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Cable transient voltages due to microphonics

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Abstract

Expressions for the voltage generated by tribocharging between a cable's dielectric and outer conductor, and the maximum voltage across a resistive load of a cable, are derived as a function of time. For a reasonably large load resistance and cable capacitance, the expressions reduce to simple single-time-constant equations that can be used to estimate the highest frequency of interest of the generated noise. The derived expressions can also assist the designer in weighing the tradeoffs associated with changing the ohmic resistance and capacitance of low-noise cables.

Keywords: Microphonics; Microphony; Tribocharging; Low-noise coaxial cables; Triboelectric noise

1. Introduction

When a cable is mechanically stressed through twisting, compression, or flexion, the cable itself generates noise, referred to as microphonics. This noise can be due to piezoelectric effects, changes in cable capacitance, and tribocharging. The limited literature in this area [1–5] indicates that tribocharging between the dielectric and the conductors is often the major contributor of this cable-generated noise. Assuming a cable is properly selected so that effects such as reflections and crosstalk are negligible, microphonics can be important for some small-signal applications. The signal-to-noise ratio can be severely affected in these applications.

2. The model

In this paper, the simple model used by Perls [2] to model the voltage generated by a separation of charge between the conductor and dielectric is analyzed and refined. Assume that positive charge exists (or is "generated") on the inner surface of the outer conductor of an initially uncharged coaxial cable, and minus charge of equal magnitude exists on the outer surface of the dielectric in direct contact with this conductor over some local area. This charge displacement can be produced by contact and friction between these two materials. The actual sign and magnitude of these charges is a complicated function of factors such as the material composition, contaminates, contact area, and rubbing velocity. Assume that very quickly (compared to the smallest relevant time constant in the system, including the propagation time down the cable) the conductor and dielectric are separated, resulting in a charged capacitor C_1 having an air dielectric as shown in Fig. 1. Mechanical energy is imparted to the system and converted initially to an electrical energy of $C_1 V_1^2/2$. Although generally a dielectric surface is not an equipotential surface, this surface is assumed to be approximately so in this discussion, so that the capacitance between the dielectric surface and conductor can be (easily) defined. This surface and conductor can be considered two "plates" of a capacitor. As the separation distance increases, this capacitance decreases and is time varying. Since the total charge Q_1 on each of the plates is constant where $Q_1 = C_1 V_1$, the voltage across this air capacitor increases as the separation distance increases. This separation is assumed to occur instantaneously or at least much faster than the connecting circuitry can respond. Hereafter, the previously considered variable C_1 becomes the final fixed value of this capacitance. The capacitor C_2 is the local fixed capacitance between the dielectric surface and the inner

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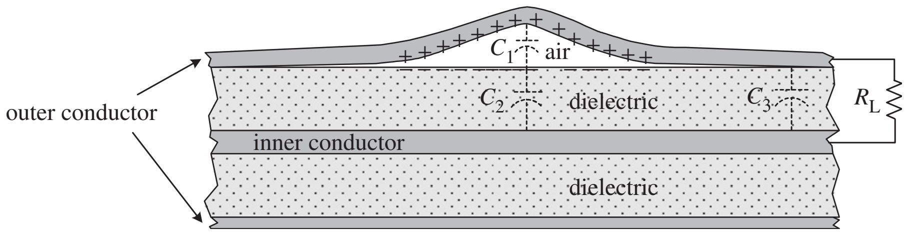

Fig. 1. Tribogenerated charges over a small area in a coaxial cable.

conductor near this air capacitor. The capacitor C_3 is the sum of the remaining capacitance of the cable and load. These other two capacitors are assumed initially uncharged. Again, the electrical energy initially exists only in C_1, even though C_1 is in series with C_2.

3. Analytical analysis

This model assumes that the voltage across C_1 changes instantaneously from 0 to a positive $v_1(0^+)$ at $t = 0$. The voltage across C_3 (and hence the load resistor R_L) cannot change instantaneously since C_3 is distributed and a nonzero impedance exists between C_1 and C_3. This impedance is simply modeled as R_s in Fig. 2, which is the ohmic resistance of the conductors. This resistance also prevents the voltage across C_2 from changing instantaneously. The inductance of the conductors is not modeled.

Without inductance, the response of this circuit is obviously overdamped and nonoscillatory, and the response has two time constants. Although these time constants will be determined rigorously shortly, an approximation for them can be determined by inspection. Initially, C_3 looks like a short circuit since it has 0 V across it. An approximation for the time constant of this initial response, assuming one time constant is much larger than the other, when the voltage across the load is rising is

$$\tau_r = R_{eq}C_{eq} = R_s\frac{C_1C_2}{C_1+C_2}. \tag{1}$$

After C_3 is charged to some value near its peak, the current through R_s will decrease, and the time constant of the response when the voltage across the load is falling is about

$$\tau_f = R_{eq}C_{eq} = R_LC_3. \tag{2}$$

The capacitors C_1 and C_2 appear like opens during this period under this approximation. It is reasonable to assume that $C_3 \gg C_2$ and $C_2 \gg C_1$ and $R_L \gg R_s$; therefore, $\tau_f \gg \tau_r$. The initial charging of C_3 is fast while the discharging through R_L is slow.

The expression for the voltage across the load is determined using Laplace transforms. The s-domain circuit is shown in Fig. 3 where $C_x = C_1C_2/(C_1+C_2)$. The initial voltage across C_1 is modeled in the circuit through $v_1(0^+)/s$, which is also the Laplace transform of a step voltage of amplitude $v_1(0^+)$. The expression for the load

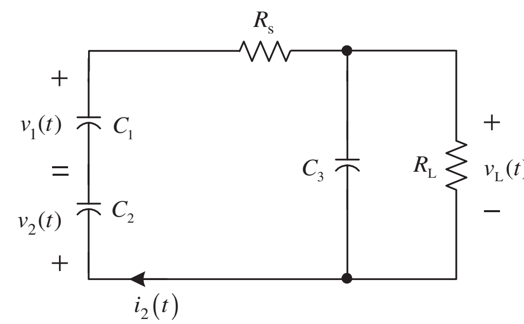

Fig. 2. Lumped-circuit model of the situation shown in Fig. 1.

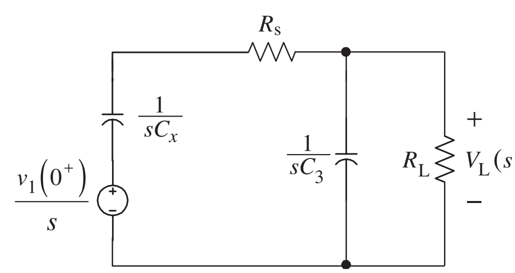

Fig. 3. Frequency-domain version of the circuit in Fig. 2.

voltage is obtained using voltage division

$$\begin{aligned} V_L(s) &= \frac{v_1(0^+)}{s}\frac{R_L\|(1/sC_3)}{(R_L\|(1/sC_3)) + R_s + (1/sC_x)} \\ &= \frac{v_1(0^+)/R_sC_3}{s^2 + s((R_LC_x + R_sC_x + R_LC_3)/R_sR_LC_xC_3) + (1/R_sR_LC_xC_3)}. \end{aligned} \tag{3}$$

(The units for this expression are V sec. When the inverse transform is taken, the units become V.) The Laplace transform pair from [1]

$$\left(\frac{e^{-at} - e^{-bt}}{b-a}\right)u(t) \Leftrightarrow \frac{1}{(s+a)(s+b)}, \tag{4}$$

can be used to determine the inverse transform. The variables a and b are obtained using the quadratic equation

$$a, b = -\frac{-\left(\frac{R_LC_x+R_sC_x+R_LC_3}{R_sR_LC_xC_3}\right) \pm \sqrt{\left(\frac{R_LC_x+R_sC_x+R_LC_3}{R_sR_LC_xC_3}\right)^2 - \frac{4}{R_sR_LC_xC_3}}}{2}, \tag{5}$$