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Revision of (sub)nanosecond pulser for IRI Van de Graaff electron accelerator aided by field propagation calculations

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The shorted air line stub used for subnanosecond pulsing of the grounded-grid cathode gun structure of the IRI 3 MV Van de Graaff electron accelerator is revised. Three-dimensional high-frequency field propagation calculations provide better insight into the performance of different geometrical shapes. Effects on rise- and decay time, and ringing on the output pulses are considered. Practical possibilities for improvement are discussed. Comparison with sampling measurements on several device modifications confirms the reliability of the calculations. The calculation method is subsequently used as design aid for the construction of a “1 ns” device using a quartz loaded shorted stub to fit into the geometry of the existing variable pulse length unit. Capabilities for short pulsing of the accelerator are improved and extended by application of the results obtained. © 2005 American Institute of Physics. [DOI: 10.1063/1.1847652]

I. INTRODUCTION

In 1976 our nanosecond pulsed 3 MV Van de Graaff electron accelerator at IRI was equipped with a subnanosecond pulser for the cathode.1 The modification was obtained by adding a shorted coaxial stub at the exit of the existing nanosecond pulser. The latter was based on the mercury switched coaxial line discharge pulser described by Ramler, Johnson, and Klipper in 1967. For practical reasons, accuracy of matching to the CP Clare mercury reed switch environment and voltage holding, the unit was made from a typical 50 Ω air line General Radio 874 T connector. The branch perpendicular to the through 50 Ω line was modified as required for 25 Ω characteristic impedance by an increase of the center conductor diameter, and shorted at the end. The length was chosen to determine the desired subnanosecond pulse length by its transmission time. At the time of first realization a correction was made to improve the apparent pulse length by its transmission time. At the time of first length was chosen to determine the desired subnanosecond pulse length unit. Capabilities for short pulsing of the accelerator are improved and extended by application of the results obtained.

3 MV Van de Graaff electron accelerator is revised. Three-dimensional high-frequency electromagnetic pulse propagation calculations were performed using finite-difference time-domain software (CST Microwave Studio, Darmstadt, Germany) for solving truly 3D problems. Different step functions were used as input. For a realistic approach smooth (integrated Gaussian) pulses are limited to a 1 ns rise time detection. Because of the far from ideal pulse shape obtained from a direct 1 ns pulse line discharge, particularly in the decay time, it was decided to add a 1 ns pulse length to the existing switchable subnanosecond pulse unit.

II. SIGNAL TRANSMISSION IN VARIOUS MODIFICATIONS OF THE SHORT PULSE-FORMING STUB

Electromagnetic pulse propagation calculations were performed using finite-difference time-domain software (CST Microwave Studio, Darmstadt, Germany) for solving truly 3D problems. Different step functions were used as input. For a realistic approach smooth (integrated Gaussian)
step functions without delay of the form \( f(t) = \text{erf}(at) \) and Elmore rise time \( t_r = 1.8/a \) of 20 or 50 ps were chosen. The Elmore rise time is equal to the 10%–90% signal rise time. For the output signal 100% is defined as the amplitude equal to half the amplitude value of the exciting step, generally resulting in an increase in decay time as we shall see.

In an attempt to improve the rise and fall time of the device, several design modifications of the stub device are considered. First the corrected stub as described before, and shown in Fig. 1(a). For comparison the single-sided GR-874 based device without the correction [Fig. 1(b)] is considered. Also the modification with two diametrically placed 50 Ω stubs\(^7\) using GR-874 dimensions [Fig. 1(c)] and also a smaller diameter air line with \( d=1 \) mm and \( D=2.3 \) mm (1c').

For the corrected device 1a the calculations show for all excitation steps exactly the same output pulse independent of the exchange of in- and output of the device. The asymmetry in the geometry (correction respectively nearest to input or output) has no effect as is shown in Fig. 2, curves a1 and a2. This calculation result is confirmed by measurements on a real device shown in Fig. 3, curves a1 and a2. The asymmetry, however, appears in the time structure of the reflected signal, and also in the electric field pulses measured half way up the stub in the plane of the T section, at the input and output side, respectively, \( E_i \) and \( E_o \). The 1-cm-long correction (shorter than the 21 and 52 mm wavelengths of the highest excitation frequency for 20 and 50 ps rise time steps, respectively) results only in an overall change of output pulse shape.

The uncorrected device of Fig. 1(b) shows a peak on top of the rise, and a dip after the decay in the calculations in Fig. 2, curve (b). Similar effects are seen in the measurement in Fig. 3, curve (b). In our application for switching the

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FIG. 1. Schematic representation of the different geometric shapes for the sub-nanosecond stub pulse devices considered for comparison.

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FIG. 2. Calculated output pulse responses using a 50 ps Elmore rise time excitation step (long pulse). The different curves refer to the device modifications given in Fig. 1. Curves a1 and a2 are, respectively, for the corrected device excited from the side of the restriction and from the opposite side.

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FIG. 3. Curves a1 and a2 show measurements of the output pulse responses using a 50 ps Elmore rise time excitation step (long pulse) for a 1-cm-long correction (shorter than 52 mm). Curves c and c' show measurements for the sub-nanosecond stub pulse devices considered for comparison.
emission of the biased accelerator cathode for pulsing the electron beam, only the fast rise and decay are functional, provided the average peak voltage is sufficiently high and the modulations on top of the pulse and in the base line are relatively small, not to interfere with, respectively, the “open” or “closed” condition for electron emission from the grounded-grid cathode of the gun. The continuous bias voltage to block unwanted background electron emission is +200 V on the cathode with respect to the grid. For a superposed −500 V short pulse the positive (up) excursions on the “top”, and the negative (down) excursions on the base line should stay well within 20% of the peak value.

The rise and decay of the uncorrected device are faster than for the corrected device. Therefore we have decided to revise the construction and use the shape as given in Fig. 1(b). The modification 1(c), with the two opposing 50 Ω stubs 7 as a cross shape, gives in the calculation, curve 2(c), more equal rise and decay and less damped oscillations after rise and fall. This “cross” modification 1(c’) with the smaller diameter for D and d of, respectively, 2.3 and 1 mm, gives in the calculations a perfect pulse with hardly any or no ringing after rise and fall for, respectively, the step with 20 and 50 ps rise time. For the 50 ps rise time step the result is shown in curve 2(c’). The construction 1(c) with the larger GR874 size gives more ringing, particularly at decay, for the 50 ps rise time excitation. For the 20 ps rise time excitation the ringing increases (not shown in proof). This is in agreement with more (H 11) mode conversion. The 10%–90% rise time, where 0% and 100% is the level without the ringing, may occasionally be shorter than the rise time of the excitation pulse, due to a high overshoot. See Table I for a survey of calculated rise and decay times, t r and t d, for the different modifications, for 20 and 50 ps rise time excitation steps. For the thin cross construction 1(c’) rise and decay times are close to each other and also to the rise time of the respective excitation step. The interesting qualities of modifications (c) and (c’) concerning t r and t d are obvious. For reasons mentioned before and simplicity of construction we are practically restricted to the GR874 sized T devices. However, as a result of the present analysis, the former correction for pulse rise overshoot as in modification 1(a) is no longer considered an improvement.

Due to the “overcorrection” for rise time ringing in modification 1(a) the 100% value after a 50 ps rise time step is only reached after about 150 ps (Fig. 2.1a). Therefore we have obtained here the 10%–90% rise of 43.4* ps, where the asterisk is added to distinguish this value from the usual 10%–90% value. For comparison of relative slope a virtual 10%–90% t r of 9/8 × 43.4 = 48.8 ps is calculated, and given between brackets in Table I.

For the 1 ns device with quartz dielectric the design shown in Fig. 4 is calculated and made. The results of the 3D calculation with t r = 42.3 ps and t d = 70.5 ps, and the measurement of the real device with t r = 46.6 ps and t d = 74.2 ps are shown in Fig. 5, curves (a) and (b), respectively. Regarding the technical problems in the practical realization the agreement of the calculated and measured response is very good. The difference in pulse length of 27.6 ps between calculated and measured pulse is probably due to the difference between the relative dielectric constant used for quartz in the calculations (3.86) and the real value. The practical result is
found to satisfy the requirements, and has been incorporated into the modified version of the switch and subsequently into the accelerator terminal.

III. DISCUSSION

As a result from 3D simulation calculations of our sub-nanosecond stub pulser, confirmed by measurements, we find that the performance of the design can be improved in several ways. Omitting the formerly applied rise time overshoot correction gives an improvement of rise and decay time. The decay time is still considerably longer than the rise time of the exciting step. This becomes even more dramatic for a shorter rise time of the step, due to increased mode conversion losses. Further improvement may be obtained by the construction of a symmetric cross device, and even more by reduction of the diameter. This, however, complicates the mechanical construction, increases the size of the device, requires a very high accuracy and contact quality of the mechanical switching system, and decreases the voltage holding capacity for pulse voltages to 1.5 kV. In our practical situation with about 50 ps rise time, the results for the GR874 T device are, however, acceptable.

The 3D field propagation calculations are an efficient tool to save design cost for (future) new developments, as is demonstrated in the case of the quartz loaded stub device for generation of flat-topped 1 ns pulses.