EFFICIENCY OF SOLITARY-WAVES RADIATED BY THE DISCHARGE IN A CONFINED PLASMA COLUMN

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ABSTRACT

To day it is obvious to consider the radiation efficiency of the « Priore machine » which was reported to cure tumors in rats essentially imputable to the discharge in a plasma tube (1964). The ultra-sound radiation hypothesis has to be rejected because the huge transmission attenuation. We explain now the propagation of solitary-waves or solitons by the non linearity effects produced inside a confined plasma tube excited by a high frequency modulated by a low frequency square signal [10]. The soliton measured with success is the single solution of the Kortweg-de-Vries non linear differential equation. These non-scattered waves are called "pseudo sonorous" owing to the slow speed of the argon ions. The radiation is effective because the plasma column acts as a small dipole antenna in the near field area. The ion current distributions and the radiated electromagnetic fields have been measured inside two different laboratories (France and USA). The soliton theoretical magnitude has been expressed in terms of the Landau length, the mean distance between the two argon ions, and the Debye screen wavelength of the plasma. The TM wave radiated by the plasma antenna has been measured with success in a good agreement with the theoretical one. The spectral analysis showed a radiation for the low modulation frequencies comprised between 2 and 20 KHz associated with their odd harmonics. The deduced endogenous field has been recently used to calculate the ionic current induced along a nervous fiber which can be considered as an individualized electrical unit. The diffracted electric field of low frequency can reach several dozens of kV/m in a near environment [11]. The interaction between solitary waves and dielectric matter, for example the sea water, can give rise to Zenneck waves, practically propagating without attenuation [10].

INTRODUCTION

Around 1970 the analysis of the radiation of the « Priore machine » has been done as well as can be expected because of its extraordinary complexity. Nevertheless the absence of the X radiation has been proved and recently the ultrasound hypothesis has to be rejected because the huge transmission attenuation through the glass and the air medium. Most studies related to interactions between millimeter waves and living come from Russia and Eastern European countries. The Russian safety is stricter than that of most western countries, whose standards are only essentially based on the calculated thermal load that would be produced on people exposed to R.F. radiations, especially during experiments that are necessary to develop high power military systems. In fact it was important to discover the possible biological fields subtle effects. We demonstrated [1], [2], [3] that the endogenous field inside a mouse radiated by a millimeter waves device may produce only subtle biological effects. So for f = 60 GHz an endogenous electric field comprised between 3 and 18 V/m has given rise to a direct or indirect effect on promotion of malignant tumors and an increased activity. In cellular membrane electric field of some V/m at a R.F frequency of several dozen MHz can create a strong agility of different ions. It is not easy to be on the safe side of the radiation protection limits as it is shown on an example at 900 MHz [12]. Furthermore different electromagnetic fields led to various biological effects when considering separately electric and magnetic induction fields of low frequencies [4].

We thought to analyse the low frequency radiation due to the ionic current discharge of a confined plasma [10]. We suppose a plasma without collisions. A gas at a partial pressure P and at the temperature T_o is introduced inside a quasi cylindrical column of a V_p vacuum volume. The discharge is lighted by means of two conductors located at each outside end of the column (collars or spirals) which are connected to an impedance adapter. This one is linked to a f high frequency generator modulated by square signals of f_r modulation frequency. Let us V be the difference of potential applied between the two collars. The theoretical maximum speed of the electrons inside the discharge is given by (1) :

$$\left(v_e\right)_M = \left(2.V.e / m_e\right)^{1/2} \qquad (1).$$

With V = 430 Volts measured at f = 27 MHz and $e/m_e = 1.76\ 10^{11}$, we deduced : $\left(v_e\right)_M = 1.2\ 10^7 \mathrm{m/s}$.

The plasma argon corresponds to the following parameters : P = 5T = 6.65 10^2 Pascals, $T_i \cong T_o$ =300 degrees Kelvin, T_e= 3.10^4 , $\alpha = n_e / \left(n_e + n_o\right)$: (2). The ionization degree is α with n_o and n_e the argon and electron densities. For a neutral gas : $n_e \cong n_i$ where n_i is the ionic density. The mean distance d_e between two electrons, or two ions, or one ion and one electron is roughly given by : $d_e = \left(n_e\right)^{-1/3}$. With $\alpha = 10^{-4}$ and $n_o = P/KT_o$ (3) where K is the Boltzmann constant we deduced from (3) : $n_o = 1.6.10^{23}$ per m^3, and from (2) : $n_e \cong n_i = 1.6.10^{19} / m^3$. The Debye potential around argon ion is : $\Phi = \left(e/4\,\pi\,\varepsilon_o\, r\right) \exp\left(-\, r / \lambda_{D_e}\right)$ (4), with the Debye electronic wavelength : $\lambda_{D_e} = \left(\varepsilon_o K T_e / n_e.e^2\right)^{1/2}$ (5).

The Landau length is : $r_o = e^2 / 4\pi\varepsilon_o\, KT_e$ (6) and the Debye screen wavelength : $\lambda_S = \lambda_{D_e} / \sqrt{2}$ for a single ionized gas. We deduced : $\lambda_{D_e} = 3\mu\mathrm{m}$, $r_o = 5.6.10^{-4}\ \mu\mathrm{m}$, $\lambda_S = 2.1\mu\mathrm{m}$, $d_e = 0.4\mu\mathrm{m}$. In that case the plasma is a cinetic classic one with : $r_o << d_e << \lambda_S$. It can be given as a perfect gaz faintly ionized. The discharged column is equivalent to a dipole of L length. That is the problem of plasma antennas [6]. Let us assess v_i the ion speed. Three assessments are given :

- Impact ion-electron : $\left(v_i\right)_c \# \left(2m_e / m_i\right)\left(v_e\right)_M$ (7) , with $m_i = 6.63.10^{-26}$ Kg
- Thermic speed : $\left(v_i\right)_{th} = \left(2KT_i / m_i\right)^{1/2}$ (8), with $K = 1.38.10^{-23}$ J/deg.
- Laplace formula : $\left(v_i\right)_L = \left(\gamma\ KT_o / m_i\right)^{1/2}$ (9), with $\gamma = 1.402$.

We found with the previous values : $\left(v_i\right)_c = 324 \mathrm{m/s}$, $\left(v_i\right)_{th} = 352 \mathrm{m/s}$, $\left(v_i\right)_L = 296$ m/s. The phase speed C_S is given by : $C_S = \left(KT_e / m_i\right)^{1/2}$ (10). It is a no dispersive wave [7] and C_S equal to : 2500 m/s.
The radiation of the ionic current is explained because of the discharge length L = 0.30 m is in some idea with the wavelength C_S / f_r. In effect for $1 \le f_r \le 10\mathrm{KHz}$, we have $0.25 \le C_S / f_r \le 2.5\mathrm{m}$. The radiated wave kind is of transversal electromagnetic. The theoretical electric field $\left|\left(E_\theta\right)_{f_r}\right|$ radiated at the distance r from the ionic discharge current : $\left|I_{f_r}\right|$ is given by :

$$\left|\left(E_\theta\right)_{f_r}\right| = L.\left|I_{f_r}\right| / r^3 .4\,\pi\,\varepsilon_o.\omega_r \qquad (11)$$

The relation (11) is available if : $\left(\mu_o \varepsilon_o\right)^{1/2} \omega_r r << 1$ and $r >> L$.

$$\left|I_{f_r}\right| \text{ is given by : } \left|I_{f_r}\right| = 2\,\pi\, f_r e \left(\Delta n_i\right)_{f_r}.V_P \qquad (12)$$

$(\Delta n_i)_{f_r}$ is the argon ion density used in the discharge, in non correlation with the non linear effects. From (11) and (12) we deduced the useful argon ions :

$$(\Delta n_i)_{f_r}.V_p = \left|(E_\theta)_{f_r}\right| r^3 4\,\pi\,\varepsilon_o \,/\, eL \qquad (13)$$

For various frequency f_r (0.5, 1, 4, 6, 8 and 10 KHz) the measured field $\left|(E_\theta)_{f_r}\right|$ was practically constant. So with (13) we can conclude that the useful argon ions are independent of f_r . We will put : $\Delta n_i = (\Delta n_i)_{f_r}$ (14). The table I shows for f_r =2KHz the measured electric field and the theoretical one calculated for $\left|I_{f_r}\right|$ =0.14 10^{-6} A, expressed in terms of r (11).

r(m)	0.90	1.10	1.30	1.50	1.70	1.90	2.20	2.35
Measured	33	27	13	10	6	3.3	2.6	1.9
Theory (11)	40	22	13	8.7	6.0	4.3	2.8	2.3

Table I : Electric field (mV/m) $\left|E_\theta\right|$ at f_r =2 kHz [10]

We put : $\Psi_M = \Delta n_i \,/\, n_i$ (15) which is the solution of Kortweg-de-Vries non linear equation, called solition [9]. With $\left|E_\theta\right| = 4.3.10^{-3}$ V/m (Table I) and from (13) for $r = 1.90\text{m}, f_r = 2.10^3\text{Hz}, V_p = 10^{-3}\text{m}^3$, and $L = 0.3\text{m}$, we find : $\Delta n_i = 6.8\,10^{10}$ ions / m^3 and $\Psi_M = 4.2\,10^{-9}$.

The purity of the spectra for the most characteristic rays is shown in Table II and III measured at fr = 2 and 10 KHz, with r = 0.75m.

f(k Hz)	0.45	0.8	1.2	1.6	2	2.45	2.8	3.2	3.55	4	4.45
$\left|E_\theta\right|$ m V/m	3.3	3.3	7.5	1.7	70	1.3	10	2.6	3.3	3.3	2.6

Table II - Purity of the electrical field radiated : $f_r = 2$ kHz $r = 0.75$m [10]

f(k Hz)	6.5	7.5	10	11.5	12.1	13.5	14.5
$\left|E_\theta\right|$ m V/m	1.3	2.7	107	13	3.4	1.7	0.8

Table III - Purity of the electrical field radiated : $f_r = 10$ kHz, $r = 0.75$m [10]

The induction magnetic field deduced from (11) is equal to : $\left|(H_\phi)_{fr}\right| = \varepsilon_o\, \omega_r\, r \left|(E_\theta)_{f_r}\right|$ (16).

So for 0.9 < r < 2.35m et $f_r = 2.10^3$Hz, we deduced the very weak values : $5.10^{-15} \le \left|\beta_\phi\right| < 7.5.10^{-16}$ Telsa. The experimental results shown in Tables I, II, III, have been obtained at the University of Rennes 1.

The following measurements of the discharge ionic current were carried out in Albuquerque (USA) using an equivalent device shown in fig 1, which is more powerful. In effect the plasma is started from a 50 Telsa pressure, that is $6.65.10^3$ pascals, of argon 80 %, neon 20 % mixed with a small amount of mercury added into the tube. Tube length, without electrodes, is approximately 60cm. Tube outer diameter is 25mm. Inside diameter is about 22 mm (fig 1). Antenna tuner with a balun allows a correct matching between the tube electrodes and the amplifier output. The S.W.R indicates the optimum functioning. Typical power levels for all frequencies were around 295 to 300 watts (instead of 100 watts at University of Rennes). A square wave generator modulate at the frequency f_r the high frequency signal of 27 MHz : - The higher pressure makes the tube get too hot. As the mercury ionizes a much greater diameter plasma will form. The high temperature $(T_i)_{Hg}$ of mercury ions explains their reradiation at $(\lambda)_{Hg}$ comprised between 0.4 and 0.7 μm in the visible range with $(\lambda)_{Hg} = hc / K(T_i)_{Hg}$ (17). (h is the Planck constant). With $0.4 \le (\lambda)_{Hg} \le 0.7\mu m$, we deduced from (17) : $2.1.10^4 \le (T_i)_{Hg} \le 3.6.10^4$ (Kelvin). Absorbed progressive waves due to ionized mercury atoms appears inside the plasma tube (fig. 2). For $f_r = 8\,kHz$ we find with λ_{Hg} =5.9 cm after $\lambda_{Hg} = (C_S) / f_r$ (18) the phase speed $(C_S)_{Hg}$: $(C_S)_{Hg}$ =472 m/s. The table IV shows the λ_{Hg} for different frequencies f_r .

$f_r(kHz)$	2	3	4	5	6	7	8	9	10	Origin
λ_{Hg} (measures)	23.8	16.0	11.9	9.5	8.3	7.0	5.9	5.1	4.6	Albuquerque
λ_{Hg} (18) (theory)	23.6	15.7	11.8	9.4	7.9	6.7	5.9	5.2	4.7	Rennes

Table IV : Wavelengths/cm of progressive mitigated waves of mercury ions

The measurements confirm the wavelength law in inverse proportion of the modulation frequency f_r (18). This progressive wave is non-dispersive wave for C_S is independent of f_r.

Non linear waves or solitons theory. An hydrodynamic theory can explain their formation. The theory is unidimensional : [9]. Its knowledge will permit to find the argon ion density used in the discharge. The normalized potential $\phi = e\Phi / KT_e << 1$ (4) respond to a second order differential equation, the maximum of which ϕ_M being given by the equation :

$$\exp(\phi_M) + \left(\frac{V}{C_S}\right)\left[\left(\frac{V}{C_S}\right)^2 - 2\phi_M\right]^{1/2} = 1 + \frac{V}{C_S} \quad (19).$$

Let V / C_S be equal to $1 + \nu_o$. For a solitary impulse single solution, we have to respect the inequality : $\phi_M < \frac{1}{2}(1+\nu_o)^2$ (20). A limit development of (19) gives : $\nu_o = \phi_M^3 / 3$ (21). The table V shows ν_o (19) and ν_o (21) in terms of ϕ_M.

ϕ_M	10^{-3}	5.10^{-3}	10^{-2}	0.025	0.05	0.10	0.15	0.30	0.50
$\nu_o = \phi_M^3 / 3$ (21)	$3.3\ 10^{-10}$	$4.1\ 10^{-8}$	$3.3\ 10^{-7}$	$5.2\ 10^{-6}$	$4.2\ 10^{-5}$	$3.3\ 10^{-4}$	$1.1\ 10^{-3}$	$0.9\ 10^{-2}$	$4.2\ 10^{-2}$
ν_o (19)	$3.3\ 10^{-10}$	$4.2\ 10^{-8}$	$3.4\ 10^{-7}$	$5.4\ 10^{-6}$	$4.5\ 10^{-5}$	$3.9\ 10^{-4}$	$1.4\ 10^{-3}$	$1.4\ 10^{-2}$	$7.6\ 10^{-2}$

Table V : ϕ_M Solution of (19) and (21)

The normalized potential of the first kind such as : $\psi = \varepsilon\phi_1$ follows the non linear equation of Kortweg-de-Vries (22) : $\partial\psi / \partial\tau + \psi\, \partial\psi / \partial\xi + (1/2).\ \partial^3\psi / \partial\xi^3 = 0$ (22). The normalized variables are :

$$\tau = \varepsilon^{3/2}.\omega_{p_i} t \qquad \xi = \varepsilon^{1/2}\left(x / \lambda_{D_e} - \omega_{p_i} t\right) \quad (23) \qquad \text{with : } \omega_{p_i} = e\left(n_i / \varepsilon_o m_i\right)^{1/2}$$

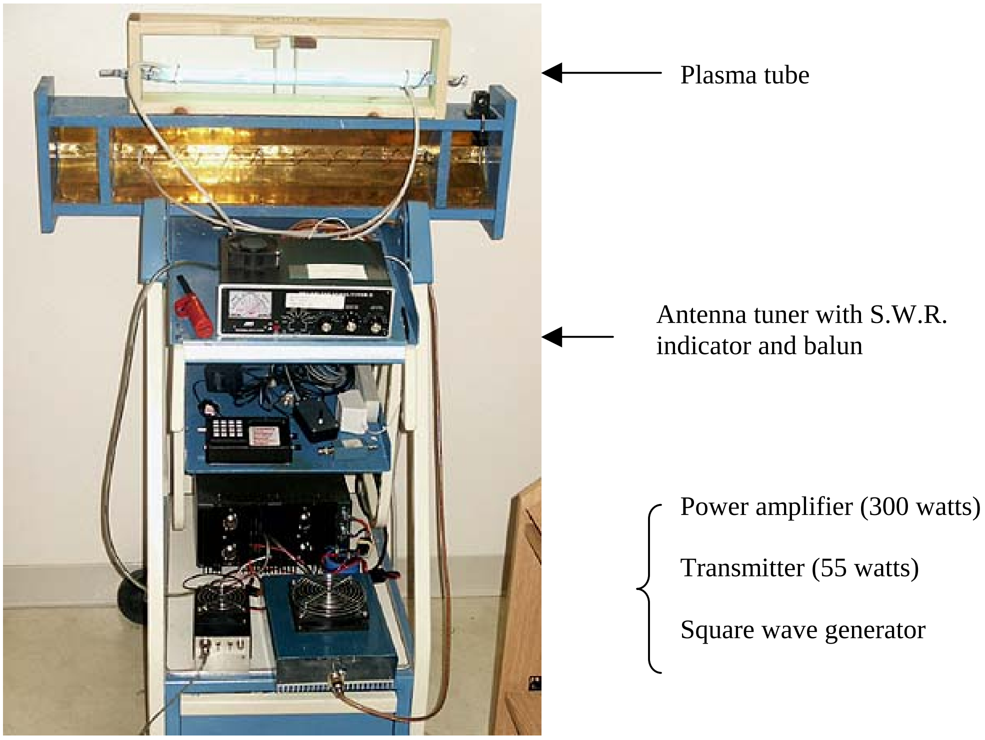

figure1 : Equipment (USA)

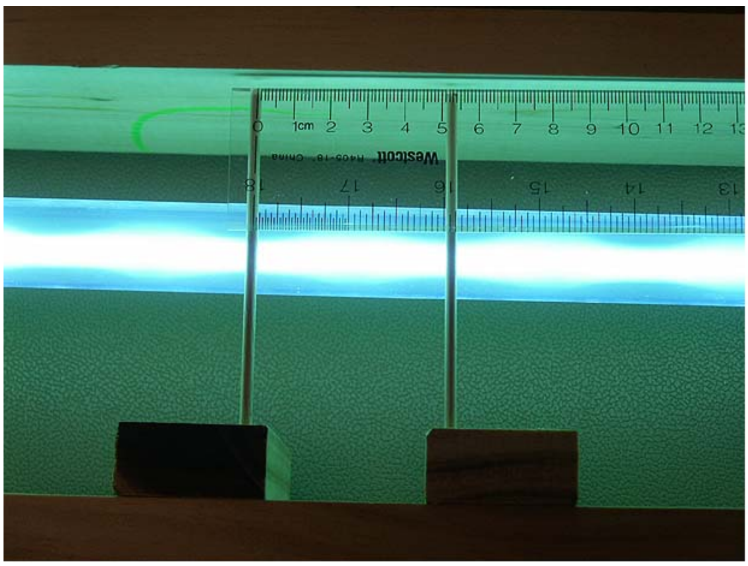

figure 2 : Progressive mitigated waves due to ionized mercury atoms ($f_r = 8.10^3$ Hz) (USA)

ω_{p_i} is the pulsation of ionic plasma : $\omega_{p_i} = e\left(n_i / \varepsilon_o m_i\right)^{1/2}$, and λ_{D_e} the Debye electronic wavelength : (5). The single solution of (22) called "soliton" is given by :

$$\psi = 3\nu_o \sec h^2 \left[(\gamma_o / 2)^{1/2} (\xi - \nu_o \tau)\right] \quad (24)$$

With (23), we can write (24) like that (25) :

$$\psi(x, t) = 3\gamma_o \sec h^2 \left\{(\nu_o \varepsilon / 2)^{1/2} \left[x / \lambda_{D_e} - \omega_{p_i} t \,(1 + \varepsilon \nu_o)\right]\right\} \qquad (25)$$

ψ is the fluctuation of the ions density following the long time scale which is normalized to the whole ions.

The function sech is lower than one. So we can write with (15) : $\psi_M = 3\nu_o = \varepsilon(\phi_M)_1 = \Delta n_i / n_i$ (26)
The soliton speed is equal to :

$$V_S = \left(KT_e / m_i\right)^{1/2} . \left(1 + \varepsilon \nu_o\right) \qquad (27)$$

From (26) we deduced : $\nu_o \varepsilon = \psi_M^2 / 3(\phi_M)_1$ and with (21) :

$$(28) \quad \nu_o \varepsilon = \left[(\phi_M)_1\right]^{5/3}, \qquad \psi_M = \left[(\phi_M)_1\right]^3 \quad (29), \qquad \varepsilon = (\phi_M)_1^2 \quad (30)$$

With the mean distance d_e between two ions : $d_e = (n_e)^{-1/3}$, (4), (6) we deduced for the normalized potential :

$$(\phi_M)_1 = \frac{r_o}{d_e} . \exp\left(-\frac{d_e}{\lambda_{D_e}}\right) \quad (31).$$

From (26) and (29) we have :

$$\psi_M = \Delta n_i / n_i = \left[(r_o / d_e) \exp\left(-d_e / \lambda_{D_e}\right)\right]^3 \qquad (32)$$

The found experimental value obtained at the University of Rennes 1 : $\Delta n_i / n_i = 4.2.10^{-9}$ (26), and related in our paper, can be compared with the theoretical one : (31). We have already calculated : $r_o = 5.6.10^{-4}\,\mu m$, $d_e = 0.4\,\mu m$, $\lambda_{D_e} = 3\mu m$. We find $\psi_M = 1.8.10^{-9}$ and from (29) or (30) : $(\phi_M)_1 = 1.2\ 10^{-3}$ and $\Phi_M = 3.1\,mV$. Besides with (4) and $r = d_e$, which is the mean distance between two ions, we calculate : $\Phi = 3.8\,mV$ and $\phi = 1.5.10^{-3}$. So we proved the correlation between the hydrodynamic theory and the experiments and confirm the judicious choice of the plasma parameters. We have to note that the soliton speed (27) with : (10) depends of its amplitude $3\nu_o$ but is near C_S. The Table VI shows the variations of the parameters ε : (30), $\nu_o \varepsilon$: (28), and ψ_M : (29) in terms of Debye's normalized potential $(\phi_M)_1$ (31).

$(\phi_M)_1$ (31)	10^{-3}	5.10^{-3}	10^{-2}	0.025	0.05	0.1	0.15	0.30
ε (30)	10^{-6}	$2.5\,10^{-5}$	10^{-4}	$6\ 10^{-4}$	$2.5\,10^{-3}$	10^{-2}	$2.2\,10^{-2}$	0.09
$\nu_o\varepsilon$ (28)	$3\,10^{-16}$	10^{-12}	$3\,10^{-11}$	$3\,10^{-9}$	10^{-7}	$3\ 10^{-6}$	$2.5\ 10^{-5}$	8.10^{-4}
$3\,\nu_o = \psi_M$ (29)	10^{-9}	10^{-7}	10^{-6}	$1.6\,10^{-5}$	$1.2\,10^{-4}$	10^{-3}	$3.3.10^{-3}$	0.03

Table VI : Non linear effect of the confined plasma

Soliton factorization in Fourier series. The short time between two impulses is equal to $1/f_r$. The time return to the balanced plasma is done following the law : exp(-t/τ_p), with the τ_p relaxation time equal to :

$$\tau_p = (1/e)(\varepsilon_o m_e / 2n_e)^{1/2} << 1/f_r \qquad (33).$$

The plasma electronic pulsation is : $\omega_{p_e} = e(n_e / \varepsilon_o\, m_e)^{1/2}$ (34).

With $m_e = 0.91.10^{-30}$ Kg, $n_e = 1.6\ 10^{19} / m^3$, we obtain : $f_p = 36$ GHz and $\tau_p = 3\text{ps} = 3.10^{-12}\text{s}$.

We have : $\tau_p << 1/f_r$. Let $\psi(t)$ be : $\psi(t) = b_o + \sum_{N=1}^{\infty} b_N \cos(N\omega_r t)$ (35)

With (25) the b and b_N coefficients are found :

$$b_o = 3f_r\nu_o \int_{-1./4f_r}^{1/4f_r} \sec h^2 \left[(\nu_o\varepsilon/2)^{1/2}.\omega_{p_i}\ t\right] dt \qquad (36)$$

$$b_N = 6f_r\nu_o \int_{-1/4f_r}^{1/4f_r} \sec h^2 \left[(\nu_o\varepsilon/2)^{1/2}.\omega_{p_i}\ t\right].\cos(N\,2\,\pi\, f_r\ t)\, dt \qquad (37)$$

ω_{p_i} is the ionic plasma pulsation : $\omega_{p_i} = e\,(n_i/\varepsilon_o\ m_i)^{1/2}$ (38). With $m_i = 6.63\,10^{-26}$ Kg, $n_i = 1.6\,10^{19} / m^3$, we find : ω_{p_i} =0.84 10^9. The numerical calculus shows the independence of the b_o and b_N coefficients in view of the frequency modulation f_r just like is the soliton : $\Psi_M = \Delta n_i / n_i$.
With $\nu_o = 1.4\,10^{-9}$, $\nu_o\varepsilon = 1.6\,10^{-15}$ and ω_{p_i} =0.84.10^9 we calculate (36) : $b_o = 1.65.10^{-9}$ and b_N given in table VII :

N	1	2	3	4	5	6	7	8	9
b_N (37)	2.10^{-9}	9.10^{-15}	7.10^{-10}	4.10^{-15}	4.10^{-10}	10^{-15}	-3.10^{-10}	$1.6.10^{-12}$	$2.3.10^{-10}$

Table VII : Fundamental and harmonics frequencies

The even harmonic levels are weaker than the odd ones as it has been found experimentally. On the other hand for a higher normalized potential ex : $(\phi_M)_1 = 2.5.10^{-2}$ instead of $1.2.10^{-3}$ all calculated harmonics are of some idea of the amount.

Expansion to a highly ionized plasma. With (13) and (32) we deduced the radiated electric field which is independent of f_r :

$$|E_\theta| = \left(e\, LV_p\, n_i / 4\,\pi\,\varepsilon_o r^3\right)\left[\left(r_o / d_e\right). \exp\left(-\, d_e / \lambda_{De}\right)\right]^3 \qquad (39)$$

With (2) and (3) we can write :

$$n_i = \alpha.P / \left[KT_o(1-\alpha)\right] \qquad (40)$$

where P is the gas partial pressure at T_o and α the ionisation degree. In (39) we have to note the LV_p homogeity : a length to the power of four.

From (6), (39) and (40) and expressed in units of international system we can write :

$$|E_\theta| = \frac{L.V_p.n_i^2\; 6.7.10^{-24}}{r^3\, T_e^3}\left[\exp\left(-\,\frac{0.015\, n_i^{1/6}}{T_e^{1/2}}\right)\right]^3 \qquad (41)$$

and :

$$n_i = \frac{\alpha}{1-\alpha}.P.2.4\,10^{20} \qquad (42)$$

P is expressed in pascals, n_i the ion number per m^3, L in meters, V_p in cubic meters, r in meters and $|E_\theta|$ in Volts per meter.

We have shown [10] that the interaction between solitary waves and dielectric matter can give rise to Zenneck wave or surface waves, practically propagating without attenuation.

SUMMARY

We brought to the fore the solitary waves radiation emitted by a confined plasma column weakly ionized by a high frequency discharge. The high frequency is modulated in square signals at low frequencies. Between two pulses the plasma is balanced again for the modulation frequency is very much lower than the plasma electronic one. The argon low ion speed creates non dispersive waves called “pseudo sonorous”. Their evaluation appeals to the non linear effects inside the plasma discharge following the hydrodynamic theory. The theoretical results are in good agreement with the experimental ones. In particular absorbed progressive waves due to some ionized mercury atoms immersed in a hot plasma of argon (80 %) and neon (20 %) have been visually detected. The solitary waves are radiated by the plasma discharge which acts like a doublet antenna functioning in TM mode. We showed that the useful ion number in the discharge is independent of the modulation frequency and its harmonics. We have expressed the soliton amplitude in terms of the fundamental caracteristics of the plasma (32) : the Landau length, the mean distance between two ions and the Debye screen wavelength. The theoretical near electric field radiated by the “plasma antenna” appears in terms of the volume and the length of the column, the ion density, and the electronic temperature (41). This emission of low frequency pulsed electromagnetic fields can be the subject of ionics currents induced along a nervous fiber and reradiation of that low frequency but high amplitude electric field in the interstitial medium [11], and then the excitation of ions which can induce an ultraviolet radiation liable to penetrate into the cells [13].

REFERENCES

[1] A. BELLOSSI, G. DUBOST, J.P. MOULINOUX, M. HIMDI, M. RUELLOUX, C. ROCHER : « Biological Effects of Millimeter-wave irradiation on Mice. Preliminary Results”. IEEE Transactions on Microwave Theory and Techniques. Vol. 48, n° 1, Nov. 2000 (p. 2104 to 2110).

[2] A. BELLOSSI, G. DUBOST : “Préventions des effets biologiques des ondes millimétriques aux fréquences 28, 38, 60, 77 et 90 à 100 GHz”, R.S.T.D. : Revue Scientifique et Technique de la Défense, 50 – 2000-4, Déc. 2000, (p. 45 à 55).

[3] G. DUBOST, A. BELLOSSI, M. HIMDI : “Effects of 60 GHz electromagnetic fields on motor activity of healthy mice”. 6th congrès annuel de la Société Française de Pharmacologie, Avril 2002, Rennes, France.

[4] A. BELLOSSI, G. DUBOST, M. HIMDI : « Effets biologiques du champ électrique et du champ d’induction magnétique aux très basses fréquences, R.S.T.D. : Revue Scientifique et Technique de la Défense, 1997-4 (p. 83 à 96) .

[5] G. DUBOST : « Propagation libre et guidée des ondes électromagnétiques. Applications aux guides et fibres optiques ». Masson, 3è Edition, 1995 (291 pages).

[6] G.G. BORG, J.H. HARRIS, N.M. MARTIN, D. THORNCRAFT, R. MILLIKEN, D.G. MILJAK, B. KWAN, TNG, J. KIRCHER : « An investigation of the properties and applications of plasma antennas ». Switzerland-Millenium Conf. on Antennas and Propagation Davos, April 2000.

[7] D. QUEMADA : « Ondes dans les plasmas ». Collection de Physique du CNES. 1968.

[8] J.P. DAVID : Cours de Radioélectricité Générale. Tome 4, « Propagation des ondes », ENST – Paris, 1948.

[9] J.L. DELCROIX, A. BERS : « Physique des plasmas ». Tomes I (375 pages), et II (499 pages). Inter Editions/CNRS, 1994.

[10] G. DUBOST, A. BELLOSSI : “Rayonnement et propagation d’ondes solitaires générées par un plasma confiné”. R.S.T.D. : Revue Scientifique et Technique de la Défense, Sept. 2002, p. 115 à 126.

[11] G. DUBOST, A. BELLOSSI : “Rerayonnement in situ d’une fibre nerveuse irradiée par un champ électromagnétique externe de très basse fréquence”. R.S.T.D. : Revue Scientifique et Technique de la Défense, 61, Octobre 2003, p. 127 à 140.

[12] G. DUBOST, A. BELLOSSI, M. HIMDI, J.P. DANIEL : “Safety irradiation of humans by R.F near fields due to dipoles”. J.I.N.A. 98, Nice, Int. Symposium on Antennas, p. 639 to 641.

[13] G. DUBOST, A. BELLOSSI : “Modèle physique de la membrane cellulaire dans les spectres infrarouge, visible et ultraviolet ». R.S.T.D. : Revue Scientifique et Technique de la Défense, n° 64, Juin 2004 (15 pages).