Comparison of the Division Ratios Measured on Different High Voltage Pulse Calibration Systems

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Abstract

Both resistive and capacitive divider standards are used to measure pulse voltages with microsecond risetimes and amplitudes of hundreds of kilovolts. The dividers are composed entirely of passive components and should exhibit relatively constant impedance as a function of frequency, risetime and voltage. To the extent that this is not the case, these factors increase the uncertainty of the divider ratio. This paper presents a statistical comparison of the ratios of several voltage dividers using different high voltage pulse generators to gain insight as to the influence of the design of the divider and characteristics of the generator on the measurements.

Background

This paper discusses high voltage pulse dividers. Both factors, high voltages and pulses, complicate the design and calibration of the dividers. Many systems such as computers, radars, lasers and weapons use pulses rather than DC levels or AC sinewaves. Systems that operate on pulses require large bandwidths compared to DC levels and AC sinewaves. Due to maximum power limitations, high voltage adds constraints on components used in measurement systems. The output of high voltage dividers are low voltage signals compatible with recorder instruments. However, for a high voltage of given peak value, passive components suitable for measuring a pulsed voltage fail when subjected to a DC or AC voltage of same peak value. This allows measurement of higher pulsed voltages than DC or AC voltages.

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O. T. Fundingsland describes the fundamentals of pulse voltage measurements via parallel RC dividers [1]. General assumptions to allow pulse measurements are discussed. For measuring pulse voltages, two types of dividers are common: resistive and capacitive. Fundingsland considers both.

Resistive dividers are normally 2 noninductive resistors connected in series. The resistors are designed to have small reactive components over the frequency range of use. A short coaxial cable terminated in 50 Ω connects the resistive divider to a digital recorder. In Figure 1, Rhi and Rlo form the resistive divider. The 50 Ω resistor Rm at the digitizer input eliminates reflections. The value of Rm normally influences the divider ratio. The resistive divider ratio, which is typically in the range 1000 to 10,000, is:

$$R_r = \frac{RloRhi + RmRhi + RloRm}{RloRm} \approx \frac{Rhi}{RloRm}.$$

When Rm is external to the digitizer, the input resistance of the digitizer Rdig is high and normally 1 MΩ. The output resistance of the pulse forming network is Rs. If the value of Rs is unknown, proper measurement of the high voltage requires that Rs is small relative to Rhi.

![Figure 1. Pulser with Resistive Divider and Digitizer](image)

Capacitive dividers are a pair of capacitors connected in series. The smaller capacitor connects to the high voltage. Capacitive dividers normally contain an internal 50 Ω resistor to limit reflections. In Figure 2, Chi, Clo and Rm form the capacitive divider. Coaxial cable with a low capacitance per length rating connects the divider to a digital recorder. The capacitance of this coaxial cable influences the division ratio. The capacitive divider ratio is:

$$R_c = \frac{Clo + Cc + Chi}{Chi},$$

where Cc is the capacitance of the cable. The input impedance of the recorder is high and normally 1 MΩ. The main advantage of capacitive divider over resistive dividers is a higher input impedance.
No ideal resistive and capacitive components exist for engineers to build pulse voltage dividers. So, a clearer statement is that the two main types of pulse voltage dividers are: (1) devices whose resistance dominates its capacitance and inductance, and (2) devices whose capacitance dominates its resistance and inductance. References [2], [4], [5] and [6] discuss these non-ideal aspects of passive components. The power rating of resistors and the voltage rating of capacitors present more constraints. The power rating $P$ of a resistor is the maximum power which it can continuously dissipate in still air without damage from heat. It limits the rms volts according to $V = \sqrt{PR}$. For equally spaced repetitive pulses, the average power determines the temperature rise. The average power is the peak power multiplied by the pulse width divided by the cycle width. Ideal capacitors store energy in the form of an electric field in its dielectric. If the voltage rating is exceeded, the capacitor's dielectric is damaged. The electrical characteristics of the voltage divider should not vary with voltage, temperature or time more than the accuracy required of the measurements.

Figure 3 shows a common model of a capacitor. The resistance, $R_p$, of the capacitor model in Figure 3 is the insulation resistance [Lindquist, 2]. The resistance $R_s$ is the series resistance and $L$ is the series inductance. Lindquist shows that the usable frequency range of a capacitor is from $1/(R_pC)$ to $1/(R_sC)$ or $1/\sqrt{LC}$ depending on whether it is low loss or high loss. Below $1/(R_pC)$, the impedance of the capacitor is $R_p$. At frequencies much higher than $1/(R_sC)$ and $1/\sqrt{LC}$, the impedance is inductive. Lindquist presents information on temperature coefficients of dielectrics, and relates dissipation factor and $Q$ to the capacitor model parameters.
Figure 4 shows a common model of a resistor discussed in [2] and [5]. The maximum useful frequency range of a resistor is $R/L$ or $1/RC$ depending on the size of the resonance at $1/\sqrt{LC}$. In low value resistors, the impedance at high frequencies is normally inductive. For high value resistors, capacitive effects dominate at high frequencies. The C models the capacitance between the terminals and parts of the resistor other than distributed capacitance, which is better modeled as a transmission line. Distributed capacitance causes the effective resistance and capacitance of the resistor to drop as the product $f \cdot R$ increases, where $f$ is frequency in Hz [5]. The high voltage resistor $R_{hi}$ of resistive divider contains some distributed capacitance. The resistance $R$ varies with temperature from 10’s to 100’s of ppm per °C. Wirewound resistors also exhibit the skin effect: the ratio of AC to DC resistance changes with frequency and the diameter of the wire.

![Resistor Model](resistor_model.png)

**Figure 4. Resistor Model**

**Experimental Data**

The shape of a measured pulse depends on the frequency response of the measurement system as well as the pulse generator. Some rules of thumb are: (1) inadequate low frequency response introduces sag into the pulse top, (2) inadequate high frequency response increases the transition duration (stretches the risetime) of the pulse, and (3) sharp decay in the frequency response near the upper bandwidth of the measurement system causes overshoot. The previous discusses why resistive and capacitive dividers are both frequency dependent and temperature dependent. As mentioned earlier, these factors increase the uncertainty of the divider ratio.

Tests are being planned in order to point out some of the effects of non-ideal divider ratio just discussed. At the conference, a statistical comparison of the ratios of several voltage dividers using different high voltage pulse generators will be presented. The different generators present pulses with different frequency components to the dividers, and thus sample some effects of impedance on the divider ratio. The data will be compared via an analysis of variance with a linear model as discussed by Mandel [3]. The influence of the different generators on the uncertainty of the measurements will be assessed.
References
