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DESIGN NOTE

Fast high-voltage resistive pulse divider

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Abstract. The construction and systematic study of a $CuSO_4$ solution filled, fast high-voltage divider is described. The results of the measurements can be used to find the optimum conditions for 1 ns risetime.

1. Introduction

The measurement of high-voltage pulse shapes is essential in the development of pulsed gas lasers, pulsed x-ray generators, etc. For practical purposes not only an extremely high division ratio, but also proper shielding of the divider should be realized simultaneously. Basically resistive voltage dividers can be used with proper broadband frequency response. The use of commercial resistors is not practical because the stray capacitance and self-inductance of the resistive layers can cause undesirable resonances and ringing. Low capacitance, good stability and easy maintenance can be realized by using $CuSO_4$ solution in the insulating tube as resistive material. This is the reason why several $CuSO_4$ based voltage dividers have been described previously [1,2]. Usually the risetime was considered as the most important parameter of the divider, and the proper and careful compensation has been ignored.

During the broadband attenuation of high-voltage pulses, the shape of the transmitted signal will only be unchanged if the risetime of the probe is zero and if the probe is compensated. According to the electrical circuit shown in Figure 1, the transfer function of the first stage for a zero risetime U_0 voltage step is [3]:

$$U(t)=U_0[R_2/(R_1+R_2)] \times \{1+[(R_1C_1-R_2C_2)/R_2(C_1+C_2)]\ \exp(-t/t_e)\}$$

where $t_e=[R_1R_2/(R_1+R_2)]\ (C_1+C_2)$.

There are three cases for the properties of the divider as follows.

(i) $R_1C_1-R_2C_2<0$. The output voltage approaches the final value with time constant t_e (figure 2(*a*)).

(ii) $R_1C_1-R_2C_2>0$. After an overshoot, the output voltage approaches the final value with time constant t_e (figure 2(*b*)).

(iii) Special (compensated) case: $R_1C_1-R_2C_2=0$. The output voltage reaches the final value immediately (figure 2 (*c*)).

It is obvious that distortionless signal transmission can be realized only with a compensated divider, having a risetime much shorter than the risetime of the pulse to be measured. The above considerations regarding necessity of the compensation of the divider have not yet been reported [1,2]. The aim of this note is to

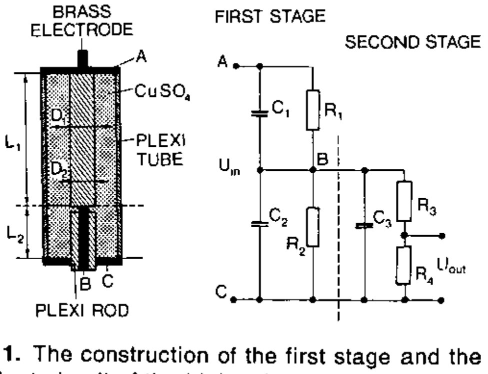

Figure 1. The construction of the first stage and the equivalent circuit of the high-voltage divider.

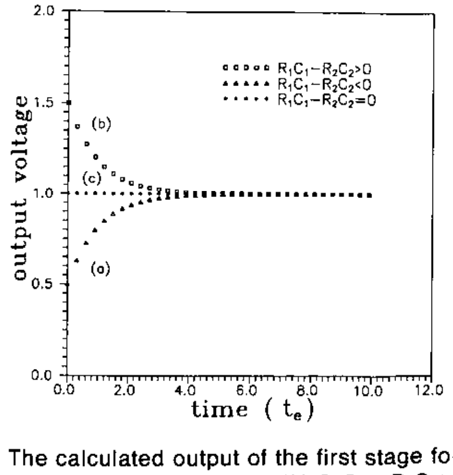

Figure 2. The calculated output of the first stage for three different cases: (*a*) $R_1C_1-R_2C_2<0$; (*b*) $R_1C_1-R_2C_2>0$; (*c*) $R_1C_1-R_2C_2=0$.

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present the construction and the capacitance tuning of a $CuSO_4$ high-voltage divider to achieve full compensation with the second divider stage.

2. Experimental arrangement

The construction and a simplified equivalent circuit of the coaxial divider is shown in figure 1. The volume between a 200 mm long Plexiglass tube with a 10.0 mm inner diameter and a Plexiglass rod of 6.0 mm diameter was filled with $CuSO_4$ solution as resistive material. The electrodes of the divider were made from brass, the coaxial middle electrode being directly coupled to a 50 Ω BNC connector. The dividing ratio was determined by the geometrical distances ($L_1 = 190$ mm, $L_2 = 10$ mm) of the electrodes, the total resistance by the concentration of the $CuSO_4$ solution. The second, lower voltage divider stage was made from low-inductance resistors. In order to eliminate the uncontrolled stray capacitance and the EMI noise, both stages were placed into a common shielding house made from a 42 mm diameter brass tube which, for the sake of simplicity, is not shown in figure 1.

3. Results

The condition of the compensated state for the complete probe is $R_1C_1 = [R_2(R_3+R_4)/(R_2+R_3+R_4)](C_2+C_3)$, because C_3 and (R_3+R_4), the capacity and the resistivity of the second stage is connected parallel to C_2 and R_2 respectively. Since C_2 and C_3 are determined by the construction of the first and the second stage, this condition can be fulfilled with proper modification of the first divider stage geometry. A simple and effective method for C_2 tuning is to change the diameter of the middle (B) electrode. Decreasing this diameter from 3 mm to 0.75 mm, the divider properties can be tuned from condition (i) to condition (ii). Actually, the compensated case (iii) with minimum distortion was measured and realized at 1 mm electrode diameter. The attenuation

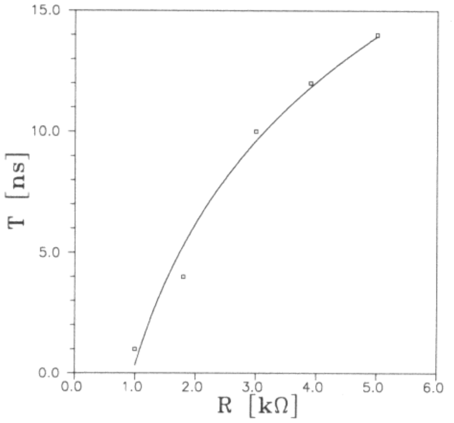

Figure 3. The risetime of the output pulses as a function of the divider resistance.

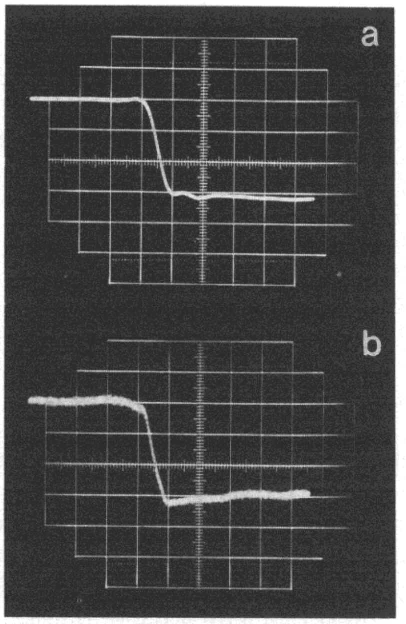

Figure 4. Pulse shapes of the input (*a*) and output (*b*) at 1 kΩ first stage resistance. Time base: 1 ns per division for both curves.

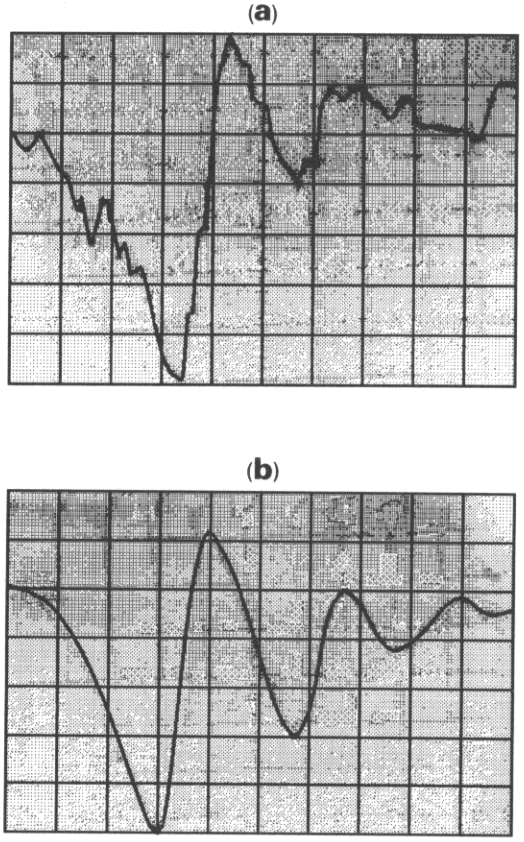

Figure 5. The measured high-voltage pulse shape on the electrodes of an excimer laser: (*a*) without shielding and (*b*) with shielding. Time base: 10 ns per division, vertical scale: 2.7 kV per division for both curves.

of the $CuSO_4$ divider was 20 and the total value with the second stage was 738.

The risetime of the system (the connected first and second stage) was tested with a Tekelec TE-20 pulse generator and an S7-12 (made in the USSR) 10 GHz sampling oscilloscope by changing the concentration of the $CuSO_4$ solution (i.e. the full resistance of the first divider stage). The input was squarewave with 1 ns risetime. Figure 3 shows the measured risetime of the output signal as a function of the divider resistance. It is found that the risetime strongly depends on the resistance. This fact can be understood as follows. The stray capacitance of the second divider stage is serially connected with the resistance of the first stage or, in other words, this capacitor has very high ohmic losses. Thus the risetime is limited by this time constant. Figure 4 shows the temporal waveform of the input (*a*) and the output (*b*) signal at 1 kΩ first stage resistance.

The shielding and the performance of the voltage divider was tested with a capacitance transfer type high-voltage pulse generator of an excimer laser. The voltage was measured with an Iwatsu SS-6200 type 200 MHz oscilloscope, whose traces were recorded by a video camera and a video digitizer computer. Figure 5 shows a single high-voltage pulse shape measured on the peaking capacitor of the discharge tube. Figure 5(*b*) shows that the strong noise emitted from the laser is effectively eliminated by the shielding of the divider.

During this experiment the hold-off voltage of the device was also tested. The results showed that the probe was able to maintain high-voltage pulses over 25 kV at a repetition rate of 25 Hz for an extended period of time. The divider has smaller dimensions than those previously reported in the literature [1,2] — thus the corresponding maximum hold-off voltage is lower. However, this disadvantage is compensated by its improved portability and its usefulness in many applications at moderately high-voltage levels, where a compact broadband high-voltage probe is required.

Acknowledgment

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