

PFN DESIGN INTERFACE WITH E-BEAM SUSTAINED GAS DISCHARGE

by

J. P. O'Loughlin
Air Force Weapons Laboratory

ABSTRACT

The non-linear time varying conductivity characteristics of electron beam sustained gas discharges require special consideration in the design interface with the pulse forming network in line type modulators. Equations and tables are used to analyze effects of varying E/N, a non-uniform electron beam, and the interaction with the PFN. Experimental data is compared to calculations and found to be in reasonable agreement.

Introduction

The fundamental equation of conduction in a gas without a magnetic field is given by (1)

$$j = en_e Vd = \sigma E \quad (\text{Amps/cm}^2) \quad (1)$$

or

$$\sigma = \frac{en_e Vd}{E} \quad (\text{MHO - cm}) \quad (2)$$

Thus to find the conductivity (σ), the electron number density (n_e), the drift velocity (Vd) and the electric field (E) must be evaluated.

The electron number density is found by solving equation (3)

$$\frac{dn_e}{dt} = SNj_{eb} - Rn_e^2 - ANn_e + INn_e - Dif \quad (3)$$

The right hand terms are respectively the source term which is the rate at which electrons are generated by the E-beam ionizing the gas, the recombination term is the rate electrons recombine with ionized molecules, the attachment term is the rate electrons attach to neutral molecules, the ionization term is the rate electrons are generated by the electric field and the diffusion term is the rate electrons diffuse from the region. R , A , I and the drift velocity Vd are given in figures 1-4. (Ref 1)

In pulse cases the diffusion term can be neglected also the ionization and attachment terms are usually negligible.

The source coefficient S is given by equation (4).

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE NOV 1976	2. REPORT TYPE N/A	3. DATES COVERED -	
4. TITLE AND SUBTITLE PFN Design Interface With E-Beam Sustained Gas Discharge		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Weapons Laboratory		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited			
13. SUPPLEMENTARY NOTES See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.			
14. ABSTRACT The non-linear time varying conductivity characteristics of electron beam sustained gas discharges require special consideration in the design interface with the pulse forming network in line type modulators. Equations and tables are used to analyze effects of varying E/N, a non-uniform electron beam, and the interaction with the PFN. Experimental data is compared to calculations and found to be in reasonable agreement.			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	SAR
			18. NUMBER OF PAGES 6
			19a. NAME OF RESPONSIBLE PERSON

$$S = \frac{1}{e} \sum_{i=1}^K \frac{P_i \frac{\partial E}{\partial m} |i}{E_i} \quad (4) \quad \text{where } \frac{\partial E}{\partial M} \text{ is figure 5 (ref 2)}$$

$P_i = \text{Mass density g/cm}^3$

$E_i = \text{effective ionization energy of the } i\text{th specie in eV (N}_2, \text{CO}_2 \approx 34 \text{ eV, He } \approx 50 \text{ eV)}$

From equation (4) the values of S for 871, 541 and 321 mixes are:

$$\begin{aligned} S_{871} &= 8.66 \\ S_{541} &= 8.92 \\ S_{321} &= 9.55 \end{aligned}$$

The drift velocity is a function of E/N and depends slightly on mix as shown in figure 4.

From the foregoing the conductivity may now be evaluated as a function of time, etc and geometrical dimensions are thereby used to predict the electrical interaction with the PFN.

Method of Analysis

To obtain a feel for the nature of conductivity behavior first consider the simple case of a small volume of gas with a constant electric field which is then step illuminated with an uniform electron beam. Since the E-field is constant, E/N is constant and the coefficients of equation (3) and Vd are constant, neglecting the A and I terms as small compared to R, equation (3) gives

$$n_e \approx \sqrt{\frac{SNjeb}{R}} \tanh(\sqrt{SNRjeb} t) \quad (5)$$

so the conductivity is

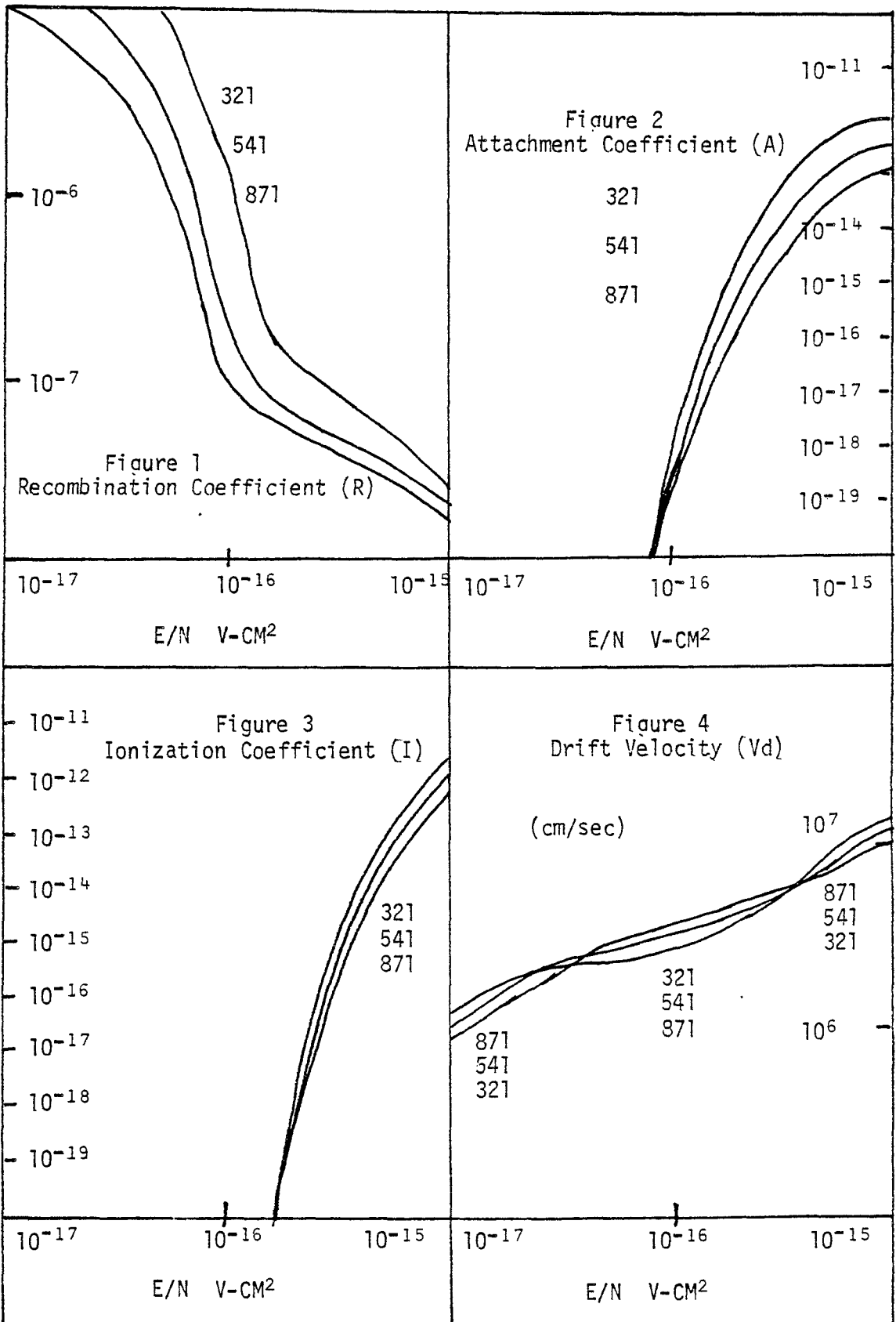
$$\sigma \approx \frac{eVd}{E} \sqrt{\frac{SNjeb}{R}} \tanh(\sqrt{SNRjeb} t) \quad (6)$$

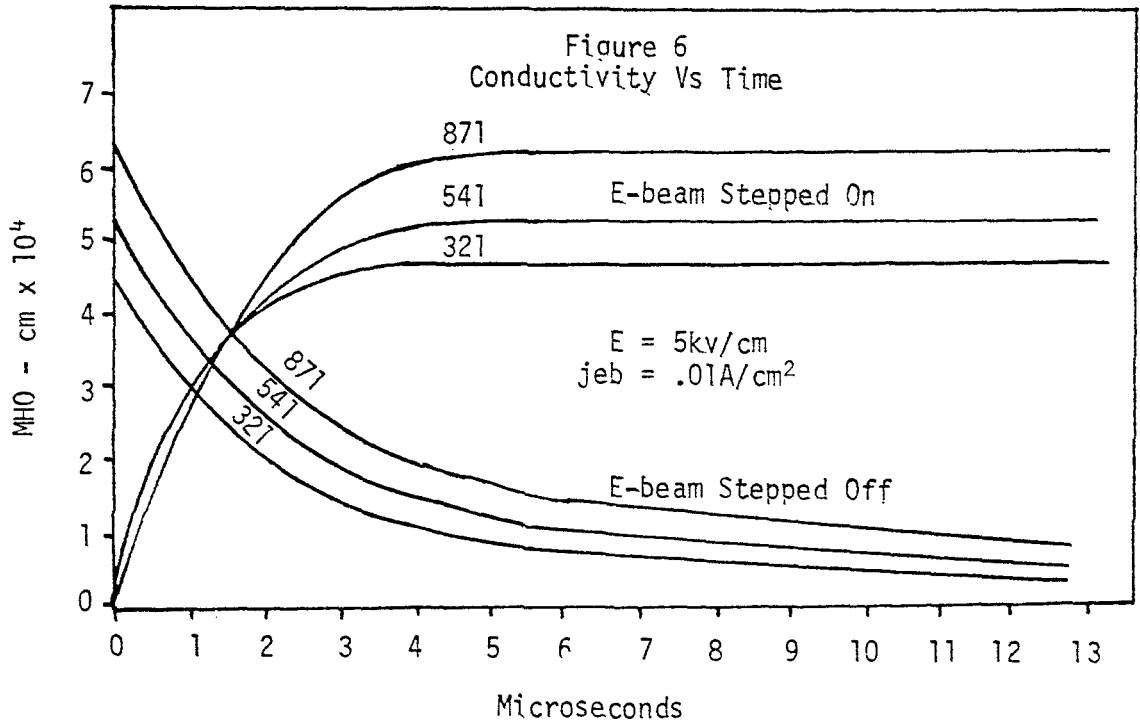
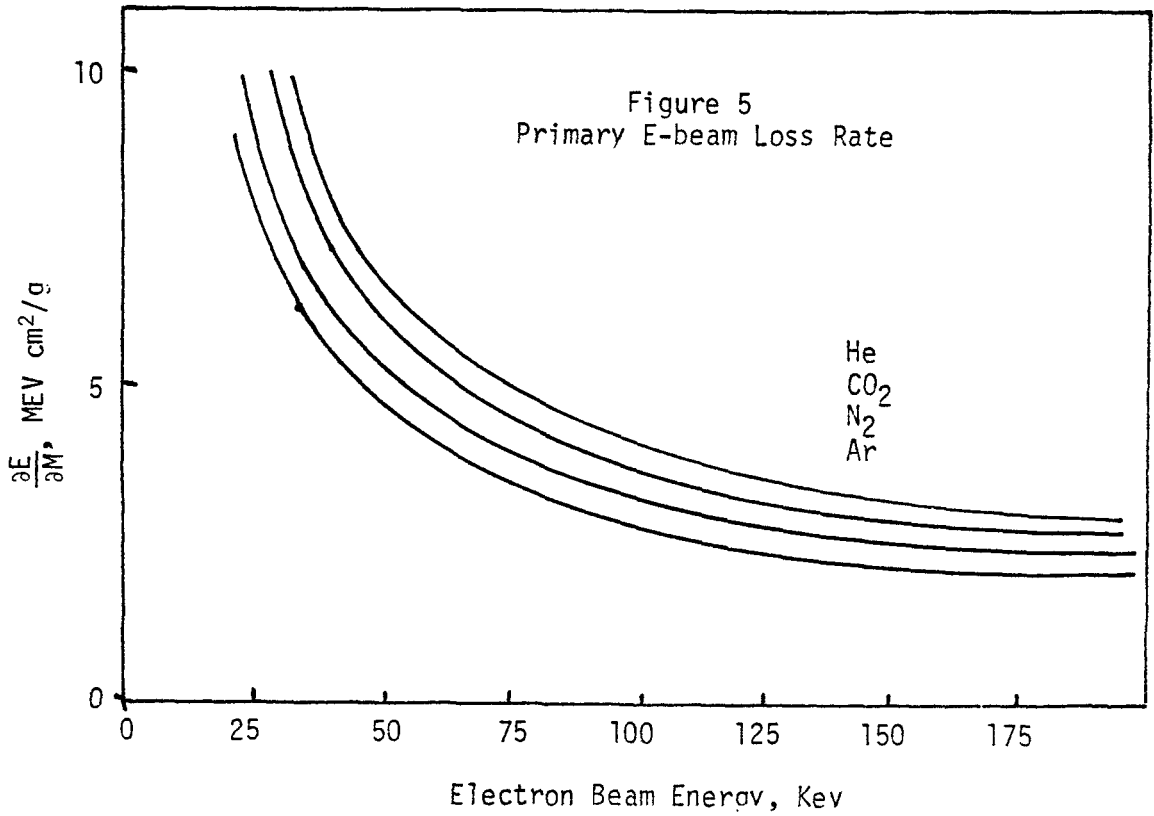
The conductivity increases from zero to a steady state value in an exponential manner. For an atmospheric 3:2:1 mix at 5 Kv/cm and $jeb = .01 \text{ A/cm}^2$ the time constant of the tanh function is about 1.25 microseconds (figure 6).

Now consider what happens to the conductivity under the same conditions except it is in steady state conduction and the E-beam is step switched off. The initial steady state electron number density and corresponding conductivity is given by

$$n_e(ss) \approx \sqrt{\frac{SNjeb}{R}}, \quad \sigma(ss) \approx \frac{eVd}{E} \sqrt{\frac{SNjeb}{R}} \quad (7)$$

Solving (3) with $jeb = 0$ and retaining the A and I terms to avoid a





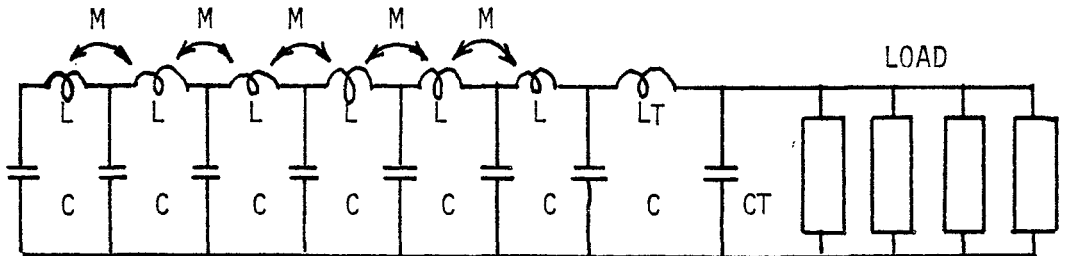
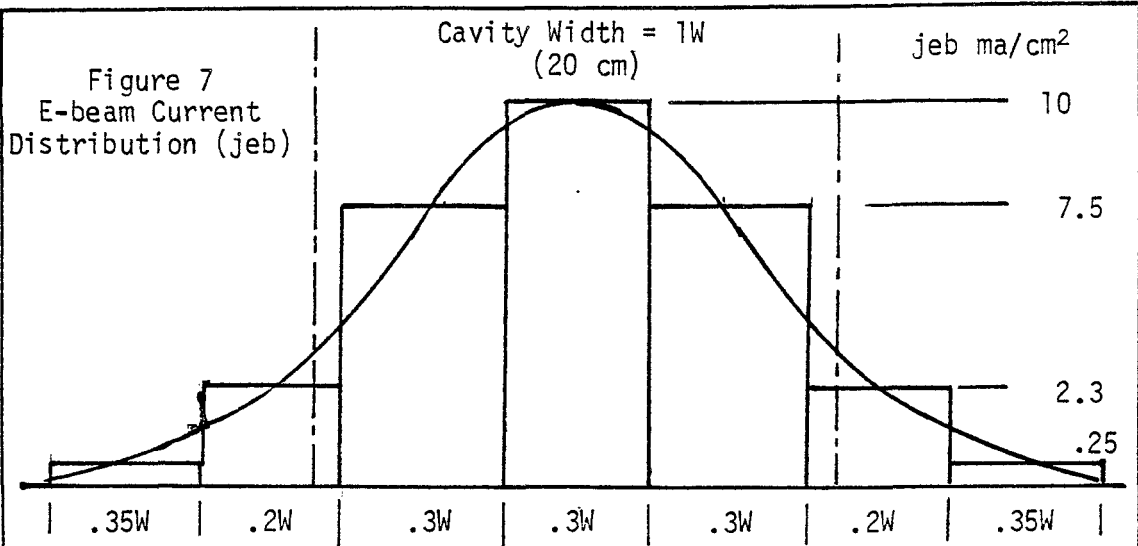
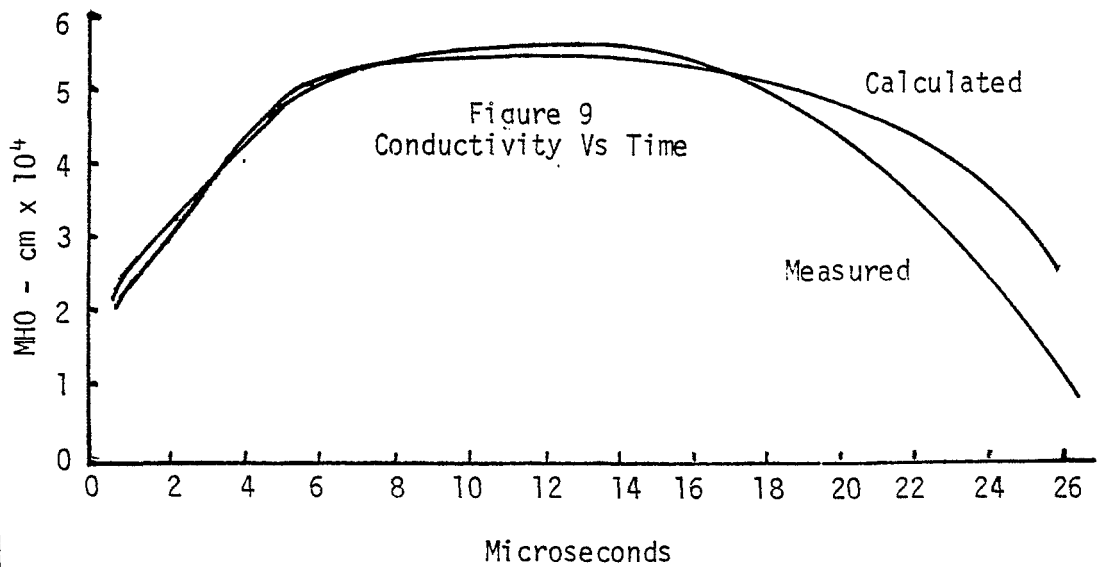


Figure 8 PFN - Load Circuit Model
 $L = 4.86\mu h$, $C = .248\mu fd$, $M = .65\mu h$
 $LT = 21\mu h$, $CT = 1000pf$



discontinuity at $t = 0$, the conductivity becomes

$$\sigma = \frac{eVd\sqrt{SNjeb} N(A-I)}{E((N(A-I)\sqrt{R} + R\sqrt{SNjeb})\epsilon^{N(A-I)t} - R\sqrt{SNjeb})} \quad (8)$$

The exponential decay time constant is about 2.75 microseconds for a 3:2:1 mix compared to 1.25 microseconds when the E-beam was switched on. These times are about the same for the other mixes. (Figure 6)

Extending the analysis to a typical real gas load must include consideration of the changing E/N during the pulse, the effect of a non-uniform E-beam current density and the interaction with the PFN impedance. This is accomplished by tabulating or fitting equations to the E/N dependent parameters, approximating the E-beam current distribution and solving the PFN load circuit equations in sufficiently small time steps via a computer program.

It is necessary to consider the E-beam current density distribution because not only the steady state conductivity but also the time constant of the conductivity is affected. To account for this, the jeb density variation may be fitted to a curve or approximated by a multistep distribution as in figure 7. Note that the density typically extends beyond the boundary of the load cavity. Each segment is treated as a parallel impedance connected to the PFN as in figure 7.

A SCEPTRE solution of figure 7 for a 3:2:1 mix in a 10 x 20 x 200 centimeter cavity at 60 Kv (20 microseconds) was run and is compared to the experimented test data in figure 8. Note that the conductivity (averaged over the whole load) tends to slowly increase over the front of the pulse. This is attributed to the fact that the lower jeb regions take longer to build up to steady state conductivity and thus contribute to the overall conductivity later in the pulse. Note also that the inductance of the first section of the PFN is 4.3 times the middle section inductance whereas for a resistive load it would be about 1.15 times. This higher value is required with the gas load to prevent voltage overshoot also it need not be lumped in the network but may be included as the leakage inductance of the pulse transformer thus allowing for a much less demanding transformer design compared to a resistive load. The decrease of the experimental conductivity more rapidly than the model in figure 9 is attributed to the presence of a small amount of O_2 which has a very high attachment rate.

References

1. Data on R, A, I and Vd provided from internal memos of Maj J. D. Hines, AFWL.
2. CO_2 Electric Discharge Laser Kinetics Handbook, AFWL-TR-74-216, D.²H. Douglas-Hamilton, R. S. Lowder.