The Buffer Op Amp
12/6/09

The Buffer Op Amp is an amplifier with 9 dB gain based on the OPA695. Two such amps fit on a single SLIM board. They can be used with the MSA to provide a 50-ohm interface to a device under test (DUT) with a minimum of signal loss. Or they can be used simply to boost the signal level for input to the MSA in Spectrum Analyzer Mode.

These amplifiers not only amplify/buffer the signal, but also provide filtering to minimize the passage of signals above 1 GHz. Such signals, especially if near the first IF signal, can be min-interpreted as signals of much lower frequency.

The Buffer Op Amp is intended primarily for use below 150 MHz, but its bandwidth extends well beyond that, as shown in Figure 1.

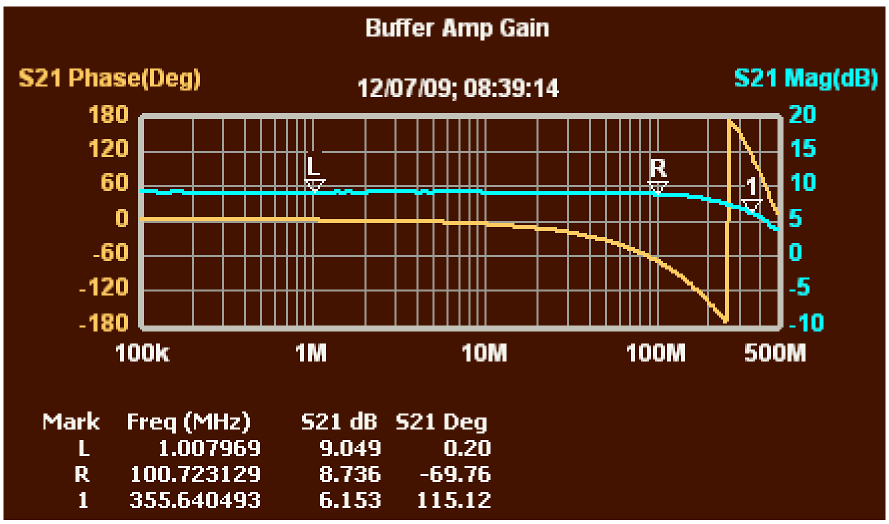


Figure 1—Gain of Buffer Op Amp

The gain is fairly level near 9 dB to 100 MHz, then gradually tapers off, with a 3 dB bandwidth of about 350 MHz.

A major purpose of the buffer amp is to present the DUT with a 50-ohm interface, whether it is sending the signal to or receiving the signal from the DUT. Figures 2 and 3 show the input and output return loss of the Buffer Op Amp.

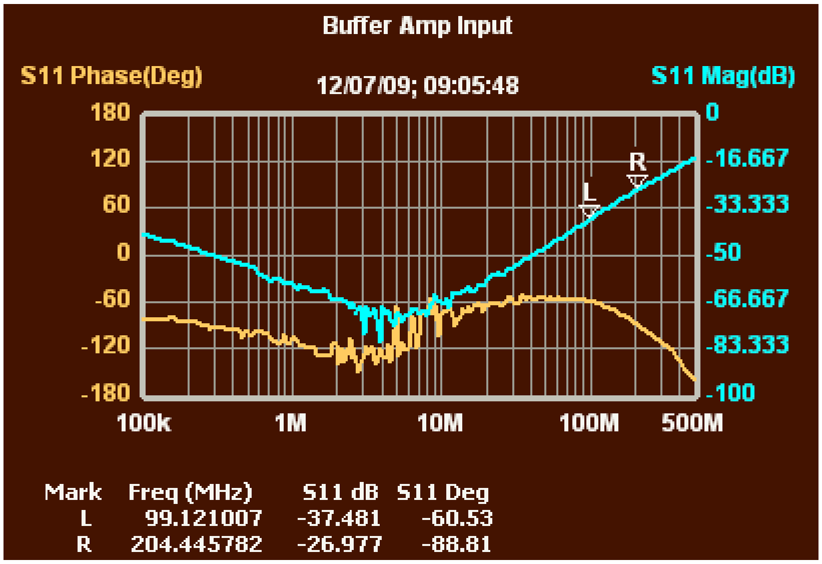


Figure 2—Input Return Loss of Buffer Op Amp
(Actually S11; Return Loss is the negative of these values)

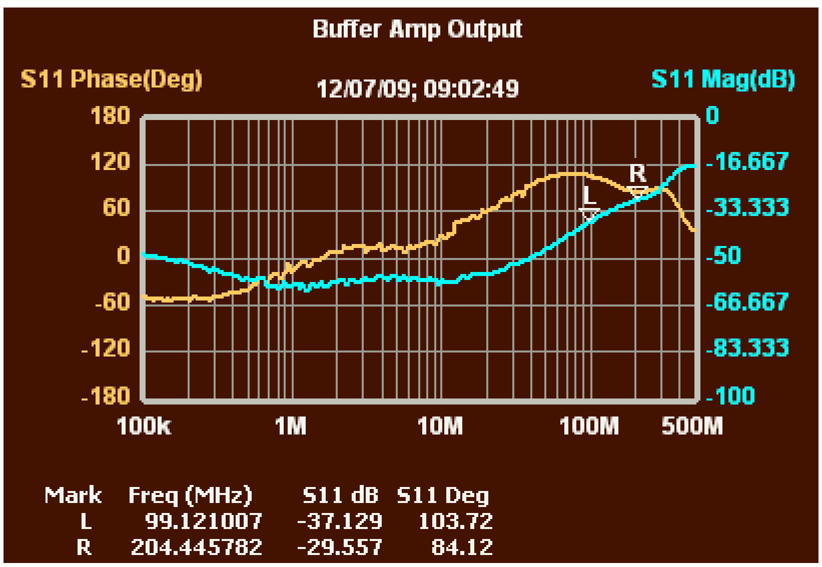


Figure 3—Output Return Loss of Buffer Op Amp

Both input and output return loss are very high at lower frequencies—better than 40 dB to 60 MHz. At 150 MHz they are approximately 30 dB. If the Buffer Op Amp is used in connection with a test fixture that contains even a modest amount of attenuation on each side of the DUT, these return losses are about as good as you could want. For direct connection to a DUT for a transmission test, there might be some benefit to adding 6 dB of attenuation at the higher frequencies, to improve the return loss by 12 dB.

The two amps on a single board can be cascaded for greater gain. This may be useful for boosting the signal in Spectrum Analyzer mode, or boosting the signal returned from the DUT in VNA mode. It may provide too much gain for directly boosting the TG signal.

Instead of cascading the amps, one can be placed on each side of the test fixture or DUT. In that case, we need to be concerned about the isolation between the two amps. Figures 4 and 5 show that isolation, measured by attaching the signal source to one amps input and measuring the output from the other amp.

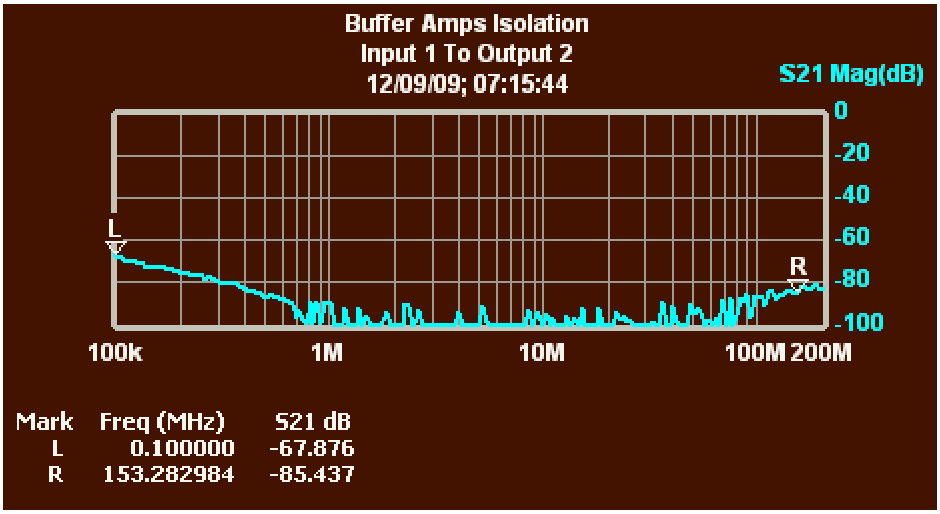


Figure 4—Isolation between amps

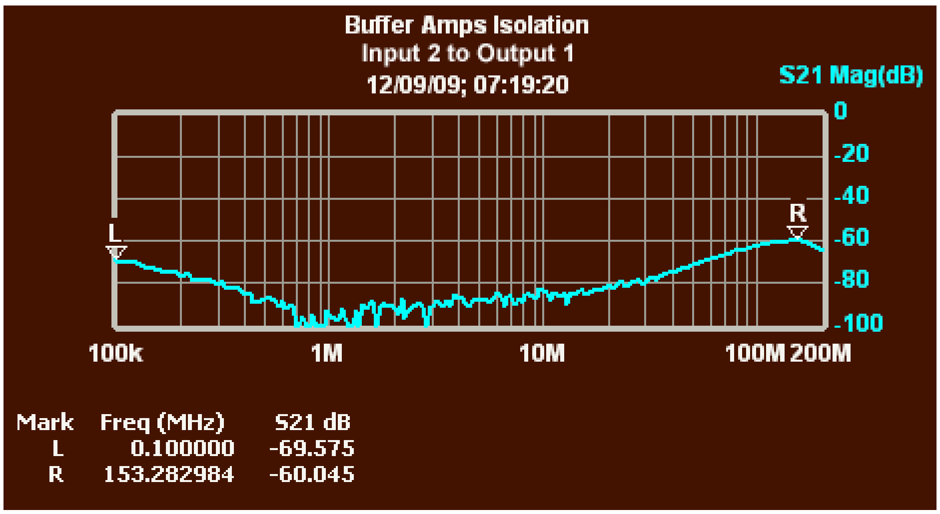


Figure 5—Isolation with the amps reversed

The worse isolation of Figure 5 is probably due to the fact that the input and output connectors are close together in that configuration. Figure 4 corresponds to the way the amplifiers would actually be used if one is placed before and one after the DUT or test fixture, and represents the extent to which the TG signal can leak directly to the MSA input, effectively bypassing the amplifiers. Figure 5 represents feedback from the test fixture output back to its input. These levels of feedback will be irrelevant to anything except a high gain amplifier, and as a practical matter any such amplifier would be tested with attenuators on its input and/or output without the need for a buffer amplifier.

Isolation is important when the signal level leaving the DUT is not strong enough to swamp the leakage between the amps. For use with a bridge, whose output is low only for DUTs very near 50 ohms, this isolation level would not be an issue. For other fixtures, only the highest and lowest frequencies may cause concern. Furthermore, if OSL calibration is used for reflection measurements with any type of fixture, this isolation is not an issue because the leakage is proportional to the TG level and thus is a linear effect that OSL can handle.

The deterioration in isolation below 1 MHz is actually not caused by the amplifiers; it is mostly the result of internal leakages in the MSA, which limit its useful range at low frequencies. The various PLO signals in the MSA contaminate each other to a small extent when they are mixed, and this can result in spurious signals being produced in other mixers. The amount of such leakage varies significantly between MSA builds, and it is stronger when the TG is being used. Figure 6 shows a scan of the leakage of my MSA, with terminations on the TG output and MSA input.

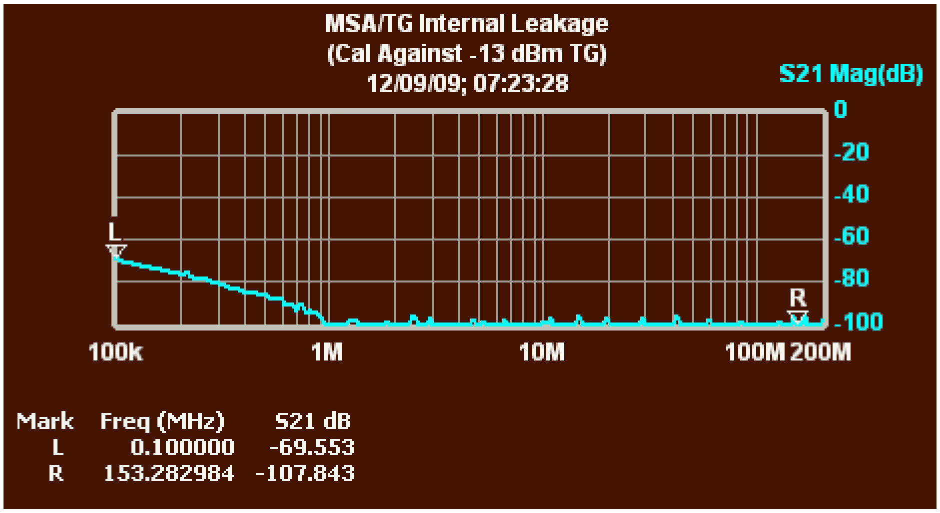


Figure 6—MSA internal leakage when using TG

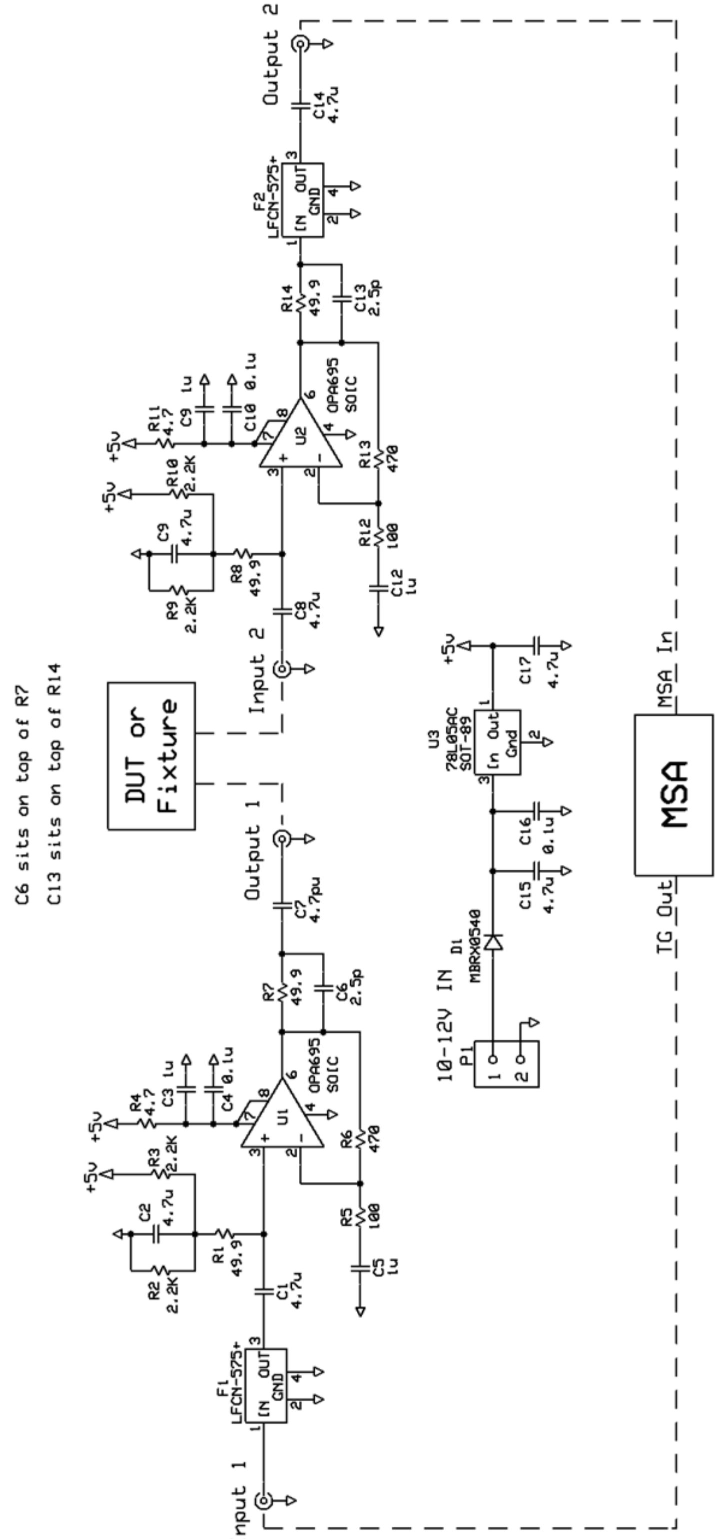
Because Figure 6 is calibrated against the TG signal, which in this case has an attenuator and is about -13 dBm, the actual leakage level of the MSA is 13 dB below that shown in Figure 6. Above 1 MHz, everything is just noise and you can't draw any conclusions about leakage other than that it is very small. (In my case, the leakage is in part due to a poor cavity filter, whose response flares out a bit too much near the bottom.)

The MSA leakage level shown here at 100 kHz could affect measurements of signals as high as -30 dB (relative to the calibration signal) by a small amount, and could affect the measurement of a -50 dB signal by nearly 1 dB. Note that the distortions caused by internal leakage are not linear effects (the leakage is a fixed amount, independent of the level of the input signal), and OSL calibration cannot compensate for the distortions.

The function of the MSA most susceptible to this leakage is Component Meter, which uses 100 kHz to measure large capacitors and inductors, but shifts to higher frequencies as soon the component values make it feasible to do so. A buffer amplifier can help keep the signal level high enough to minimize the effects of internal leakage. When using Component Meter it works well to use one of the amplifiers before and one after the test fixture. If the test fixture has 9.5 dB attenuators on each side, the attenuators and amplifiers will largely cancel and the maximum signal level will approximately equal the TG level. It is actually not required to use significant attenuation in the fixture, because of the good return loss of the Buffer Op Amp. However, cabling between the amplifier and fixture may degrade the return loss, so some amount of attenuation in the test fixture is a good idea.

As an example of the effects of leakage, a 1 ohm resistor in a shunt 50-ohm fixture attenuates the TG signal by about 34 dB. If the fixture has two 9.5 dB attenuators, the total attenuation is 53 dB. That puts the output 53 dB below the TG level, with leakage at 100 kHz of about -70 dB. The difference is only 17 dB, so the leakage can cause a measurement error greater than 10%. With two buffer amplifiers, the difference between the leakage and the true output signal is increased to 35 dB, so the leakage will have only a small effect on the measurement.

APPENDIX A--Schematic of Buffer Op Amp



(A partial shield was soldered over U2 and its components.)
(Double capacitors were used for C2 and C9.)
(An extra 1 uF (size 0603) was added in parallel with C17; it improved high frequency isolation.)