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The Radio Frequency System dedicated to the Study of Carbon Nanotubes Behaviour in RF Field

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Abstract – A new class of outstanding carriers, in the therapy of diseases from the last years, carbon nanotubes (CNTs), is under attention for its applicative potential in a variety of biomedical domains. In the present study, we observed that the SWCNTs, treated in a RF field could significantly improve the cellular death ratio in the liver carcinoma Hep2G cell line. The antenna designed for this study generates the RF field. The use of 13.56 MHz frequency leads to remarkable results in biomedical applications. The proposed device is capable to control the power of the electromagnetic wave and the time of exposure. The study approach is focusing also over the effect of the TF field inside the VOI (volume of interest). The conclusion, according to which the SWCNTs induce necrosis in tumor cells for different concentrations and RF power, is the most notable contribution. The experimental results lead to the idea according to which the SWCNTs provoke cell death in the absence or in the presence of the RF field. Putting the facts together, we state that the SWCNTs in the presence of the RF field contribute to the regulation of the death pathways of cancer cells.

Keywords: SWNT, Near Field Region, antenna, cytotoxicity, ELM Field, RF

I. INTRODUCTION

Since 2007 Richard Kanzius, an American RF Engineer, studied the effect of electromagnetic field on different nanostructures. His research was focusing on the thermal effect of nanoparticles (hypertermic cytotocicity). Knowing that the chemotherapy and radiotherapy are extremely brutal procedures, the purpose of this method is to obtain high rate of cytotoxicity with low radiation (less time, less power), developing less invasive procedures. Richard Kanzius is known as being the first who used a RF Generator, with a transmitter head on 13.56 MHz.

The device proposed in this paper has two significant improvements: eliminates the RF Receiver and the receiving head, using a probe located in the middle of the antenna. A probe inside the antenna (VOI -volume of interest) senses the signal and sends this information on, to an indicator. The frequency can be adjusted into a wide range in-between 5 to 30 MHz.

Medical experiments state that the cell viability may be judged by morphological changes in membrane permeability. Also, the cell viability is in relation with its physiological state. This interferes with the exclusion of the certain dye cells with the uptake or the retention of the others.

An evaluation of the effect over nanostructures (SWNT-COOH) together with the human hepatocellular cell line (Hep2G) with respect of the cytotoxicity is the main concern of the paper. The effect of the cytotoxicity induced by the nanostructures in the presence or the absence of the RF field plays a key role in the evaluation approach.

Section II presents the experimental scheme and reveals the basic procedures of the proposed experiment. Section II together with the experimental device also reveals the medical needs regarding to the VOI as EM fields zone and medical region, which share together the same space. In Section III, there is a detailed description of the device as a whole, and Section IV presents the results. The last section synthesizes the results and conclusions from sections V and VI.

II. EXPERIMENTAL DESIGN

Serving the purpose to offer a tool to Researches Institutes for examining the behavior of different structures (cells, nanotubes functionalized with different pharmaceuticals and others) in a RF field, we imagine the use of a High Power RF Generator together with an inductive antenna in order to define a VOI experimental region. The guideline for the design was the requirements of the Oncological Institute Ion Chiricuta from Cluj-Napoca, as follows:

- The VOI should be minimum L=127 mm, l=87 mm, h = 27 mm,
- The electromagnetic energy should be able to be measured
- The electromagnetic energy should be constant
- The electromagnetic energy should be focused mainly on the probe placed in VOI
- The operator should be protected against radiations
- The system to be able to measure both thermal effect and RF effect above the cells
- Antenna must be used in the near field region

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• The coupling with Power Amplifier (final stage) should be 50 W

In order to meet all these requirements, the loop antenna is the most suitable to fulfill the VOI constrains.

Another decisive factor related to the region in which the probe operates, known as near field region, has been taken into consideration in the design stage of the antenna.

There are three important regions around an antenna:

1. The Reactive Near Field region is that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates.

2. Radiating Near-Field region (Fresnel region) is that region of the field in-between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon the distance from the antenna.

3. Far Field region (Fraunhofer region), is bounded by the zone of the field where the angular field distribution is essentially independent upon the distance from the source.

III. SYSTEM DESCRIPTION

The system composed of a Radiofrequency Generator and a chain of RF Amplifiers generates an electromagnetic field by means of a directional antenna in the near field area (VOI - volume of interest).

The purpose of the system is to generate in the VOI a RF high power field, under control, in terms of power and frequency. The control offers the possibility of studying and experimenting the effect of the electromagnetic field on different nanostructures.

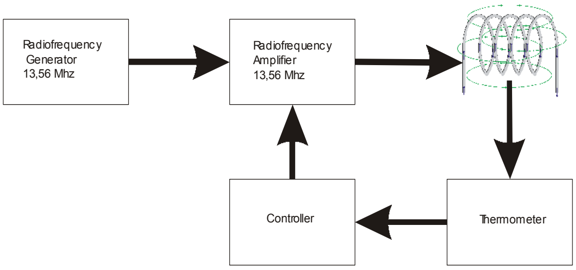


Fig. 1. Block Diagram of the system

Legally, for medical purposes, the frequencies are restricted in a narrow band around 13,56 MHz by ANCOM. The proposed device allows the modification of the frequency in the restricted range according to the ANCOM regulations to fulfill the VOI (inside the solenoid – Fig. 1).

From Fig. 2, 3 and 4 you can see an excellent tuning achievement at 13.56 MHz, the working frequency. At 13.56 MHz, the wavelength is 22 m. For a proper tuning the antenna length must be 0.25 times a wavelength. With the decrease of the frequency, the antenna design becomes extremely difficult.

At least 8 different antennas with different dimensions and diameters were analyzed. Each of the antenna sample with different diameters of the copper wire and different turns, all meeting the design requirements. After many tests and trials we concluded that the usage of an air variator is a must in order to fulfill all the requirements of the VOI. Finally, three models of antennas pass all tests: Lucky Antenna, Vivaldi Antenna and Kalashnikov Antenna.

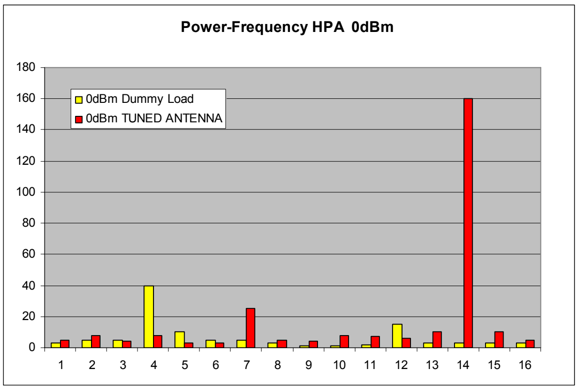


Fig. 2. The variation of power with the frequency for 1-15 MHz, measured between the High Power Amplifier and the antenna, in dummy load and in KALASHNIKOW antenna, at 0 dBm

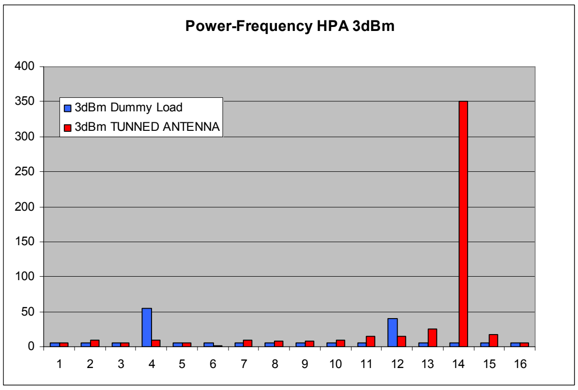


Fig. 3. The variation of power with the frequency of 1-15 MHz, measured between the High Power Amplifier and the antenna, in dummy load and in KALASHNIKOW antenna, at 3 dBm

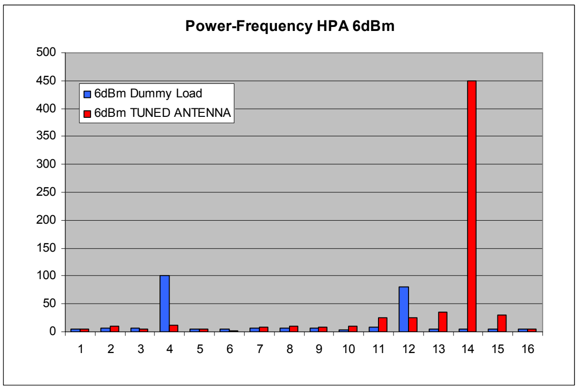


Fig. 4. The variation of power with the frequency of 1-15 MHz, measured between the High Power Amplifier and the antenna, in dummy load and in KALASHNIKOW antenna, at 6 dBm

Two different evaluation methods to analyze the behavior of the electromagnetic field inside the VOI have been used. The classic measurement method is to interpolate measured values of the field using a measurement tool between the power amplifier and the antenna. The MJF Mobile Tuner Antenna 945D,

fulfill this and indicates the Direct Power, Reverse Power and VSWR (Voltage Standing Wave Ratio).
The second measurement method is to sample the energy value exactly from the point of interest, in the middle of the antenna, using a RF probe. This method has the disadvantage of using as reference a second device and implies additional computations for transforming voltage into its equivalent electric fields, displayed in V/m. The previous graphics (Fig. 2, 3 and 4) reveal the measurements with Mobile Antenna Tuner.
Using both of the measurement techniques, we surprisingly remark that the two indications are not equal, even though they are not totally independent. This leads to the conclusion according to which, when the power transferred between the Power Amplifier and the Antenna is maximum, the RF power in the middle of the VOI is not. This phenomena change the strategy of the antenna design and the behavior of the VOI. A possible explanation comes from the near field theory, where the mathematical model is not well studied and known. The usage of the antenna in the bound proximity between the two regions (far and near) of the field changes the design strategy for medical applications. In fact, this device acts rather like a field applicator, and the second method offers the best fitting with the experimental results.

Table 1 Values of ELM Field inside Kalashnikov antenna

Line 1	Line 2	Line 3
1.10	1.58	1.33
2.55	2.74	2.35
3.52	3.30	3.42
3.01	3.13	3.14

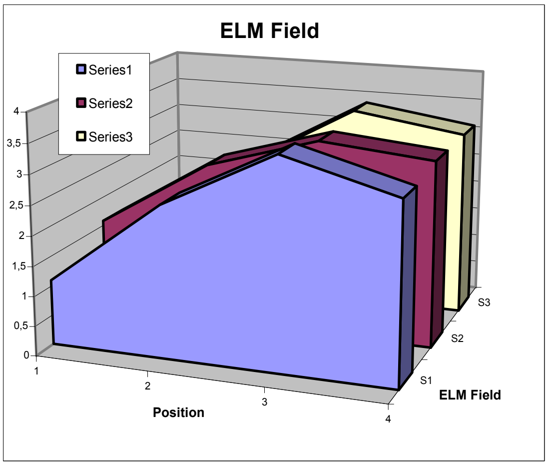


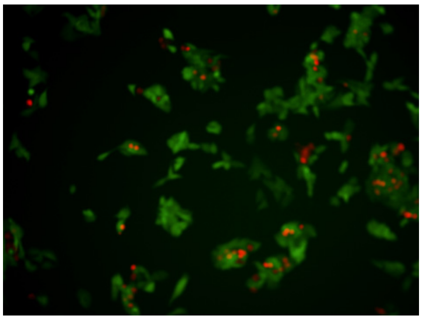
Fig. 5. Graphic of ELM Field, on lines, inside Kalashnikov Antenna

Another approach was to assure a constant ELM field inside the VOI. This constrain imposed by the Oncological Institute has been taken into account also into the stage of antenna choosing. For this, twelve punctual measurements along the multiwell plate of the medical probe have been made. All obtained results are shown in the Table 1 and in the Fig. 5.
The design of the VOI tries to keep all these values as close as possible in order to maintain the field almost constant along the multiwell plate. In Fig. 5 is the real distribution of the field which was used further to fulfill all laboratory tests.

IV. RESULTS

The first success has been encountered in designing the VOI and fulfilling the project requirements. The main objective has been offering constantly and precisely smooth the magnitude of the Electromagnetic Field inside the VOI.
Secondly, the ability to control and adjust to the desired value the Electromagnetic field, the field distribution being well defined, along the multiwell area. Finally, we have used the equipment in real laboratory conditions at Onchological Institute Ion Chiricuta following exactly the medical procedures which are described in the following:
Materials and methods. Nanosilver particles were added in Hep2G cell line. We have used two different concentrations 2,5 and 12,5 mg/L. For evaluating the results, we have used a microscopic assay with fluorescein diacetate (FDA) and propidium iodide (PI). First of all the evaluation has been made in the presence and after all in the absence of the RF field. The FDA/PI is a straightforward and rapid fluorimetric method to evaluate the integrity of the plasma membrane simultaneously based on inclusion and exclusion dyes; the method allows differentiating between viable and nonviable cells.

a) Nanosilver 12.5



b) Nanosilver 12.5 24 h

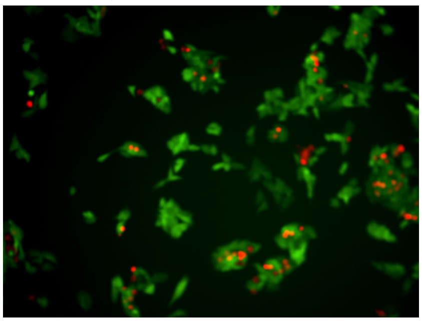
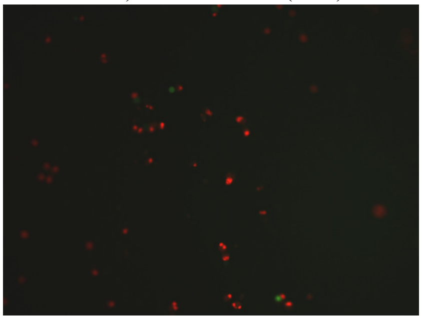


Fig. 6. Nanosilver particles, 12.5% concentration a) initial conditions, b) after 24 hours

a) Nanosilver 12.5 (1min)



b) Nanosilver 12.5 (1min) 24 h

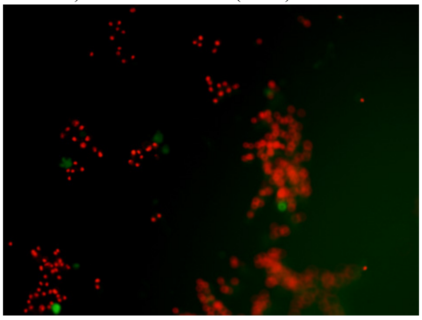
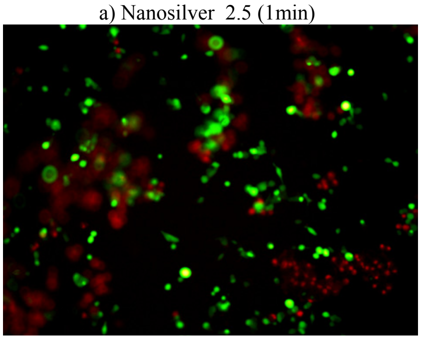


Fig. 7. Nanosilver particles, 12.5% concentration, radiated 1 min, a) initial conditions, b) after 24 hours

a) Nanosilver 2.5 (1min)



b) Nanosilver 2.5 (1min) 24 h

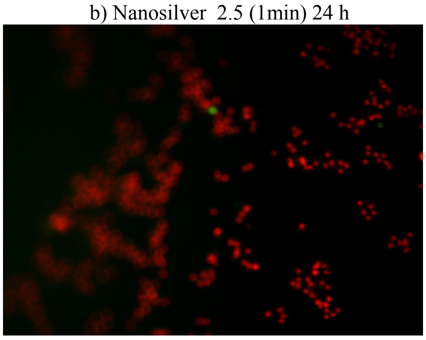


Fig. 8. Nanosilver particles, 2.5% concentration, radiated 1 min, a)initial conditions, b) after 24 hours

V. DISCUSSIONS

For the desired purpose - finding an antenna to be used in laboratory experiments, we have designed and built the antenna, meeting all project requirements by maintaining the field inside the VOI (volume of interests) almost constant. As we stated, one can use this system, to entirely control the field intensity along the multiwell plate to best fit the results for different cells. This can become an option in tumoral destruction of solid cancers.

VI. CONCLUSIONS

We have demonstrated that the cytotoxicity induced in the presence of RF is higher than it is in normal conditions. Further developments and research must be made in the direction of analyzing the changes at the level of the cell lines. These changes could be caused in different conditions of the field in terms of power, frequency and polarization adjustments. The idea of impinging the field outside the VOI, in order to extend its effectiveness to entire human body, could open a new path through other experiments and results.

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