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REMOVAL OF POST AND PREPULSES ON UNBALANCED BLUMLEINS

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Introduction

In the past few years, a great deal of effort has gone into the design and construction of high voltage Blumleins. Until recently the technology has concentrated, to a large degree, on maximizing the voltage and energy delivered to the experiment. More recently it has become increasingly important, particularly for the work being done at Cornell University, to be able to eliminate all but the main current pulse produced by the Blumlein. Voltages which arrive before and after the main pulse can cause complete failure of some of these experiments.

Voltage before the main pulse is called prepulse and arrises from an uneven charging of the lines. Large prepulse can be a problem when Blumleins are used to produce intense relativistic electron beams by preionizing the gas in the diode and producing a short.

Voltage appearing across the load after the main pulse is called post-pulse. Postpulses arrise when not all of the stored energy is delivered to the load and some remains on the line after the main pulse. These postpulses can be removed by matching which is usually accomplished by adjusting the load impedance so as to dissipate all the stored energy during the main pulse. Postpulses can also be eliminated by shorting the load after the main pulse. However, the matching technique is preferred to shorting for several reasons. With matching the maximum power is delivered to the load. In addition, stress on the Blumlein is reduced because the voltages appear across the dielectrics for the minimum length of time.

In this report, post and prepulses on an unbalanced Blumlein are investigated. A Blumlein is considered to be unbalanced if the two transmission lines are of different impedance or if they are changed to different voltages. Design conditions for the removal of post and prepulses on unbalanced Blumleins are determined.

Description

A simple Blumlein is depicted in Figure 1. It consists of two transmission lines with characteristic impedances Z_1, and Z_2, charged to voltages V_1 and V_2 respectively, with one common conductor, and a load impedance connected between the other two conductors. In addition to the normal model there is a switch in series with the load impedance. This switch simulates the action of the diode in a relativistic beam generator since the diode impedance remains open circuited until the first voltage pulse reaches it. The electrical lengths of the two transmission lines are equal.

The question at hand is whether this model can be matched, and whether having a match precludes eliminating any prepulse. The solution can be found using either of two approaches, the first being to assume there are no pulses remaining on either line after the main current pulse has ended, and the second is to demand that the total stored energy of the line be dissipated in the diode during the first pulse. The first of these two approaches was chosen since it gives a better insight into the problem.

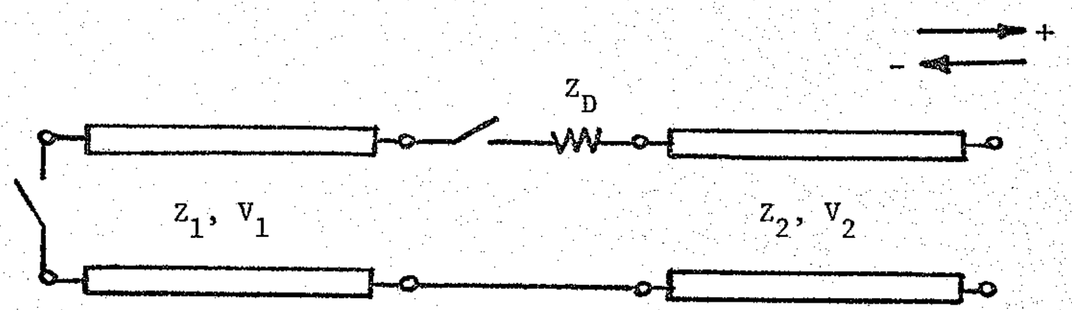

Figure 1 Blumlein Model

set equal to zero. While either of these solutions is sufficient, the latter was chosen because it appeared to give more insight into the problem. Thus, the method of setting the secondary pulses equal to zero was chosen.

The boundary conditions at the diode are

$$I_1^+ + I_1^- + I_{1R}^+ + I_{1R}^- = I_2^+ + I_{2R}^- + I_{2R}^+ \quad (4)$$

$$V_1 + V_1^+ + V_1^- + V_{1R}^+ + V_{1R}^- = aV_1 + V_2^+ + V_{2R}^- + V_{2R}^+ \quad (5)$$

where I_1^+, I_1^-, I_2^+ have been defined

I_{1R}^+ = the current pulse reflected off the shorted end

I_{2R}^- = the current pulse reflected off the open end

I_{2R}^+, I_{1R}^- are the secondary current pulses.

From these conditions and the boundary conditions on the ends, we have

$$I_{1R}^- \frac{(Z_1 + Z_2)}{V_1} = a - \frac{4Z_2\ (aZ_1 - Z_2 - Z_D)}{Z_1\ (Z_1 + Z_2 + Z_D)} - 3\ \frac{Z_2}{Z_1}$$

and $$I_{2R}^+ = \frac{V_1}{Z_1 + Z_2}\left[a - \frac{4Z_2\ (aZ_1 - Z_2 - Z_D)}{Z_1\ (Z_1 + Z_2 + Z_D)} - \frac{3Z_2}{Z_1}\right] - \frac{2\ (aZ_1 - Z_2 - Z_D)\ V_1}{Z_1\ (Z_1 + Z_2 + Z_D)}$$

since $\frac{Z_1 + Z_2}{V_1}$ is finite, the condition for $I_{1R}^- = 0$ is

$$a - \frac{4Z_2\ (aZ_1 - Z_2 - Z_D)}{Z_1\ (Z_1 + Z_2 + Z_D)} - \frac{3Z_2}{Z_1} = 0 \quad (8)$$

with $Z_2 = bZ_1$ and $Z_D = cZ_1$

Solution

At t = 0, side 1 of the line is shorted, initiating a pulse

$$I_1^+ = -\frac{V_1}{Z_1} \qquad (1)$$

Note: A numerical subscript denotes the side of the diode and a sign superscript denotes the direction of the pulse (+ = right).

When this pulse reaches the load, part of it reflects off of the diode and the rest begins propagating down the right hand side of the line. Boundary conditions determine that these two pulses I_1^- and I_2^+ are

$$I_1^- = -\frac{V_1\ (a\ Z_1 - Z_2 - Z_D)}{Z_1\ (Z_1 + Z_2 + Z_D)} \qquad (2)$$

$$I_2^+ = I_1^- - \frac{V_0}{Z_1} \qquad (3)$$

where $V_2 = aV_1$ $\qquad a = \frac{V_2}{V_1}$

The two pulses propagate to the ends of the Blumlein, reflect off of them under the B.C. that the L.H.S. is shorted and the R.H.S. is open, and arrive simultaneously again at the diode (the electrical lengths of the two sides are assumed equal).

While these two pulses are propagating down the line and back, the major current pulse is being driven through the diode, thus if all the energy is to be dissipated there are two possible constraints that can be put on the system. Either the total energy dissipated through Z_D can be set equal to the initial energy in the line, or the secondary reflections off of the diode, i.e. the pulses on the line after the major current pulse has ended, can be these two equations give

$$-3a + 3b + ab - ac + c - 1 = 0 \qquad (9)$$

$$a - 3b + ac - 3ab + b^2 + bc = 0 \qquad (10)$$

These two equations represent surfaces in 3-space, and their intersection (a line) gives the constraint on Z_1, Z_2, V_1, V_2 and Z_D for a match. The solution is

$$a = b = c-1 \qquad (11)$$

or $$\frac{V_2}{V_1} = \frac{Z_2}{Z_1} = \frac{Z_D}{Z_1} - 1 \qquad (12)$$

or in words, the ratio of the charging voltages must equal the ratio of the line impedances, must equal the ratio of the diode impedance to the switched line impedance minus one. This formula has some interesting consequences.

Conclusions

Postpulses can be removed and all the energy deposited in the load if the match condition, Equation 12, is satisfied. If the Blumlein is balanced, this condition is easily achieved by adjusting the load impedance to be twice the natural impedance of the transmission lines, However, unbalanced lines are more difficult to match. In fact from Equation 12, it can be seen that on such a line, if $V_2/V_1 \neq Z_2/Z_1$, a match is impossible. To achieve a match on such lines the impedance imbalance must be accompanied by a charging imbalance. This required voltage imbalance can be accomplished by the proper choice of charging inductors for the transmission lines and the firing of the Blumlein precisely when $V_2/V_1 = Z_2/Z_1$. Coaxial lines present a difficult but not impossible matching problem because they, by design, have an impedance imbalance.

The condition for no prepulse is simply that $V_2/V_1 = 1$ and this can be combined with the match condition, Equation 12, to give the general condition for no post or prepulse.

$$\frac{V_2}{V_1} = \frac{Z_2}{Z_1} = \frac{Z_D}{Z_1} - 1 = 1 \qquad (13)$$

From Equation 13, it can be seen that for no post or prepulse the Blumlein transmission lines must have equal impedances, the lines must be charged equally and terminated in a load impedance twice the line impedance. In coaxial systems $Z_2 \neq Z_1$ and consequently, if they are matched to removed postpulses, the prepulse is inherent. The only way around this prepulse problem is to keep Z_1 and Z_2 as close in value as possible or to use a shorting switch if preionization becomes a problem.