High Accuracy Pulse Measurements using Differential Probes

Measuring the amplitude of a pulsed voltage simply using an oscilloscope and a standard probe is limited by the resolution of the ATD (**a**nalog **t**o **d**igital) converter of the oscilloscope. Typical resolutions are 8 bit. So measuring for instance a bandgap (usually about 1.23V) can be done in a 2V range. The resolution of the oscilloscope (assuming 8 bit ATD) is about 8mV.

For evaluating precision electronics this is insufficient. So othr solutions must be found.

Using a Differential Probe

A differential probe allows comparing the unknown pulse amplitude with a known DC voltage. The DC voltage can be measured with high accuracy using a digital voltmeter.

Example:

The DC voltage is 1.2V while the puolse amplitude is expected to be in a range of 1.2V to 1.3V. So the expected difference of less than 0.1V can be resolved using the full 8 bit accuracy of the ATD. This leads to a theoretical accuracy of 0.1V/256=0.4mV.

The follwing circuit shows the pricipal setup.

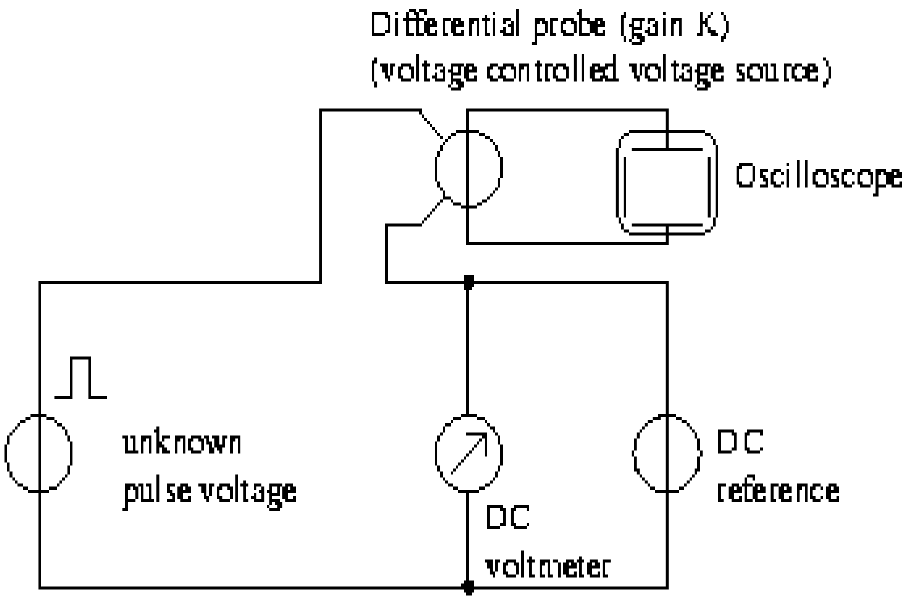

Fig. 1: Test setup for high accuracy pulse measurement

Using this circuit the voltage displayed on the oscilloscope is:

$$V_{scope}=K*(V_{pulse} - V_{DC})$$

The accuracy of the measurment depends on the accuracy of the DC voltmeter, the accuracy of the gain K of the differential probe and the resolution of the oscilloscope now operating in a lower voltage range. When the DC voltage is tuned close to the pulsed voltage the voltage on the oscilloscope approaches 0V. The gain accuracy <u>after propper settling of the differential probe</u> is of minor interrest.

When is the Differential Probe Settled?

Usually the cut off frequency of a probe is specified (−3dB point). At cut of frequency the gain has dropped to about 70% of the low frequency gain. A typical estimation of the time constant (aproximating the prope as a first grade low pass filter) is:

$$T = 1/(\Pi * f_g)$$

Example: A probe with a cut of frequency of 100MHz is submitted to an input step of 1V. After about 3ns the output is expected to have a deviation of less than $V_{step}/e = 0.3V$.

The deviation reduces with time by:

$$Error(t) = V_{step} * \exp(-t/T)$$

Comming back to the example we would like to measure 1.23V (this is out V_{step}) with a resolution of 1mV (Error(t). So we have to solve the above equation for t.

$$t = T * \ln(V_{step}/Error)$$

For a resolution of 1mV after a step of 1.23V we obtain t=7.114 * T. Comming back to the 100MHz probe the minimum settling time is 21.3ns.

Note: This Calculation only applies to single path differential amplifiers with one dominant pole.

Unfortunatelly many wide band amplifiers are composed of an AC coupled RF amplifier and a DC coupled slow high accuracy amplifier. A simplified circuit can be found in (1) on pages 342 and 361.

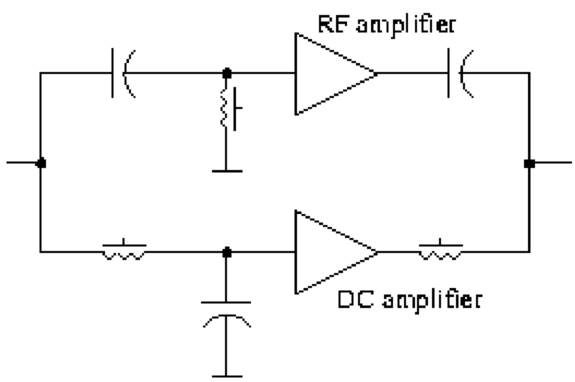

Fig. 2: Dual Path Broadband Amplifier

The beauty of this topology is the wide bandwidth of the RF amplifier combined with the good offset characterisic of the slow DC amplifier.

The problem of this topology is that the AC gain and the DC gain are not exactly equal. The step response of this dual path amplifier has two time constants.

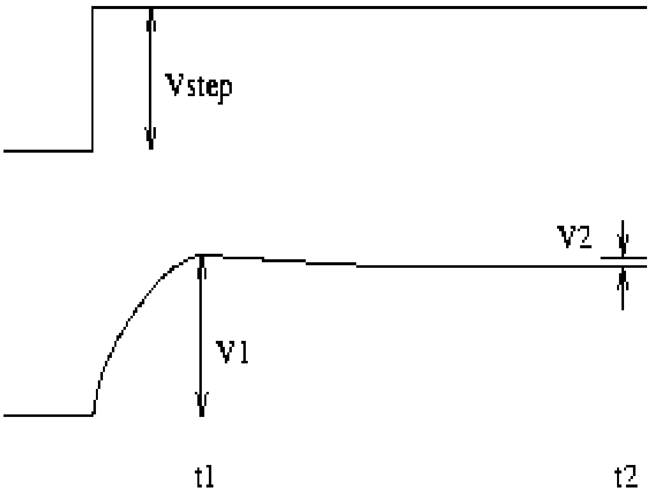

Fig. 3: Step Response of a Dual Path Broadband Amplifier

At t1 the AC amplifier has settled and V1 is $K_{AC}*V_{step}$. After t2 the significantly slower DC amplifier has settled. Now the output voltage is $K_{DC}*V_{step}$. The pulse at the amplifier output is not flat. The voltage V2 can be calculated as:

$$V2 = V_{step} * (K_{AC} - K_{DC})$$

To meet the accuracy target with a split path amplifier a longer settling time of

$$t = T_{DC} * \ln(Error * abs(K_{AC} - K_{DC})/(K_{DC} * V_{step}))$$

with T_{DC}: Time constant of the DC amplifier

must be choosen!

A Practical Example

The following figure shows measurements done with a setup according to figure 1 using a single path amplifier and a multi path amplifier. In this example the DC gain is higher than the AC gain.

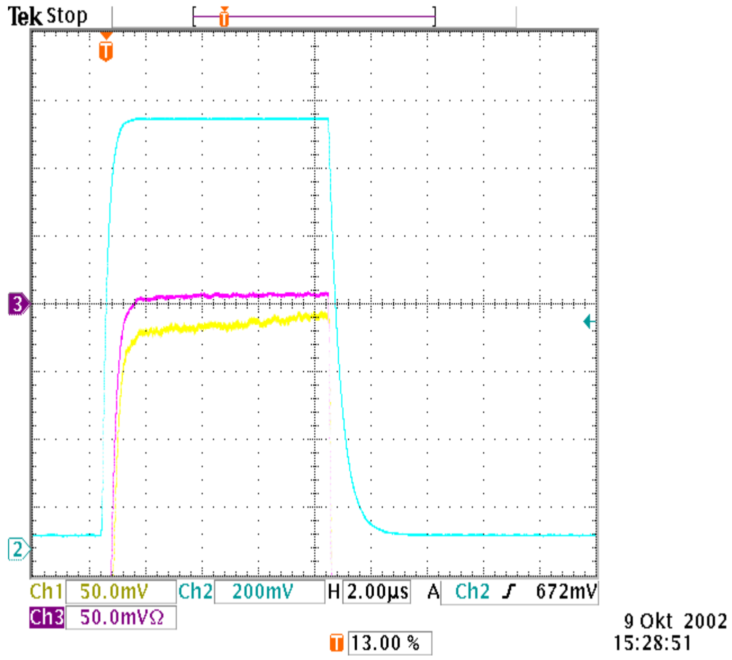

Fig. 4: Measurements done with different probes.

Blue: Absolute pulse voltage
violet: Pulse measured with a single path differential probe with 80MHz bandwith.
Yellow: Pulse measured with a dual path differential probe with 100MHz bandwidth.

The setup using the dual path differential probe (yellow) can not be calibrated with a DC signal as long as the duration of the non horizontal part of the pulse response is not known.

The single path ampliefier on the first glance provides a better accuracy.
Single path broadband amplifiers suffer from the fact that the DC signal must be processed with the small RF transistor geometries. These small geometries are less reproducable than those of a slow but large low frequenc transistor as used in the DC path of the dual path differential probe.
As a consequence the single path probe has to be zero adjusted frequently between the measurements. The resulting circuit is shown below.

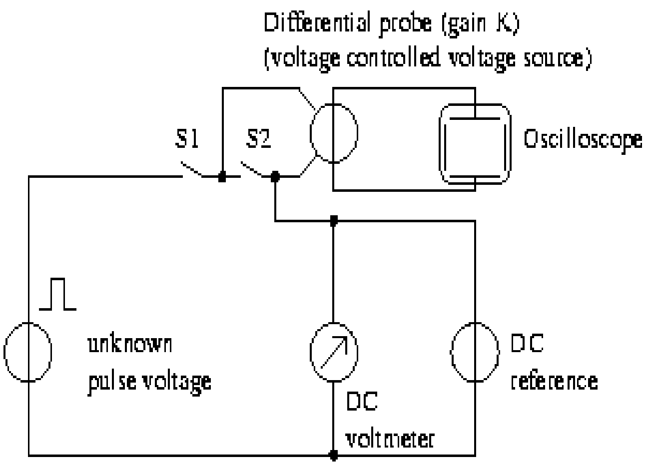

Fig. 5: Setup to measure pulse amplitudes with a drifting differential probe.

Before each measurement S1 is opened and S2 is closed to zero adjust the amplifier. To measure S2 is opened and S1 connects the differential probe to the pulse source to be measured.

The circuit of the single path differential probe can be downloaded from www.erckert−ibe.de/all/hardware/diffprobe .

Alternative Solutions

If frequent zero adjusting can not be done a dual path differential probe can be used provided:

1. the setup can be calibrated with a known pulse source and the measurement always takes place at the same time with respect to the edge of the pulse.
2. The voltage step always starts at the same initial voltage.

If the pulse is magnitudes shorter than the settling time of the DC path the angle of the roof of the pulse at the output of the differential probe can be neglected. In this case making the DC path slow on purpose and calibrating the AC gain of the probe is a valid option.

A high accuracy sample & hold circuit with a high resistive voltmeter connected to the sample capacitor also is an option provided the shape of the pulse needs not to be monitored.

Conclusion

The paper shows a method of measuring a pulse amplitude with high accuracy. The limitations of the method strongly depend on the topology of the differential probe amplifier. Using a single path topology offers a higher accuracy provided frequent zero adjusting can be tolerated to overcome DC offset and drift of the high frequency amplifier also handling the DC signals. Alternative solutions are proposed but not discussed n detail.

Literature

1. Tieze, Schenk, 'Halbleiter Schaltungstechnik', 5th release, Springer, 1980
2. www.erckert−ibe.de/all/hardware/diffprobe
3. 'Linear Integrated Circuits Data Book, MC1733', Motorola Inc., 1971