Application Note 021

M.S. Kennedy Operational Amplifiers

MS Kennedy Corp.; Revised 9/19/2013

Introduction

M.S. Kennedy has an extensive line of standard product amplifiers as well as many industry replacement amplifiers. We offer a wide variety of amplifiers for use in many different applications. Our hybrid operational amplifiers take advantage of the most current design and construction techniques to offer many favorable electrical characteristics, including high speed, ultra-accurate, high voltage and high power.

We have available many different amplifier styles, including, but not limited to FET input differential, FET input buffer, high speed feed forward, high power, high voltage, ultra accurate and video. Our experience with amplifiers has also allowed us to offer replacement components for many amplifiers discontinued by other manufacturers. MS Kennedy is also listed as the source of supply on many standard military drawings. Also, because of our background in custom hybrid design, we are able to offer competitive pricing, design and delivery for custom amplifier projects.

We have selection guides for each amplifier type in our data book as well as on our web site. If you are unable to find what you need, please contact our Engineering/Sales Department and we will help you select the best product for your application.

Absolute Maximum Ratings

All M.S. Kennedy operational amplifiers have absolute maximum ratings for input voltage, peak output current, supply voltage, etc. While it is possible that any one of the specifications may be exceeded at any time without permanent damage to the device, it is good operating practice to stay within these maximum ratings to ensure full amplifier life.

Safe Operating Area

The safe operating area curve is a graphical representation of the power handling capability of the operational amplifier under various conditions. The SOA curve takes into account the wirebond current carrying capability, transistor junction temperature, internal power dissipation and secondary breakdown limitations.

The horizontal axis on the SOA curve represents the voltage across the output stage of the operational amplifier. This axis does not represent the total supply voltage. It is the voltage differential from the supply to the output. This voltage will be seen across the output stage that conducts current to the load.

The vertical axis of the SOA curve is the current that the operational amplifier is supplying to the load through the output pin. This current is limited by the current handling capabilities of the wirebonds as well as the die metallization of the transistors or MOSFETS in the output stage.

The SOA curves show a marked effect by temperature on the overall operation of the amplifiers. With this in mind, it is obvious that thermal design considerations must be incorporated into the use of all amplifiers that might be used at or near the maximum ratings. Operation beyond the safe operating area will result in decreased amplifier life and quite possibly destruction of the device.

Power Supplies

Bypassing/Decoupling

It is very important with all M.S. Kennedy amplifiers to provide adequate power supply decoupling. An effective decoupling scheme consists of a 0.1 µ F ceramic capacitor (high frequency bypass) in parallel with a 4.7 µ F tantalum capacitor for each amp of output current (low frequency bypass). This capacitor scheme should be used for all supply voltages and should be located as close to the device supply pins as possible. With high power op amps it is also a good idea to place a 30-50 µ F non-electrolytic capacitor with low ESR in parallel with the other two capacitors. This third capacitor will help to eliminate any peak output voltage clipping which may occur due to poor power supply load regulation.

Current Limit

Most of our amplifiers have external current limit capability. This current limit is extremely useful for keeping an amplifier functioning within its SOA. It is very important to select current limit resistors to keep output current below the absolute maximum as the amplifier may be destroyed if operated beyond that maximum.

In some cases, if current limit is not required the current limit pin(s) should not be considered no connects. Floating current limit pin(s) can cause device failure. The current limit pin(s) should be tied to corresponding supply or output pins. This is shown in the individual data sheets for the amplifiers and is device specific.

Calculation of current limit resistors varies with individual amplifiers as well. Consult the data sheets for further information regarding these calculations.

Stability

Although most of our amplifiers are internally compensated or have external compensation capabilities, a frequently experienced problem is instability. There are many causes of instability when working with amplifiers, however by following some basic design practices every circuit can be stabilized. Some of the more common instability problems are caused by improper power supply bypassing, ground loops and incorrect feedback capacitance.

Power supply bypassing as close to the supply pins as possible is a crucial step in avoiding op amp oscillations. A small ceramic capacitor in parallel with larger tantalum capacitor will provide good high frequency grounding of the supply lines. Good grounding practices must also be followed to help eliminate oscillations. Many oscillation problems can also be eliminated by the use of a feedback capacitor in parallel with the feedback resistor. If a small value variable capacitor is used here, it can also be adjusted to optimize the rise time and the overshoot of the amplifier.

Thermal Issues

Internal Power Dissipation

In most amplifier applications it is important to provide a proper heat sink to maintain a junction temperature below that which may cause damage to the op-amp. Maximum internal power dissipation and maximum junction temperature must be known to choose a proper heat sink.

At this point it is important to note that internal power dissipation and output power to the load are not always the same. The two are only equal with a resistive load when output voltage is equal to 1/2 supply voltage. This is also the case when internal power dissipation is maximized.

There are actually two different types of power dissipation in amplifiers; AC and DC. First, we will discuss DC power dissipation and explain the calculations for this. The first part of power dissipation is the quiescent power that is dissipated due to quiescent current and supply voltage. By simply multiplying the total supply voltage by the quiescent current we attain the quiescent power dissipation.

$$PD_Q = I_Q(+V_S - (-V_S))$$

Secondly, there is dissipation in the output stage of the amplifier. This dissipation is calculated by multiplying the output current times the voltage drop across the op amp.

As was mentioned earlier, maximum power dissipation (with a purely resistive load) occurs at $V = 1/2 \ V_{Supply}$. The formula for this is:

$$PD_{OUT} (max) = \frac{V_S^2}{4R_L} \qquad \text{Where } V_S = \text{Supply Voltage}$$
$$R_L = \text{Load Resistor}$$

To find the total internal power dissipation, add these two dissipation components.

$$PD_{Tot} (max) = PD_Q + PD_{Out} (max)$$

These formulas must be changed in order to calculate maximum internal power dissipation with an AC output or a reactive load. When performing the following calculations it is important to assume the use of symmetric power supplies and sinusoidal signals.

For Resistive Loads:
$$PD_{OUT} (max) = \frac{2 V_S^2}{\pi 2 R_L}$$

For Primarily Resistive Loads:
($\ominus < 40°$)
$$PD_{OUT} (max) = \frac{2V_S^2}{\pi^2 Z_L \, COS\ominus}$$

For Primarily Reactive Loads:
($\ominus > 40°$)
$$PD_{OUT} (max) = \frac{V_S^2}{2Z_L} \left| \frac{4}{\pi} - COS\ominus \right|$$

Where:
$$V_S = | +V_S | \quad \text{or} \quad | -V_S |$$
$$Z_L = \text{Load Impedance}$$
$$\ominus = \text{Phase angle of load impedance}$$

Heat Sinking

To determine the correct heat sink for your application, refer to the thermal model and governing equation below:

$$T_J = PD_{Total} * (R\theta_{JC} + R\theta_{CS} + R\theta_{SA}) + T_A$$
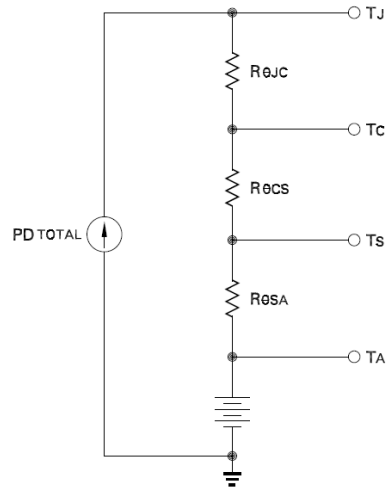
Where:
T_J = Junction Temperature
PD_{Total} = Total Power Dissipation
$R\theta_{JC}$ = Junction to Case Thermal Resistance
$R\theta_{CS}$ = Case to Heat Sink Thermal Resistance
$R\theta_{SA}$ = Heat Sink to Ambient Thermal Resistance
T_A = Ambient Temperature

Thermal Model

It is possible to lower power dissipation by tight control of the power supplies. To get power dissipation to a minimum it is important to keep supply voltages just high enough to provide the required output voltage swing. This will reduce the voltage drop across the amplifier and therefore serve to reduce total power dissipation.

The reduction of total thermal resistance can be accomplished through the use of proper mounting techniques as well as use of heat sinks. The thermal resistance from case to heat sink to ambient air can greatly impact the overall junction temperature and should be considered important for design considerations.

Reference to the individual device data sheets will provide examples for heat sink selection, if it is required.

Amplifier Compensation

Stability of the amplifier was discussed earlier. The following are a few examples of methods used to provide stability through the use of R-C compensation circuits, output snubber networks and feed back capacitors. The following paragraphs give a brief overview, however more detailed information can be found in the individual data sheets.

Output Snubber Networks

Simple R-C networks from the output to ground can be used to eliminate oscillations due to inductive loading. Typically these networks are unnecessary, however if compensation in such a circuit is required, the use of an R-C network can help to provide a low impedance resistive load at higher frequencies. Resistance values can be low—in the 10 to 100 ohm range while capacitance can typically be between 0.1 µ F and 1 µ F.

Feedback Capacitors

For most high speed amplifiers, a simple feed back capacitor can be employed to eliminate unwanted oscillation. Typically a 0.5 to 10 pF capacitor in parallel with the feed back resistor can be used. Many amplifiers offered by M.S. Kennedy have available compensation pins to which a small capacitance value can be applied to remove instability. In amplifiers that do not have this option, the parallel capacitor may be used. It is possible to use an adjustable capacitor and to optimize amplifier rise and fall times while also removing device oscillation. Please refer to data sheets for further information regarding this use.
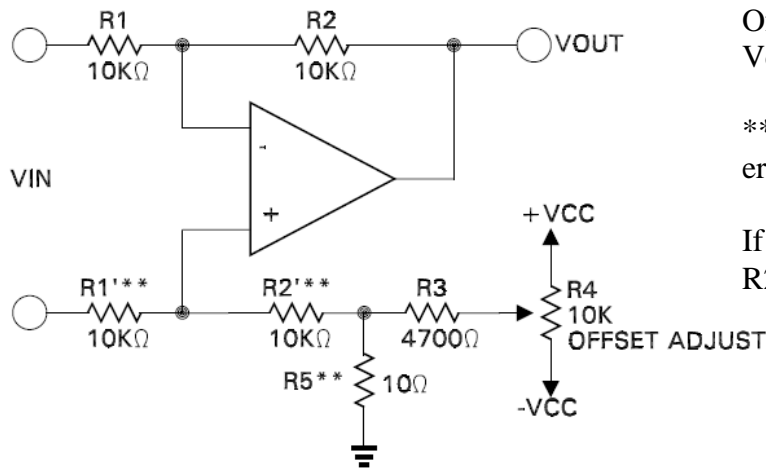
R-C Compensation Circuits

As previously mentioned, some MS Kennedy amplifiers have internal compensation circuitry. Through the use of selected R-C circuits the amplifiers can be optimized for a variety of gain settings. Under normal circumstances these R-C circuits would be unnecessary when the amplifiers are operated at a high enough gain factor. This gain factor varies per amplifier and individual data sheets need to be consulted.

Offset Voltage Adjust

Some of our amplifiers offer the ability to perform input offset voltage null through the use of balance pins. This is very helpful in applications that require a high degree of dc accuracy. This obviously would become more useful at increasingly high gains as dc error would be greatly amplified. Through the use of the balance pins and a potentiometer to the supply rail, input offset may be nulled to optimize dc performance of the amplifiers.

It is also possible to provide external null circuits for amplifiers that do not provide internal circuitry. The following diagrams show examples of how this can be achieved for various amplifier styles.

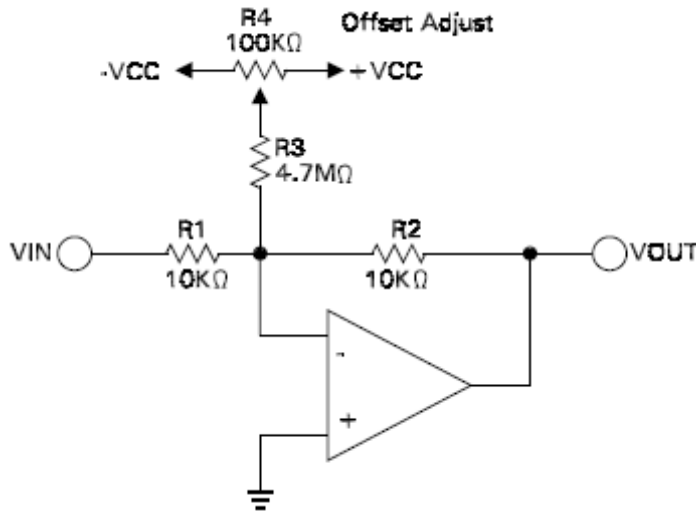*External Offset Null Adjust – Differential Amplifier*

Offset Adjustment Range = +/-
Vcc(R5/R3)(R'/(R1' + R2'))

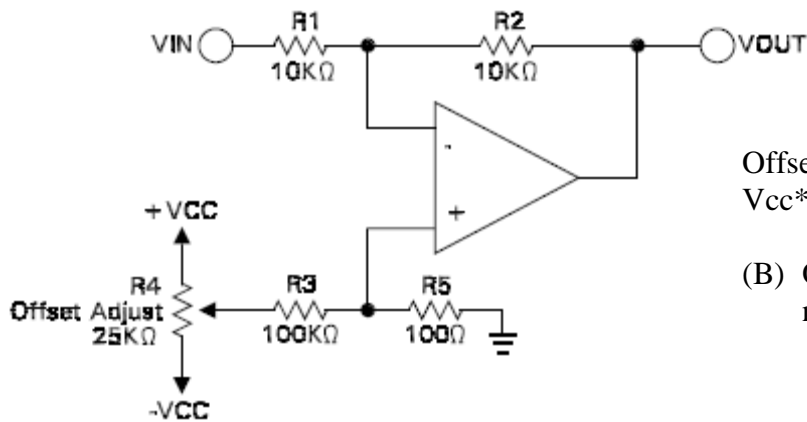**R5 introduces a common-mode error, since R2/R1 = (R2' + R5)/R1'

If necessary, trim R2' such that R2/R1 = (R2' + R5)/R1'

External Offset Null Adjust – Inverting Amplifier

Offset Adjustment Range = +/- Vcc*(R1||R2)/R3
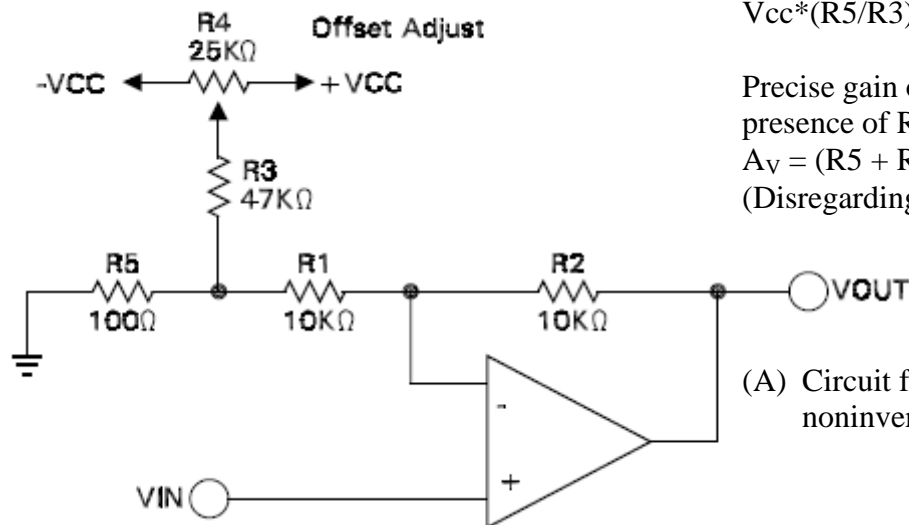
(A) Offset voltage applied to the inverting input

Offset Adjustment Range = +/- Vcc*R5/R3

(B) Offset voltage applied to the noninverting input

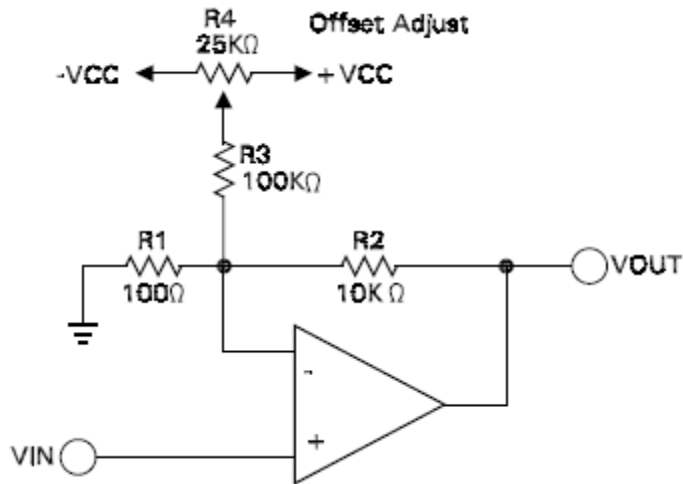## External Offset Null Adjust – Noninverting Amplifier

Offset Adjustment Range = +/- Vcc*(R5/R3)(R2/(R1 + R2)

Precise gain of stage modified by presence of R5 in series with R1: $A_V = (R5 + R1 + R2)/(R5 + R1)$ (Disregarding R3||R5, since R3>>R5

(A) Circuit for low-gain, noninverting amplifier

R4
25KΩ

Offset Adjust

-VCC ◄——— W ———► +VCC

R3
100KΩ

R1
100Ω

R2
10KΩ

VOUT

VIN

Offset Adjustment Range = +/- Vcc*(R1/R3)

(B) Circuit for high-gain, noninverting amplifier

Class "C" Operation

M.S. Kennedy offers some operational amplifiers that operate in the "AB" or "C" mode. This selection can be made by the user depending on system requirements. If zero point distortion is not critical and quiescent power dissipation must be minimized, class "C" can be selected. With these amplifiers, when Class "C" operation is selected, the bias control network in the output stage is disabled. This lowers quiescent current and a small amount of crossover distortion will appear on the output waveforms. This mode of operation is recommended for switching type applications where distortion is not a critical specification.

These devices will operate in the "AB" mode without any special connections made.