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APPROXIMATE DESIGN CRITERIA AND PERFORMANCE ESTIMATES FOR A DISTRIBUTED SWITCH ARRAY BASED ON GAS SPARK GAPS

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ABSTRACT

Calculations of the risetime of a distributed switch array including the effects of switch jitter, wavelauncher geometry and dimensions, and switch inductance are provided in this note.

1. INTRODUCTION

The objective of the design of a distributed array is assumed to be to obtain close to the shortest possible risetime in the far field, with some compromise made in order to keep the numbers of switches and the size of the wavelaunchers realistic.

2. DISTRIBUTED SWITCH ARRAY RISETIME

The risetime can be approximated in terms of the following parameters describing the array:

2a = wavelauncher width (parallel to the H-field) in the aperture plane (meters) (1)

2b = wavelauncher height (parallel to the E-field) in the aperture plane (meters) (2)

ℓ = wavelauncher length (meters) (3)

E = charging field in the aperture plane (MV/m) (4)

E_g = electric field in the switch gap at time of closure (MV/m) (5)

t_j = switch closure jitter (standard deviation). (nsec) (6)

The risetime in the far field is made up of three components. One is the result of the dimensions of the individual wavelaunchers. Another is the risetime of the pulse produced by each individual switch in the wavelauncher it drives. The third component is the spread of switch closure times. In each case the risetime will be estimated using the t_{max} rate definition [1] that is, the total field change divided by the peak rate of change of field.

If the far field signal is made up of a large number of signals from different wavelaunchers that would arrive simultaneously if all switches closed simultaneously, then the risetime component (τ_j) due to spread in closure times is the integrated distribution of closure times. If the distribution is Gaussian, the maximum rate of rise occurs when half the contributing switches have closed, and is such that

$$\tau_j \cong 2.5\ t_j \quad . \tag{7}$$

The risetime component associated with the wavelauncher geometry (τ_g) may be dominated either by a or b. The dimension b can be made small enough not to dominate, but the dimension a cannot be made arbitrarily small because parallel switches will be too close and some will not close because others have removed their voltage. If the risetime is dominated by a, then

$$\tau_g \approx g\, a/c \tag{8}$$

where g is a factor that depends on the wavelauncher geometry.

The value of a must be chosen so that parallel switches are isolated for a time larger than the spread in closure times. This condition can be written

$$2a/c = n\, t_j \tag{9}$$

or

$$a = nc\, t_j/2 \tag{10}$$

where the choice of n is influenced by the shape of the closure distribution, the reliability with which all switches are desired to close, and the degree of interaction between switches allowed by the wavelauncher design. Then

$$\tau_g = (g\, n/2)\, t_j\ . \tag{11}$$

The third risetime contribution, that of the switch driving an individual wavelauncher, is produced by the inductance and resistive phase of the spark channel or channels, and the geometry of the switch electrodes that connect the spark channel into the wavelauncher. Of these, the resistive phase is usually small, and the most easily identified is the inductance of the spark channel. The voltage on each wavelauncher is the product of its spacing in the aperture plane and the electric field there;

$$V = 2Eb\ . \tag{12}$$

The length of the switch channel is given by

$$\ell_{sw} = V/E_g = 2b(E/E_g) \tag{13}$$

Assuming a single channel with an inductance of 1.5 μH/m, the channel inductance is given by

$$L_c = 3 \times 10^3\, b(E/E_g)\ (\text{nH}) \tag{14}$$

where b is in meters. Assume that the switch electrodes connecting the spark to the wavelauncher in effect double this inductance, the switch risetime is

$$\tau_L = L/Z = 6 \times 10^3 \ b(E/E_g)/Z \quad (\text{ns}) \qquad (15)$$

where Z is the wavelauncher impedance in ohms. Considering both the forward and the backward waves launched by the array, the impedance is

$$(1/2) \times 120 \ \pi \times (b/a) = 60 \ \pi \ (b/a) \qquad (16)$$

Hence,

$$\tau_L = 100 \ a \ (E/E_g)/\pi \qquad (17)$$

Using the previous result, $a = n \ c \ t_j/2$,

$$\tau_L = 50 \ n \ c \ t_j \ (E/E_g)/\pi \ . \qquad (18)$$

Collecting the risetime contributions, we have for the closure time spread

$$\tau_j = 2.5 \ t_j \qquad (19)$$

for the array geometry,

$$\tau_g = (g \ n/2) \ t_j \qquad (20)$$

and for the switch

$$\tau_L = (50 \ nc/\pi) \ (E/E_g) \ t_j \qquad (21)$$

All three terms are proportional to the switch jitter, t_j. In the case of the first term above, this dependence is obvious. In the array term, it arises because the requirement to transit-time isolate parallel switches makes the largest wavelauncher dimension (the width) proportional to jitter. In the inductance term, the current per switch is proportional to the wavelauncher width, and since dI/dt is constant for a spark closing under a certain field, the risetime is proportional to current.

Thus switch jitter dominates the risetime obtainable from a distributed switch.

The three risetime terms can be evaluated approximately for a planar array. Again it is assumed that b is made considerably smaller than a. Then [2] shows that the array risetime is a/c, i.e. g = 1. In addition, parallel switches are separated by straight conductors of length approximately 2a. If the transit time isolation is made four standard deviations to ensure that switches almost always close independently, n = 4. Then,

$$\tau_g = 2t_j \ . \tag{22}$$

To evaluate the switch risetime term, assume that $E_g \cong 10$ E; i.e., the switch is pressurized to about 10 atmospheres and can operate at about ten times the external gradient. Then with n = 4, c ≅ 0.3 m/ns,

$$\tau_L = \left(\frac{50 \times 4 \times 0.3}{10\pi}\right) t_j \tag{23}$$

or

$$\tau_L \cong 1.9 \ t_j \ (\text{ns}) \ . \tag{24}$$

Collecting the three risetime components, we have

$$\begin{aligned} \tau_j &= 2.5 \ t_j \\ \tau_g &= 2.0 \ t_j \\ \tau_L &= 1.9 \ t_j \end{aligned} \tag{25}$$

Thus all three are similar, but the direct jitter contribution is somewhat larger. If the components add in quadrature [3], the net risetime in the far field will be given by

$$\tau \approx 3.7 \ t_j \ . \tag{26}$$

The array geometry contribution (τ_g) can be reduced by using conic lines instead of planar bicones, and the switch risetime can be reduced by creating multiple channels, optimizing electrode design, increasing the switch field or decreasing the array field. However, the best that can result if these risetime contributions are essentially eliminated is that the net far field risetime decreases by about one-third, from 3.7 t_j to 2.5 t_j.

Consider next the use of conic wavelaunchers to reduce the array geometry risetime, τ_g. Figure 1 shows a view of the E-field direction. The length ℓ of the individual wavelaunhcers needs to be chosen. It is again assumed that b is substantially smaller than a.

As discussed above, the parallel switches in Figure 1 must be transit time isolated by a time nσ to ensure that all close. After a time 2 a/c, neighboring switches interact by line-of-sight radiation; however, this interaction may be relatively weak, and it may be sufficient to keep the interaction through the shortest conducting path from occurring before a time nt_j. In that case, the edge of the wavelauncher can have a length $nt_j/(2c)$ (see Figure 1).

An approximation to the contribution to the far-field risetime (τ_g) of the wavelauncher is the time for signals from the switch to spread over the aperture. In the case of planar bicone wavelaunchers (ℓ = 0), the risetime so calculated is a/c, which agrees with the result of [2]. For the conic wavelaunchers in Figure 1, this time arises from the difference in the paths along the edge of the wavelauncher and the shortest path ℓ; that is,

$$\tau_g = (n\ t_j/2) - (\ell/c)\ . \tag{27}$$

This equation states that as ℓ is increased, the risetime decreases linearly with ℓ from the planar bicone value $nt_j/2$ to zero. At the same time the wavelauncher width is decreasing. Figure 2 plots the risetime and wavelauncher width as a function of ℓ, along with the half-angle of the conductors forming the wavelauncher.

Examination of Figure 2 suggests that a desirable length for the wavelauncher is roughly 0.35 nt_j c. This value reduces the risetime to 30% of the value for a planar bicone, but only decreases the line-of-sight switch distance by less than 30% from the distance via conductors, and only increases the number of switches needed (inversely proportional to the wavelauncher width) by about 40%.

For this configuration, under the same assumption as used previously for the planar array (n = 4, E_g = 10 E), the array geometry term becomes 0.3 x $2t_j$ = 0.6 t_j. The switch risetime term reduces in proportion to a, becoming 1.4 t_j. The results are

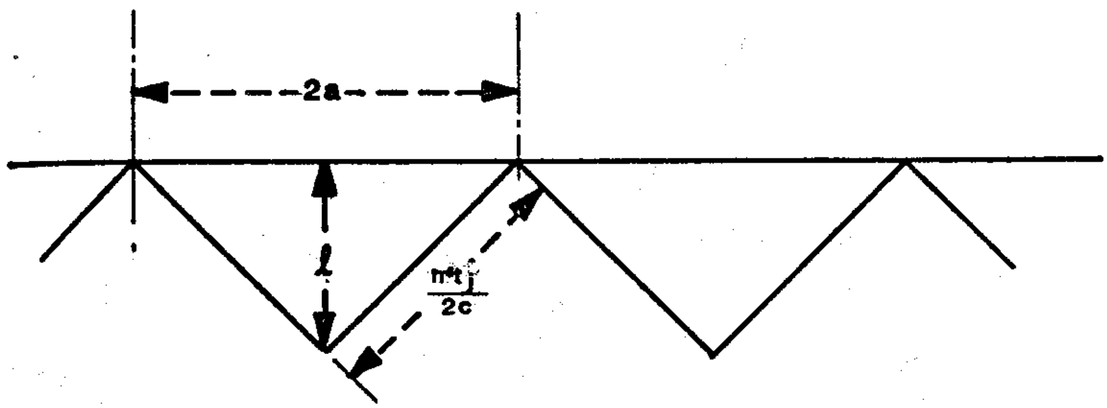

Figure 1. Conic line array.

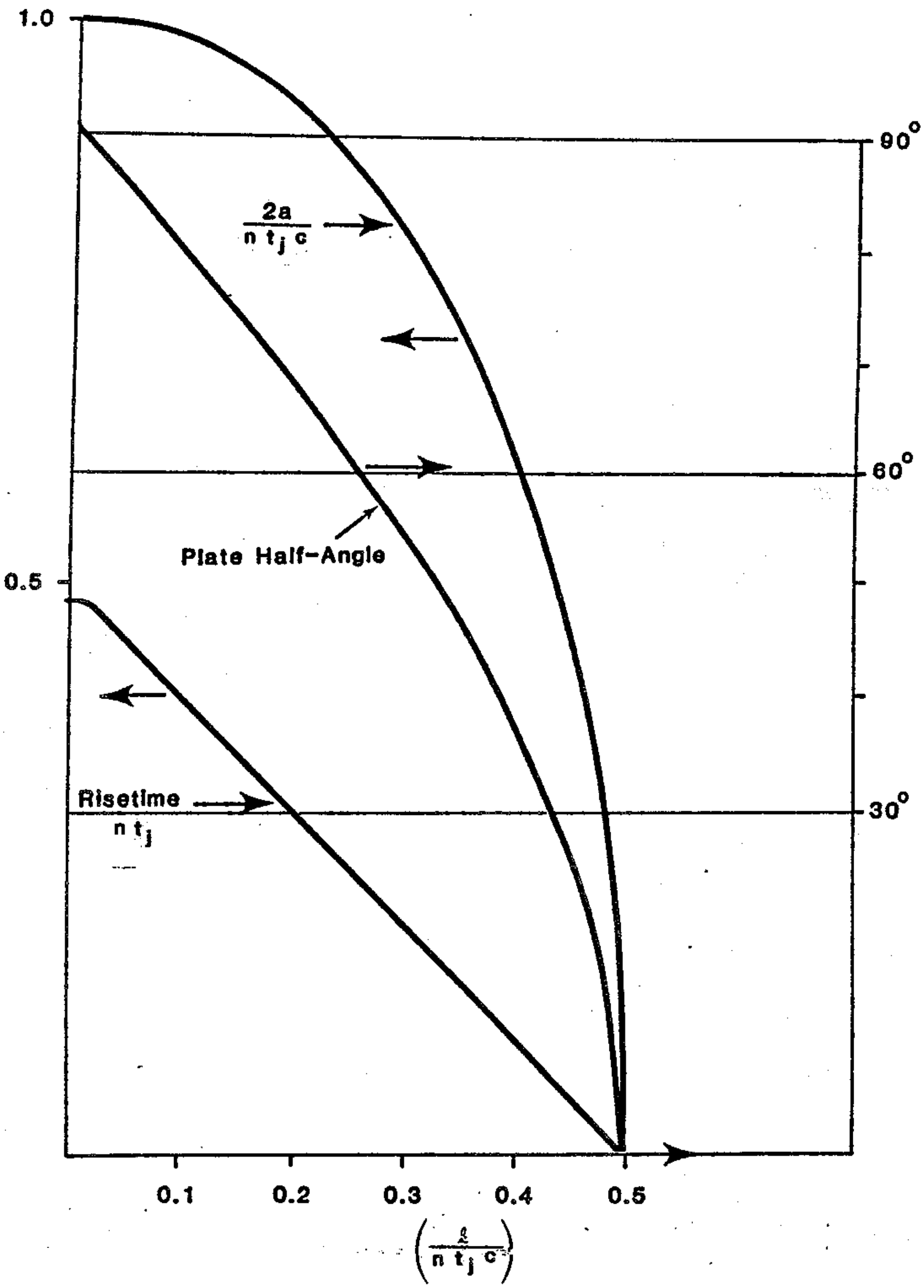

Figure 2. Effect of wavelauncher length on width, risetime, and plate angle of wavelauncher.

$$\tau_j = 2.5\ t_j$$

$$\tau_g = 0.6\ t_j \qquad (28)$$

$$\tau_L = 1.4\ t_j.$$

Assuming quadrature addition, in the far field,

$$\tau \cong 2.9\ t_j \qquad (29)$$

compared with $\tau = 3.7\ t_j$ for the planar bicone array. The effect of the conic wavelaunchers has been to reduce by a factor of three the amount by which the far-field risetime exceeds the jitter-limited minimum of 2.5 t_j.

3. REFERENCES

1. J.P. Castillo, K.C. Chen and C.E. Baum, "Relation of Risetime Definitions for Various Waveforms," Atlas Memos, Memo 20.

2. D.V. Giri and Carl E. Baum, "Early Time Performance at Large Distances of Periodic Arrays of Flat-Plate Conical Wavelaunchers," Sensor and Simulation Note 299, 1 April 1987.

3. D.V. Giri, "Effective Risetime Resulting From a Convolution of Waveforms With Exponential and Gaussian Line Characteristics," Measurement Note 33, 14 May 1987.