A 300MHz active probe design

Objective:

Generally, we have seen and might have used the passive probes in any normal electronics related laboratories. It is made up of passive components such as Resistor and capacitors which can load the circuit at higher frequency. Because of this phenomenon the bandwidth of passive probes is limited to 500MHz. So, to measure signals at higher frequencies without loading we will make use of active probes which are mainly made up of opamp in voltage follower mode which should have high input impedance, less input capacitance in pF results in less distortion of the signal and loading. In the path of developing an active probe opamp selection plays a major role. In this paper we will go through each key parameter to consider while choosing an opamp in detail with the help of measurements done against the opamp opa858.

Add point about low-cost probe with help of low-cost nano VNA measurements

Characterization of opamp:

Maximum and Minimum voltage measurement possible:

A screen shot of a graph

Description automatically generatedA screen shot of a graph

Description automatically generatedFirst, opamp should be capable of operating with dual power supply, otherwise will end clipping of all the negative parts of an AC signal. Then we should look for what is the minimum and maximum output voltage we can get out of the opamp after considering the dropout voltage, noise and offset.

*Figure 1. Shows that the op858 can sense upto 10mV and even though rated to operate at the voltage supply of 5.5V peak to peak due to a dropout voltage of 0.9V end up outputting 3.4V peak to peak as operating voltage. After considering the noise the comfortable output range would be 3.2Vpp.*

Gain and bandwidth:

To measure the signal, we need a buffer to sniff out the signal without any distortion or loading it. So, the opamp will be used in voltage follower mode due to its high impedance property to get the signal as it is without causing any distortion. Bode plot is a suitable method of measuring the transfer function between gain vs bandwidths. The alternative is to measure the S21 S-Parameter response using the VNA. The S21 will be constant over the operating bandwidth and drop off afterwards.

*A graph of a graph with different colored lines

Description automatically generated*A graph paper with a diagram and text

Description automatically generated *A graph of a graph showing the number of signals

Description automatically generated with medium confidenceFigure 2. The left image is the S21 response of opa858 in voltage follower mode. The 6dB gain instead of 0dB is due to the high impedance of opamp. The opamp has high input impedance so reflection coefficient is nearly equal to 1, so all signal reflects. At that point the op amp non-inverting terminal sees twice the amplitude of incident signal, so voltage follower output will be twice that of incident signal implies 6dB gain. From an eyeball measurement we can clearly say that opa858 operating bandwidth will be around 2GHz for small signal(<200mVpp) because the nano VNA that I am using have a output signal power of -10dBm.*

*Figure 3. Further analysis with the large signal such as 14.35dBm(3.3Vpp) and 4dBm(1Vpp) with the help of ZNL VNA where output power can be varied unlike nano VNA further narrows down the operating bandwidth to 300MHz.*

* *Remove return loss from the responses*
* *Add comparison between nano VNA amplifier and attenuator experiment*

Measuring input impedance and input capacitance:

The signal under test should not be distorted, so the opamp input bias current should be less along with high input impedance and low input capacitance to minimize loading. So knowing the values will help understand the bias and distortion.

A graph with red lines

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Description automatically generated*Figure 4. Using the S11 measurements we can find the input impedance Z = 50\*(1+S11)/(1-S11). The real and imaginary part of impedance results will lead us to resistance and capacitance of seen by the signal at the input of the opamp.*

* *Missing real part -> resistance*
* *Capacitance -> 4pF*

Measuring the rise time and slew rate

In one of the paper <https://www.signalintegrityjournal.com/articles/2092-bandwidth-of-signals-what-is-important-rise-time-or-slew-rate> already discussed that the slew rate and rise time are one and the same. This rise time helps define the signal quality at higher frequencies.

A screenshot of a computer

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Figure 5. A high rise time pulse of 30ps is generated and applied to an opamp and seen an rise time of 524ps which indirectly shows consistency in defining the bandwidth BW = 0.35/Rise time = 0.35/524ps = 1.91GHz ~2GHz

A rainbow colored lines on a black background

Description automatically generatedA rainbow colored ovals on a black background

Description automatically generatedThe eye diagram and eye closure wrt to eye violation talks about the quality of the signal

*Figure 6. The eye diagram shown above shows that there is not much eye closure between the incident signal and the output signal.*

* *New measurement is required with new boards*
* *Compare to small signal such as USB3(300mVpp)*

Anticipate the uncertainty by thorough analysis of design in initial phase of development