ADVANCED
LINEAR
DEVICES, INC.

APPLICATION NOTE AN1700

USER PROGRAMMABLE OFFSET VOLTAGE (V_{OS}) OF EPAD® OPERATIONAL AMPLIFIERS

INTRODUCTION

The ALD172xE is a family of monolithic single CMOS rail-to-rail operational amplifiers with on-chip Electrically Programmable Analog Device (EPAD). They provide user electrical offset voltage adjustment capability. With its programmable features, the programmed target V_{OS} is not necessarily zero, but can be defined as any desired value to account for other system requirements, such as compensation for external sensor errors, or changing desired output voltage ranges. These devices have industry standard 8 lead pinout, and in many instances can be used as direct substitutes for a variety of operational amplifiers circuits.

ALD272xE is also available from Advanced Linear Devices as a family of dual EPAD operational amplifiers housed in 14 pin PDIP, SOIC, and Hermetic Ceramic DIP packages.

ALD EPAD operational amplifiers provide the user with precision operational amplifiers that can be electrically trimmed with user application-specific programming or in-system programming.

Figure 1 shows the distribution of the Total Input Offset Voltage, V_{OST}, before and after EPAD programming. V_{OST} includes V_{OS} as V_{OS} is traditionally specified; plus the V_{OS} error contributions from PSRR, CMRR, TCV_{OS}, and noise, plus any external system level equivalent V_{OS} error. The ALD1722E, for example, typically has V_{OST} equal to approximately ±25µV.

ALD EPAD operational amplifiers are designed for low voltage, low power systems where a precision offset voltage trimming function is desirable. They are used where for economic, convenience, functionality, or for access feasibility reasons, a computer controlled and automated trimming capability is required. These operational amplifiers can be programmed before being placed into a circuit, or they can be designed into a circuit function so that "In-System Programming" can be performed after the amplifiers and other components have been installed onto the printed circuit board.

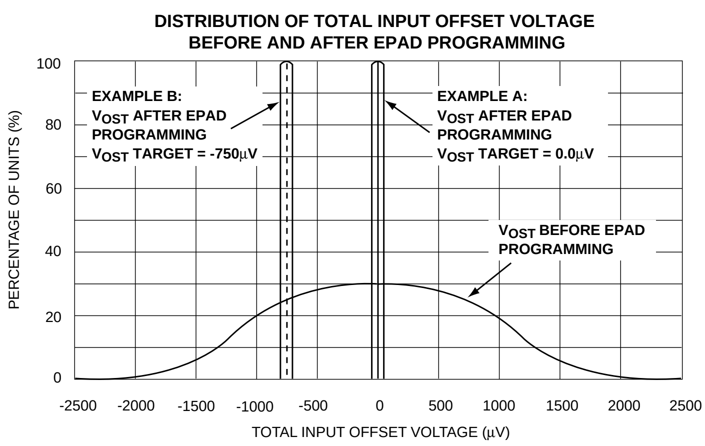
For some applications, EPAD operational amplifiers are an alternative to chopper stabilized operational amplifiers that require expensive extra components and add extra board space. EPAD operational amplifiers are internally DC biased and do not contain any internal frequency clocking circuitry that may introduce clock noise or interference. Consequently, there is no AC power consumed by any clocking circuitry associated with chopper stabilized operational amplifiers. There is also no internal null loop that can cause output overload conditions. Furthermore, EPAD operational amplifiers are completely self contained and require no external components for functionality. Once they are initially programmed by the user, EPAD operational amplifiers do not require any periodic recalibration.

The application circuits discussed herein are intended for demonstration of applications used in telecommunications, instrumentation, medical devices, and industrial process control systems. Although automation can be an important end goal, a primary goal may be to simplify the manufacturing and control process, by electrically altering an analog circuit transfer function without resorting to a system of micro-controllers, Rams and ROMs, EPROMs, data converters and an overhead of circuit and system functions. In many applications, where there is a need to eliminate moving mechanical parts, or where access to a trimmer potentiometer is no longer available, such as in an epoxy potted module, adjustment of circuit parameters using EPAD operational amplifiers is a simple and economical solution.

GENERAL DESCRIPTION

The ALD172xE and ALD272xE are monolithic CMOS operational amplifiers capable of input offset voltage adjustment by the user. They utilize Complementary Metal Oxide Semiconductor Field Effect Transistor (CMOS FET) with electrically settable threshold voltages to adjust and set the amplifier input offset voltages. Their on-chip offset voltage trimming circuits employ differential temperature effect matching and error cancellation design techniques. As a result of using these design techniques, the programming of input offset voltage from one level to a different level

Figure 1



does not appreciably alter the temperature coefficient of the input offset voltage or other electrical characteristics.

For simplicity, the ALD1722E operational amplifier is chosen as an example for the description in this Application Note. This description is applicable to the entire ALD EPAD operational amplifier family.

The ALD1722E has been pre-programmed at the factory and tested for guaranteed input offset voltage program range. For applications where pre-programming at the factory under standard operating conditions suffice and where little or no electrical programming by the user is necessary, a version of ALD1722E is available as ALD1722.

The ALD1722E operational amplifier is based on the standard ALD1702 operational amplifier, with the added feature of user offset voltage trimming. This added feature is built with ALD EPAD technology, using electrically programmable device technology refined for analog circuit applications. The ALD1722E uses EPADs as an internal circuit element for "trimming or setting" a bias voltage characteristic. This bias voltage can be programmed remotely and automatically via software control using a personal computer.

In addition to offering high precision and electrically programmable V_{OS}, EPAD operational amplifiers also offer rail-to-rail input and output voltage ranges, low voltage and low power operation, tolerance to overvoltage input spikes, unity gain stability, extremely low input bias and offset currents, and high slew rate per unit of power consumption.

The basic EPAD is a monotonically increasing voltage adjustable device. The ALD1722E has a pair of EPAD circuits connected such that one EPAD is utilized to adjust V_{OS} in one direction and the other is used to adjust V_{OS} in the other direction. The EPAD circuits can be adjusted many times to control the V_{OS} in both directions. Once programmed the set V_{OS} levels are stored permanently, even when the EPAD power is removed, but can be reprogrammed if desired.

The ALD1722E provides the user with an operational amplifier that can be trimmed with Application Specific Programming or In-System Programming conditions.

Application Specific Programming refers to the situation where the ALD1722E can be trimmed as a unit to the actual intended application circuit operating conditions. In-System Programming refers to the condition where the EPAD adjustment can be accomplished after the ALD1722E has been inserted into the application circuit board. Examples of Application Specific Programming and In-System Programming are illustrated in Figures 14 and 15 respectively.

INPUT OFFSET VOLTAGE (V_{OS}) ADJUSTMENT

General System Requirements

EPAD operational amplifiers offset voltages are programmed using an ALD E100 EPAD programmer unit and the appropriate Adapter Module. The user provides a personal computer, a parallel printer cable, and an external DC power supply. The entire system can be set up and ready to program in a matter of minutes.

Adapter Modules

In conjunction with the ALD E100 EPAD Programmer, two specific Adapter Modules are available for programming EPAD operational amplifiers. The EA103 Adapter Module is used to program single operational amplifiers such as ALD1721E, ALD1722E and ALD1726E. The EA104 Adapter Module is configured to program ALD dual operational amplifiers, such as ALD2721E, ALD2722E and ALD2726E. Within these Adapter Modules, an operational amplifier loop with a gain of 100 is used. Both of these Adapter Modules can be readily modified for In-System Programming by the user to suit a specific operating condition.

Control Software

Software is supplied with an EPAD Adapter Module to control the programming routines and to send commands to the EPAD Programmer to control, measure and compute programming conditions for the specific Adapter Module. With EA103 and EA104 Adapter Modules, the program is set to meet the V_{OS} specified by the user. In many cases, the recommended custom adaptation of this control software is to input a different desired V_{OS} value. The control software algorithm then takes over. In programming mode, the programming terminals VE_1 and VE_2 are pulsed in a controlled fashion along with an optimal sequence of voltage biasing conditions. VE_1 and VE_2 must not be connected to a low impedance source that could interfere with the programmer pulses in order for the programming system to function properly.

Each ALDE100 EPAD Programmer Adapter Module is controlled by a different control program, which is included with each Adapter Module shipment. EPAD control programs are available as follows:

- Standard EA series adapter version
- Standard WINDOW'S version (WIN 3.X, WIN 95)
- Standard E100 programmable version
- Optional developer's version, in Quick Basic 4.5 (for fully automated and integrated software development).
- Optional developer's version, in Turbo C++ 4.5 (for fully automated and integrated software development)

For further information on software availability and description, consult the factory applications department.

FUNCTIONAL DESCRIPTION

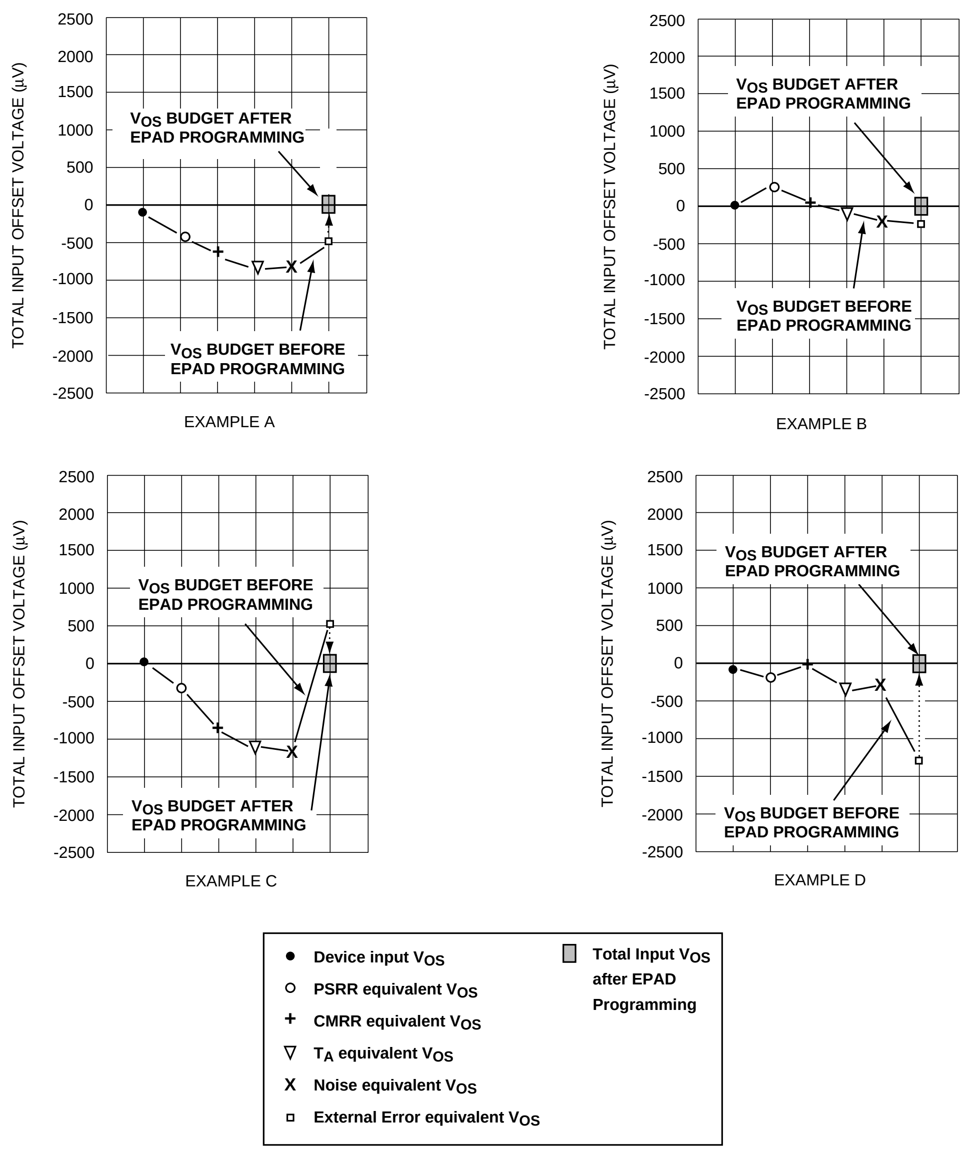
Total Input Offset Voltage

The Total Input Offset Voltage, V_{OST}, is the sum total of all the equivalent input offset voltage errors. This includes input offset voltage, equivalent input offset voltage errors due to PSRR, CMRR, ambient temperature T_A, equivalent input noise voltage (due to noise voltages and noise currents), and external equivalent input offset voltage error. For applications where source impedance is high, or where variation of external circuit equivalent input offset voltage is greater than the operational amplifier internal offset voltages, the V_{OST} can be significantly different from that of the sum of equivalent input offset voltages as operational amplifiers have been traditionally specified.

External circuit equivalent input offset voltage error is traditionally not accounted for in an operational amplifier specification. External equivalent input offset voltage errors, such as that resulting from an external sensor, or from other circuit components, are usually trimmed by the user after the circuit has been built. However, in an EPAD operational amplifier, this system level equivalent input offset voltage error can be compensated for by programming (trimming) the operational amplifier at in-system level. At that point, a specific sensor component has been paired with a specific operational amplifier. Therefore any equivalent input offset voltage error caused by sensor component to component variation can be trimmed by user programming.

Examples of applications in different application specific operating conditions are shown in Figure 2. Note that the input offset voltage can be programmed to any user specified value. In many cases the target input offset voltage of programming is not equal to zero offset voltage, but instead equals to a different input offset voltage that achieves other goals as well.

Figure 2. Application specific/ in-system programming examples of applications where accumulated total input offset voltage from various contributing sources is minimized under different sets of user-specified operating conditions



FUNCTIONAL DESCRIPTION OF EPAD FEATURE FOR V_{OS} CORRECTION

Each ALD1722E EPAD operational amplifier has two additional pins named VE_1 and VE_2. Each pin is internally connected to an EPAD circuit. VE_1 and VE_2 have initial typical values of approximately 1 to 2 Volts. The voltages on these terminals can be programmed using the ALD E100 EPAD Programmer and an appropriate Adapter Module. The useful programming range of VE_1 and VE_2 is 1 to 4 Volts in 0.1mV steps.

VE_1 and VE_2 pins have two functions. The first function is to set a bias voltage during normal operation. Each VEx pin is biased at an internal bias voltage that controls and adjusts the offset voltage of the operational amplifier. An increases in VE_1 results in a decrease in the input offset voltage of the operational amplifier, while increases of VE_2 increases the input offset voltage of the operational amplifier. (In the case of ALD2721E and ALD2726E, increases of VE_1 increases the input offset voltage, whereas increases of VE_2 decreases the input offset voltage.)

The second function of VE_1 and VE_2 is to perform as programming pins, used during device programming. The programming pin is used during electrical programming to inject charge into the internal EPADs bias circuit. The injected charge is then permanently stored. This stored charge results in an increased threshold voltage of the EPAD, which in turn determines the input offset voltage of the operational amplifier. After EPAD programming the VE_1 and VE_2 pins must be left open to settle on a voltage determined by the internal bias currents.

During programming, when connected to an EPAD programmer, the voltages on VE_1 or VE_2 are increased incrementally to set the input offset voltage, V_{OS}, of the operational amplifier to the desired level. Note that the desired V_{OS} can be any value within the offset voltage adjustment ranges, and can be either equal to zero, a positive value or a negative value. Once programmed, the V_{OS} value is retained indefinitely, regardless of whether the device is powered on. This V_{OS} value can also be reprogrammed to a different value at a later time, provided that the useful VE_1 or VE_2 programming voltage range has not been exceeded.

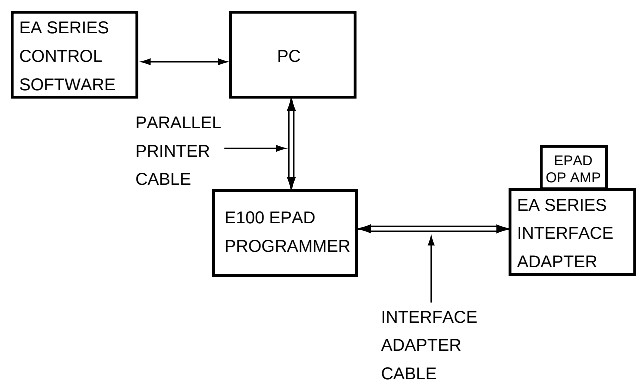
VE_1 and VE_2 are high impedance terminals, as the internal bias currents are set very low, typically to a few microamperes to conserve power. For certain applications, these high impedance terminals may need to be shielded from external coupling sources. For example, digital signals running nearby may cause unwanted offset voltage fluctuations. Care in isolating the pins from digital lines during the printed circuit board layout would generally eliminate such coupling effects. When necessary, ground traces should be placed around these pins to further isolate them. In addition, optional decoupling capacitors can be added to VE_1 and VE_2 pins.

Dual EPAD operational amplifiers have separate VE_1 and VE_2 pins for each amplifier. Please refer to the individual datasheet for the pinouts and functions of each device.

EPAD PROGRAMMING

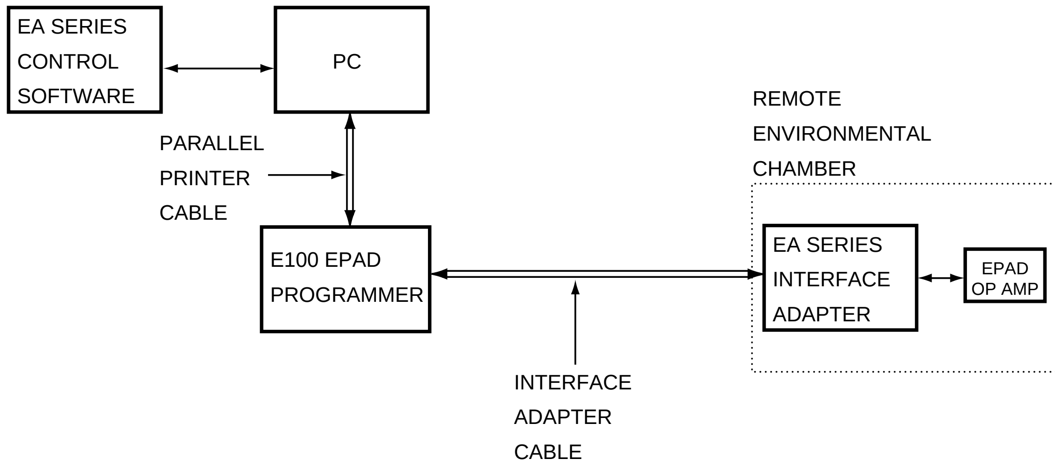
Figure 3 represents a block diagram of a standard standalone EPAD programming system. Using this configuration, the setup and user programming can be accomplished in a simple and straightforward manner. EPAD operational amplifiers with V_{OS} adjustment can be programmed using the EA103 or the EA104 Adapter Module, as interface modules to the ALD E100 EPAD programmer unit.

Figure 3.
Standard Stand Alone
EPAD Programming System



In order to program an EPAD operational amplifier as an Application Specific or In-System element, V+, VE_1 and VE_2 pins need to be pulsed at 12V during the programming process. The application circuit in which the EPAD operational amplifier is used can be powered by any user selected voltage, within the limits of specification. However, it must allow the VE_1 and VE_2 pins to be pulsed without a low impedance path to other circuit nodes, so that the EPAD programmer pulsing circuit can function properly. After programming, VE_1 and VE_2 pins must also be left open without any low impedance path to any other circuit nodes. Both of the above stated conditions, either during programming or during normal operation, can be met simply by leaving the VE nodes in a high impedance state, shielded by ground traces, as necessary.

Figure 4. EA Series Interface Adapter Module Custom Tailored to Application Specific Conditions and Environment



* EA Series Control Software, Interface Adapter Cable And Interface Adapter can All be customized by User for specific application, if necessary.

APPLICATION SPECIFIC PROGRAMMING

For applications where custom setup and special conditions are desired, such as operating at different power supply voltages, different bias current or reference voltage conditions, and/or different temperature environments, the supplied Interface Adapter Module can be readily modified by the user to reflect these conditions.

For example, an application circuit may have +6V and -2.5V power supplies, and the operational amplifier input biased at +0.7V due to a sensor connection, with the average operating temperature at 55ºC. This circuit can be wired up to these operating conditions in an environmental chamber, and the ALD1722E can be inserted into a test socket connected to this circuit and trimmed as required. Any V_{OS} error due to these biasing and environmental conditions will be zeroed out by user programming. The V_{OS} error, V_{OST}, is limited only by the adjustable range and the stability of V_{OS}, and the input noise voltage of the operational amplifier. V_{OST} now includes V_{OS} as traditionally specified plus the V_{OS} error term contributions from PSRR, CMRR, TCV_{OS} and noise. The typical V_{OST} is approximately ±25µV for the ALD1722E. The block diagram of this setup is illustrated in Figure 4.

An EA series Adapter Module can be modified to desired user operating conditions and placed inside a remote environmental chamber, along with each EPAD operational amplifier to be programmed. In this way, each operational amplifier can be programmed optimally for a specific application and its particular environment.

In using the EA series Adapter Module, especially when using an environmental chamber, care must be taken to insure that the voltage and temperature ratings of the Adapter Modules are not exceeded. For continued high temperature applications, the user is advised to set up a custom adapter circuit board to meet those conditions, with a connection to a separate socket for the operational amplifier.

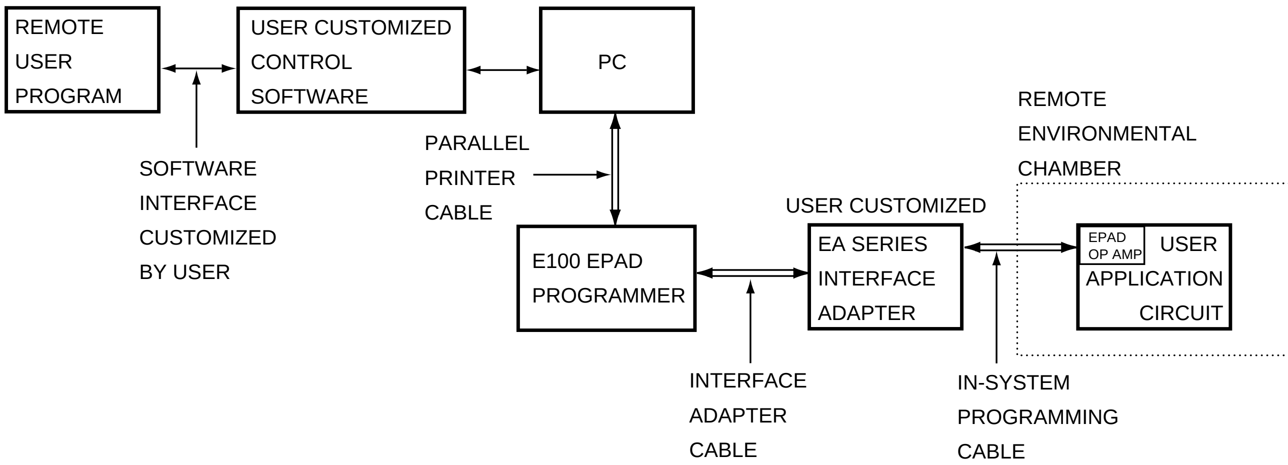
Entire lots of ALD1722E operational amplifiers can be programmed to a user's specific application conditions with a single modified adapter module. These ALD1722E units are then available for assembly use.

IN-SYSTEM PROGRAMMING

One of the benefits of In-System Programming is that not only the ALD1722E operating bias conditions have been accounted for, any residual errors introduced by other circuit components, such as resistor or sensor induced voltage errors, can also be accounted for and programmed out. In this way, the "in-system" circuit output can be adjusted to a desired " calibrated" level.

For In-System Programming, any of the EPAD operational amplifiers can be designed into an application circuit where they are embedded as an integral part of the circuit function. Each EPAD operational amplifier is programmed through the use of an in-system programming cable or a number of pre-assigned edge connector pins.

Figure 5. In-System Programming With EPAD Incorporated into User Application Circuit.



For in-system applications, the EPAD operational amplifier is soldered onto the printed circuit board before EPAD programming. In-system programming is accomplished by designing the application circuit to accommodate the two different modes of operation, the normal operating mode and the programming mode.

During in-system programming mode, the VEx, the input, output and V+ pins are pulsed with programming pulse sequences by the EPAD programmer. Other low impedance nodes in the application circuit can be isolated from these pulses by adding fixed resistors as isolation resistors. A typical isolation resistor is a 1/4W, 50KΩ (10KΩ to 100KΩ) 5% carbon resistor.

In normal operating mode, the designer only needs to ensure that these isolation resistors do not interfere with circuit functionality or cause added errors. For CMOS analog circuits, extremely high input impedance of the CMOS inputs and normal CMOS output loading in the 10KΩ to 100KΩ range would be compatible with using these isolation resistors. Once such a circuit has been designed, a special in-system programming cable can be built to implement In-System Programming as referred to in Figure 5.

This special in-system programming cable can be designed to temporarily connect the EPAD Programmer to the in-system EPAD operational amplifier directly within the application circuit when programming is desired. After programming, the special in-system programming cable can be disconnected and used again for the next circuit.

CHANGE IN POWER SUPPLY VOLTAGE

The Power Supply Rejection Ratio (PSRR) of an operational amplifier specifies its equivalent input offset voltage change as a result of change in power supply voltage. Other precision operational amplifiers currently available on the market are trimmed at the factory under a specific set of power supply conditions.

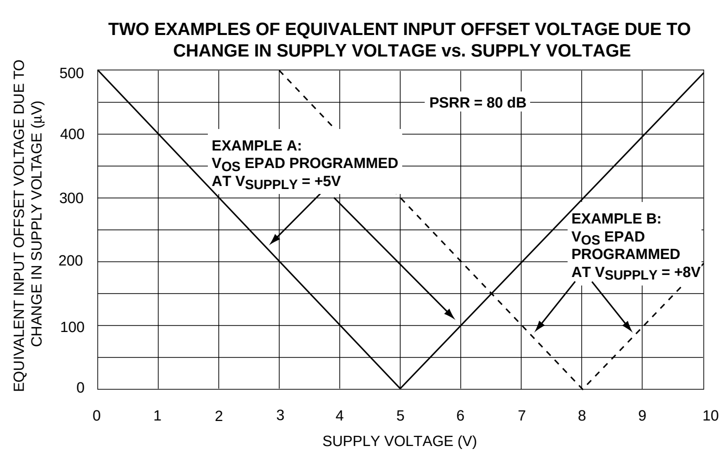
For example, a specific operational amplifier may be laser trimmed at ±15 V. If a user plans to use such a device in an application circuit where the power supplies are actually at ±4 V, and the PSRR specification is 35µV/V, then the equivalent input offset voltage error due to PSRR is equal to ±11V multiplied by the PSRR.

Equivalent input offset voltage error due to the power supply voltage change is given by:

$$\Delta V_{OS} = 11V \times 2 \times 35\mu V/V$$
$$= 770\mu V$$

Consider another example with the use of an operational amplifier that was calibrated at the factory using a single 5V supply. The fact that this operational amplifier may have a PSRR of 100 µV/V actually works out to have a lower equivalent input offset voltage error due to power supply voltage change because the actual change in power supply voltages from factory calibration conditions is smaller.

Figure 6



In this case, equivalent input offset voltage error due to power supply voltage change can be calculated as follows:

$$\Delta V_{OS} = [\,(4 \times 2) - 5\,]V \times 100\mu V/V$$
$$= 300\mu V$$

All ALD EPAD operational amplifiers offer the benefit of user offset voltage programming under the actual operating voltage conditions. Examples of equivalent input offset voltage error with offset voltage trimmed at two separate supply voltages, 5V and 8V, are illustrated in Figure 6.

Take the case of Example A in Figure 6, where the operational amplifier has its offset voltage trimmed at 5V, then at 8V the equivalent input offset voltage error is 300µV. However, if the EPAD operational amplifier is programmed at 8V, as shown in example B, then the equivalent input offset voltage error at 8V due to power supply voltage change is zero.

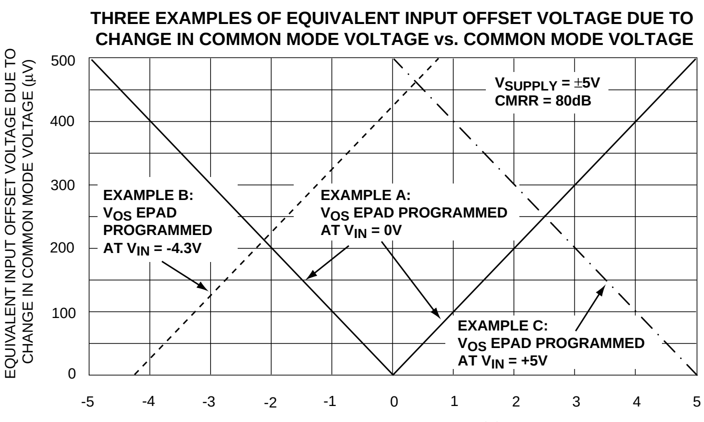
The user now only has to contend with a further change in power supply voltage from 8V in the application and its effect on the equivalent input offset voltage error. For a well controlled state-of-the-art regulated power supply, as one may find in a precision measurement system, the variation in supply voltages due to power supply regulation is very small, in the order of less than 100mV. Using a typical PSRR value of 100µV/V, this translates into an equivalent input offset voltage error due to power supply fluctuations of 20µV.

Equivalent input offset voltage error due to power supply voltage change is calculated as:

$$\Delta V_{OS} = (\,0.1 \times 2\,)V \times 100\mu V/V$$
$$= 20\mu V$$

In this way, the power supply voltage effects causing equivalent input offset voltage errors at the input of the operational amplifier can be minimized or eliminated in many applications.

Figure 7



CHANGE IN COMMON MODE VOLTAGE

ALD EPAD operational amplifiers are designed for a wide range of input signal voltage levels. For large input voltage signals, the rail-to-rail feature of the operational amplifiers offers the largest possible input voltage range available for a given power supply voltage. For small signal amplification, and for very small DC input voltage levels, the common mode voltage range for a specific application can be determined. Examples of three different input voltage DC bias levels are illustrated in Figure 7. Assuming a Common Mode Rejection Ratio (CMRR) of 80 dB for the operational amplifier, the benefits associated with user programming of the equivalent input offset voltage error due to common mode voltages become apparent.

In comparison with factory trimmed operational amplifiers, which may be set up at common mode voltages of 0.0V, EPAD operational amplifiers can be user programmed at supply voltage at any common mode voltage, which in this case is any voltage between V+ and V-.

Note that while the CMRR of the operational amplifier does not change appreciably at different input common mode voltages, the resultant effect of user programming is quite dramatic. In the example illustrated in Figure 7, an operational amplifier trimmed at a common mode voltage of 0.0V (as may be the case in a factory trimmed operational amplifier) would have a common mode equivalent input offset voltage error of 500µV when the input common mode voltage is at +5V. This equivalent input offset voltage error due to CMRR can be eliminated when the user programming of the input offset voltage error takes place when input is set at +5V and the equivalent input offset voltage error becomes part of the V_{OST}.

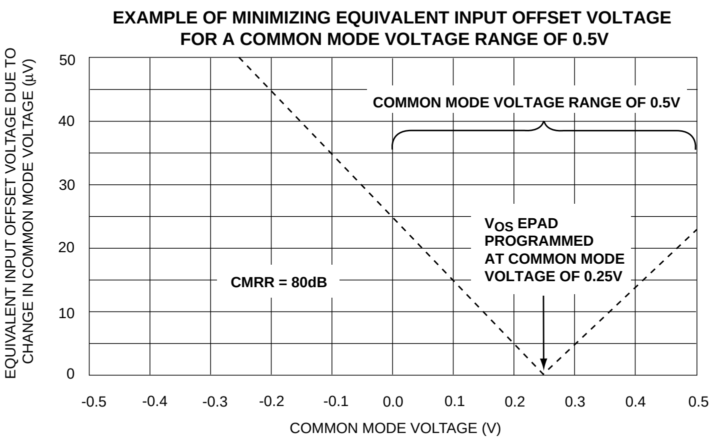
Using example A of figure 7, an operational amplifier that was trimmed at the factory with the power supplies at ±5V and the common mode input voltage set at 0V, with a CMRR specification of 80dB, the equivalent input offset voltage error due to common mode voltage when input common mode voltage is a +5V is:

$$\Delta V_{OS} = 5 \times 100\mu V/V$$
$$= 500\mu V$$

Examples B and C in Figure 7 show different equivalent input offset voltage errors at various common mode voltages with input offset voltage trimmed at different input voltages.

For input signals that have an input common mode voltage range, a specific optimized input common mode voltage within that range can be selected by the user when programming. For example, Figure 8 shows the equivalent input offset voltage error throughout an input voltage range of 0.5V. This input offset voltage can be minimized by user programming at a common mode input voltage of 0.25V. This is accomplished in application-specific or in-system mode by simply programming the EPAD operational amplifiers with the input common mode voltage set at 0.25V.

Figure 8



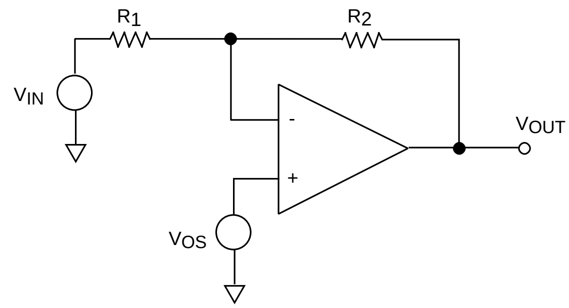
For applications that utilize not only part of the input voltage range, but also have large input signals that essentially utilize the full rail-to-rail input voltage range, user offset programming would not offer the benefits of a predetermined common mode voltage. However, in this case, since the input signal voltage is a large signal, the available gain of the closed loop amplifier has to be limited to a low value so as not to saturate the output transistors. Hence the relative percentage error of the output due to CMRR equivalent input offset voltage errors are kept small.

One example described below illustrates how user offset voltage programming can still be used to an advantage for large rail-to-rail signal range. In a unity gain amplifier application with rail-to-rail input signals, the maximum input and output voltages are the same, and they are equal to the power supply voltage range. There may exist, within this input voltage range, a common mode voltage point where an offset voltage adjustment is desirable, and where an offset voltage shift at that point would significantly enhance the overall system accuracy throughout the range. The user can, upon analyzing the situation, determine where that voltage point should be and proceed to program the offset voltage at that common mode voltage. That voltage point is where “system calibration” can be performed.

BASIC INVERTING AND NON-INVERTING AMPLIFIER CIRCUITS

The best way to visualize the effect of electrically programming of V_{OS} is by modeling the V_{OS} term as a separate voltage source, as shown in Figure 9 and Figure 10.

Figure 9
EPAD Inverting Amplifier



V_{OUT} = - (R2/ R1) * V_{IN}+(1+R2/R1) * (V_{OS})

In the case of the inverting amplifier, the V_{OS} voltage source is a voltage source at the input of the non-inverting input. The virtual ground of the inverting amplifier is directly affected by the magnitude of the V_{OS} voltage source. When V_{OS} is electrically programmed to +1.00 mV, for example, the virtual ground is shifted to +1.00 mV.

The relationship between V_{IN} and V_{OUT} is given by:

$$(V_{OUT} - V_{OS}) / R2 = - (V_{IN} - V_{OS}) / R1$$

assuming leakage currents to be negligible

Therefore

$$V_{OUT} = - (R2 / R1) * V_{IN} + (1 + R2 / R1) * V_{OS}$$

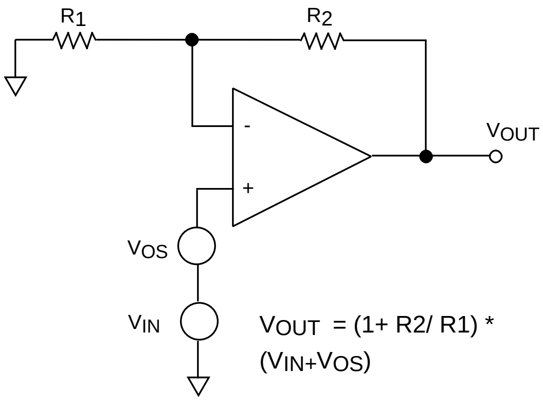
For the case where R2 / R1 > > 1,

$$V_{OUT} \cong - (R2 / R1) * (V_{IN} - V_{OS})$$

For positive values of V_{OS}, the output V_{OUT} is shifted to a positive value. For negative V_{OS} values, V_{OUT} is shifted in the negative direction.

As V_{OS} is programmed internally based on differential and matched circuits in close proximity to each other, the net temperature effect on V_{OS} change due to electrical programming is typically less than the case when external components such as a trimmer potentiometers are introduced into the circuit for V_{OS} adjustment.

Figure 10
EPAD Non-Inverting Amplifier



For non-inverting amplifier applications, the V_{OS} voltage source is a voltage source in series with the input, V_{IN}, as shown in Figure 10.

The relationship between input and output is:

$$V_{OUT} = (1 + R2/R1) * (V_{IN} + V_{OS})$$

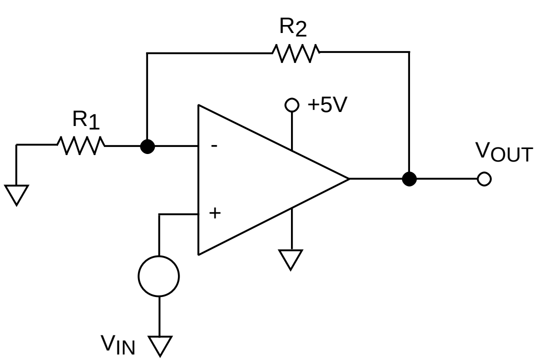
For the case where R2 / R1 > > 1,

$$V_{OUT} \simeq (R2/R1) * (V_{IN} + V_{OS})$$

PRECISION LOW LEVEL VOLTAGE DETECTOR/ COMPARATOR

Using the circuit in Figure 10 above, a direct and immediate application is to use the programmable offset voltage feature of the EPAD operational amplifier to electrically set a precision low level voltage detector, as shown in Figure 11. In this example, the objective is to set up a 2.5 mV ± 50µV threshold voltage detector on the ground line using a single 5 volt supply. The offset voltage is electrically programmed to -2.5 mV.

Figure 11
Precision Low Level Voltage Detector/ Comparator



The input to the non-inverting input is now the ground terminal. Any time the input exceeds 2.5 mV (to within ± 50 uV), the output voltage turns positive and the gain of the circuit is equal to (1 + R2 / R1). The output voltage is therefore equal to the amount of the input voltage exceeding 2.5 mV, the overdrive voltage, multiplied by this gain. To use this circuit as a voltage comparator, the gain is set very high (R2 >> R1). The output voltage is then a highly amplified signal, suitable as an input signal to a digital gate.

OUTPUT VOLTAGE LEVEL SHIFTER

Another example of how EPAD operational amplifiers can be used as an output level shifter is described below.

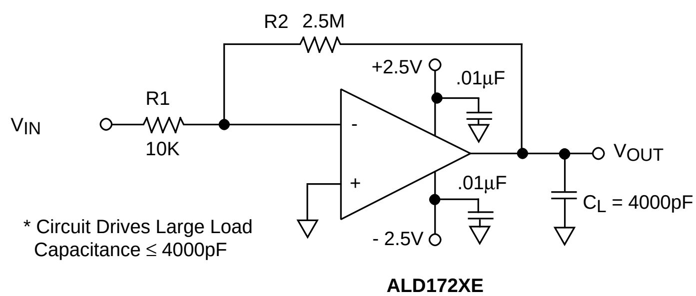
In the inverting amplifier circuit shown in Figure 12, the output offset voltage is given by:

Output offset voltage = [1 + R2/R1] x V_{OS}

The input offset voltage of an ALD EPAD operational amplifiers can be programmed to be equal 2.000mV ±25 uV.

If R2 = 2.5MΩ and R1=10KΩ, and V_{OS} = 2mV, then V_{OUT} is equal to 500mV ±6.25mV for input voltage at 0V.

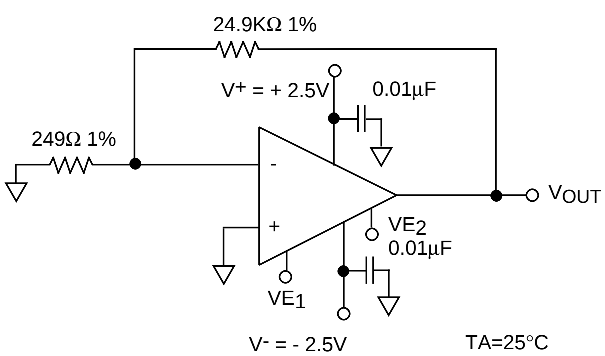
Figure 12
Low Offset Inverting Amplifier



DEFAULT FACTORY-SETTING CONDITIONS

Standard default factory-setting conditions for input offset voltage trimming is shown in Figure 13. This condition is used for the ALD1722E input offset voltage programming, with the input common mode voltage set at ground potential and the fixture set at ambient temperature of 25ºC using dual power supplies. All factory trimmed operational amplifiers, of course, would have to specify a particular set of standard factory default trimming conditions. As input offset voltage is trimmed under those conditions, all other operating condition changes would entail some degree of equivalent input offset voltage change. Common among these changes would be changes in power supply voltages, input source conditions, operating frequencies, common mode voltages, and operating temperatures.

Figure 13
Input Offset Voltage Trimming With Factory-Setting Default Conditions



As many of these operating conditions change, the actual impact of a particular operating condition change is not necessarily well understood. In most cases, the specifications that appear on the data sheet of a given operational amplifier reflect the most favorable operating conditions.

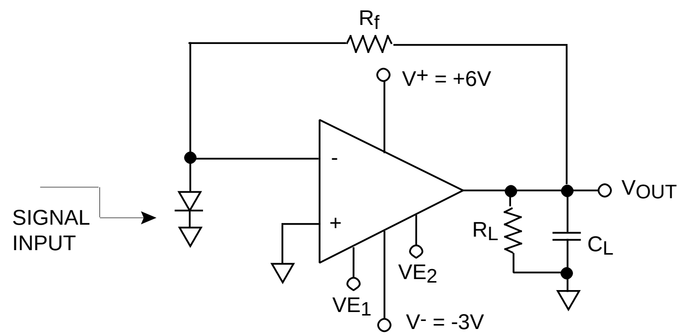
For example, it is often assumed that a well designed and well characterized operational amplifier has a rather uniform and linear power supply rejection ratio at all power supply voltages within the specified operating ranges. This, of course, is not necessarily true at all. However, if the change in power supply rejection ratio at different supply voltages is non-linear, and if it does happen to have an impact on a given application, the user will find out about it not from the data sheet, but at the prototype stage or during production.

Again, the example quoted above illustrates the merit in giving the user the ability to select an actual operating supply voltage setting to perform input offset voltage trimming, where fluctuations of the input offset voltage from that nominal supply voltage level can be minimized, approximated and linearized. EPAD operational amplifiers with electrical programming are designed for this purpose where the user can implement Application Specific Programming described in the example below.

APPLICATION SPECIFIC PROGRAMMING

An example of an user specified Application Specific Programming condition is shown in Figure 14. In this example, the power supply voltage levels, the input common mode voltage levels, output loading conditions, as well as the nominal average operating ambient temperatures, are all different from the standard factory default trimming conditions.

Figure 14
Example of A User Application-Specific Trimming



Therefore the actual equivalent input offset voltage is unknown. However, it is expected that the actual equivalent input offset voltage value will be different from that of the factory trimmed conditions. This value can be readily estimated by calculation using the data sheet information on various parameters affecting equivalent input offset voltage. The fact is that unless an operational amplifier is custom trimmed at the factory, no operational amplifier available on the market will provide equivalent input offset voltage trimmed under the exact set of operating conditions as shown in this example.

A standard factory trimmed EPAD operational amplifier, however, would enable users to customize a setup at their facilities and perform a secondary trimming of the input offset voltage under these specific conditions. With EPAD operational amplifiers, users now have the ability to customize a standard operational amplifier in their own facilities and tailor it to their own specific circuit environments.

In fact, a single EPAD operational amplifier type can be customized for different circuits to many sets of operating conditions using different user customized adapters. Note that in Application Specific Programming mode, no change in the user's application circuit is required. Only a special programming adapter is needed.

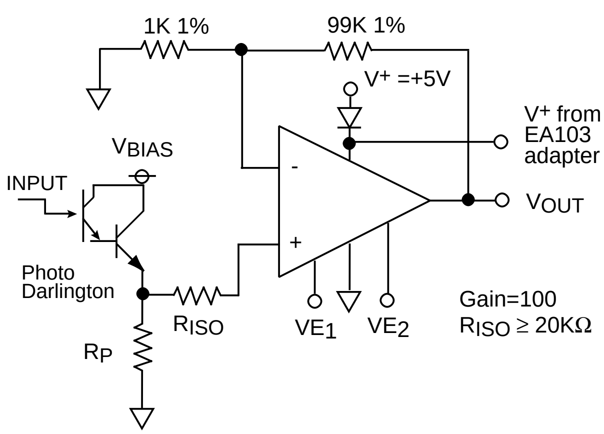
An interface adapter module such as EA103 can be modified by the user to bias an EPAD operational amplifier to a set of custom conditions, and then to proceed to trim input offset voltage. Hence Application Specific Programming can, in many cases, improve the final accuracy required in the system by virtue of the fact that an EPAD operational amplifier is capable of being electrically trimmed under a particular user's exact application conditions.

IN-SYSTEM PROGRAMMING

In-System Programming takes the programmable feature of the EPAD operational amplifier one step further than in Application Specific Programming mode, at the expense of making some modification to the application circuit. Now the programmable feature is also used as an electrically trimmer circuit not only for correcting the operational amplifier's own input offset voltage, but also for correcting other system variables. System variables can be any kind of system errors coming from other system components or changes in the system desired for calibration purposes.

An example of In-System Programming is illustrated in Figure 15, in which the output of the photo darlington is calibrated by using a calibrated light source. V_{OUT} is electrically programmed to a corresponding desired voltage value, which can be a calibrated voltage value. This calibrated voltage can be precisely set for each individual unit of different batches of photo darlington devices, each with greater unit to unit output variation than desired. This calibrated voltage can now be used as a precision system control threshold voltage.

Figure 15
Example of In-System Programming of an EPAD - Based Operational Amplifier



In this particular example, In-System Programming is used to adjust for variation of individual sensor (photo darlington) output current corresponding to a given light input intensity to provide a calibrated output. This calibration is performed after a sensor and an EPAD operational amplifier have been kitted and assembled into one assembly, along with other circuit components. In the example shown in Figure 15, another component value variation, that of the current sensing resistor value of Rp, is also taken into account. Since the input to the operational amplifier is a voltage, which is the product of the sensor current and the sensing resistor value, a voltage adjustment includes both sensor current value and resistor resistance value variations. This example circuit can be easily adapted to be used, for instance, in a ground-sensing amplifier application.

DESIGN PRECAUTIONS

ALD EPAD operational amplifiers are designed for use in low voltage, micro-power circuits. The maximum operating voltage during normal operation should remain below 10 Volts at all times. Care should be taken to insure that the applications in which the devices are used would not experience any positive or negative transient voltages that cause any of the terminal voltages to exceed this limit.

EPAD programming takes place at a voltage determined by the EPAD programmer, typically at about 12V. In-System Programming requires a programming mode where other circuitry can accommodate EPAD programming pulses and conditions.

All inputs or unused pins except the programming pins (VE_1 and VE_2) should be connected to V- so that they do not become floating pins, since input impedances at these pins are very high. If any of these pins are left open, they may cause unwanted oscillation or intermittent excessive current drain. As these devices are built with CMOS technology, normal ESD and latchup handling precautions should be observed. Operating and storage temperature limits as stated in the datasheet must also be observed.

CONCLUSION

EPAD V_{OS} trimming is applied to a new generation of operational amplifiers that empower the analog circuit designers to customize their analog circuits with a new set of capabilities that is simple and economical to use. The precision achieved can be optimized for a unique individual system requirement, where most of the system parameters may be at different levels from that of the standard IC factory environment. Under standard IC operating conditions, offset voltage of a precision operational amplifier would be minimized under only one factory mandated, rather than user specified, setting.

Using EPAD operational amplifier programming, external parameter variations introduced by other system components can also be trimmed at the same time. Hence, EPAD operational amplifiers are capable of performing the dual role of a precision operational amplifier function and an all solid-state electronic trimming function simultaneously. Once the application circuit is designed, the task of programming can be fully automated and controlled with the ubiquitous and inexpensive PC.

For further assistance on Application Specific Programming or In-System Programming, please contact the ALD applications department. Send a fax or e-mail to:

Fax (408) 747-1286 - Attention: Applications

E-Mail: Applications@aldinc.com