

# Increasing the Output Current from a Signal Generator

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## Introduction

In this note we describe methods of increasing the output current of a signal generator. These notes apply specifically to the Syscomp CGR-101 CircuitGear (figure 1) and WGM-201 Advanced Waveform Generator, but will be useful with any signal generator.

The CGR-101 and WGM-101 signal generators are particularly convenient to use since they derive their operating power from a USB connection to the host computer. However, the standard USB connection is limited to 500mA of current at 5VDC power, and that limits the output current available from the signal generator. For that reason, the CGR-101 output is limited to  $\pm 3$  volts from  $150\Omega$ . The WGM-201 output is  $\pm 10$  volts from  $150\Omega$ . For many applications, the load resistance is much larger than 150 ohms, and this works well. The  $150\Omega$  internal resistance limits the output current so that the generator will not be damaged by a short circuit load.

A *buffer amplifier* presents a high impedance to the source and provides a lower driving impedance to the load. The voltage gain is usually taken as 1, that is, the magnitude of the output voltage is the same as the input. The magnitude of the output current is much larger than the input current, so the amplifier provides power gain. For that reason, the amplifier will require a separate DC power supply.

For a buffer amplifier that must operate down to zero frequency (DC), the signals must be direct coupled and the power must come from a *bipolar* power supply, such as  $\pm 15$  volts.

For an amplifier that operates on AC signals only, it may be possible to couple the signals into and out of the amplifier with coupling capacitors. The input would be biased at half the supply voltage, using a voltage divider.

## Cooling

Even for relatively modest output currents, there can be significant power dissipation and heating in the buffer amplifier. It is therefore essential to check the thermal management to ensure the amplifier is properly cooled.

As a rough indicator of the power dissipation, the maximum value occurs when the output voltage is half the supply voltage. For example, for a 10 volt maximum output into a 50 ohm load. the worst case output current occurs for 5 volts output, or  $5/50 = 0.1$  amps. Then the power dissipation in the device is the difference between the power supply and output voltage, times the output current. In this case, that would be  $5 \times 0.1 = 0.5$  watts.

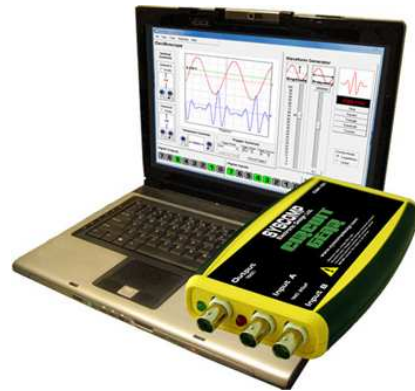


Figure 1: Syscomp CGR-101

This power flows through the thermal resistance of the device, raising the device temperature, according to:

$$T_j = T_A + P_D \theta_{ja} \quad (1)$$

where  $T_j$  is the device temperature in °C,  $T_A$  is the ambient temperature in °C,  $P_D$  is the power dissipation in watts, and  $\theta_{ja}$  is the junction-ambient thermal resistance in °C/watt. This last term is the sum of all the thermal resistances between the inside of the device to the outside air.

If the amplifier is intended to be operated without a heatsink,  $\theta_{ja}$  will be given on the datasheet. If a heatsink is possible, then  $\theta_{ja}$  typically has three components:

$$\theta_{ja} = \theta_{jc} + \theta_{cs} + \theta_{sa} \quad (2)$$

where  $\theta_{jc}$  is the thermal resistance between the chip and the case,  $\theta_{cs}$  is the thermal resistance between the case and any heatsink, and  $\theta_{sa}$  is the thermal resistance of a heatsink. The value of  $\theta_{jc}$  will be on the datasheet. The value of  $\theta_{cs}$  is typically something like 0.2°C/watt. The engineer's job is to choose a heatsink to satisfy the required value of heatsink thermal resistance  $\theta_{sa}$  so that the junction temperature  $T_j$  is not exceeded in the worst case power dissipation and highest ambient temperature. *A direct reading of the output current capability of an amplifier can be very misleading. The output current may be limited by the power dissipation capability of the chip, that is, one of its thermal resistances.* This is a very nasty problem to discover after the circuit is built.

### Slew Rate

The maximum output frequency of a device simply indicates that the device is capable of producing a signal of some unspecified amplitude at that frequency. Check the data sheet to ensure that the device can produce the desired amplitude of signal at the maximum desired frequency of operation.

Alternatively, you can calculate the *slew rate*, which relates the two for a sine wave:

$$SR = 2\pi f V_p \quad (3)$$

where  $f$  is the frequency in Hz and  $V_p$  the peak voltage in volts. For example, to provide a 10 volt peak sine wave at 20MHz, the required slew rate is:

$$SR = 2\pi f V_p = 2 \times 3.14 \times (20 \times 10^6) \times 10 = 1256 \times 10^6 \text{ volts/second} = 1256 \text{ volts/microsecond}$$

### High Speed, Unity Gain Buffers

These amplifiers are very straightforward to use. They provide a voltage gain of unity with a large current gain. One of the earliest available devices of this type is the LH0002 from National Semiconductor, shown in the 1988 edition of the National Linear Databook. The LH0002 is still available, but modern devices have higher output current capability and amenities such as short-circuit current limit.

Modern devices include the following:

Device	Supply Voltage	Output Current	Maximum Frequency	Slew Rate	Approx Price
Linear Technology LT1010	±18V	150mA	20MHz	75V/μSec	\$5
Texas Instruments BUF634	±18V	250mA	180MHz	2000 V/μSec	\$5
Calogic CLM6321	±15V	230mA	100MHz	300 V/μSec	\$5

The CLM6321 originated at National Semiconductor as the LM6321.

The combination of high frequencies and significant currents can lead to problems of oscillation and signal interaction. It is critical that the amplifier be properly decoupled with a combination of capacitors (typically 100nF ceramic in parallel with 10μF electrolytic) on the supply lines. Leads should be kept short and direct. Read the *Application* section of the device datasheet carefully.

## High Speed, High Output Current Amplifiers

Increasing the signal voltage swing beyond the output of the generator requires a voltage amplifier. The amplifier would generally be operated in the non-inverting configuration, where the ratio of two resistors determines the voltage gain.

This type of device is known as a *power op-amp*. There is a tradeoff among bandwidth, output current and cost: high power at high frequency is expensive. Two devices of this type are the following:

Device	Supply Voltage	Output Current	Maximum Frequency	Slew Rate	Approx Price
Linear Technology LT1210	$\pm 15\text{V}$	1100mA	35MHz	900V/ $\mu\text{Sec}$	\$14
Texas Instruments OPA541AP	$\pm 40\text{V}$	5000mA	1.6MHz	10V/ $\mu\text{Sec}$	\$24

## Discrete Component Buffers

An extremely simple buffer amplifier is shown in figure 2(a).

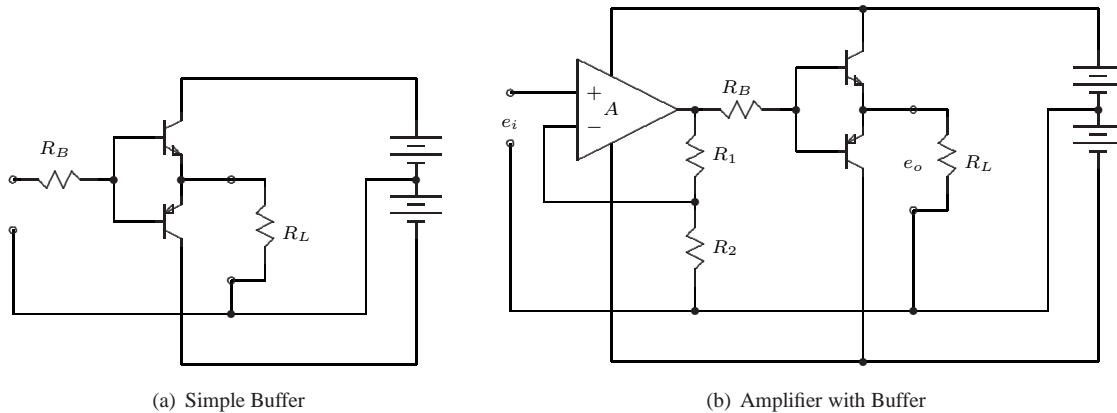


Figure 2: Low Frequency Buffer Amplifiers

The upper transistor conducts as an emitter follower on positive half cycles, the lower transistor on the negative half cycles. This has the effect of presenting the source with a load that is  $\beta$  (beta) times the load resistance  $R_L$ , where  $\beta$  is the current gain of the transistor. Alternatively, the load resistor sees a source resistance that is  $1/\beta$  times the source resistance. For example, if the generator resistance is 150 ohms, and the value of  $\beta$  is 100, the load sees a source resistance of  $150/100 = 1.5\Omega$ .

The resistor  $R_B$ , typically a few tens of ohms, is sometimes necessary to prevent the transistors from oscillating.

This circuit has the virtue of simplicity, but it distorts the waveform with so-called *crossover distortion*. There is a dead spot within  $\pm 0.6$  volts of zero where the output does not follow the input. This is quite visible on sine wave and triangle wave signals. On square waves, it doesn't normally matter.

If voltage gain is required, it can be added ahead of the buffer as shown in figure 2(b). The voltage gain of the op-amp stage is given by the ratio of resistors  $R_1$  and  $R_2$ :

$$\frac{e_o}{e_i} = 1 + \frac{R_1}{R_2} \quad (4)$$

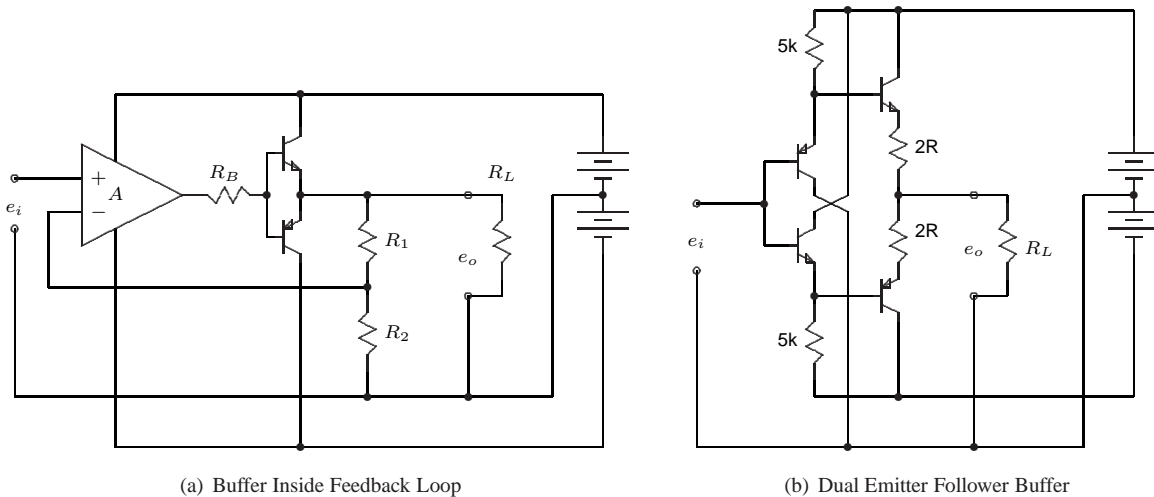


Figure 3: Low Frequency Buffer Amplifiers (2)

The crossover distortion effect can be greatly reduced by putting the emitter-follower buffer inside the op-amp feedback loop, as shown in figure 3(a).

The effect of this modification is to make the op-amp compensate for the dead zone around crossover. It switches the output very rapidly through that region, and as a consequence the crossover distortion is greatly minimized. This works at low frequencies, where the switching time is a small fraction of the waveform period, but fails at higher frequencies.

Since this simply involves rearranging the components, why not do it this way in preference over the circuit of figure 2(b), where the emitter followers are outside the feedback loop? Unfortunately, the emitter follower transistors may be slower in response than the op-amp, and this will cause the system to oscillate. The solution is to slow down the response of the op-amp in some manner or use faster transistors in the emitter follower stage. In either case, the circuit is no longer quite so reliable and simple to make functional.

Another option is to add another pair of emitter followers at the input to the emitter-follower stage. This can be used to reduce the distortion in the buffer stage itself. The concept (based on the National Semiconductor LM0002 integrated circuit buffer) is shown in figure 3(b). The input emitter followers can be small signal devices. They provide the necessary level shift of one base-emitter voltage to (approximately) match the drop in the output stage emitter followers. The  $2\Omega$  resistors act to limit the standing current in the output emitter followers. This circuit could be driven open-loop by an op-amp, as in figure 2(b) or, for the adventurous and those desirous of low distortion, inside the feedback loop as in figure 3(a).

Notice that none of the discrete emitter-follower buffers have any sort of short-circuit protection. With signal applied and a shorted load, the output transistors will die in fairly short order.

### Increased Current with Op-Amps in Parallel

It has been suggested that IC amplifiers can be stacked in parallel, with and then the pins soldered together, to obtain greater output current [5].

This is a bad idea for two reasons. First, there is no guarantee that the output voltages will match. When you parallel voltage sources in this manner, a large current will flow into the lowest voltage source, causing it to heat up. Second, the chips in the middle have no access to cooling air, so they are very likely to overheat. Indeed, messages in a forum suggest that's exactly what happens.

Op-amps *can* be operated in parallel to increase the total output current, with some precautions in combining their output current. For a wide bandwidth application where voltage gain and current gain are required, and the output current is not large (a few hundred mA) this approach might be attractive. Circuits for that approach shown in [6] and [7]. A high power version for audio and servo amplifiers is in [8].

### Further Reading

Further information on the the design of heatsinks and emitter followers is in *Analog Circuit Design*, [1].

### Acknowledgements

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