<u>Some Reflections on Gas Discharges and PAGD Pulses</u>

By

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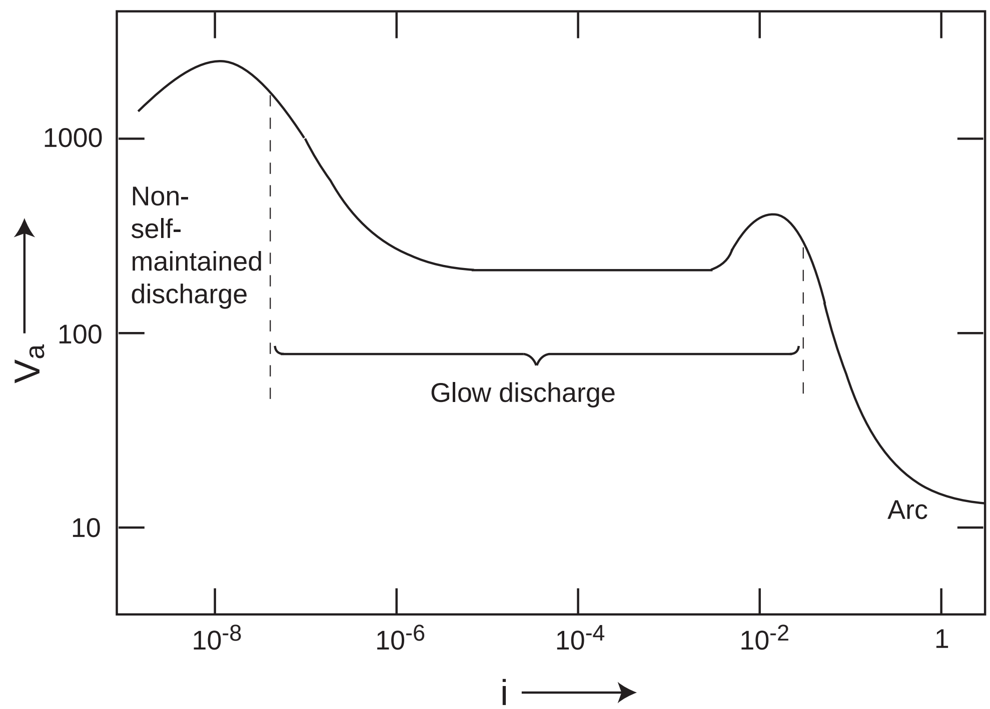
A typical graph relating the voltage difference, V_a, between parallel planar electrodes and the discharge current, i, in a gas discharge tube is shown in Figure 1.

Figure 1. Current-voltage characteristic showing transition from a non-self-maintained discharge to a glow and finally an arc discharge.



It is the small bump in the V_a-i curve on the right side of the glow discharge region that is of interest to us here. It is called the abnormal glow discharge region. This develops after the glowing region of area **a** on the cathode covers the entire surface area so that, any further increase in i means that the current density, j_n = i/**a**, and therefore the average field, E, must increase. Since E/p is now no longer optimum where p is the gas pressure, the gas ionization is less efficient and increases in i are now attended by an increase in running voltage otherwise the glow could not be maintained.

The running voltage, V_r, for the normal glow discharge depends upon both the nature of the gas filling the tube and the cathode surface material. It also tends to fall as the filling gas pressure increases and tends to become asymptotic to

$$V_r = V_g + (1/\eta_g)\log_e(1/\gamma) \qquad (1)$$

where v_g and η_g are fundamental constants of the gas while γ depends on both the cathode surface and the impinging ion. Table 1 gives v_g and η_g for common gas fillings while Table 2 gives γ for the appropriate impinging ion and cathode surface.

Table 1.

Gas	V_i	V_*	V_g	η_m x 10^{-1}	η_g x 10^{-1}	Impinging ions
He	24.5	19.8	20.0	0.012	0.020	Helium
Ne	21.5	16.6	17.0	0.015	0.022	Neon
A	15.6	12.5	12.5	0.022	0.0295	Argon
H_2	15.4		15.0	0.015	0.015	Hydrogen
Ne-A (99.5:0.5)	16.6		17.0	0.029	0.037	Argon
He-A (99.5:0.5)	19.8		20.0	0.024	0.0315	Argon
He-Ne (95: 5)	24.5		20.0	0.012	0.0175	Neon

Unfortunately, η_g is not a simple function of E/p. When E/p = 0, $\eta_g = 0$ and, as E/p increases, η_g first rises to a maximum value denoted η_m at E/p = Z_m and then falls steadily as E/p $\rightarrow \infty$. The current density j = i/A_c, where A_c is the cathode area, is given by

$$j = Jp^2 \qquad (2a)$$

where

$$J = 4 \times 10^{-13}\, k_i Z_m^3 / V_r \qquad (2b)$$

and where k_i is the mobility of the relatively heavy positive ions. Values for J and Z_m are given in Table 3.

Table 2. Values of $\log_e (1/\gamma)$

Cathode impinging ion	Mo sputtered	Ni sputtered	Ni Unsput-tered	Mg	Ba Evapor-ated	Ba (from $BaCO_3$)	K	C
Helium	1.8	2.3	2.6	1.8	1.22			
Neon	2.0	2.65	3.05	2.25				3.92
Argon	2.6	3.6	4.5	2.45	1.7	1.42	1.65	
Hydrogen	4.2	4.35			2.2			

Table 3.

Gas	$J \times 10^6$	Z_g	Z_m
Helium	2	30	50
Neon	2	30	100
Argon	10	100	200
Neon-argon (99.5:0.5)	1	30	25
Helium-argon (99.5:0.5)	2	30	25
Helium-Neon (95: 5)	2	50	50
Hydrogen	70	120	120

Since the gas discharge tube is always in a circuit having some time-dependent equivalent impedance, $Z_c(t)$, the actual source voltage, V_a, for the circuit must be given by

$$V_a = V_r + i\, Z_c(t). \qquad (3)$$

In the abnormal glow region, cathode sputtering can seriously limit the lifetime of a tube. The lightest metals, Al, Mg and Ba fall into one group and are slow to sputter while the group Mo, Ta, Ni, Cu, and Ag are more readily sputtered with the rate of sputtering generally increasing in this order. Here, the gas pressure, p, is an important controlling factor with low pressures giving more rapid sputtering. Empirically, one finds that

$$\text{Rate of Sputtering} \propto p^{-n} \qquad (4)$$

where n > 2 and typically n ~ 5. Of course, a higher sputtering rate also leads to a steady decrease in gas pressure (via physical adsorption of the gas) and this leads to a "runaway" phenomena. Thus, as a result, all cold cathode tubes show a fall in pressure during their active life. However, some manufacturing techniques are available to extend the tube life.

<u>The PAGD Regime Function of the Correas' Tubes</u>

In their patent # 5,416,391, the Correas represent that their basic tube circuit shown in Figures 2 and 3 (their Figures 14 and 15) exhibit a V - i characteristic like that shown in Figure 4. Although this has the same general form as Figure 1, the anomalous glow discharge region is highly accentuated, perhaps because of their circuit design.

Their output voltage characteristics have much in common with the old free-running multivibrator circuits of the 1940's radar days which used triodes instead of diodes. However, in both cases, the large parallel capacitances across the tube play a strong role in the output V(t) characteristic. Without going into fine details, when the input voltage to the anode exceeds the breakdown voltage of the tube either one or both cathodes begin to glow (rise time of current

Figure 2.

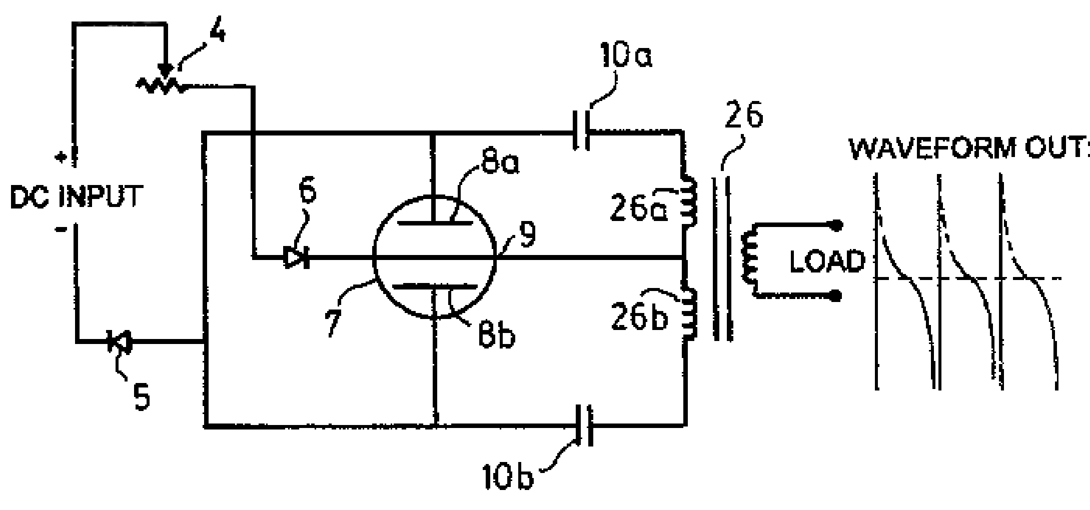


Figure 3.

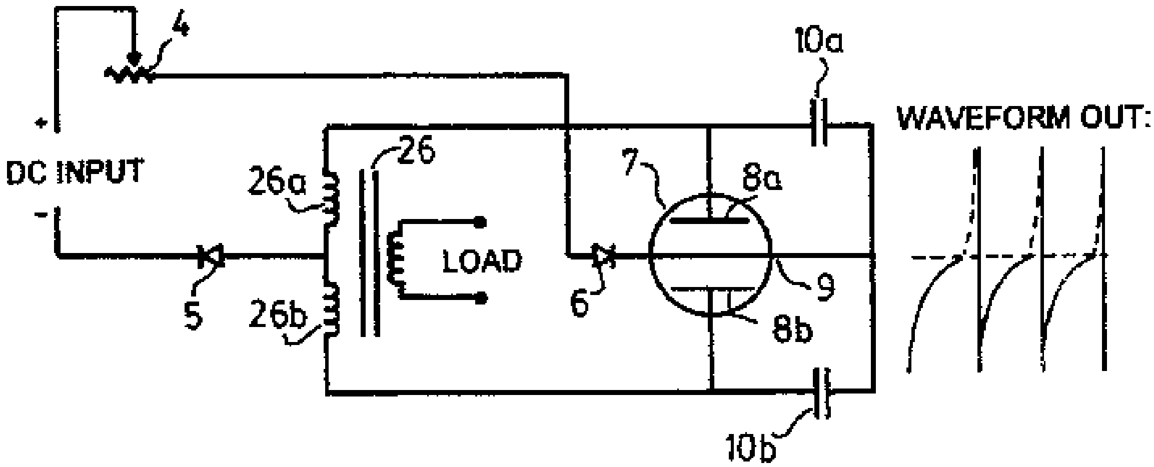
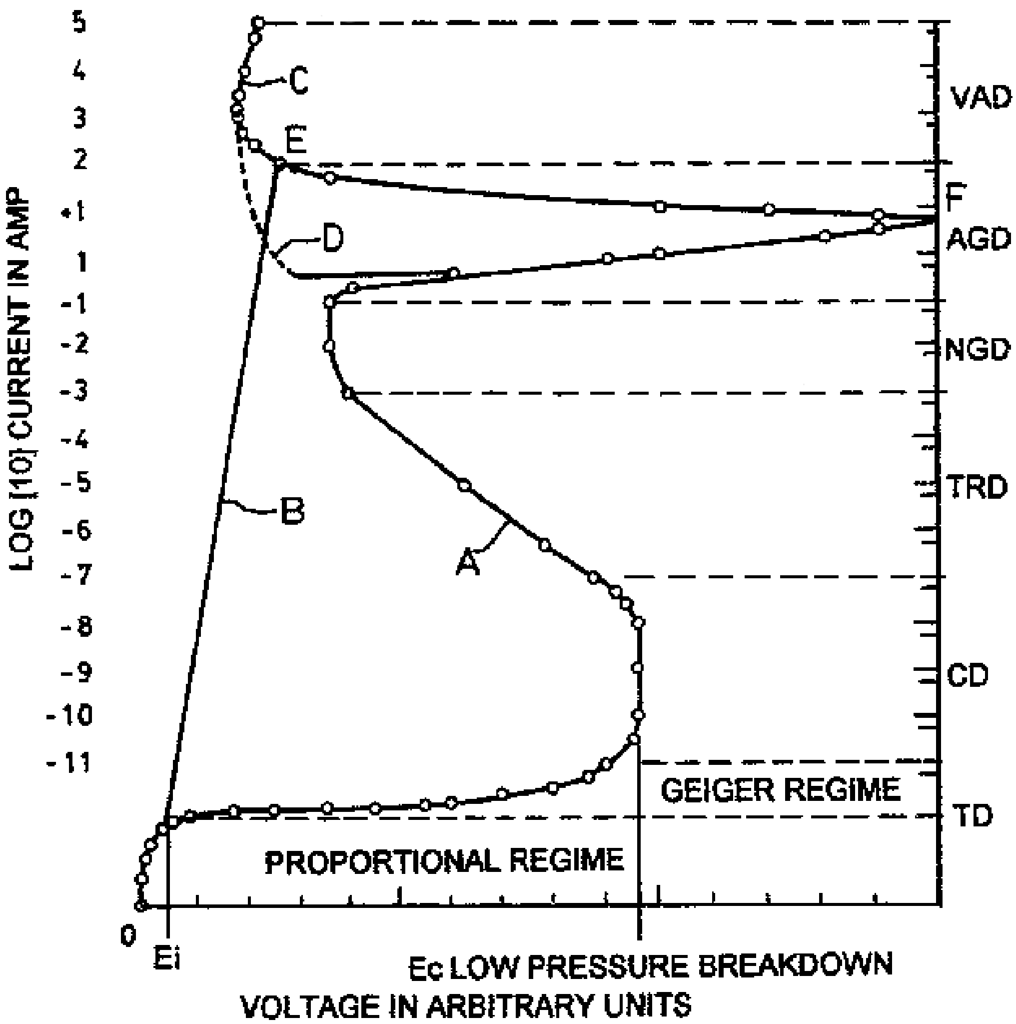
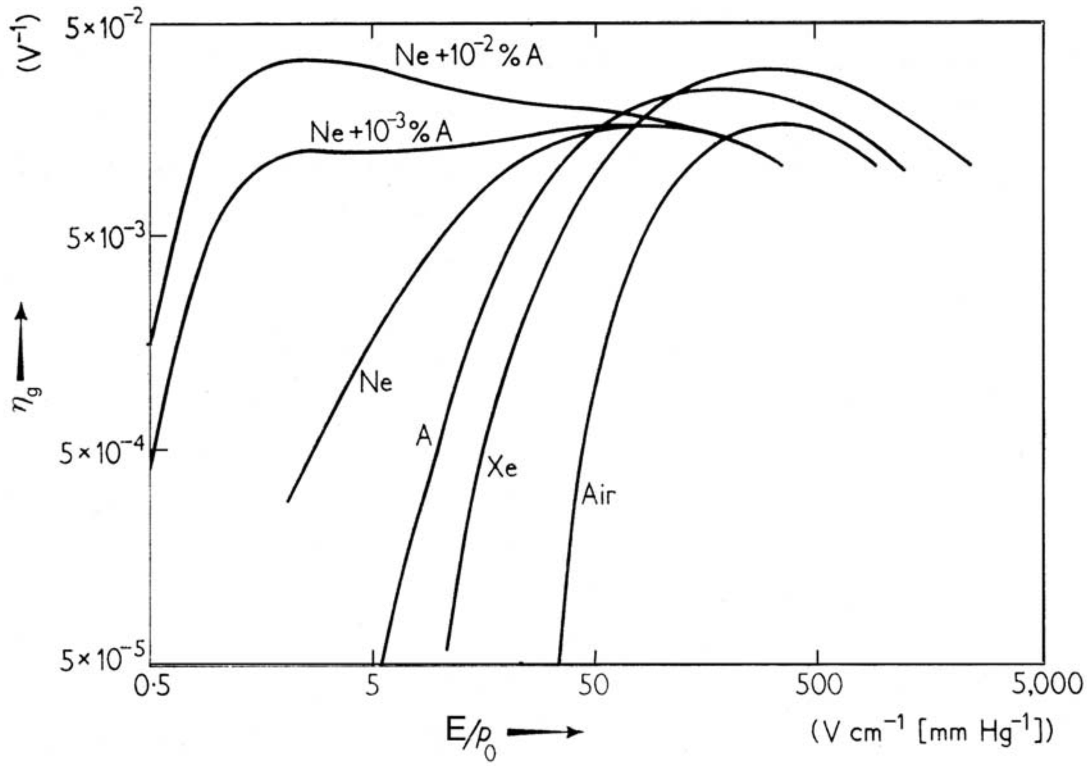


Figure 4.



development being a few μsecs). This current charges the capacitors and places a growing positive bias on the cathodes at a rate depending upon the time constant for the parallel circuit. Eventually this bucking voltage is sufficiently large that the actual voltage between cathode and anode falls below V_r for the tube and the glow is extinguished. The capacitor has been continuously discharging at some rate back to the DC voltage source throughout this glow regime and, after the glow is extinguished, current continues to flow through the tube until the space charge in the tube has disappeared. Thus, the bucking voltage across the tube decays with some time constant until the applied voltage to the anode is once again sufficient to allow its initiation voltage and a new current pulse develops.

Figure 5. Electron ionization coefficient as a function of E/p_0 for various gases and mixtures.



The aspect of one cathode or two cathodes glowing sequentially vs. simultaneously is a detail that can be neglected in the big picture. The important details concerning the number of current pulses delivered per second and the total current per pulse is determined by (1) the anode voltage, (2) the standard glow current density, j, (see Equations 2), (3) the charging time constant, τ_2, for the capacitor-input source circuit and a few other less important factors. One immediately sees from this proposal that reducing the gas pressure reduces j and thus i through the tube so that it takes longer to build up the critical bucking voltage for discharge quenching and the number of pulses per second is reduced. Increasing p does just the opposite. Of course, another avenue of opportunity is to manipulate the magnitude of J in Equation 2b via variations in Z_m and V_r. Figure 5 illustrates how η_g varies with E/p for a variety of gases and Penning mixtures. Certainly xenon looks like a good choice to increase J compared to either argon or air. Xe-CO_2 mixtures might yield even better performance (around 70% Xe – 30% CO_2). From Table 3, hydrogen looks to be an interesting possibility. Even the Penning mixtures might be useful if one wishes to operate at lower applied voltages and higher or lower pressures.