DESIGN AND TEST OF A FAST CAPCITIVE HIGH VOLTAGE PROBE

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Abstract

We designed a fast capacitive high voltage probe for a Marx generator. Since the capacitive probe works on differential mode, we designed also a fast passive integrator to integrate the signals. We tested the probe's performance by using a simple pulse generator to simulate the Marx generator signals. We calibrated the probe using a calibrated water load which act as a resistive voltage divider. We present and discuss the results of the experiments.

I. INTRODUCTION

Marx generator is widely used in pulsed power systems generating high voltages up to several MV. In order to measure the output voltage of Marx generators, several types of high voltage probes are commonly used. Capacitive voltage probes are generally used because of those simple structures to make easily installation inside the Marx generators.

According to the characteristics of signals which we want to measure, the mode of a capacitive voltage probe is determined. When the rise time of the signal is shorter than the probe's characteristic time constant, the capacitive voltage probes are operated in differential mode. Therefore, the output signal from the capacitive probe must be integrated to measure the voltage of the signals by using a proper integration method.

The first method to integration the probe signal is numerical integration. Since the current digitalized data acquisition instruments like as digital storage oscilloscopes or fast analog digital converters provide raw data, we can integrate the probe signals by using data integration software.

Modern high-end digital storage oscilloscopes provide the function to integrate the signals taken by those channels. Since, however the raw data have several unwanted data like as a base line shift or noise, we must separated out from the raw acquired data. This signal aliasing problem becomes more serious when the probe's signal level is small comparing to background level or noise level. Several numerical data analysis tools or algorithms are developed to overcome this problem. Nevertheless, since this numerical method is inconvenient to measure signals in real time by using an oscilloscope, electronic integrators are widely used in this case.

We present a simple technique to measure high voltage signals using a differential capacitive probe and a fast passive RC integrator. The capacitive probe was designed for a half mega volt Marx generator which consists of several pulse forming networks to define pulse width and impedance. The signals of the capacitive probes were integrated by the fast RC integrator. We calibrated the capacitive voltage probe by using a resistive voltage divider which works also as a load for the Marx generator.

II. CAPACITVE PROBE

The equivalent circuit of the capacitive voltage probe is shown in Figure 1. The voltage signal V_1 is coupled through the capacitor C_1. The capacitance of C_1 is intrinsic capacitance between the high voltage electrode to measure and the probe electrode. The capacitor C_2 is a sampling capacitor. The capacitance of the C_2 is sum of the capacitance of the probe and additional capacitors. The capacitance of the probe is a kind of intrinsic capacitance between the probe electrode and the surround ground electrode. The capacitive voltage probe acts as a capacitive voltage divider or a D-dot probe. The differential equation of the equivalent circuit is

$$\frac{dV_1}{dt} = \frac{V_1}{R \cdot C_1} + \frac{C_1 + C_2}{C_2}\frac{dV_2}{dt} \tag{1}$$

where R is $R_s + Z_o$ and V_2 is voltage across R [1].

The resistor R_s is connected to load impedance Z_o in series. The capacitive probe operates in two different modes according to its characteristic time. When the characteristic time of a voltage signal is τ, if the τ is much larger than the time constant $R(C_1 + C_2)$, the capacitive voltage probe works as a D-dot probe. The voltage signal across the R is given by

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$$V_2 = RC_2 \frac{dV_1}{dt} \qquad (2)$$

Therefore the output signal is proportional to the time derivative of the input voltage signal.

When the τ is much smaller than the characteristic time constant, the capacitive voltage probe acts as a capacitive voltage divider. In this case the output voltage signal is proportional to the input voltage signal and to the ratio between the C_1 and C_2. In order to obtain high divide ratio in voltage divider mode, the C_2 is to be much larger than the C_2 or the resistance of R_s is to be large. However, this make it difficult to design a fast capacitive voltage divider because the intrinsic or stray inductances in capacitors and resistors.

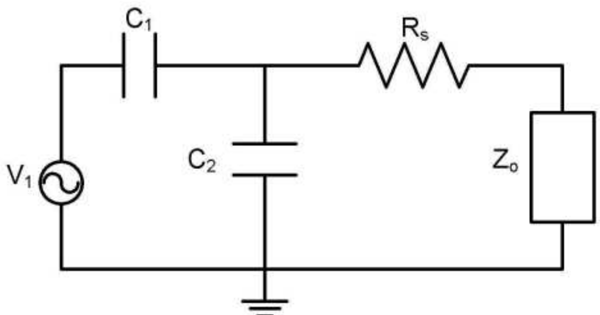

Figure 1. The equivalent circuit of a capacitive voltage probe.

Figure 2 is a schematic drawing of simple capacitive voltage probe. The capacitor probe 3 was installed on the Marx generator chamber 3 filled with high pressure SF_6 gas for insulation. The center high voltage electrode 2 and the probe center electrode make a capacitor C_1. The probe center electrode was insulated with polyethylene from the grounded outer case, which makes a capacitor C_2.

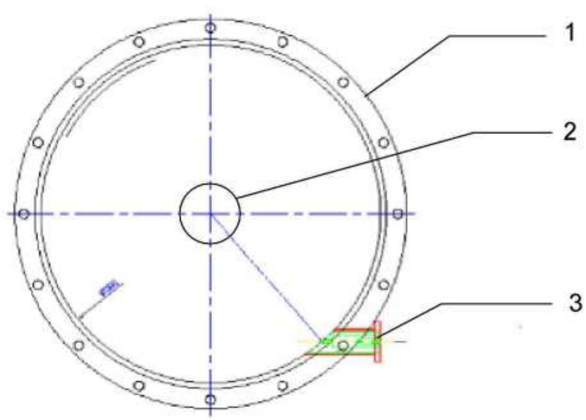

Figure 2. Schematic diagram of the capacitive probe.

The center electrode and the grounded outer case of the probe were made of brass and aluminum, respectively. We determined the dimensions of the probe electrode considering the capacitances and the electric field strength by using electromagnetic field analysis tools. The outer case was contacted with a finger stock connection to obtain good electrical contact, and a hermetically sealed BNC connector was used.

III. PASSIVE INTEGRATOR

Figure 3 shows an equivalent circuit of a passive integrator similar to a Prodyn passive integrator [2]. Since the input signal V_D is generally transferred through a coaxial cable, the matching resistor R_M was used. The resistor R_1 and C_1 consists of an integration circuit. We used a resistor R_2 considering the stray input capacitance of an oscilloscope with high input impedance. The coaxial capacitor C_1 has an inner conductor made of a graphite rod covered with a soft thin copper plate. The inner conductor was insulated from the outer aluminum case with a thin kapton tape. The resistors were Alen Bradley resistors of 1/4 watt.

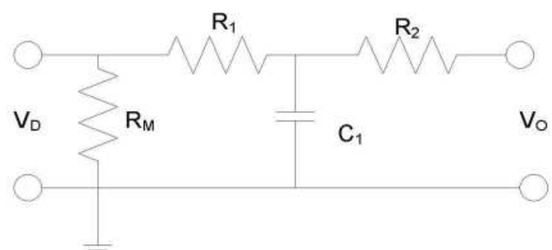

Figure 3. The circuit of a passive integrator.

Typical performance of the passive integrator is shown in figure 4. When a 100 ns square pulse was applied with a DG535 pulse generator, the passive integrator shows a linear line during the pulse width and slightly declining line after the end of the pulse.

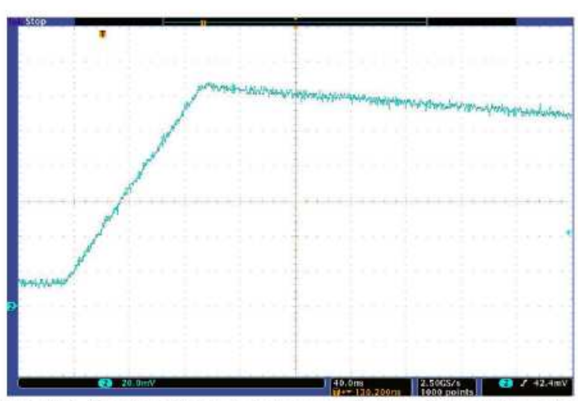

Figure 4. Typical integrated wave form of the integrator.

IV. CALIBRATION

We calibrate the capacitive probe using a resistive voltage divider. The resistive voltage divider uses aqueous solution of sodium chloride. We chose the resistance of the aqueous resistor is similar to the one of the Marx generator. Before calibrating the capacitive voltage probe, we calibrated the resistive voltage probe using a pulse generator to generate square pulse of 100 ns pulse width and of several kV. Figure 5 shows a typical oscilloscope waveform of the pulse generator measured with different probes. The red waveform is the signal from the resistive voltage divider, which is well matched with the waveform detected with the Tektronix P6015A high voltage probe.

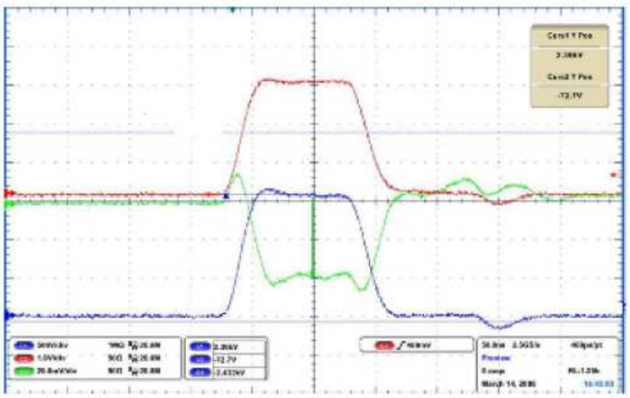

Figure 5. Typical waveform of the resistive voltage divider.

The capacitive voltage probe installed at the Marx generator was calibrated by using the aqueous resistive voltage divider which was used as termination load resistor. Figure 6 show the typical results recorded with a Tektronix 7100 DPO of 1 GHz bandwidth. The capacitive voltage probe signal was integrated with the passive integrator. The waveform of the capacitive voltage probe is well matched with the waveform of the aqueous resistive voltage divider. The scale of the capacitive voltage probe's waveform at the tail of the pulse is a little smaller than the aqueous resistive divider's. This is because of the capacitive voltage probe characteristics near end of the pulses as already shown in figure 4.

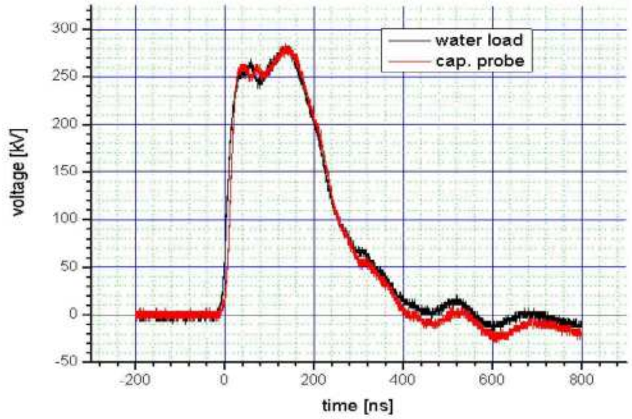

Figure 6. Typical waveform of the Marx generator detected with the capacitive voltage probe and the aqueous resistive divider.

V. SUMMARY

We developed a capacitive voltage probe suitable for measuring above 1 MV and several hundreds ns pulses. Since the capacitive voltage probe works in differential mode, we also made a fast passive RC integrator. The capacitor voltage probe was installed at a Marx generator and calibrated with a specially designed aqueous resistive voltage divider. The capacitive voltage probe signals were matched well with the aqueous resistive voltage divider signals.

VI. REFERENCES

[1] P. Choi, M. Favre "A fast capacitive voltage monitor for low impedance line," Proc. Of 10th IEEE PPC, 1995, p.880.

[2] http://prodyntech.com/home/page/integrators.