APPENDIX B

INPUT BUFFER AMPLIFIER REQUIREMENTS

The Necessity of an Input Buffer

The characteristic input impedance of the AD536A is approximately 16.7kΩ, the AD637 8kΩ, and that of the AD636 closely approximates 6.7kΩ.

Virtually all "packaged" rms to dc converters have an input resistance of less than 100k ohms. These impedance values are far too low for the rms converters to be used directly following high impedance inputs, such as input attenuators – they must be driven by some type of buffering amplifier for these applications.

Using the AD536/AD636 Internal Buffer Amplifier as an Input Buffer

With the circuit of Figure 77, the 1MΩ resistor provides a dc return for the signal path to ground. Without this resistor, the input bias current will charge up C_{IN} and saturate the buffer amplifier.

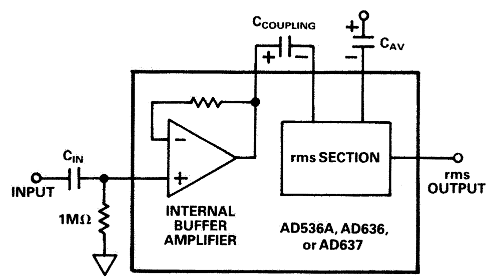


Figure 77. A Simple Input Buffer Connection Using the Internal Buffer Amplifier of an rms Converter

This simple input buffer scheme has several disadvantages. The 1MΩ input impedance is still too low a value for use following input attenuators (typically 10MΩ impedance). Also, the amplifier is prone to

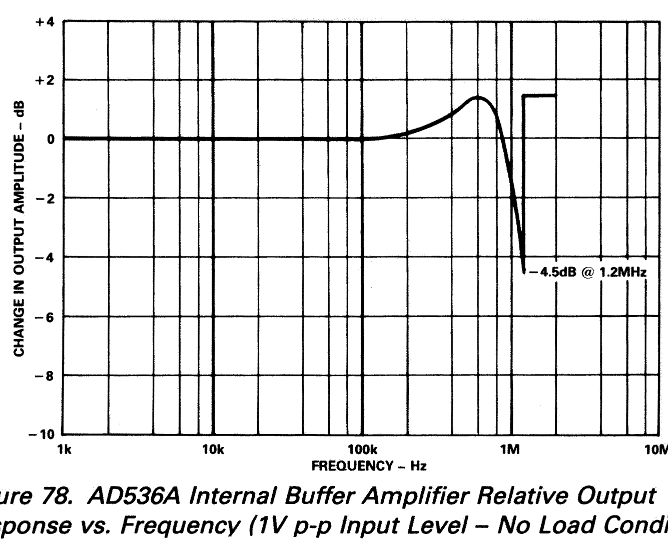


Figure 78. AD536A Internal Buffer Amplifier Relative Output Response vs. Frequency (1V p-p Input Level – No Load Condition)

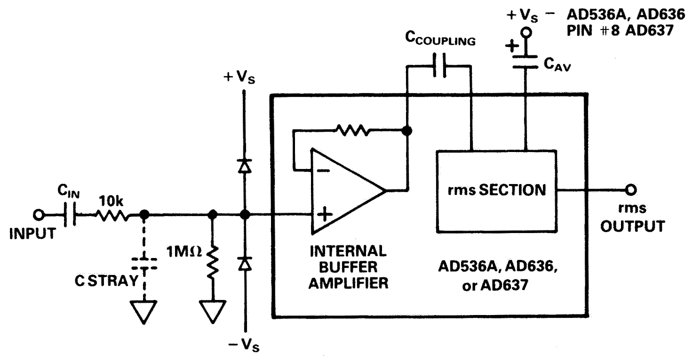


Figure 79. An Improved Input Buffer

input overload at the higher frequencies (above 100kHz).

One simple improvement to this circuit is the addition of a series input resistor, R_{IN}, which in conjunction with the stray input capacitance of the operational amplifier forms a low pass filter. The input signal is then sufficiently attenuated at frequencies above 100kHz to prevent input overload. A further improvement, the addition of a 10kΩ series resistor and two low leakage diodes, provides a high degree of input protection from transients (via external sources) which could destroy the buffer (see Figure 79).

BOOTSTRAPPING AN RMS CONVERTER'S INTERNAL BUFFER AMPLIFIER

What is Bootstrapping?

A very effective method for dramatically raising input impedance is through the use of bootstrapping. This has the effect of multiplying the input impedance by the open loop gain of the amplifier.

With the buffer connection of Figure 79, the input resistor is returned to ground setting the effective input impedance approximately equal to the value of that resistor. The trick with bootstrapping is that since the buffer amplifier is operated as a unity gain voltage follower, its output voltage will equal the voltage of its input. Using the bootstrapping circuit of Figure 80, the input resistor, R_2, is now connected between the amplifier's input and output. Since (assuming an ideal amplifier) both sides of this resistor are at equal potential, the input impedance of the buffer amplifier is not affected (ideally) by the resistor and remains extremely high. With practical circuits, the amplifier does not have infinite open-loop gain and an error voltage will appear across R_2. This makes the effective input resistance of the circuit equal to the series protection resistor R_1 plus the

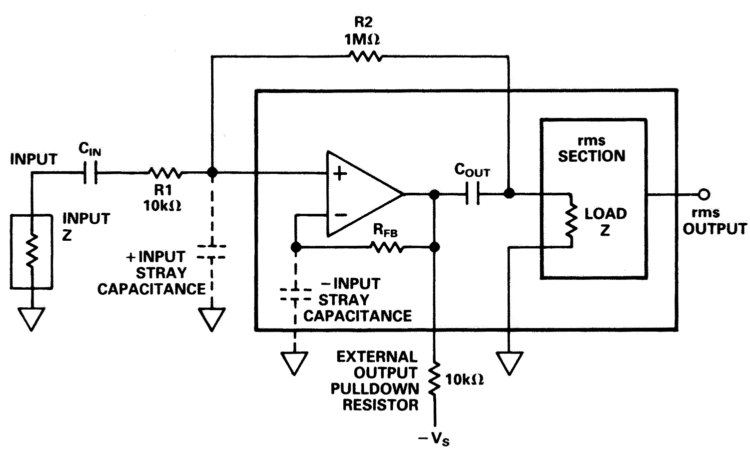


Figure 80. Using the Internal Buffer Amplifier as a Bootstrapped Input Buffer

product of input resistor R_2 multiplied by the open loop gain of the amplifier.

$$R_{IN} = R_1 + (R_2 \times A_{OL})$$

R_{IN} can be quite high ($10^9\Omega$) since the buffer amplifier (of the AD536A and AD636) typically has an open loop gain of 2,000 at dc.

Some Precautions

Bootstrapping does require a few precautions: Problems may arise due to stray capacitance at the inverting input of the amplifier. At high frequencies, the internal feedback resistor (R_{FB}) of the converter's buffer amplifier in conjunction with the stray capacitance at the inverting input form a voltage divider. (A second divider is formed via resistor R_1 and the stray capacitance at the noninverting input.) Depending on both the magnitude of the strays and the input signal frequency, the circuit's stray capacitances may cause the amplifier to operate *with gain* and cause instability. Capacitor C_{OUT} ac couples the buffer output; connecting the input resistor R_2 to the input *after* this coupling capacitor prevents dc latchup problems.

The dc return path for the buffer's input current is via the load impedance of the rms section of the rms converter following the buffer. The bias current travels through resistor R_2 and then to ground via the relatively low input resistance of the rms section.

BUFFER AMPLIFIER OUTPUT STAGE CONSIDERATIONS

The AD536A/AD636/AD637 buffer amplifier does not employ the usual Class AB complementary output stage but uses a Class A emitter follower output instead (see Figure 81). This allows the output voltage to swing fully to ground during single supply operation as an output buffer.

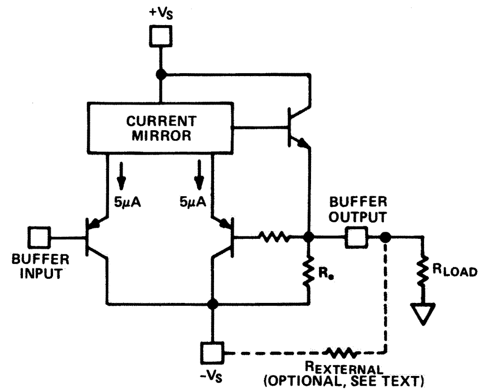
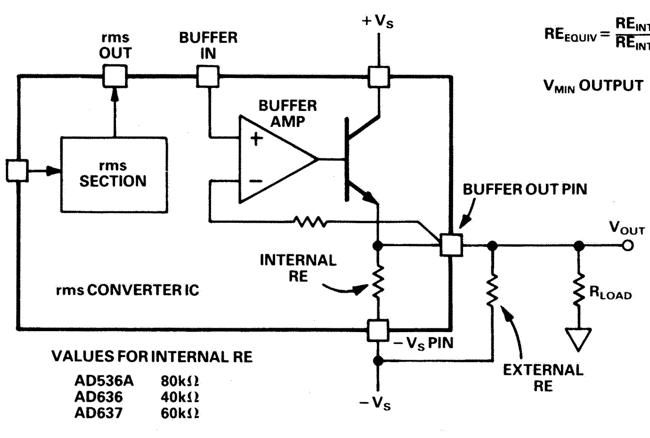


Figure 81. AD536A, AD636, AD637 Internal Buffer Amplifier Simplified Schematic

However, when using this amplifier as an *input* buffer, steps must be taken to insure an adequate negative output voltage swing. For negative outputs, current must travel through the buffer's internal emitter resistor, R_e. The maximum current that the output stage can obtain from the negative supply is therefore limited by the value of R_e. This in turn limits the maximum negative output voltage swing the buffer may provide for a given value of load resistance (i.e., resistor R_e and the load resistance R_{LOAD} form a voltage divider limiting the maximum negative voltage output of the buffer, see Figure 82).



$$RE_{EQUIV} = \frac{RE_{INTER} \times RE_{EXT}}{RE_{INTER} + RE_{EXT}}$$

$$V_{MIN}\ OUTPUT = -V_S \frac{R_{LOAD}}{RE_{EQUIV} + R_{LOAD}}$$

Figure 82. The Effect of $R_{E\ equivalent}$ and R_L on the Maximum Output Swing of the AD536A, AD636 and AD637 Internal Buffer Amplifier

An obvious way to increase negative output voltage swing is to add an external resistor between the amplifier output (a transistor's emitter) and $-V_S$. Unfortunately, the addition of this resistor ($R_{E\ external}$) will increase the buffer amplifier's quiescent current. Therefore, *proper operation of the buffer will be a compromise between maximum output voltage swing and amplifier quiescent current.*

A 30% overrange below the minimum desired output voltage swing is a good rule of thumb. The effective R_E between the transistor's emitter and $-V_S$ is the parallel combination of the two resistors R_E and $R_{E\ external}$.

That is: $$R_{E\ effective} = \frac{R_E \times R_{E\ external}}{R_E + R_{E\ external}}$$

The equation for maximum output swing is:

$$V_{MAX} = V_S \times \frac{R_{LOAD}}{\dfrac{R_E \times R_{E\ external}}{R_E + R_{E\ external}} + R_{LOAD}}$$

Combining the two equations:

$$R_{E\ external} = \frac{R_E R_L (V_S - V_{MAX})}{R_E V_{MAX} + R_L (V_S - V_{MAX})}$$

This formula may be used for calculating the value of the external emitter resistor required.

An alternative method for determining $R_{E\ external}$ is to use Figure 83. This should be done after calculating the ratio of $V_{MAX}/V_{-SUPPLY}$ for the particular application. The value of $R_{E\ external}$ is the point on the graph where $-V_{MAX}/V_{-SUPPLY}$ intersects the value of R_L.

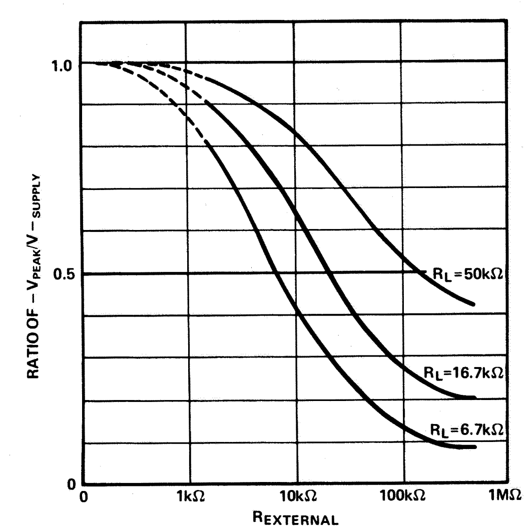


Figure 83. AD536A, AD636, AD637 Internal Buffer Amplifier – Ratio of Peak Negative Output Swing to $-V_S$ vs. $R_{E\ external}$ for Several Load Resistances

Note: The AD637 buffer amplifier is too slow to drive its rms section over its entire bandwidth. However, it is useful in applications where 100kHz bandwidth is adequate and the greater accuracy of the AD637 (as compared to the AD536A) is important. The following section of this guide explains the special performance requirements demanded of an input buffer used with a wide bandwidth rms converter such as the AD637.

AD637 INPUT BUFFER AMPLIFIER REQUIREMENTS

Bandwidth and Slew Rate Limitations

The AD637 is a very high speed rms converter, providing up to 5MHz bandwidths with 1 volt rms input signals. However, with this much bandwidth available, serious consideration must be given to the choice of the input buffer amplifier if the full high frequency performance of the rms converter is to be realized. Obviously, an input buffer such as that shown in Figure 84 must have a ±3dB bandwidth several times greater than that of the rms converter

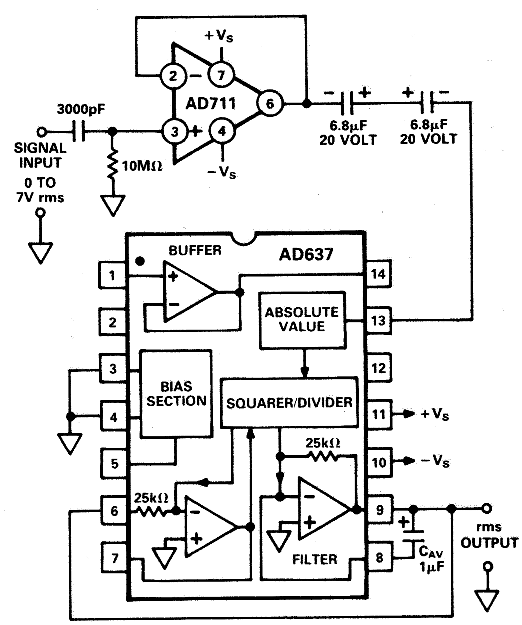


Figure 84. AD637 rms Converter with External 4MHz High Impedance Input Amplifier

to avoid introducing additional errors. This fact is usually considered when an input buffer is selected, and several commonly available amplifiers have adequate bandwidths to meet this requirement. What is most commonly over looked is the fact that the amplifier's *slew rate* requirements may be considerable! As an example:

For an input buffer amplifier driving a 5MHz rms converter with a *sinewave* of 1.4 volts peak amplitude (1 volt rms), the maximum slew rate required can be found:

$V = A_m \sin\omega T$

WHERE: V = Instantaneous Voltage
A_m = Peak Amplitude of the waveform
ω = 2π Times the frequency of the input waveform
T = Period of the input waveform

Since. . . Slew Rate $= \frac{\Delta V}{\Delta T}$ Then:

$$\text{Slew Rate} = \frac{dV}{dT} = A_m\,\omega\,\cos\omega T$$

The maximum slew rate of a sine wave is at the origin and at this point $\cos\omega T = 1$
Therefore:

$$\text{Maximum Slew Rate} = \frac{\Delta V}{\Delta T} = A_m\,\omega =$$

$V_{peak}(2\pi F)$ where F = input frequency in Hz

This means that the maximum slew rate required from an amplifier in volts per microsecond will equal V_{peak} times 6.28 times the input frequency in megaHertz. For the example given above:

> Maximum Slew Rate required will equal 1.4 volts times 6.28 times 5 megaHertz or 44 volts per microsecond.
> For a three volt rms input level, the maximum slew rate required would be 133 volts per microsecond.

Figure 85 displays the full range of minimum slew rate required for a sine-wave input of up to 7 volts rms applied. This may be used for roughly calculating input buffer requirements.

Figure 86 shows the actual −3dB bandwidth of the circuit of Figure 84. Note that up to approximately 400mV this circuit is bandwidth limited by the bandwidth versus input characteristics of the rms converter; above this level, however, the slew rate limitations of the 20V/µs input amplifier limit the overall bandwidth of the system. Peak bandwidth for this circuit occurs where converter bandwidth is high and where the input amplifier is still slewing adequately.

A final consideration regarding input amplifier slewing rate: the amplifier must slew symetrically, that is, go as fast in the negative direction as in the positive,

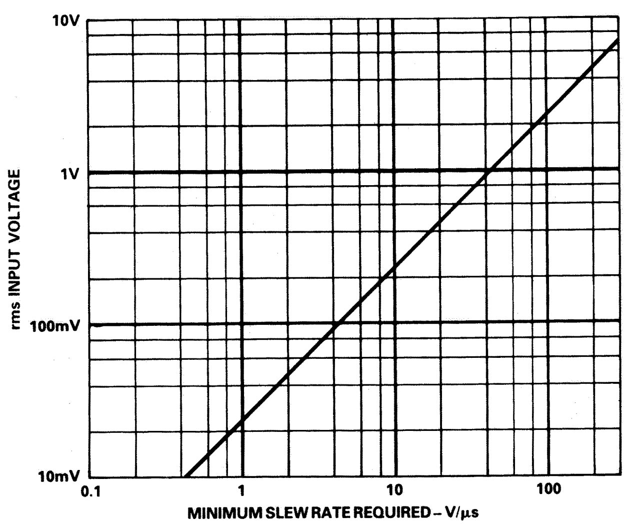


Figure 85. Minimum Slew Rate Required from an Input Buffer Amplifier Driving a 5MHz rms Converter in Volts/Microsecond

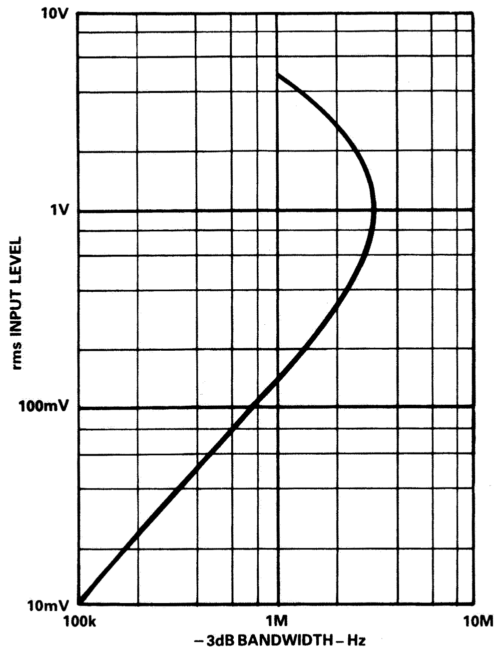


Figure 86. AD637 with AD711 Input Buffer Amplifier −3dB Bandwidth vs. Input Level

otherwise the slew rate in the slower direction will limit overall bandwidth. It is especially important to avoid using some common bifet amplifiers whose slew rates vary as much as 2 to 1 thus making them unsuitable for this high speed application. The AD711 operational amplifier is a good example of the type of amplifier which should be used ahead of an rms converter as an input buffer; it has a high slew rate with symmetrical characteristics, adequate bandwidth, good dc specifications, and it is a low noise device.

Buffer Amplifier Frequency Compensation

Input buffer amplifiers that are externally compensated should be carefully "tweaked" for the best possible square-wave response since overshoot, ringing, and other instability problems in op amps will cause peaks in the bandwidth characteristics of these amplifiers.