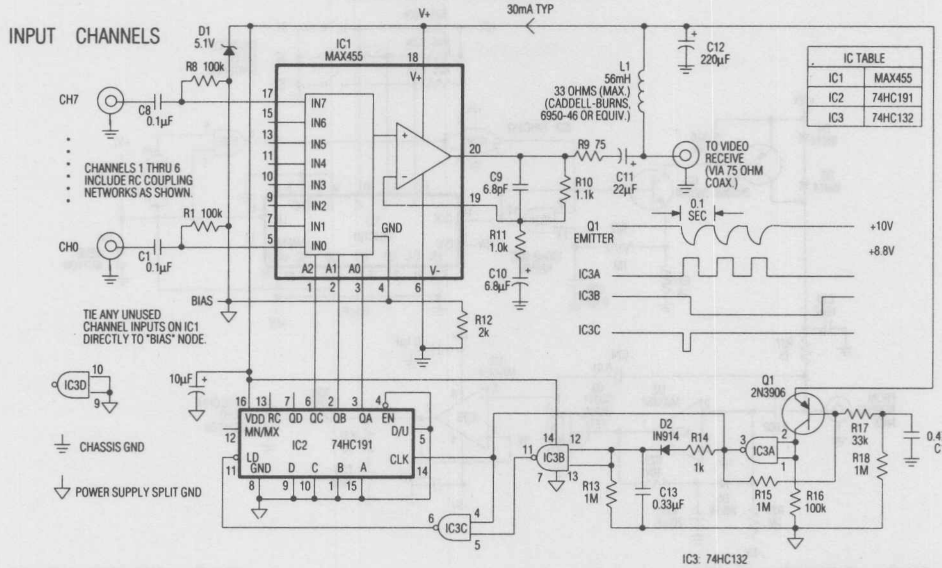
SINGLE COAX CARRIES VIDEO, POWER, AND CHANNEL-SELECT SIGNALS



The heart of the remote multiplexer box is a combination 8-channel multiplexer and amplifier (IC1). C11 couples the multiplexer's baseband video output to the coax, and L1 decouples the video from DC power arriving on the same line. This power — approximately 30mA at 10V — supplies all circuitry in the multiplexer box.

Channel-select signals generated at the interface box (1 pulse for channel 0; 8 pulses for channel 7) pulse the 10V supply to 8.8V and back at a 10Hz rate. Q1 and associated components in the remote multiplexer box convert these pulses to 5V-logic levels, which clock the 4-bit counter IC2, which in turn selects the desired multiplexer channel. The first pulse of a burst selects channel 0. Subsequent pulses, arriving before discharge of the timeout network R13C13 advance IC2 by one count each. Thus, channel 0 appears almost instantly, and channel 7, when selected, appears near the end of a 0.8sec burst.

SINGLE COAX CARRIES VIDEO, POWER, AND CHANNEL-SELECT SIGNALS



In the channel control box, a desired channel is encoded by three bits, set either by switches as shown or by an applied digital input. Momentary depression of the Send Button triggers down-converter IC1 and gated oscillator IC2A to initiate a channel-selection burst. (Maxim's MAX635 and MAX638 switching converters, operating on 12V, can generate the ±5V supply required for the interface circuitry.)

Supply current flows to the remote multiplexer box through Q1 (normally on and saturated), R27, and the coax center conductor. R27 also terminates the coax via C21. When Q1 turns off momentarily, forward bias across D3 and D4 develops a negative 1.2V channel-select pulse. This 1.2V drop in supply voltage does not affect the remote multiplexer's video output. Consequently, the video monitor's display does not flip during channel changes, provided the channel signals have common sync timing.

The short time constant associated with coupling of video to the coax (C11 and R9 in the remote multiplexer box and R27 in the channel select box) enables selection of any channel in less than one second, but it also allows the composite video's sync-pulse baseline to shift with picture content. To counter this shift and its effect on the monitor's video synchronization, peak detector IC3A drives DMOSFET Q3, which applies DC restoration ahead of the video buffer IC3B: During each negative sync pulse, Q3 turns on just long enough to reclamp the pulse tip at 0V.

MAX405 HIGH-SPEED BUFFER AMPLIFIER

SPEED

- 180MHz Bandwidth
- 650V/μs Slew Rate
- 35ns (50ns max) Settling to 0.1%

PRECISION

- 0.99V/V Min Gain When Loaded Over Temp.
- 0.01Ω R_{OUT}
- 0.1% Nonlinearity Over Temp.

POWER

- Guaranteed 60mA Continuous Output Current
- Drives 4 Back-Terminated 75Ω Loads to ±2.25V

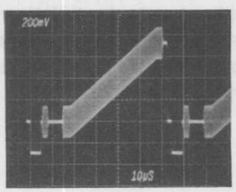
FEATURES

- Gain Adjust
- Pin-Out Minimizes Input Capacitance

MAXIM

The MAX405 buffer combines high speed with precision. It guarantees precisely trimmed gain while continuously driving up to 4 back-terminated 75Ω loads by virtue of only 0.01Ω output resistance. Differential gain and phase performance is ideal for high quality video signal buffering: 0.03% and 0.01°.

SUPERIOR DIFFERENTIAL GAIN AND PHASE SPECS — MAX405



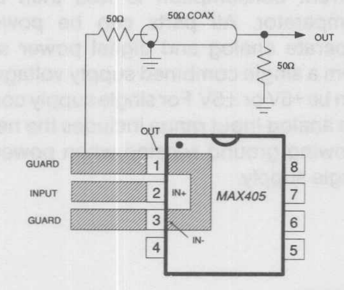
- 0.01° Differential Phase Error
- 0.03% Differential Gain Error

MAXIM

The MAX405 is also unique because its gain can be trimmed above 1V/V as well as below (Gain in conventional buffers can only be trimmed down by adding an input voltage divider). An inverting input allows adjustment from 0.99V/V to 1.10V/V with external resistors.

MAX405 PIN POSITIONS ALLOW GUARD TRACE

INPUT CAPACITANCE REDUCED



MAXIM

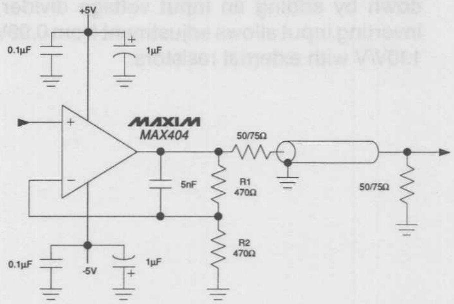
Pin placement in the MAX405 is very conductive to AC input guarding. IN+, IN–, and OUT are all adjacent. Since they are at the same potential, the low-impedance output can drive a shield for the input. The driven shield nullifies the effect of capacitance on input traces, ensuring that the input signal is not rolled off at high frequencies. For a pole to be created ($R_{SOURCE} \times C_{STRAY}$), current must flow from the input line (loss). Since, with guarding, the voltage across this capacitance does not change with time, no current flows, and the pole that diminishes bandwidth is not created.

THE MAX404 HIGH-SPEED OP AMP

- 500V/µs Typ. Slew Rate
- 80 MHz Typ. Bandwidth: $A_{VCL} = 2$
- Settles to 0.1% in Typ. 70ns
- Differential Gain: 0.05% Typ.
- Differential Phase: 0.01° Typ.
- Output Current up to 50mA Min.
- Drives Unlimited Capacitive Loads

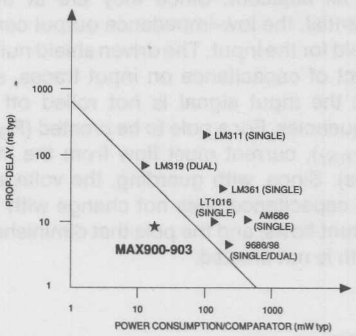
The MAX404 is a high-speed op amp optimized for AC performance, output drive, and stability in the face of varying load conditions. Featuring 80MHz gain-bandwidth, 500V/µs slew rate, and 0.01°/0.05% differential phase and gain, this amplifier is ideal for video and other high-speed applications. Unlike current-feedback amplifiers, the MAX404 can be used in virtually all high-speed amplifier applications because it has fully symmetric differential inputs, 70dB CMRR, and 66dB of open-loop gain.

GAIN OF 2 DRIVERS FOR BACK-TERMINATED COAX



The MAX404 remains stable while driving unlimited capacitive loads. As a result, flash A/D converter inputs, long distance coaxial cables, and other large or varying capacitive loads can be driven without output oscillation or ringing. Here it is connected as a back-terminated 50Ω or 75Ω coax cable driver in a noninverting gain of 2. Gain at the cable end is of course 1.

MAXIM'S MAX900-903 BREAK THE SPEED/POWER BARRIER



The MAX900-MAX903 analog comparators provide high speed performance at a fraction of the supply current of existing devices. Typical propagation delay is only 8ns, while the maximum current consumption is less than 3.5mA per comparator. All parts can be powered from separate analog and digital power supplies or from a single combined supply voltage. Supplies can be +5V or ±5V. For single supply convenience, the analog input range includes the negative rail, allowing ground sensing when powered from a single supply.

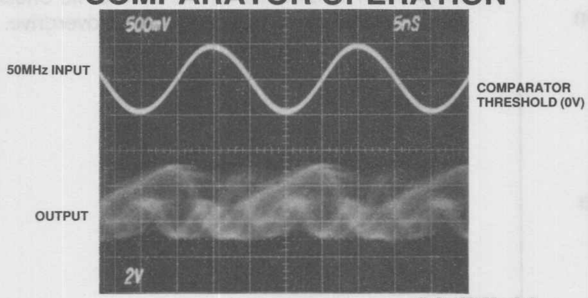
MAX900-903 HIGH-SPEED SINGLE-SUPPLY COMPARATORS

- 8ns Typ. Propagation Delay
- 3.5mA Max Supply Current per Comparator
- Separate Analog and Digital Supplies
- Flexible Analog Supply: +5V to 10V or ±5V
- Input Range to Negative Supply -100mV
- TTL Compatible Outputs
- TTL Compatible Latch Inputs
- Single, Dual, and Quad Versions

MAXIM

The MAX900 and MAX901 are quad comparators, while the MAX902 and MAX903 are dual and single respectively. All but the MAX901 are equipped with independent TTL-compatible latch inputs. All comparator outputs are also TTL-compatible.

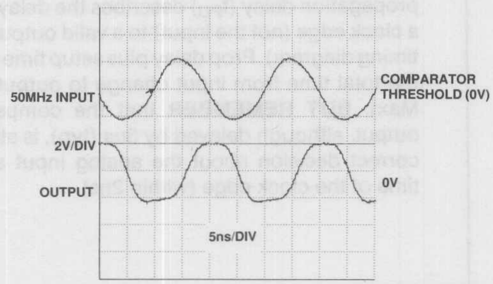
EFFECT OF POOR LAYOUT ON MAX9686 HIGH-SPEED COMPARATOR OPERATION



MAXIM

While negative feedback is common with op amps, when capacitive coupling introduces it to comparators, it can have mischievous effects on performance. As the photo shows, poor layout provides the worst results when stray capacitance couples the comparator output to its inverting input. The resultant negative feedback keeps the comparator in its linear region for a greater input range. Not only is the comparator more sensitive to noise and more prone to oscillation, but its speed may be decline as well. If the problem cannot be cured by layout, then positive DC or AC feedback (hysteresis) may be needed.

MAX9686 HIGH-SPEED COMPARATOR WITH PROPER LAYOUT



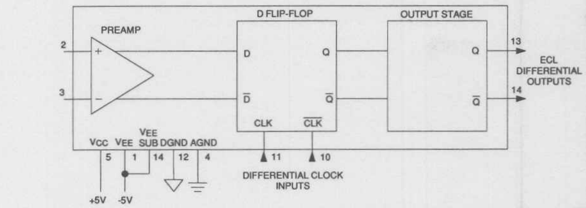
MAXIM

Proper layout of the same comparator circuit as in the previous photo results in a noise free output for a 50MHz sinewave input. This waveform is achieved without external hysteresis.

HIGH-SPEED COMPARATOR ELIMINATES OUTPUT-INPUT FEEDBACK

MAX905/906 COMPARATORS IMMUNE TO OSCILLATION

MAX905



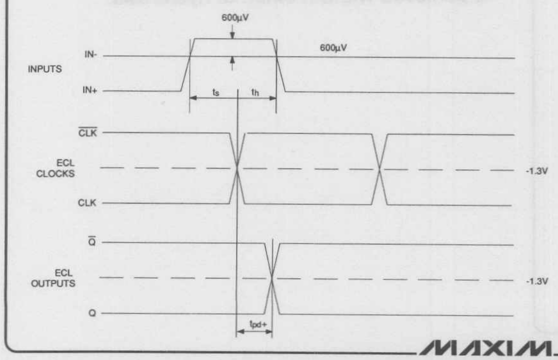
ECL comparators are particularly prone to oscillation because of the speeds involved. The MAX905/906 take a "once-and-for-all" approach to solving this problem with a high speed "clocked" design. In this scheme, a differential input preamp drives a D flip-flop. The flip-flop Q and $\overline{Q}$ outputs drive the outputs via an ECL driver. Oscillation is eliminated because the output can only change state when it is clocked. The MAX906 is a dual version of the MAX905.

MAX905/906 ALLOW 1mV INPUT RESOLUTION

- **Only ECL Comparator with 1mV Resolution**
- **Resolution Dictated by**
  - **100µV V_{OS}**
  - **300µV of Input-Referred Noise**
  - **Required Input Overdrive—600µV**
- **Propagation Delay 3ns max.**
- **Propagation Delay Insensitive to Overdrive**
- **Input Setup Time 4ns max. (2ns typ.)**
- **Input Hold Time 1ns max.**

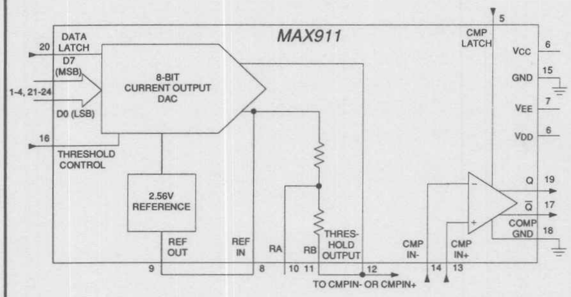
The MAX905/906 have the highest resolution available in a high speed comparator. Signals as small as 1mV can be resolved. The resolution of a comparator is dictated by the sum of its offset voltage, noise, and the required input overdrive.

MAX905/906 TIMING



The clocked design can confuse normal comparator terminology when describing specs. Normally "propagation delay" is the most important comparator speed spec. In the MAX905/906, propagation delay (t_{PD}) describes the delay from a **clock edge** (not the input) to a valid output (see timing diagram). Prop delay plus setup time (t_S) is the total time from input change to output (7ns Max). **BUT REMEMBER** that the comparator output, although delayed by 3ns (typ), is still the correct decision about the analog input at the time of the clock edge (within 2ns).

MAX910/11 HIGH-SPEED, THRESHOLD-PROGRAMMABLE COMPARATORS



The MAX910 and MAX911 high-speed comparators include an on-chip DAC to program the comparator threshold. The MAX910 comparator has a single TTL-compatible output (5ns prop delay); the MAX911 has differential ECL-compatible output (2ns prop delay). Both comparators have latchable outputs. The threshold level is set in either 10mV or 20mV steps (2.56V or 5.12V full-scale range) as set by the DAC and two on-chip span resistors. The threshold can be updated within 20ns. The MAX910 and MAX911 have separate analog and digital grounds for noise rejection. The devices are normally powered from ±5V, although the traditional -5.2V ECL power rail is also permissible.

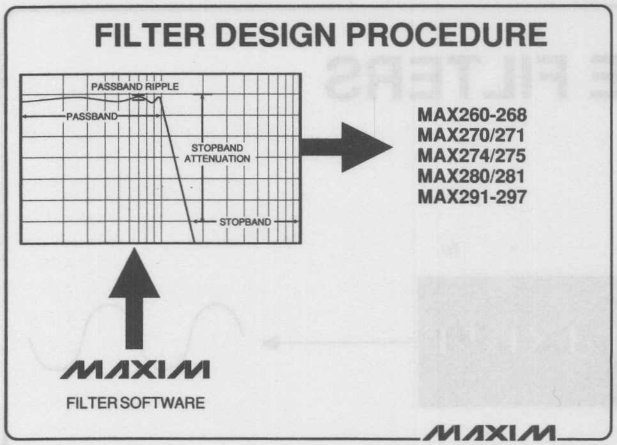
HIGH-SPEED COMPARATORS

DEVICE	PROP. DELAY (ns)	OUTPUT TYPE	CONFIGURATION	COMMENT
MAX900	8	TTL	Quad	All but MAX901 include latch. Lowest prop. delay x power product in industry.
MAX901			Quad	
MAX902			Dual	
MAX903			Single	
MAX905	2	ECL	Single	Input-output isolation with latch. 1mV threshold resolution.
MAX906			Dual	
MAX910	5	TTL	Single	Digital programming of threshold. Comparator latch included.
MAX911	2	ECL		
MAX9685	1.2	ECL	Single	Comparator latch included, except in MAX9690. All drive 50Ω.
MAX9687	1.4		Dual	
MAX9690	1.3		Single	
MAX9686	6	TTL	Single	Comparator latch included.
MAX9698			Dual	

ACTIVE FILTERS

- Choosing Lowpass Filters
- Continuous vs. Switched Cap
- New Continuous "MF10" — No Clock

MAXIM



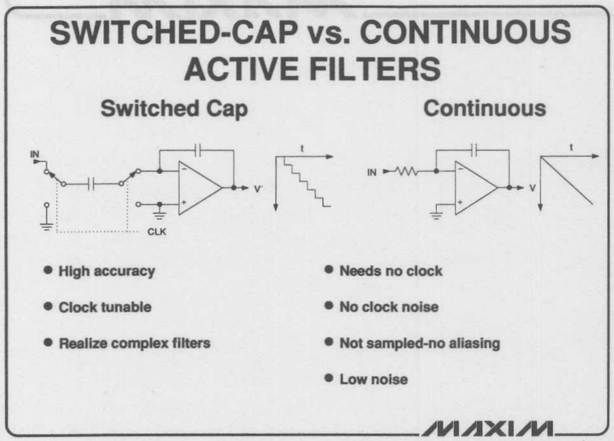
When considering a filter design, the desired response is first expressed in terms of:

Passband and stopband edges
The attenuation required in the stopband
Tolerable passband ripple

From these parameters, the filter order, and the center frequencies and Q's of the filter sections, are determined. This is accomplished with look-up tables, calculations (with help from H.P. or K+E) or computer programs (i.e. Maxim's Filter Software).

The next step involves turning the paper design into a hardware prototype. While many filters are built from discrete components, designers prefer "prepackaged" filters available as ICs or modules. This avoids difficulties with the design itself, pc-board layout, and component tolerance and drift. Often, pre-packaged switched-capacitor and μP programmable filters allow "on-the-fly" adjustment.

When selecting monolithic filters, pay close attention to specifications. Dynamic performance is critical in Digital Signal Processing (DSP) applications, for example, but low offset voltage is more critical in DC measurements. No single filter satisfies all applications.



Since one filter type can't satisfy all applications, Maxim takes numerous approaches to active filter products. These fall into two basic categories: Switched-Capacitor and Continuous (not sampled).

SWITCHED-CAP FILTERS

In switched-cap filters, clocked switched capacitor integrators "simulate" continuous op amp integrators. The integrator time constant is proportional to the clock frequency so the filter can be tuned by simply varying the clock rate. The MAX291-297, for example, are lowpass filters whose cutoff frequencies can be swept from 0.1Hz to 50kHz simply by varying the clock. Other advantages are high accuracy and lack of external components.

Switched-capacitor filter output signals do include some clock feedthrough and noise, although this is easily filtered externally since the clock noise is at frequencies much higher than (typically 100 times) the pole frequency. Input signals must be band-limited to below one-half the filter clock rate, since the filters are in fact "sampling" systems and aliasing is possible with wide-band inputs.

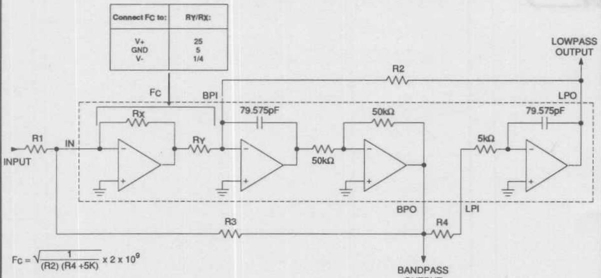
CONTINUOUS FILTER TABLE

PART	MAX270	MAX271	MAX274	MAX275
ARCHITECTURE	Sallen-Key		"MF-10" -type, state variable	
PROGRAMMING	µP, or Pin-Strap		4 resistors per section	
ORDER	4 (2 sections)		8 (4 sections)	4 (2 sections)
RESPONSE	0.15dB Chebyshev		Configurable	
FC RANGE	1-25kHz		100Hz-150kHz	100Hz-300kHz
NOISE/DYNAMICS	96dB Dynamic Range, 70dB SINAD		86dB SINAD	
FEATURES	Extra Op Amp	Track and Hold		

MAX274/MAX275 FEATURES

- **Continuous Filters – No Clock, No Clock Noise**
- **External Resistors Only (No Caps!)**
- **8th-Order, Quad 2nd-Order (MAX274)**
  4th-Order, Dual 2nd-Order (MAX275)
- **Low Noise; -86dB (Typ) THD**
- **±0.9% Pole Frequency Accuracy Over Temp**
- **Pole Frequency Range: 100Hz to 150Hz (MAX274)**
  100Hz to 300kHz (MAX275)
- **Cascadable for Higher Order**
- **DIP and Small Outline Packages**

SINGLE 2ND-ORDER SECTION IN A MAX274/MAX275



$$F_C = \sqrt{\frac{1}{(R2)(R4+5K)}} \times 2 \times 10^9$$

$$Q = \sqrt{\frac{1}{(R2)(R4+5K)}} \times R3 \times \frac{R_Y}{R_X}$$

$$\text{L.P. Gain} = \frac{R4}{R1} \times \frac{R_Y}{R_X}$$

CONTINUOUS FILTERS

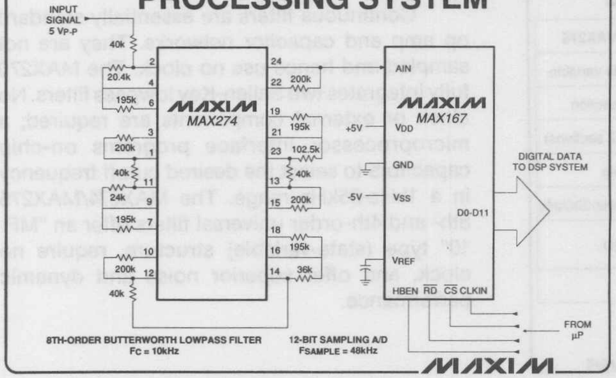
Continuous filters are essentially standard op amp and capacitor networks. They are not sampled and hence use no clock. The MAX270 fully integrates two Sallen-Key lowpass filters. No clock or external components are required; a microprocessor interface programs on-chip capacitors to select the desired cutoff frequency in a 1kHz-25kHz range. The MAX274/MAX275 8th- and 4th-order universal filters offer an "MF-10" type (state-variable) structure, require no clock, and offer superior noise and dynamic performance.

The MAX274 and MAX275 are 8th-Order and 4th-Order continuous-time analog filters, respectively. Similar in topology to switched-capacitor type-filters (such as the MF-10), the MAX274/5 contain 8/4 independent, cascadable 2nd-Order biquad filter sections. Each filter section can implement any all-pole bandpass or lowpass filter response (such as Butterworth, Bessel, and Chebyshev), and is programmed with only four external resistors. No external capacitors, except for supply bypass caps, are needed so a major source of component induced error is eliminated.

The filters' continuous-time design offers low noise and low distortion by eliminating clock and aliasing problems common in their switched-capacitor counterparts. THD is typically less than -86dB and RMS noise is less than 60μV for most filter configurations. This performance is ideal for anti-aliasing and D/A converter output smoothing in high-resolution, data-acquisition applications. Settable pole frequencies range from 100Hz to 150kHz (MAX274) and 100Hz to 300kHz (MAX275). Frequency accuracy is comparable to many switched capacitor filters: 2% when the poles are set with 1% resistors.

The MAX274 and MAX275 filter architecture employs a four-amplifier state-variable design. The on-chip capacitors and amplifiers, together with external resistors, form cascaded integrators with feedback to provide simultaneous lowpass and bandpass filtered outputs. No external capacitors are used. On-chip capacitors are factory trimmed to provide better than ±1% pole frequency accuracy over temperature. This accuracy is hard to beat in a discrete design. ±1% tolerance resistors provides a ±2% accurate pole frequencies. Accurate filter Q's can also be obtained by compensating for amplifier bandwidth limitation using graphs provided in the data sheet.

ANTI-ALIASING IN A DIGITAL SIGNAL PROCESSING SYSTEM

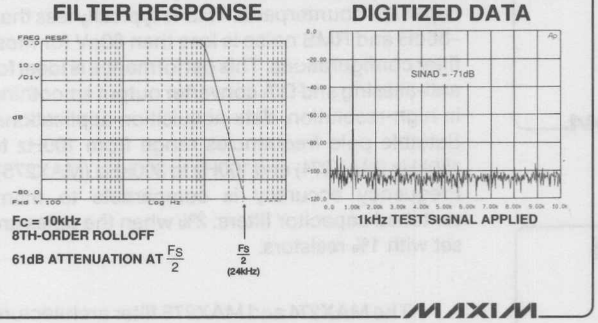


The MAX274 provides a front-end 10kHz lowpass filter to a Digital Signal Processing System. Signals between DC and 10kHz are digitized by a 12-bit sampling A/D (MAX167). The DSP processor receives samples at a rate of 48kHz.

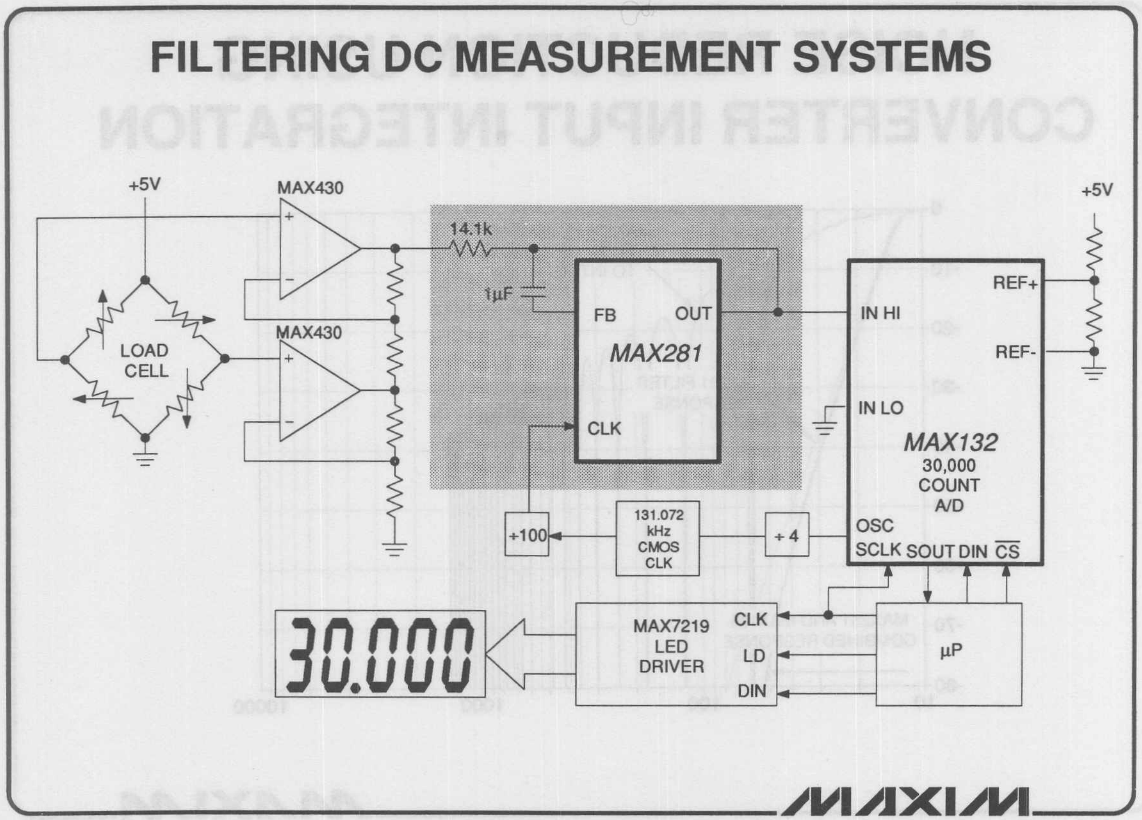
The input signal is filtered by a MAX274 configured as a 10kHz 8th-Order Butterworth Lowpass; signals above 24kHz (the Nyquist frequency) are attenuated 60dB. Additional rolloff in the incoming signal reduces potential alias frequencies below the theoretical 74dB noise floor of the 12-bit system.

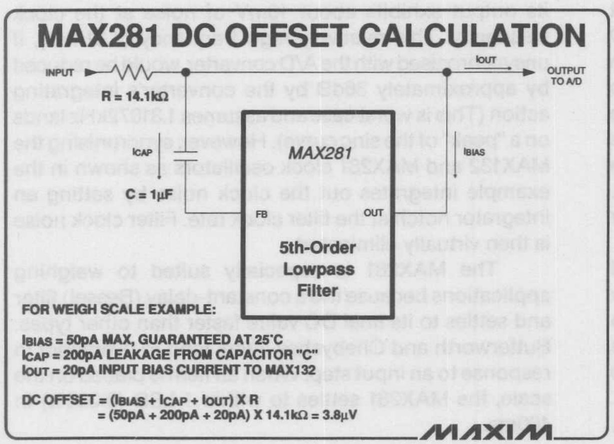
The MAX167 specifies more than 70dB SINAD (Signal to Noise-And-Distortion Ratio). The figure shows an FFT plot of a 1kHz test signal applied to the input and digitized by the A/D. Harmonic spurs are below -90dB, and measured SINAD is 71dB. The MAX274 introduces negligible noise and distortion to this 12-bit system. The MAX274 typically offers 84dB SINAD, providing enough headroom for 13-bit systems.

MAX274 ANTI-ALIASING FILTER RESPONSE / FFT OF FILTERED AND DIGITIZED DATA



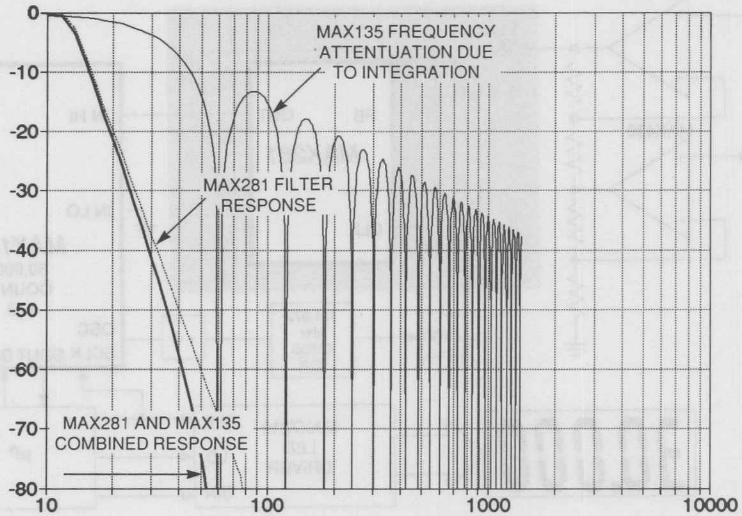
The MAX274/MAX275 does not allow reprogramming "on the fly"; once resistors have been chosen and installed, the filter response and pole frequencies are fixed. If the anti-alias filter cutoff frequency requires tuning, to accommodate several A/D sampling frequencies for example, choose the MAX291-297 family of clock-tunable, fixed response 8th-order lowpass filters. Since these are switched-capacitor filters, clock noise should be filtered with an R-C network at the output, and care should be taken not to allow input signal frequencies above 1/2 the filter clock rate to prevent aliasing. Typical THD of the MAX292 is –74dB at 1kHz.





In DC measurement applications such as weigh scales, filtering must be accomplished without adding DC error or drift. This weigh scale example features a $\pm$30,000 count A/D (MAX132) capable of resolving $10\mu V$. The MAX281 (and MAX280) architecture adds virtually no DC error to the measurement. As shown in the diagram, error sources amount only to leakage terms flowing in the input resistance, R, and in this case total less than $4\mu V$.

NOISE REDUCTION USING CONVERTER INPUT INTEGRATION



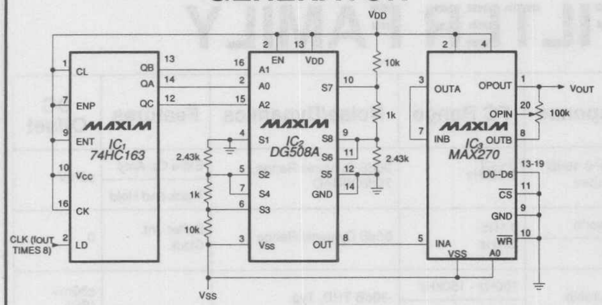
Both the MAX281 and the MAX132 filter the input signal. The noise rejection inherent in an integrating A/D follows a sinx/x (sinc) function. Notches in this function represent nearly 100% rejection, and correspond to frequencies with an integral number of cycles in the MAX132's integration period. A common practice clocks the A/D so its conversion period includes a whole number of power-line cycles, thereby nulling line noise. The clock shown drives the A/D with 32,768Hz for optimum line rejection (see MAX132 data sheet)

The MAX281 provides an ideal filter for the load cell while adding no DC error. 5th-order rolloff and low (13Hz) corner frequency guarantee over 60dB rejection for all relevant noise frequencies. This rejection combines with the sinc filtering effect of the MAX132. 10mV of line noise is reduced to about 3μV, much less than 1/2 LSB.

Because the MAX281 is a switched capacitor filter, its output exhibits about 10mV of noise at the clock frequency. This relatively high frequency (1.31kHz), if unsynchronised with the A/D converter, would be reduced by approximately 36dB by the converter's integrating action (This is worst case and assumes 1.31072kHz lands on a "peak" of the sinc curve). However, syncronising the MAX132 and MAX281 clock oscillators as shown in the example integrates out the clock noise by setting an integrator notch at the filter clock rate. Filter clock noise is then virtually eliminated.

The MAX281 is especially suited to weighing applications because it is a constant-delay (Bessel) filter and settles to its final DC value faster than other types. Butterworth and Chebyshev filters tend to overshoot in response to an input step. When an item is placed on the scale, the MAX281 settles to within 1 LSB (0.005%) in 400ms.

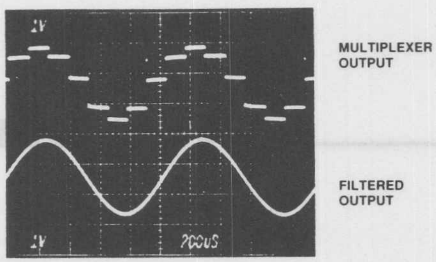
HIGH-PURITY SINEWAVE GENERATOR



• **Adjustable Output Frequency: 1kHz-25kHz**

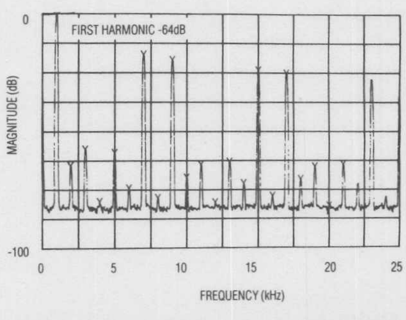
MAXIM

8X-OVERSAMPLED WAVEFORM SIMPLIFIES FILTERING

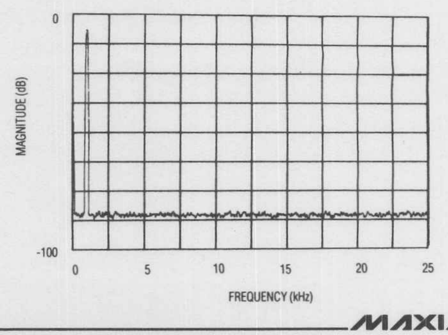


MAXIM

BEFORE FILTERING (MULTIPLEXER OUTPUT)



SINEWAVE GENERATOR SPECTRAL OUTPUT



MAXIM

By combining a MAX270 4th-order lowpass filter, a 74HC163 counter, and an 8-channel analog multiplexer, high-purity 1kHz-to-25kHz sinewaves can be generated with THD less than -80dB. The lowpass filter is set to the desired frequency and a clock eight times the sine frequency is applied to the counter (74HC163), The MAX270's uncommitted op amp sets the filter's output level. Gain accuracy is set by the MAX270's gain at the corner frequency, which is guaranteed between -2.4dB and -3.6dB at 1kHz. The 100kΩ potentiometer provides gain control if desired.

Two resistor dividers provide the input voltages required at the multiplexer inputs. When the mux switches through channels 0-7, an 8-times oversampled staircase approximation of a sinewave is generated. Compared with a squarewave, the oversampled waveform greatly reduces smoothing-filter requirements by pushing the first significant harmonic out to seven times the fundamental.

All higher-order harmonics are filtered to below -80dB by the MAX270. The MAX270 specifies -70dB THD, but in this application the filter attenuates harmonics contributed by itself and the mux to below -80dB.

LOWPASS FILTER FAMILY

Part	Architecture	Programming	Order	Response	FC Range	Noise/Dynamics	Features	DC Offset
MAX270	Sallen-Key		4 (2 sections)	Approx. 0.15dB Chebyshev	1-25kHz	96dB Dynamic Range, 70dB SINAD	Extra Op Amp	±2mV
MAX271							Track and Hold	
MAX280	Switched Cap No DC Error	Requires Ext. R,C (not Clock Sweepable)	5	Butterworth	0.1Hz-25kHz	85dB Dynamic Range	Buffer, Int. Clock	0
MAX281				Bessel				
MAX274	Continuous, State-Variable	4 Resistors per section	8	Configurable	100Hz - 150kHz	-86dB THD, Typ		±50mV (BP)
MAX275			4		100Hz - 300kHz			
MAX291-MAX297	Switched-Cap, Butterworth, Bessel, Elliptic	Clock Sweepable	8	Butterworth (MAX291, 285) Bessel (MAX292, 296) Elliptic (MAX293, 294, 297)	0.1Hz - 50kHz	73dB SINAD, Typ	Extra Op Amp	±300mV

A/D D/A

- **Serial Interfaces**
- **Single-Chip A/D Systems**
- **On-Chip Track-and-Hold Advantages**
- **Single-Chip Quad 12-Bit DAC**

MAXIM

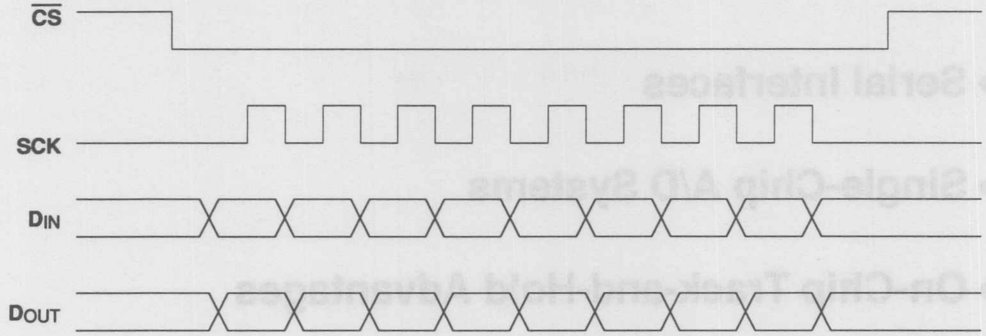
WHY GO SERIAL?

- **Compact Board Area**
  - **Less Area for Data Bus**
  - **Smaller Package Sizes**
- **Reduced Noise and Interference**
  - **Digital Feed Through**
  - **Analog Interference**
- **Isolation**
  - **Lower Cost — Fewer Lines to Isolate**

MAXIM

What advantages can be gained from serially interfaced data acquisition components? When 8-bit devices dominated the data acq world the advantages were not as significant. But with 12-bit and higher resolution devices, and with multiple converters on one chip, differences between serial and parallel interfaces are of greater consequence. Key considerations are board area, digital noise, and ease of electrical isolation.

MAXIM'S SERIAL INTERFACE



NOTE: D_{IN} CLOCKED IN ON SCK RISING EDGE.
D_{OUT} CHANGES ON SCK FALLING EDGE.

MAXIM

A serial interface reduces the number of I/O pins, simplifying board layout. With fewer digital lines injecting noise, digital feedthrough to analog circuitry is reduced. It is also easier to route the reduced number of I/O lines away from sensitive analog circuitry. If the alternative to a serial digital interface is a long range analog link, then the reduced susceptibility to noise should also be considered.

Serial interfaces also are far easier to opto- or transformer isolate, and cost less compared to either parallel digital, or analog, isolation. Isolation provides a convenient means of accommodating different ground potentials, breaking ground loops to prevent noise, and preventing contact with dangerous voltages.

A SERIAL PERIPHERAL PRIMER

Maxim's serial interface insures the largest degree of compatibility with several established standards. The following section describes the popular serial interfaces and shows how Maxim's data converters work in relation to those serial interfaces.

Motorola's SPI (Serial Peripheral Interface) is a very flexible interface incorporated in a large number of products. Four lines communicate to each peripheral:

SCK — serial clock
$\overline{SS}$ — slave select, from decoded address lines (This input does NOT determine if a device is a master slave)
MISO — master in slave out
MOSI — master out slave in

If the slave has no digital output (e.g. a D/A), MISO can be deleted. In the basic protocol, the master (typically a microcontroller) selects the slave by: dropping $\overline{SS}$, clocking an 8-bit frame by driving SCK and MOSI while simultaneously receiving 8 bits via MISO, then raising $\overline{SS}$ to end the frame. Clock phase and polarity are software programmable in the master. Most SPI slaves determine clock phase on the fly by latching the clock level when $\overline{SS}$ goes low.

National Semiconductor's Microwire, also a four wire interface, is similar to SPI. Again, a large variety of products are also built around this interface. Microwire also is set on 8-bit frames. Differences between SPI and Microwire are 1) in Microwire, SCK latches data on the rising edge only, while SPI allows either clock phase or polarity, and 2) a variable number of bits per word are possible in Microwire.

Signetics' (Phillips) I²C (Inter-Integrated Circuits bus) is a two wire interface popular in consumer electronics. It uses a clock (SCK) and a bi-directional data line (SDA). Rather than offering chip select lines which must be decoded, I²C uses address decoding to enable bus participants. Once a slave is selected, transmission continues until that slave is deselected. Both the SCK line and the SDA line are wire-ORed (There is an external pullup resistor on both lines). Only masters (microcontrollers) can manipulate SCK, but everybody on the bus can manipulate SDA. The protocol is necessarily more complex than either SPI or Microwire.

Intel's serial interfaces fall into three categories: 1) RS-232 compatible, 2) shift register compatible, and 3) microcontroller bit manipulation (toggling port lines through software). The RS-232 interface has both addressed and non-addressed versions. The shift register mode has poor framing (start and stop detection) and thus is seldom used except for controller-to-controller applications. Bit manipulation is used very frequently.

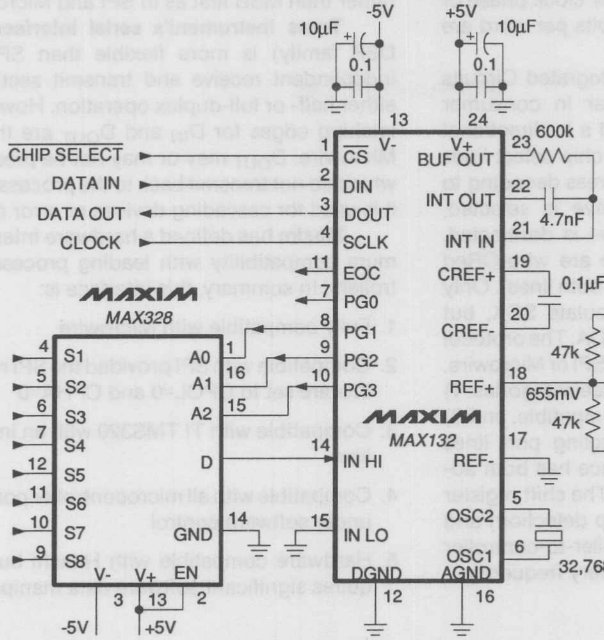
Hitachi's SCI (Serial Communication Interface) is again very similar to Microwire. SCI shifts data LSB first, rather than MSB first as in SPI and Microwire.

Texas Instrument's serial interface (in TMS320 DSP family) is more flexible than SPI. Completely independent receive and transmit sections allow for either half- or full-duplex operation. However, the clock latching edges for D_{IN} and D_{OUT} are the opposite of Microwire. D_{OUT} may or may not be present in devices which do not transmit back to the processor; if available, it is used for cascading devices or error checking.

Maxim has defined a hardware interface for maximum compatibility with leading processors and controllers. In summary, this interface is:

1. Fully compatible with Microwire
2. Compatible with SPI provided the SPI register control bits are set to CPOL=0 and CPHA=0
3. Compatible with TI TMS320 with an inverter on SCK line
4. Compatible with all microcontroller port lines toggled under software control
5. Hardware compatible with Hitachi but bit order requires significant software data manipulation.

SERIAL 16-BIT A/D CONTROLS EXTERNAL MUX



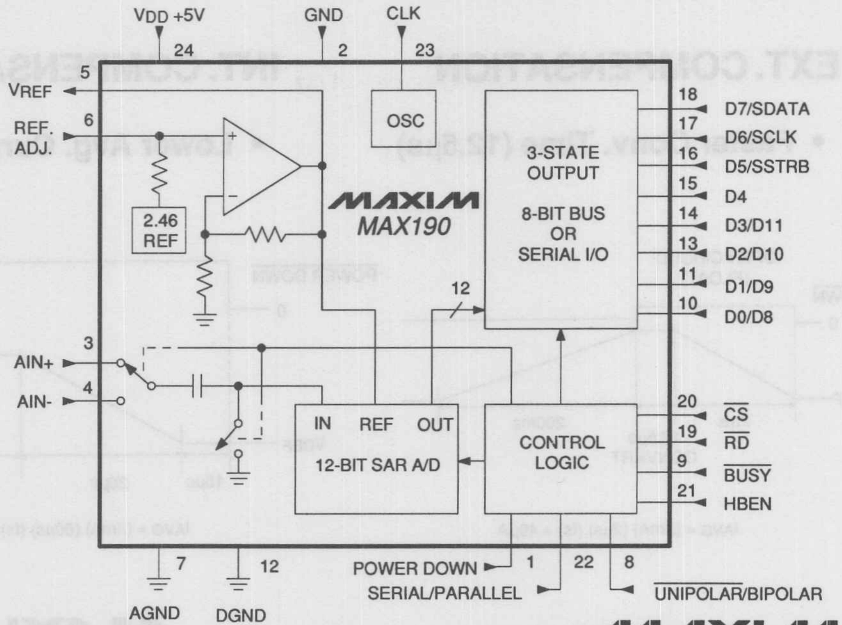
16-BIT INTEGRATING ADC MAX132

- **±32,000 Count Resolution**
- **Mux Controller Output**
- **Low Operating Current - 125µA**
- **Low Standby Current - 10µA**
- **Low Input Bias Current - 10pA**
- **Serial Interface - Binary Output**
- **24 Pin Skinny DIP Package**

The MAX132 provides an excellent serial interface example, including both serial data input and output. The A/D is a 16-bit modified dual-slope converter. In addition to the main 16-bit output, the A/D also provides 3 guard-band bits which add resolution in the A/Ds noise region, but can raise resolution if software averaging is employed.

The MAX132 has one differential input channel, but features a unique digital mux driver which is addressed via the A/Ds serial input. Four programmable output bits (PG0-PG3) can address a mux, programmable gain amp, or other device. These bits are set through the A/D's serial input. To save power the A/D or external circuitry can also be shutdown via serial input commands. When in shutdown, the MAX132 draws 5µA, as opposed to 70µA during normal operation at up to 100 conversions/ sec. The MAX135 is a parallel output version of the A/D, but omits the PG0-PG3 outputs.

12-BIT, +5V POWERED SAMPLING A/D WITH POWER DOWN - MAX190

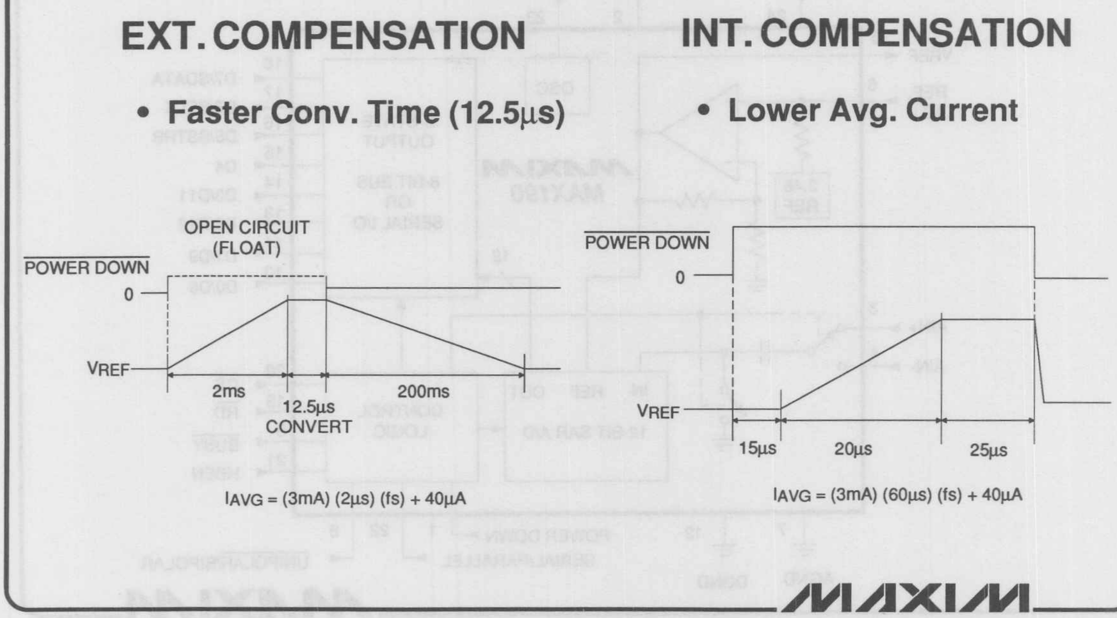


HIGH PRECISION AND LOW POWER MAX190 12 BIT SAMPLING ADC

- Single +5V Supply
- 40µA Standby Mode
- 12.5µs Conversion Time
- Internal Track/Hold
- Serial and Parallel Output
- Only ADC with Power Down & Internal Reference

The MAX190 combines sampled 12-bit A/D conversion with single 5V supply operation and capability for ultra-low-power operation. With the A/D's Power-Down input, the converter can be disabled between conversions, consuming less current (20µA typ, 40µA max) than even low power integrating A/Ds. A 12.5µs conversion time (up to 75 ksamples/sec) includes acquisition time for the on-chip track/hold. Supply current at the max sample rate is 5mA. The internal hold capacitor disconnects from the input after a sample (but before a conversion) to minimize noise and eliminate the need for an input buffer. The MAX190 provides both serial and 8-bit parallel interfaces.

MAX190 CURRENT CONSUMPTION vs. SPEED



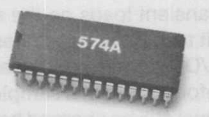
By activating Power Down between samples, a 100 conversions/sec sample rate requires no more than 100μA from a single 5V supply. Low supply current (20μA typ) during power down is made possible by an on-chip reference which idles at 20μA but turns on and stabilizes quickly after power up. An external reference can also be used, but will not turn off during power down. Other A/Ds with disable features do not have on-chip references, so a complete power down is not possible without adding a switch to the reference. Even then, many external references do not stabilize quickly after power up and may require long settling time before a conversion can be started.

The MAX190 power down performance can be optimized for a given conversion rate by selecting either internal or external reference compensation:

Internal Compensation — In this mode, the reference stabilizes quickly enough to allow a conversion to be started within 20μs after the A/D is reactivated (POWER DOWN pulled high). However, because the reference is lightly compensated, it settles less quickly during SAR bit decisions, requiring the clock rate (and conversion time) to be slowed. With internal reference compensation, the minimum allowed conversion time (and the time during which the A/D draws 3mA typ) rises from 12.5μs to 25μs.

External Compensation — In this mode, an external 4.7μF capacitor compensates the reference output amplifier, lowering the minimum conversion time to 12.5μs and reducing conversion noise. However, when reactivating the A/D after power down, the reference takes 2ms to charge the 4.7μF cap, so more time is required before a conversion can start.

12-BIT SERIAL 3.5μs A/D

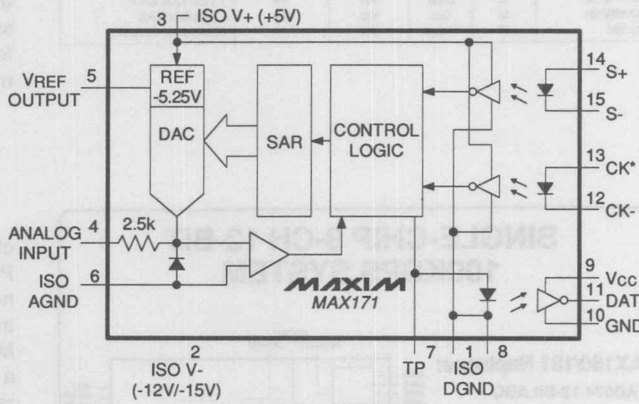


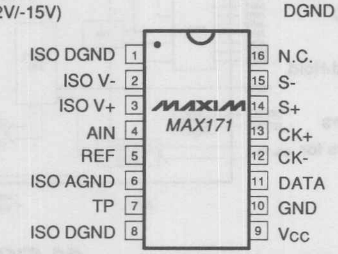
The MAX176 combines a high speed 12-bit A/D, track-and-hold, and reference in an 8-pin package. Conversion time, including track-and-hold acquisition time, is under 4μs. The MAX176 is pin-compatible with the MAX170, but has a bipolar ±5V input range rather than the MAX170's 0 to 5V input range. 12-bit output data is transmitted via a compact serial interface.

MAXIM

OPTO-ISOLATED SERIAL OUTPUT 5.8μs 12-BIT A/D CONVERTER

- Optical Isolation to Over 1,500V_{RMS}
- UL Recognized (File E118032 to UL1577)
- 12-Bit Resolution and Linearity
- 5.8μs Conversion Time
- No Missing Codes Over Temperature
- Serial Output
- Complete with On-Chip Reference
- Standard 16-Lead Plastic DIP





MAXIM

Serial output A/Ds are more convenient to isolate because fewer data lines need to be isolated as compared with parallel systems. The MAX171 takes this advantage one step further by including opto-couplers along with the MAX170 A/D in a standard 16-pin plastic DIP. The analog input and digital output are then completely isolated from each other. The MAX171 has a 1500V_{rms} isolation rating and is UL recognized.

- Easy to Drive Input
- Noise Rejection
- Combined Error Spec for T/H + A/D
- Dynamic Specs
- Simpler Supply Needs
- Cost

MAXIM

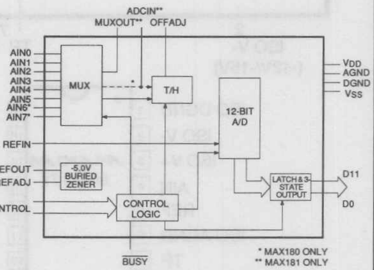
A/Ds WITH TRACK/HOLDS

	BITS	t_{CONV}	INT. REF	CHANNELS	Comments
MAX150/154/158	8	2.5μs	Yes	1/4/8	
MAX151	10	2.5μs	—	1	300kHz sample rate
MAX153	8	400ns	—	1	Shutdown
MAX163/164/167	12	8μs	Yes	1	5V/±5V/±2.5V input
MAX176	12	3.5μs	Yes	1	8 pins, serial
MAX178/182	12	60μs	Yes	1/4	1 LSB total error
MAX180/181	12	6μs	Yes	8/6	Complete DAS
MAX190	12	12.5μs	Yes	1	Shutdown, ser/par

SINGLE-CHIP 8-CH 12-BIT 100KSPS SYSTEM

MAX180/181 Replaces:

- **AD574 12-Bit ADC**
- **DG508 Mux**
- **HA5330 Track-and-Hold**
- **Glue Logic**
- **Precision Resistors**
- **Bypass Capacitors for Multiple Chips**



MAXIM

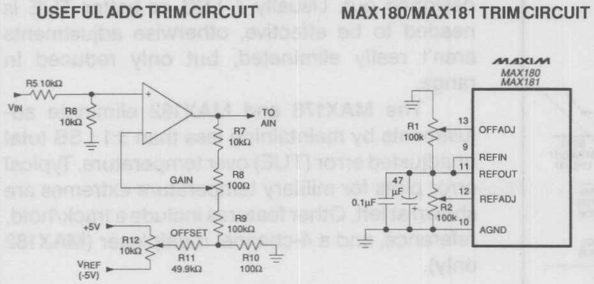
A/D's internal track/hold doesn't draw transient currents from the input signal during bit test in the conversion. An unsampled SAR A/D places transient loads on the signal source during each bit test. If the input doesn't settle in time, then the A/D comparator bases its decision on errant information. In a sampled A/D, input capacitance must still be charged before the conversion starts, but this is a much more benign load and must be charged only once per conversion. These same sampling characteristics help reject noise as well.

Dynamic Specs — All Maxim's ADC's incorporating a Track-and-Hold are specified dynamically for DSP applications. An unsampled A/D converter cannot be specified for AC performance because so much depends on the specific track/hold and the analog interface.

Combined Error Specs, Simpler Supplies —Once a T/H is included with the A/D, the error budget simplifies since one set of specs describes both devices. The analog connection between the T/H and A/D is also eliminated as an error source. Power routing also gets cleaned up with fewer bypass caps, since fewer components are needed.

A complete data-acquisition system on a chip eliminates the problem of designing one on a PC board. Interface problems like ground loops, noise coupling, and stray capacitance can be avoided when interconnects are eliminated. The MAX180 contains an 8-channel analog multiplexer, a wide-bandwidth track/hold, a 25ppm/° C voltage reference, and a 7.5μs A/D with a fast, parallel 8- or 16-bit microprocessor interface. Each channel is μP-configurable for differential/single-ended and unipolar/bipolar input ranges. This data acquisition system is specified with both DC and dynamic testing.

ADC OFFSET AND GAIN TRIM

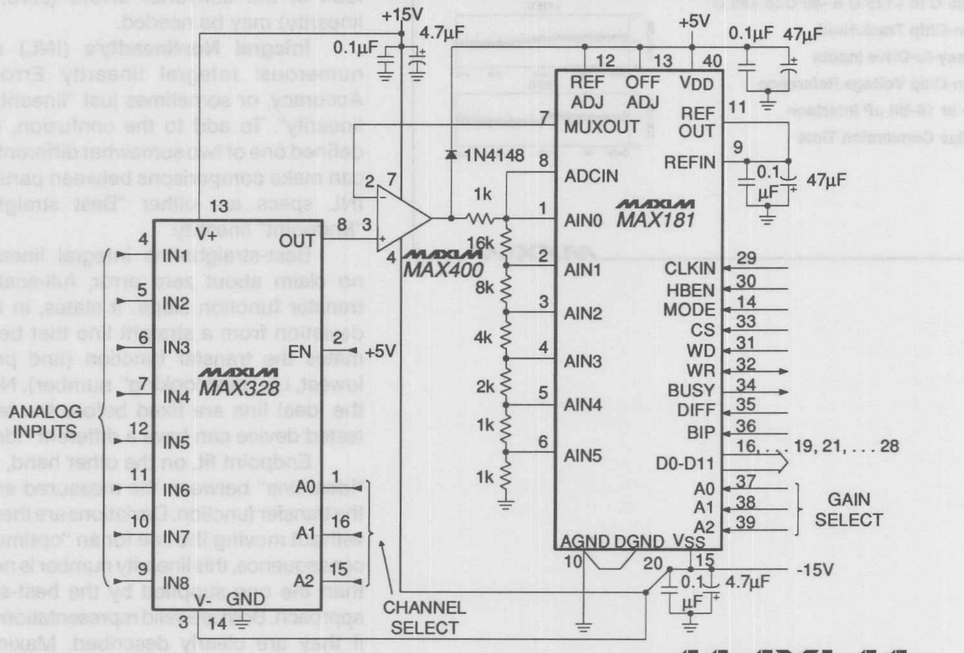


Few precision A/Ds can be conveniently adjusted for zero and full scale. In some cases trims are so awkward that the manufacturer recommends using op amp offset adjust pins to zero A/D errors. This approach not only suffers from limited trim range, but can actually increase errors by increasing the amplifier's temperature drift.

The left hand circuit shows an effective way to add zero and gain adjustment to an A/D (or any analog signal path). The component values shown provide ±20mV of zero adjustment and ±0.5% of full scale trim range.

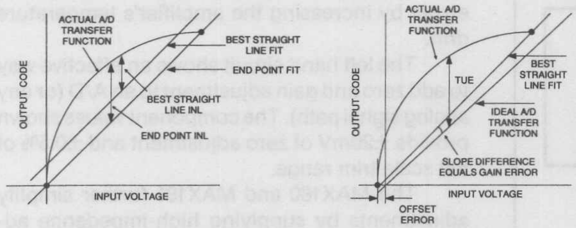
The MAX180 and MAX181 further simplify adjustments by supplying high-impedance adjustment inputs for both zero (OFFADJ) and full scale (REFADJ). Only two trim pots are needed. Trim range is ±1.2% (±50 LSBs) for gain and ±200mV (±18 LSBs) for zero. The capacitors shown bypass the reference and are required with or without trims.

FAULT-PROTECTED 8-CHANNEL 18-BIT DYNAMC RANGE ADC



For applications requiring a programmable-gain amplifier or a filter following the mux, the 6-channel MAX181 accesses the mux output. This allows the use of a single programmable-gain amplifier or filter where several would otherwise be necessary. A. In the drawing, the MAX181's internal mux forms a PGA with digitally selected gains of 1, 2, 4, 8, 16, 32, 64, and 128. An external fault-protected multiplexer, the MAX378, selects from 8 input channels and protects the input for up to ±60V voltage levels.

INTEGRAL NONLINEARITY AND TOTAL UNADJUSTED ERROR

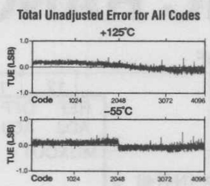


Tight Accuracy is worthwhile in high resolution systems if it allows adjustments to be designed out. Usually 1 LSB or better TUE is needed to be effective, otherwise adjustments aren't really eliminated, but only reduced in range.

The MAX178 and MAX182 eliminate adjustments by maintaining less than $\pm$1 LSB total unadjusted error (TUE) over temperature. Typical error plots for military temperature extremes are shown at left. Other features include a track/hold, reference, and a 4-channel multiplexer (MAX182 only).

12-BIT A/D — NO ADJUSTMENTS OVER -55°C TO +125°C

- 1LSB Total Unadjusted Error Over: -55°C to +125°C & -40°C to +85°C
- On-Chip Track/Hold
- Easy-to-Drive Inputs
- On-Chip Voltage Reference
- 8- or 16-Bit µP Interface
- 60µs Conversion Time



Accuracy is the absolute difference between the actual and ideal ADC or DAC transfer function. This is sometimes called Total Unadjusted Error (or TUE) and includes all error sources. It is very convenient when the device's limits are within the error budget. When they are not, then a closer look at the converter errors (zero, full scale, linearity) may be needed.

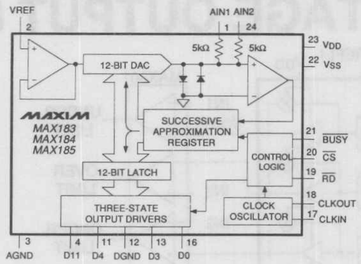
Integral Nonlinearity's (INL) aliases are numerous: Integral linearity Error, Relative Accuracy, or sometimes just "linearity" or "nonlinearity". To add to the confusion, INL is also defined one of two somewhat different ways. This can make comparisons between parts uncertain. INL specs are either "Best straight line" or "Endpoint" linearity.

Best-straight-line integral linearity makes no claim about zero error, full-scale error, or transfer function slope. It states, in LSBs or %, deviation from a straight line that best approximates the transfer function (and provides the lowest, i.e. "best looking", number). No points on the ideal line are fixed before the test so each tested device can have a different "ideal" line.

Endpoint fit, on the other hand, presets the "ideal line" between the measured endpoints of the transfer function. Deviations are then measured without moving the line for an "optimum fit". As a consequence, this linearity number is never smaller than the one supplied by the best-straight-line approach. Both are valid representations of linearity if they are clearly described. Maxim uses the endpoint method for all DAC and A/D specifications.

12-BIT LOW-COST 3μs A/D

- ±1/2LSB Max INL
- "No Missing Codes" Over Temp
- +5V, +10V, ±5V Input Ranges
- Crystal or an External Clock Source
- Small-Footprint 24-Pin DIPS and SOICs

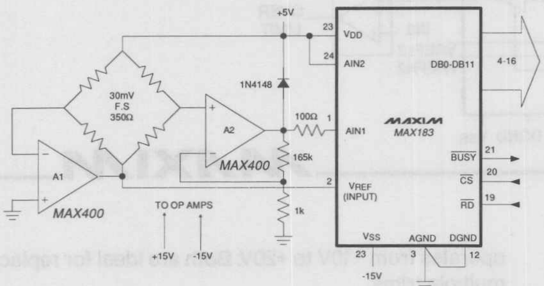


The MAX183/184/185 12-bit 3μs A/Ds are similar to Maxim's MAX162 and MAX172, but allow an external reference to be connected. An on-chip amplifier buffers the reference input for low current drain. The MAX184 and MAX185 are 5μs and 10μs versions of the MAX183. +5V, ±5V, and +10V input ranges can be configured with on-chip resistors.

The MAX162, 3μs 12-bit A/D includes an internal 25ppm/°C or 45ppm/°C reference. The MAX172 conversion time is 10μs.

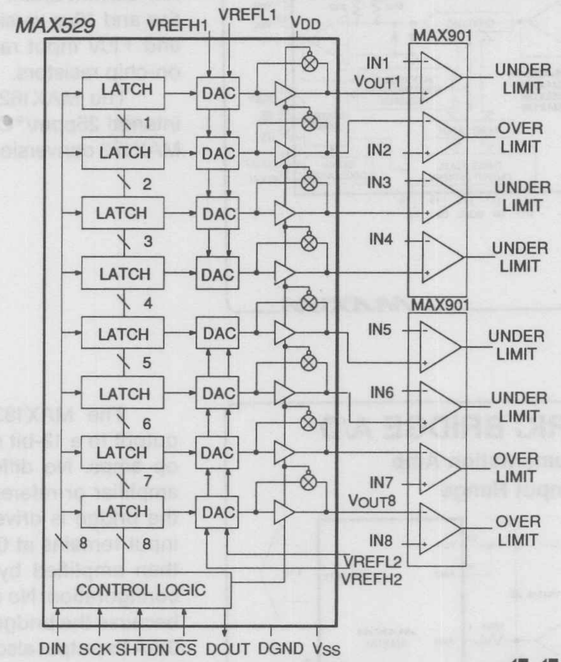
RATIOMETRIC BRIDGE A/D

- No Instrumentation Amp
- Bipolar Input Range



The MAX183 directly converts a bridge output to a 12-bit code using only two precision op amps. No differential-input instrumentation amplifier or reference is needed. The bottom of the bridge is driven by A1 so that its inverting input remains at 0V. The other bridge output is then amplified by A2 in a basic noninverting configuration. No differential amplifier is needed because the bridge output to A2 is referenced to 0V. A1's output also drives the MAX183 V_{REF} input so reference changes (V_{DD} is the reference) in the bridge excitation and the A/D track each other.

PROGRAMMABLE THRESHOLD DETECTION
MAX529 OCTAL, VOLTAGE OUTPUT 8-BIT DAC

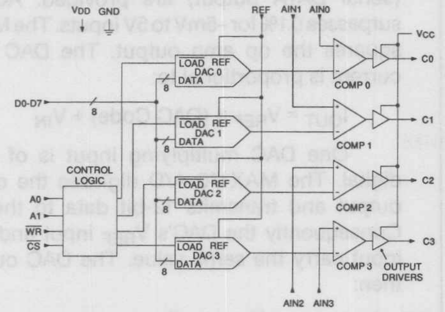


In many test and control applications, an analog input signal is compared to a preset threshold. A MAX529 octal 8-bit DAC generates 8 such thresholds that are compared to external inputs by two high-speed quad comparators (MAX900). Both window and single-limit comparisons can be done in under 12ns.

The MAX528 and MAX529 include eight 8-bit DACs and a compact serial interface. Direct outputs from the DAC resistor ladders, or buffered outputs, can be digitally selected. The MAX529 operates from a single +5V (+5V to +10V) power supply while the MAX528 operates from +10V to +20V. Both are ideal for replacing multiple trims.

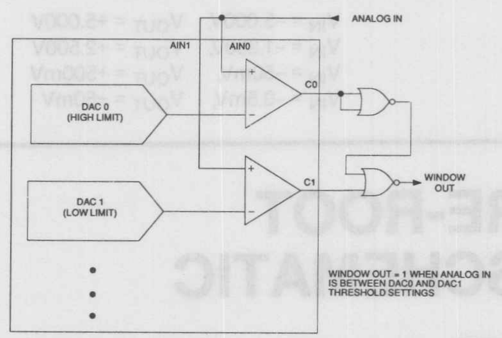
When high-impedance loads are driven by the MAX528/529, resistor ladder outputs can connect directly to the load. This bypasses the on-chip buffers and lowers current consumption to less than 0.5mA. Buffers can be activated as needed. If all are turned on, the chip consumes 8mA. A "Half-Buffer" mode allows only unipolar output currents, but consumes only 2.5mA. When shut down, less than 25μA is drawn but digital data is retained.

QUAD DAC-PROGRAMMED CMOS COMPARATORS



The MAX516 takes DAC integration one step further by combining four 8-bit, R-2R ladder DACs with four analog comparators. Eight-bit performance is achieved over the full operating temperature range without external trimming. Operation is enhanced for single power supplies between 5V and 15V by a comparator input range which includes ground. All four DACs share a common reference.

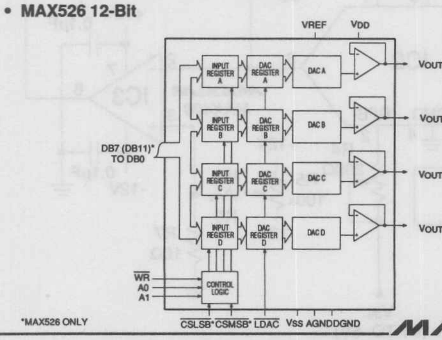
MAX516 DOES WINDOWS



The MAX516 is ideal for implementing μP-controlled window comparators. The connection for window comparison is straightforward. DAC0 provides the upper trip point, DAC1 the lower trip level. The difference between the trip points is the window size. Inputs AIN0 and AIN1 are tied together. Output C0 is inverted and then NORed with C1. The window output goes high when the analog input sits between the thresholds set by DAC0 and DAC1. The external logic can also be simulated in software: A single comparator then performs a window comparison by comparing the input signal to two threshold limits in succession and noting the comparator results for each.

QUAD VOLTAGE OUTPUT DACs

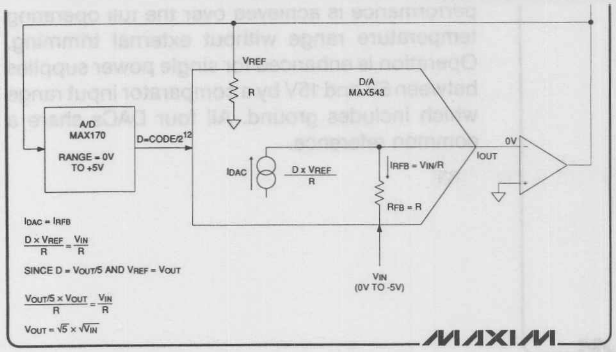
- **Buffered Outputs**
- **MAX505 8-Bit Single +5V Supply**
- **MAX526 12-Bit**



Maxim supplies a number of multiple-output voltage output DACs. They provide digital control of analog functions in applications ranging from gain control and auto-calibration to simply replacing trim pots. Two new devices are:

MAX505/506: Quad 8-bit Voltage Output DAC. Operates from a single +5V supply (or ±5V if desired). The MAX505 includes four separate reference inputs and double-buffered logic.

MAX526: Quad 12-Bit voltage-output DAC with an 8-bit interface.



(serial DATA output) are provided. Accuracy surpasses 0.1% for −5mV to 5V inputs. The MAX543 squares the op amp output. The DAC output current is proportional to:

$$I_{OUT} = V_{REF} \times (\text{DAC Code}) + V_{IN}$$

One DAC multiplying input is of course digital. The MAX170 A/D digitizes the op amp output and transmits 12-bit data to the DAC. Consequently the DAC's V_{REF} input and digital input carry the same value. The DAC output is then:

$$I_{OUT} = \sqrt{5} \times V_{OUT}^2 + V_{IN}$$

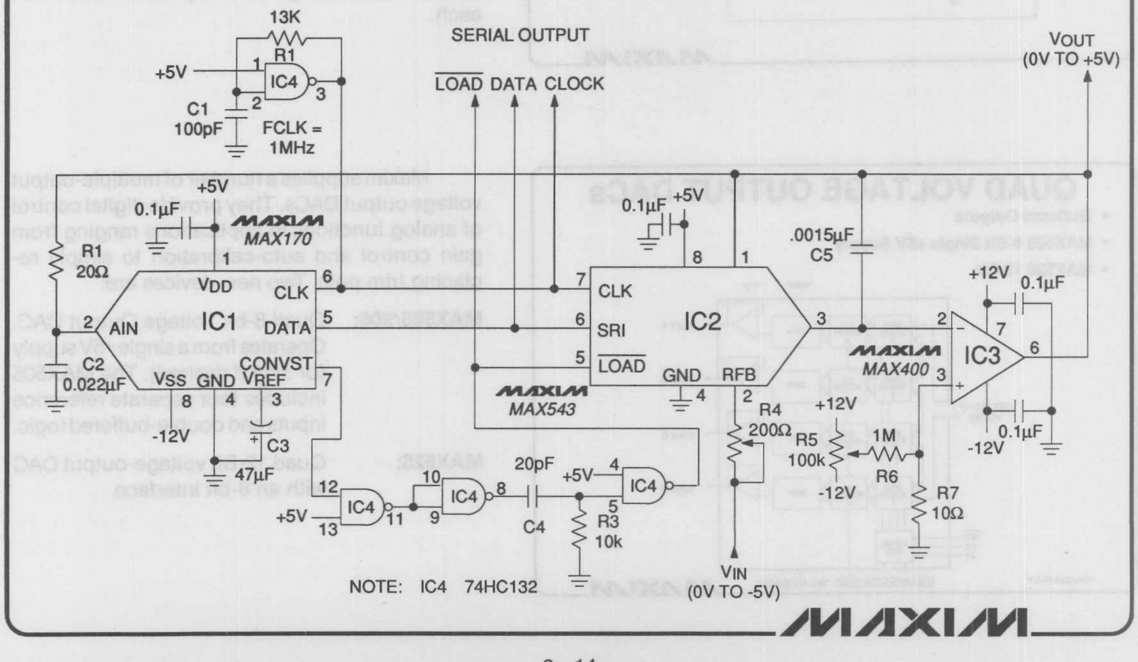
The Op amp sets the DAC output current to zero so that:

$$V_{OUT} = \sqrt{5} \times \sqrt{-V_{IN}}$$

Input-Output examples are:

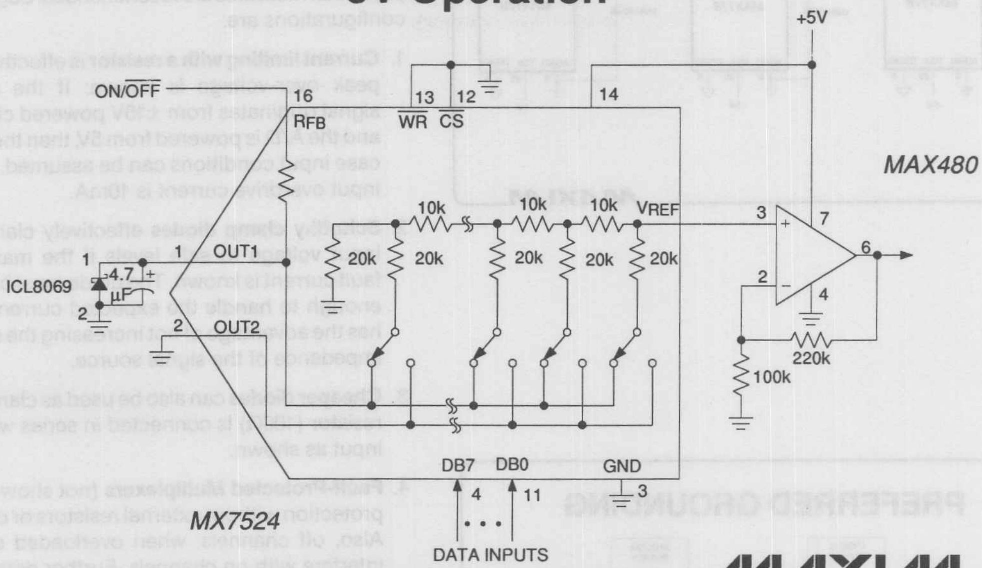
$V_{IN} = -5.000V$, $V_{OUT} = +5.000V$
$V_{IN} = -1.250V$, $V_{OUT} = +2.500V$
$V_{IN} = -50mV$, $V_{OUT} = +500mV$
$V_{IN} = -0.5mV$, $V_{OUT} = +50mV$

SQUARE-ROOT CIRCUIT SCHEMATIC



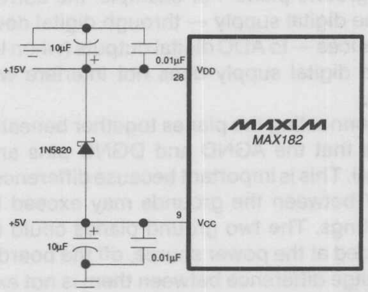
VOLTAGE OUTPUT DAC

- 10µA Shutdown
- 5V Operation



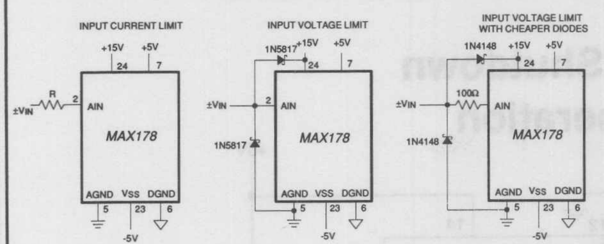
A MX7524 8-bit current-output DAC is connected in inverted configuration (voltage mode) by driving its I_{OUT} pin with a 1.23V reference (ICL8069). The DAC output drives a MAX480 whose gain is set so that full scale output is 4V. The remarkable feature of this connection is that its power consumption is below 1mW, and much less when shut down. When the ON/OFF input is at 5V, the circuit operates. When it is at 0V, supply current falls to 15µA and the amplifier output falls to 0V (and DAC input data is retained if WR is used). Digital input lines must be driven with CMOS logic levels (rail-to-rail) to minimize supply current.

POWER-SUPPLY SEQUENCING



Although a growing number of Maxim's data conversion products operate from a single power supply (often +5V), multiple supplies are still common for many products. When a device requires two or more positive (or negative) voltages, proper sequencing of supplies of the same polarity can be a concern. In general the highest positive voltage should rise first. For example, the MAX178/182 connects to both +5V (V_{DD}) and +15V (V_{CC}) and can draw excess current if V_{CC} rises first. If sequencing cannot be controlled so that +15V rises before the +5V, a Schottky diode must be connected from V_{CC} to V_{DD} as shown. This ensures that the +15V supply is never more than a Schottky diode forward-voltage drop below the +5V supply.

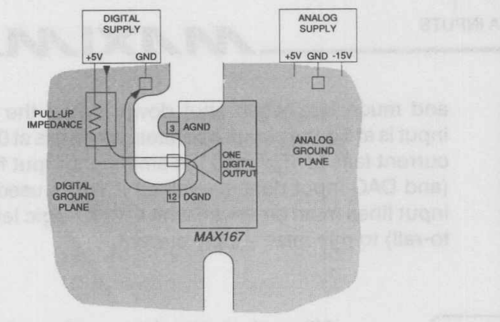
CMOS INPUT PROTECTION



Perusing the Absolute Maximum input specs of A/Ds, one finds that some devices allow input voltages considerably above and below the supplies, while others require that inputs remain within the supply rails. The later case is typical for a number of converter designs, especially A/Ds with internal track/holds. If inputs are expected to exceed the power supplies in these devices then protection measures are recommended. Suggested configurations are:

1. **Current limiting with a resistor** is effective if the peak over-voltage is known: If the analog signal originates from ±15V powered circuitry and the A/D is powered from 5V, then the worst case input conditions can be assumed. A safe input overdrive current is 10mA.
2. **Schottky clamp diodes** effectively clamp the input voltage to safe levels if the maximum fault current is known. The diode must be large enough to handle the expected current. This has the advantage of not increasing the source impedance of the signal source.
3. **Cheaper diodes** can also be used as clamps if a resistor (100Ω) is connected in series with the input as shown.
4. **Fault-Protected Multiplexers** (not shown) add protection without external resistors or diodes. Also, off channels, when overloaded do not interfere with on channels. Further details are described in the "Analog Switches and Multiplexers" section.

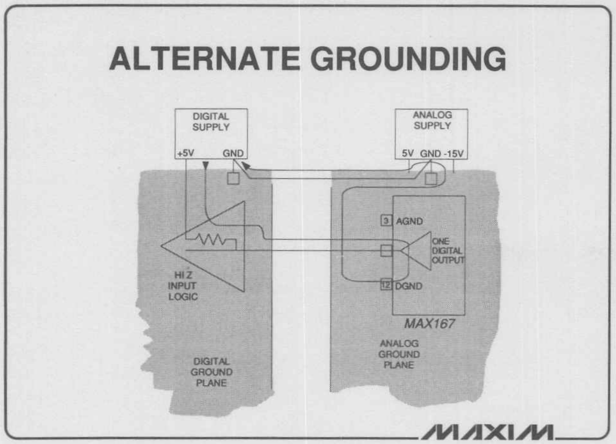
PREFERRED GROUNDING



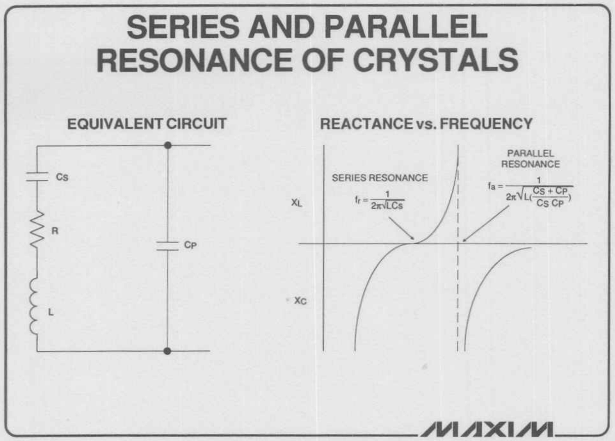
Optimum grounding in systems with mixed analog/digital ICs can be confusing to say the least. Many data acquisition devices supply separate analog and digital ground pins to alleviate some problems, but layout or power routing restrictions still often stand in the way of "ideal" grounding. The key is to work an effective compromise between grounding "rules" and practical restrictions.

In the optimum approach to a typical ADC's AGND and DGND connections, all digital supply currents flow entirely through the digital ground plane. This keeps the analog ground plane free of noise induced by current returning to the digital supply. Note that even the "interface current" returns to the digital supply via the digital ground plane. For example: the current flowing from the digital supply — through digital device pullup impedances — to ADC digital outputs (when low) — and back to digital supply does not interfere with analog signals.

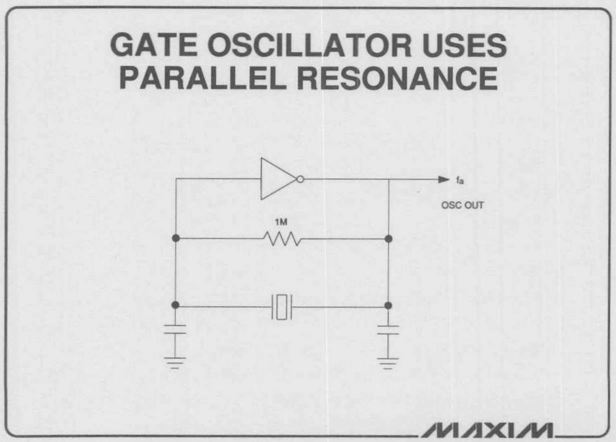
Connecting the planes together beneath the ADC assures that the AGND and DGND pins are at same potential. This is important because differences as small as 0.3V between the grounds may exceed the ADC's max ratings. The two ground planes could instead be connected at the power source, off the board, provided the voltage difference between them is not excessive at the ADC's AGND and DGND pins.



A bit less thorough, but often acceptable, approach grounds AGND and DGND to only the analog ground plane. If the load placed on the ADC's digital outputs is light, i.e. no large data bus or small pullup resistance, noise can still be quite low. The load limitation is necessary because "interface current" now returns to the digital supply through the analog ground plane, which could be disturbed if this current is large. One benefit of this method is that multiple ADCs (or DACs) are more easily accommodated than when the ADC "straddles" ground planes.



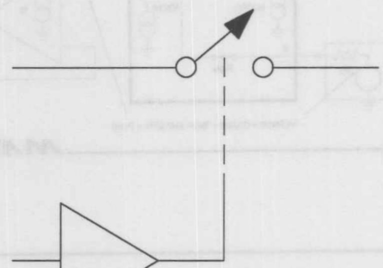
When a crystal oscillator is used with a data converter, uncertainties about crystals surface. Major questions include: "What are series-resonant and parallel-resonant crystals and when can I use which?". All oscillators in Maxim's data converters are designed to operate in parallel-resonant mode, but both crystal types can still be used. This because all crystals resonate in both modes, but not at quite the same frequency in both. The plot of Reactance vs. Frequency for a typical crystal shows the series- (f_r) and parallel-resonant (f_a) points. When a crystal is labeled "parallel-resonant", its specified frequency is at f_a; a series-resonant crystal is specified at f_r. The difference between f_a and f_r is typically only 0.04%, so switching types generates only a small, and usually quite acceptable, frequency shift.



Shown here is the basic form of the gate oscillator found in Maxim's A/D Converters and other clocked products. The crystal operates at (actually VERY near) its parallel-resonant frequency, specifically at a frequency where the crystal's reactance is highly inductive (see Reactance vs. Frequency). This inductance, in conjunction with two capacitors (typically 0-100pa, depending frequency) at the inverter's input and output, forms a pi network which phase-shifts the inverter output 180°. The phase shift from the pi network, coupled with that from the inverter, creates the 360° phase shift necessary for oscillation.

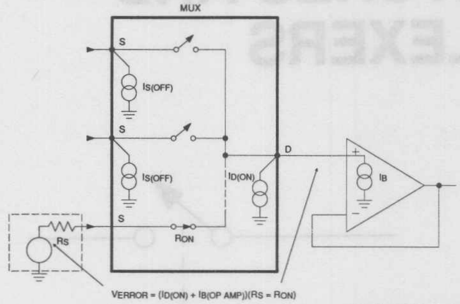
ANALOG SWITCHES AND MULTIPLEXERS

- Minimizing Leakage
- Fault Protection
- New Products



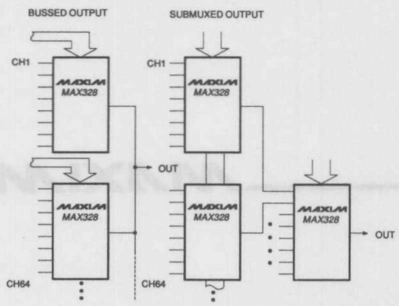
MAXIM

WHAT ON AND OFF LEAKAGES MEAN



MAXIM

SUB-MULTIPLEXING MINIMIZES LEAKAGE ERRORS



MAXIM

BUSSED OUTPUT:

$V_{ERROR} = (I_{D(ON)} + 7I_{D(OFF)})\ (R_S + R_{ON})$
$= (20nA + 7 \times 20nA)\ (10k + 1.5k)$
$= 160nA\ (11.5k)$
$= 1.84mV$

SUBMUXED OUTPUT:

$V_{ERROR} = I_{D(ON)}\ (R_S + R_{ON}) + I_{D(ON)}\ (R_S + 2R_{ON})$
$= 20nA\ (10k + 1.5k) + 20nA\ (10k + 3k)$
$= 0.49mV$

MAXIM

For many signal routing applications, CMOS switches perform as nearly "ideal" elements. However, as accuracy requirements increase, leakage currents contribute increasingly to measurement error. The error is the product of switch leakage current and the signal source resistance (including switch on-resistance, $R_{DS}ON$). Leakage specs are divided into several types. In a multiplexer these are:

$I_{S(OFF)}$: Leakage in or out of an **OFF input** channel. This does not affect output error unless the OFF channel is connected to an ON-channel on a different multiplexer.

$I_{D(OFF)}$: Leakage in or out of an **OFF output** (The mux ENABLE input must be low for the output to be off). This contributes to error if the mux output is connected to other mux outputs (for more channels).

$I_{D(ON)}$: Leakage into the **ON mux output** when a channel is selected. This is the largest contributor to error except where mux outputs are paralleled (see "Submuxing . . ." ahead). Since the channel is on, this spec includes both the input and output leakage.

Low leakage improves accuracy by reducing the voltage error across source impedances and on-resistances. It also enables higher-valued input resistors to provide improved input protection without adding to error.

When a large number of signals are to be multiplexed (in this example, 64), sub-multiplexing can reduce leakage induced errors. The traditional method, connecting eight multiplexer outputs in parallel, is shown on the left. Assuming a 10kΩ source resistance and 1.5kΩ switch ON resistance, the over-temp error voltage for the the MAX328 is:

$$V_{ERROR} = (I_{D(ON)} + 7I_{D(OFF)})(R_S + R_{ON})$$
$$= (20nA + 7 \times 20nA)(10k\Omega + 1.5k\Omega)$$
$$= 160nA \times 11.5k\Omega = 1.84mV$$

By sub-multiplexing, the OFF-channel leakage currents are eliminated, and the error voltage becomes:

$$V_{ERROR} = I_{D(ON)}(R_S + R_{ON}) + I_{D(ON)}(R_S + 2R_{ON})$$
$$= 20nA\ (10k\Omega + 1.5k\Omega) + 20nA(10k\Omega + 3k\Omega)$$
$$= 0.49\ mV$$

ULTRA-LOW LEAKAGE AND CHARGE INJECTION SWITCHES AND MUXES

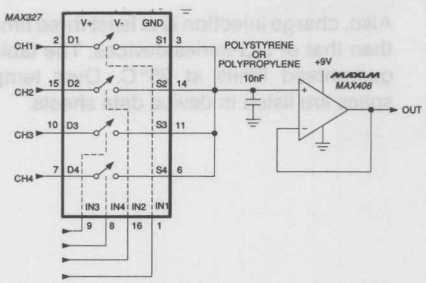
	$I_{D(ON)}$ (pA max)	$I_{D(OFF)}$ (pA max)	Charge Injection (pC typ)	$r_{DS(ON)}$ Matching (% typ)	Comments
MAX326 Quad SPST Switch	±20	±10	3	5	Normally Closed DG201A/211 Upgrade
MAX327 Quad SPST Switch	±20	±10	3	5	Normally Open DG202/212 Upgrade
MAX328 Analog Mux	±50	±20	2	2	Single-ended, 1-of-8 DG508A Upgrade
MAX329 Analog Mux	±25	±10	2	2	Differential, 2-of-8 DG509A Upgrade

For data-acquisition systems requiring high precision, the MAX326/327 switches and the MAX328/329 multiplexers offer leakage currents typically under 1pA, and guaranteed below 10pA at 25° C (below 5nA over temperature — MAX326). Also, charge injection is at least three times lower than that of DG-series devices. The table shows guaranteed limits at 25° C. Over temperature specs are listed in device data sheets.

MAX328 vs. DG508 LEAKAGE SPECIFICATIONS

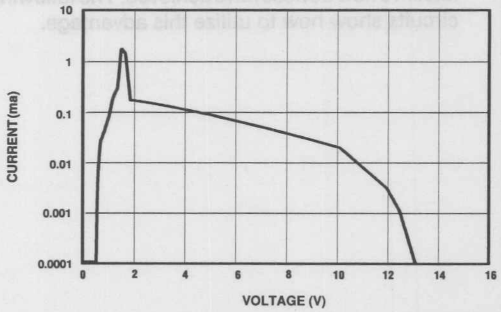
@ 25°C	MAX328 (pA max)	Maxim's DG508A (pA max)	Industry DG508A (pA max)
$I_{D(ON)}$	±50	2,000	10,000
$I_{D(OFF)}$	±20	2,000	10,000
$I_{S(OFF)}$	±10	500	1,000

A comparison of the leakage currents in the MAX328, Maxim's DG508A, and a typical commodity DG508A shows the magnitude of improvement Maxim's new devices have achieved. The following circuits show how to utilize this advantage.



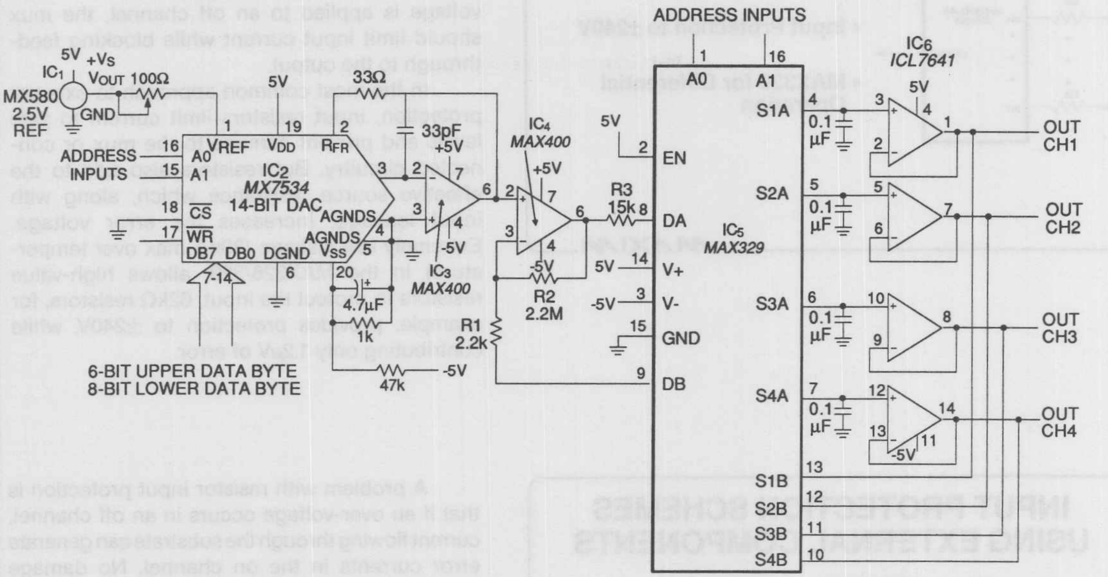
is that besides having very long droop times with low capacitance values (even at elevated temperatures), it consumes extremely low power. (The MAX406 consumes only 1.2μA from the battery.) The MAX327 guarantees no more than 250μA supply current with $\pm$15V supplies, but most of this is drawn by internal logic level-translators. By using rail-to-rail logic (CD4000, 74C00, or 74HC00 families) to drive IN1-IN3, the level translators are turned off and the supply current falls well below 1μA when the switches are off. This technique turns any Maxim switch or mux into an ultra-low power device.

MAX327 ISUPPLY vs. SWITCH CONTROL



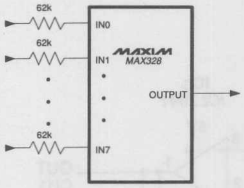
MAXIM

FOUR 14-BIT OUTPUTS FROM ONE DAC



The MAX329's leakage performance provides an economical way to create four 14-Bit DAC outputs from only one 14-Bit DAC. Four 0.1μF capacitors and an ICL7641 quad op amp sample the DAC voltage presented by the multiplexer. The "A" section of the MAX329 scans hold capacitors while the "B" section closes a feedback loop which connects the appropriate buffer within IC6 to a precision op amp (IC4). This loop effectively removes the buffer offset voltage. If a typical multiplexer charge injection of 4pC and a typical leakage (plus op amp bias) of 1pA are assumed, the voltage stored on each capacitor will droop no more than 1 bit (out of 2^{14}) over 2.5 seconds at 25°C. At higher temperatures the discharge is greater, but this can be compensated by clocking the multiplexer at a faster rate to update the hold capacitors.

INPUT PROTECTION SCHEMES USING EXTERNAL COMPONENTS



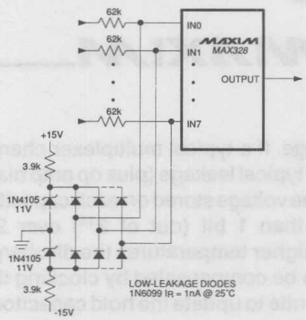
- 50pA Max Leakage Current
- Input Protection to ±240V
- MAX329 for Differential Operation

MAXIM

When multiplexer inputs are exposed to the "outside world", it's likely that input voltages exceeding the supplies may occur (over-voltage). When this happens: 1) Inputs should not draw excessive current during over-voltage. 2) The output should be limited to a safe level so that output circuitry is not damaged. 3) When an over-voltage is applied to an off channel, the mux should limit input current while blocking feed-through to the output.

In the most common approach to external protection, input resistors limit current to safe levels and prevent damage to the mux or connected circuitry. But resistors also add to the effective source resistance which, along with input leakage, increases the error voltage. Extremely low leakage (20nA max over temperature) in the MAX328/329, allows high-value resistors to protect the input. 62kΩ resistors, for example, provides protection to ±240V, while contributing only 1.2μV of error.

INPUT PROTECTION SCHEMES USING EXTERNAL COMPONENTS

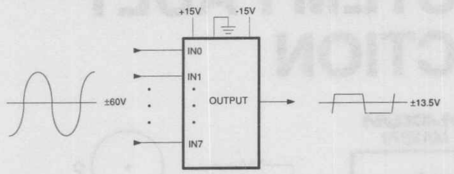


- No OFF-Channel Overload Error
- Input Protection to ±240V

MAXIM

A problem with resistor input protection is that if an over-voltage occurs in an off channel, current flowing through the substrate can generate error currents in the on channel. No damage occurs to any components, but the accuracy of the measurement is subverted. Resistor/diode networks, which are clamped to voltages below the supplies (11V zener diodes here), limit both the input voltage and input current. When the mux is powered from ±15V, an over-voltage does not send current into the substrate, and thus off-channel faults don't affect on channels. Low-leakage diodes should be used for clamps. (Schottky diodes leak too much and are not recommended.)

BUILT-IN INPUT PROTECTION



- **Fewest Components: One**
- **MAX378/MAX379/MAX388/MAX389 Protection:**
  ±75V With Power Off
  ±60V With ±15V Supplies

ADDITIONAL FAULT PROTECTION FEATURES

- **If Power Off, All Channels Open**
- **If Power On (±4.5V to ±18V)**
  - **Off Channel(s) Open**
  - **On Channel(s) Open If Overvoltage Occurs**
    - **Output Limited to Less than Supplies**
- **Protects in Both Directions**

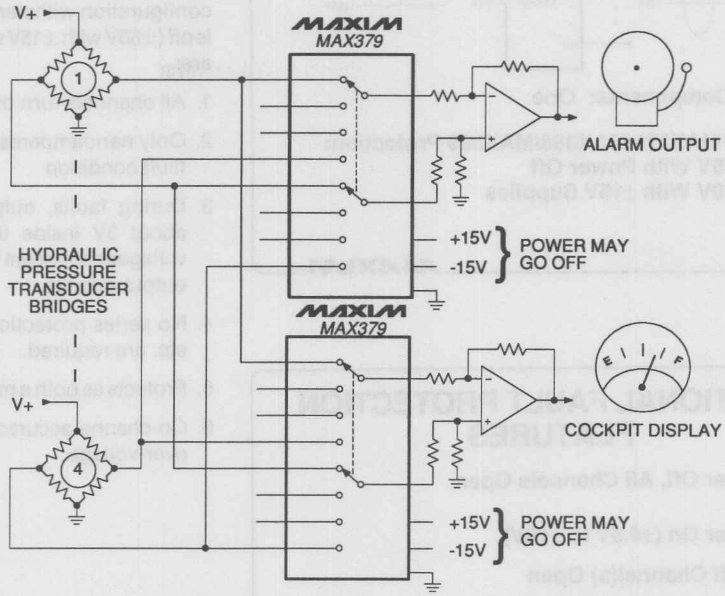
FAULT PROTECTED MUXES

	PROTECTION VOLTAGE	8-CH	4 CH DIFF	
MAX358	±35V (Power Off)	X		
MAX359			X	
MAX368		X		Latched Channel Address
MAX369			X	
MAX378	±75V (Power Off)	X		
MAX379			X	
MAX388		X		Latched Channel Address
MAX389			X	

The simplest protection scheme is often the best. The MAX358/359, MAX368/369, and MAX378/379 are single-ended and differential multiplexers with built-in fault protection afforded by three series FET switches (N-channel, P-channel, and N-channel). In the MAX378/379, this configuration withstands ±75V when mux power is off (±60V with ±15V supplies). Major advantages are:

1. All channels turn off when power is removed
2. Only nanoamperes of current flow during any fault condition
3. During faults, output signals are limited to about 3V inside the supply voltages. High voltages cannot get through the mux to damage output circuits.
4. No series protection resistors, clamp diodes, etc. are required.
5. Protects as both a multiplexer or demultiplexer.
6. On-channel accuracy unaffected by off-channel over-voltage.

AIRCRAFT SYSTEM FAULT PROTECTION



MAXIM

The MAX379's fault protected design is fully exploited in high-reliability data acquisition environments. In this example, multiple pressure sensors in an aircraft hydraulic system are scanned by both a computerized alarm generator and a cockpit display. Both multiplexers must block the effects of a failed transducer, whose terminals may then source the full aircraft-battery voltage (28V). Furthermore, the multiplexers must provide this protection with their power applied or removed. In the event that power is lost in either system, the other must indicate properly. Also, during maintenance, power from any component can be disconnected and reconnected at random (of course . . . retired baggage handlers . . .). Conventional multiplexers, even with external protection networks, cannot avoid loading the signal when their power is turned off.

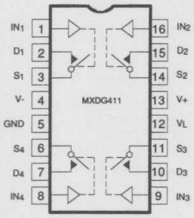
MUX AND SWITCH PERFORMANCE WITH ±5V SUPPLIES

- 2 to 3X R_{ON} Increase
- TTL Compatibility Remains
- 2 to 3X Switch Delay Increase
- 1/3 Supply Current of ±15V
- 1/2 Switch Leakage Current of ±15V
- <1µA I_{Supply} With Rail-to-Rail Logic and Switches Off

MAXIM

Most switches and muxes are specified with ±15V supplies, however many new analog designs use ±5V power. The table outlines what performance differences can be expected when ±5V is used to power Maxim's switch and multiplexer products. As can be seen, some specs improve. Similar performance can also be expected when operating on single +12V supplies (with V- connected to GND). Several device data sheets also provide further information on operation with reduced supply voltages.

NEW MXDG400 SERIES ANALOG SWITCHES AND MUXES



★ PART NO.	DESCRIPTION	FEATURES
MXDG411	Quad SPST	0.4nA Max $I_{D(ON)}$, 35Ω Max $R_{DS(ON)}$
MXDG401	Dual SPST	150ns Max t_{ON}
MXDG441	Quad SPST	1 pc Typ Charge Injection
MXDG408	1-of-8 Mux	1nA Max $I_{D(ON)}$, 100Ω Max $R_{DS(ON)}$, 250ns Max t_{ON}

★ 20 New MXDG4XX Products – See Selector Guide

Maxim is now introducing the MXDG family of high-performance analog switches and multiplexers. This series will soon grow to over 20 products, providing significant improvements in every major spec category. On-resistance, charge injection, leakage current, and turn-on time have all been improved over existing analog switch families. Pin compatibility with existing products allows greater accuracy to be designed in quickly, at prices comparable to industry standard devices. For greater convenience in new designs, many also operate from single supplies. Package options include skinny DIP and small outline.

MAXIM SWITCHES AND MUXES AVAILABLE TO 883

SWITCHES	MULTIPLEXERS
* DG200A	MAX310/311
DG201A/202	* MAX328/329
DG300/1/2/3A	MAX358/359
DG304/5/6/7A	* MAX368/369
DG308A/309	* MAX378/379
DG381/84/87/90A	* MAX388/389
HI201	* MX7501/2/3
IH5040-47	MX7506/7
IH5048-51	DG506A/507A
IH5140-47	DG508A/509A
* IH5341	DG528/529
* IH5352	IH6108/6208
MAX331/332	* MXDG406/407
MAX333	* MXDG408/409
* MXDG401-403	
* MXDG411-413	
* MXDG417-419	
* MXDG441/442	

* Available FY Q2

Maxim's MIL-STD-883 (/883) program tests the devices per Method 5004 and performs Quality Conformance Inspection per Method 5005, Groups A, B, C, and D. As a result, Maxim's /883 products comply fully with paragraph 1.2.1 of MIL-STD-883. Complete electrical specifications on the available /883-compliant products are published in Maxim's Military Product's Databook, but be sure to contact the factory for data on products recently qualified.

FAILURE ANALYSIS

Failure Verification

Failure Location/Isolation

Identification of Mechanism/Cause

Initiation and Support of Corrective Action

RESULT: IMPROVED PRODUCTS

MAXIM

SAMPLE OF TECHNIQUES AND EQUIPMENT CAPABILITIES

Analytical Probe Stations

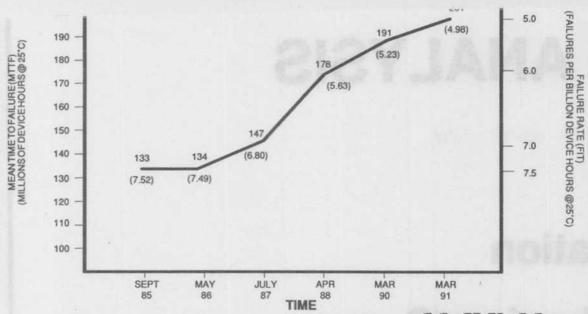
Liquid Crystal "Hot Spot" Analysis

Scanning Electron Microscope (SEM) w/Voltage Contrast

Laser Cutter – for fast circuit isolation and selective removal of individual device layers

Emission Microscopy

MAXIM



HI-REL MILITARY PRODUCT AVAILABILITY

- Standard Military Drawing (SMD)
  - Factory inventory
- MIL-STD-883B, Rev. C compliant NON-JAN
  - Supported by /883B military device data sheets
  - Factory inventory
- "/HR" Hi-Reliability processing/screening flow
  - Emulates MIL-STD-883B, methods 5004/5005
  - Any military temperature range product available in this flow
  - Some inventory of popular types
  - Alternative to fully qualified /883 material

MAXIM QUALIFIED MILITARY DISTRIBUTORS

- Arrow Electronics
  - Brookhaven, New York
- Bell Industries
  - Dayton, Ohio
- Pioneer Electronics
  - Woodbury, L.I., New York Branch
- Hall-Mark Electronics
  - Dallas, Texas
- Wyle Electronics
  - Orange Country, California, will be qualified Dec., 1991

DESC APPROVED DEVICES TO STANDARD MILITARY DRAWINGS (SMDs) CURRENTLY AVAILABLE

SMD P/N	MAXIM P/N
5962-8987701EA	MAX232MJE/883B
5962-8977012C	MAX232MLP/883B
5962-8958101GC	REF01AJ/883B
5962-8958101PA	REF01AZ/883B
5962-8958102GC	REF01J/883B
5962-8958102PA	REF01Z/883B
5962-8551401GC	REF02AJ/883B
5962-8551401PA	REF02AZ/883

SMD P/N	MAXIM P/N
5962-8948101VA	MX7541ASQ/883B
5962-89481012G	MX7541ASE/883B
5962-8948102VA	MX7541ATQ/883B
5962-89481022G	MX7541ATE/883B
5962-8759101LA	MX7572SQ12/883B
5962-8759102LA	MX7572TQ12/883B
5962-8759104LA	MX7572SQ05/883B
5962-8759105LA	MX7572TQ05/883B
5962-8876401LA	MX7824TQ/883B
5962-8876402LA	MX7824UQ/883B
5962-8876403XA	MX7828TQ/883B
5962-8876404XA	MX7828UQ/883B

MAXIM

883 COMPLIANT PRODUCTS

A/D CONVERTERS
MAX150/MX7820
MAX154/MX7824
MAX158/MX7828
MAX160/MX7574
MAX161/MX7581
MAX170
MAX172/MX7572
MX574
MX674A
MX7575
MX7672

D/A CONVERTERS
MAX543
MX7224
MX7225
MX7226
MX7228
MX7520/30/33
MX7521
MX7523
MX7524
MX7528
MX7537
MX7541/41A
MX7542
MX7543
MX7545A
MX7548
MX7547
MX7628

SWITCHES
*DG200A
DG201A/202
DG300/1/2/3A
DG304/5/6/7A
DG308A/309
DG381/84/87/90A
HI201
IH5040-47
†IH5048-51
†IH5140-47
*IH5341
*IH5352
MAX331/332
MAX333
*MXDG401-403
*MXDG411-413
*MXDG417-419
*MXDG441/442

MULTIPLEXERS
MAX310/311
*MAX328/329
MAX358/359
*MAX368/369
*MAX378/379
*MAX388/389
*MX7501/2/3
MX7506/7
DG506A/507A
DG508A/509A
DG528/529
IH6108/6208
*MXDG406/407
*MXDG408/409

POWER SUPPLY DC-DC
MAX634
MAX638
MAX680

LINEAR REGULATOR
MAX663
MAX664
MAX666

MOS DRIVERS
*MAX626
*MAX627
*MAX628
*TSC426
*TSC427
*TSC428
*ICL7667

REFERENCES
MX580
MX581
MX584
REF01
REF02

MAX674
MAX675

INTERFACE
MAX231
MAX232
*MAX250
*MAX251

OP-AMP
OP07

ICL7642
ICL7650

*MAX452/453

SUPERVISORY
MAX690
MAX691
MAX692
MAX693
MAX694
MAX695
MAX696
MAX697
*MAX1232

†AVAILABLE Oct., 1991
*AVAILABLE Jan., 1992