NRL REPORT 3953

HIGH IMPEDANCE CHAMBERS

D. S. Toffolo

Electromagnetics Branch
Electricity Division

March 26, 1952

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

ABSTRACT

The maximum impedance of an ionization chamber which is filled with an argon-carbon dioxide mixture and which generates a voltage signal for propagation by a coaxial transmission line is shown to be a function of the applied dc potential.

PROBLEM STATUS

This is a final report on this phase of the problem.

AUTHORIZATION

NRL Problem H09-01
RDB Project NR459-010

Manuscript submitted February 26, 1952

HIGH IMPEDANCE CHAMBERS

In order to simplify the problem of matching an ionization chamber to a transmission line, the problem of increasing the chamber impedance was investigated. In general, to raise the impedance of a chamber from 7 to 50 ohms, it would be expected that the potential difference applied to the chamber has to be increased.

The maximum impedance of a chamber should be considered under the following conditions: (a) potential difference, 4,000 volts; (b) voltage arriving at oscilloscope to remain constant; that is, for the same source signal to a 7-ohm chamber and to a chamber whose dimensions are to be determined, the resulting voltage from each chamber arriving at the oscilloscope would be the same.

Suppose that the source signal has a certain time dependence, f(t), for gamma emission. These gammas will produce a certain number of electrons per unit time per unit volune in the chambers. The function f(t) is such that all unit volumes can be considered as having the same number of electrons at any time (neglecting electron collection). Hence the electron density will not be a function of r but will be a function of the pressure. At the level of the present applied pressure, the ionizing power of gammas and compton electrons is directly proportional to the number of gas molecules per unit volume. This in turn is directly proportional to the absolute pressure. The drift velocity is independent of E only for a range $0.7 < E/P < 3.0$, and the present chambers are operated at $E/P = 1.0$ (indicating that they are filled to the highest pressure allowable, i.e., so that the drop in field strength due to the induced signal will not bring E/P below 0.7). For the sake of the argument, then, P may be set equal to E, or

$$E = \frac{V}{b \ln \frac{b}{a}} = P.$$

Now, the induced current per electron is given by

$$I_e = \frac{e\omega}{r \ln \frac{b}{a}},$$

where e is the electronic charge, ω is the drift velocity, and r is the distance from the origin at which the electron finds itself. The total induced current per unit axial length (it is assumed that the length of the chamber will not be changed) will be

$$I_t \approx \int_a^b \frac{e\omega}{r \ln \frac{b}{a}} \cdot \frac{V}{b \ln \frac{b}{a}} \, 2\pi r \, dr \cdot n(t),*$$

or

$$I_t \approx \frac{2\pi e \omega V}{b\left(\ln \frac{b}{a}\right)^2} (b - a) \cdot n(t).$$

The impedance of the chamber Z_0, is given by

$$Z_0 \approx \ln \frac{b}{a}.$$

The induced voltage per unit length is then

$$I_t Z_0 \approx \frac{2\pi e \omega V \, (b - a)}{b \ln \frac{b}{a}} \cdot n(t),$$

or, neglecting the constants, which are the same for all chambers,

$$I_t Z_0 \approx \frac{V(b - a)}{b \ln \frac{b}{a}} \cdot n(t).$$

The induced voltage can be stepped up by a factor of $\sim 1/\sqrt{\ln b/a}$ or as close to this factor as desired. Thus the voltage arriving at the oscilloscope, V_s, is

$$V_s \approx \frac{V\,(b - a)}{b\left(\ln \frac{b}{a}\right)^{3/2}}.$$

Since a and b will always have a definite ratio,

$$b = \lambda a, \; (\lambda > 1)$$

$$V_s \approx \frac{V(\lambda a - a)}{\lambda a \left(\ln \frac{\lambda a}{a}\right)^{3/2}}$$

$$\approx \frac{Va(\lambda - 1)}{\lambda a (\ln \lambda)^{3/2}}$$

$$\approx \frac{V(\lambda - 1)}{\lambda (\ln \lambda)^{3/2}}.$$

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* Since the time function is independent of chamber impedance and is assumed to be the same for all chambers and since its effect on the chamber response has been adequately covered by Dr. A. J. Ruhlig in NRL Report 3952, "Distortion of Transients in the Cylindrical Ion Chamber," March 1952, it will be neglected in the discussion that follows.

Let $\lambda = 7/6$ and $V = 2{,}000$ for the present chamber and $V = 4{,}000$ for the chamber to be determined. Equating thus making V_S the same for both chambers,

$$\frac{4{,}000\,(\lambda - 1)}{\lambda(\ln\lambda)^{3/2}} = \frac{2{,}000\left(\frac{7}{6} - 1\right)}{\frac{7}{6}\left(\ln\frac{7}{6}\right)^{3/2}},$$

$$\frac{2(\lambda - 1)}{\lambda(\ln\lambda)^{3/2}} = \frac{1}{7\left(\ln\frac{7}{6}\right)^{3/2}},$$

$$\ln\frac{7}{6} = 0.1542,$$

$$0.1542^{3/2} = 0.061,$$

$$\frac{2\,(\lambda - 1)}{\lambda\,(\ln\lambda)^{3/2}} = \frac{1}{0.427} = 2.342,$$

$$\frac{\lambda - 1}{\lambda\,(\ln\lambda)^{3/2}} = 1.171.$$

From these equations it can be seen that V_S will be independent of the magnitude of either a or b, depending solely on their ratio (provided, of course, that for any given ratio, as a and b are varied in magnitude, the potential difference is kept the same for all a and b corresponding to the given ratio).

Solving the last equation yields $\lambda \approx 1.6$. The Z_0 for this chamber is $60 \ln b/a = 60 \ln 1.6$, or about 28 ohms. For $\lambda = 2.3$, which corresponds to a 50-ohm chamber, the following voltage would be needed:

$$\frac{x(2.3 - 1)}{2.3\,(\ln 2.3)^{3/2}} = 2.342.$$

This yields $x \approx 3.2$, or a voltage of $2{,}000 \times 3.2 = 6{,}400$ volts. Conversely, if 4,000 volts is maintained, with $\lambda = 2.3$, the signal obtained on the oscilloscope would be in percentage of the present signal,

$$\frac{\dfrac{2\,(2.3 - 1)}{2.3\,(\ln 2.3)^{3/2}}}{2.342} \times 100 = 63.5.$$

The only remaining possibility, though not very feasible, would be to increase the length of the chamber by 36.5 percent in order to use a 50-ohm chamber at 4,000 volts.

Since a 28-ohm chamber can be directly connected to a 50-ohm line with about a 5 percent loss in amplitude of the signal transmitted from the chamber to the line, it is possible to connect a 28-ohm chamber to a 50-ohm line in this way without suffering a large loss in signal voltage. From the standpoint of distortion, this procedure recommends itself since it eliminates the matching transformer, which is necessary for the coupling of a 7-ohm chamber to a 50-ohm line, and which gives rise to distortions. In addition, by properly loading the chamber at the open end, thus presenting an essentially resistive load matched to the chamber impedance, no reflections will occur from this end of the chamber. Thus any reflections occurring at the line end of the chamber will travel down the chamber to this load and be absorbed. Consequently, the signal entering the line and proceeding toward the oscilloscope will have no distortion in it, and only the distortions introduced by the line itself then need to be considered.

The design of such a match-loaded 28-ohm impedance chamber has now been completed.

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NAVY-DPPO PRNC. WASH., D.C.