Volume-3, Issue-7, July-2014 • ISSN No 2277 - 8160

Research Paper Engineering

# Measurement of The Strong EM Near-Field and its Effect Over The Carbon Nanotubes in The Proximity of The Multi Turns Inductive Solenoid


| | |
|---|---|
| **Dan Pantis** | ROMATSA Cluj-Napoca, Romania |
| **Nicolae Crisan** | Faculty of Electronics, Telecommunicationsand InformationTechnology Cluj-Napoca, Romania |
| **George MIHAI** | Development and Testing National Institute for Electrical Engineering - ICMET Craiova, Romania |
| **Monica Borda** | Faculty of Electronics, Telecommunicationsand InformationTechnology Cluj-Napoca, Romania |



**ABSTRACT** *The aim of the paper is to characterize the distribution of the electromagnetic field inside and near the solenoid applicator which should destroy the nanocarbon samples inside a multiwell culture plate. This approach, involving the use of nanotechnologies is of great interest nowadays in Cancer treatment. The paper presents some technical achievements as a result of ongoing collaboration between Ion Chiricuta Oncological Institute and Technical University of Cluj-Napoca. The anticipated demand in patients ongoing treatment led to the idea of broadening the frequency band of the applicator in-between 5-25 MHz, against other existing methods, that allow only a narrow band around 13.56 MHz. This approach has a great impact over the samples and increases the rate of cell necrosis.*


**KEYWORDS : VOI-(Volume of Interest), Electromagnetic Field, Field Intensity, twelve multiwells plate**

## 1. Introduction

In normal circumstances, a multi turn solenoid is used to produce a constant magnetic field along its core. The magnetic energy is preserved mostly in the near field of the coil. At lower frequencies up to 20 KHz the mathematical model accurately follows the behavior of the field but for higher frequencies especially in SW radio band there are no such models. Because of this complexity and of the the coupling dependency with the frequency a mathematical model that completely characterized the field will be in acurate. Accordingly there should be different mathematic models for different frequencies almost as many as radio bands. The complexity of the model goes beyond the expectations because of its dependency with the shape and the volume of the load which makes the mathematical modeling almost impossible. Another difficulty is encountered in the near field zone when the fields are too strong. The mathematical model has to consider the distortion of the signal too. All those problems and concerns make the point of study in this research work due to the properties of the carbon nano tubes in the presence of the strong fields of about hundreds of [H/m] or [V/m]. The aim of the paper is to characterize the distribution of the electromagnetic field inside and near the solenoid applicator, along and around the multi well culture plate. The system was designed according to the demands and requirements of the „Ion Chiricuta" Oncology Laboratory. These demands are presented in Chapter 2 and allow the behavior study of the Carbon Nano tubes in tumor samples. It is necessary to characterize very precisely the radiation field in the near field zone and to reduce as possible the radiation of the EM field in the far field zone (Table 3). Accordingly, a twelve multi well plate is inserted inside a solenoid (the field applicator) together with the cell probes (tissue samples).

The system proposed here offers an innovative tool to investigate the change at the chemical level of each sample under the effect of the EM field. Nor pharmacology terms neither oncology neither the medical interpretations are the topic of this paper. Only the characterization of the field and its effect over the carbon nano structures are the topics of the research. The medical results have been published separately in a different journal [ ]. In spite of the fact according to a mathematical model the magnetic field is constant along the solenoid for low frequencies, our experiments show that this assumption is no longer true for high frequencies. The determination of the field distribution is vital for a good outcome of the cancer treatment. In this article,we will follow the description of the EM distribution. According to the measurements, we will show in section 4 that the system allows a wider band of frequencies against the classical approaches that experience a relatively narrow bandwidth for a single frequency. This is the major contribution of the presented paper, contribution that broaden the spectrum in cancer treatment scheme.

## 2. The designand implementation

The requirements according to the research results [ ] developed in the framework of the project Role of Carbon nano structures in Cancer Research ongoing on Ion Chiricuta Oncological laboratory are following the main characteristics of the medical sample concerning its shape and size mainly. According to this, the main geometrical shapes of the multi well plate are shown in figure 2. Also the requirements that are following the EMI constraints are called further:

- At least 50% of the EM field must be applied inside inductive solenoid enclosed by the VOI (Volume of Interest)
- VOI should have at least: L=127 mm, l=87 mm, h=27 mm
- The EM energy should be measurable near each cell of the multi well plate
- The EM energy should be constant in time in every cells of the multi well plate
- The EM energy should be focused
- The system should be capable to measure the effect of the EM field above the plate
- The operator should be protected against radiations

## 3. The hardware implementation and design

To fulfill the requirements of this research, we used a radio frequency power amplifier [Pa-02], together with a multi loop antenna. A very good paper related to the design of the multi loop antenna is reachable at [Ch-1] and [St-3]. The design of the multi loop follows the mathematical approach proposed by Prof. Nikolovna in [Na-4]. This approach takes into the consideration the mutual coupling between the turns and optimizes the efficiency of the solenoid as an inductive radiator (antenna). This approach does not fulfil the prior expectation because of the radiation resistance which is too high. Here,this resistance must be smaller (almost zero) and under the control of the system controller unit. This is because of the fact the EM energy is not radiated but rather focused in the VOI. In normal circumstances,any antenna radiates its power mainly on this radiation resistance. Here, is almost no radiation outside the VOI, so the value of the radiation resistance must be lower under one ohm. The replacement of the radiation resistance with an equivalent resistance that introduces the effect of the multi well plate makes the change of the design strategy. The idea is that the load must be the plate it self together with its samples, not the air or surroundings objects. Only this plate must absorb the energy of the field and this energy must encounter the probes. The main strategy of the design is here in opposition with the common design of an inductive antenna. From this point of view,the radiation efficiency must be reduced. In this case,the EM energy will be transferred to the near field (inside the VOI) not to the far field which is outside. The lower the radiation efficiency the closer to the solenoid model the device is. The higher the efficiency the closer to the antenna model. Still the behavior of the system must be under the control of the control unit, using a feedback. This feedback works trough the probes that measure the intensity of the field continuously and flying the information back to the control unit. This information is useful to focus the field in each cell of the plate accordingly to the best value reachable. Also,the control unit avoids the region in which the solenoid approaches a higher Q factor. This factor is kept lower than in normal circumstances under 50 and higher than the Q factor for an inductive antenna.

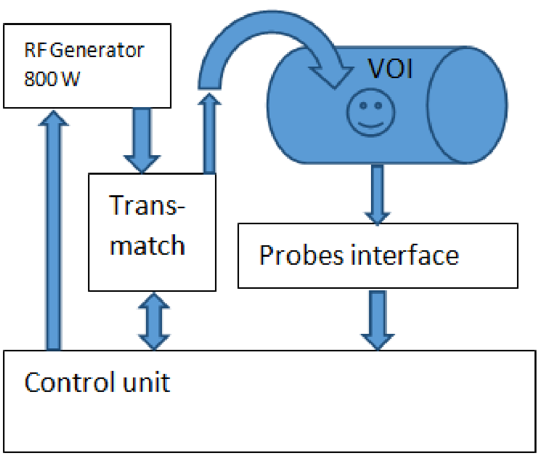



**Figure 1. The design of the system**

The strategy has proven successfully. The applicator behaves in-between an antenna and a solenoid normally do. The static measurements (without signal), made with an Agilent U1731C, shows different results compared to the small signal case. The static parameters of the VOI measured at the solenoid terminals are: L=0.205 μH and C=668 μF.

**The dynamic measurements (with signal, at 13,56 MHz, between input and ground), made with Antenna Analyzer MJF 259B, are:**

$X_L$= 17 Ω
$X_c$=17 Ω
We also have:
VSWR= 3,2,
R=40 Ω , where VSWR is Voltage Standing Vawe Ratio.

In the design requirements, a key role has the placement of the12-well plate inside the antenna. This placement takes into account the feedback signal provided by the probes. Unfortunately, the placement of the plate is manually made.

In these well sare inserted substances subjected to laboratory analysis, in different concentrations, so that a single measurement can analyze12 tests simultaneously. The dimensions of the 12 multi well plate are:

Length 125mm,
Width85 mm,
Height23 mm,
Cell diameter:22mm,
Cell depth: 23 mm.

The important issue is that the tuning of the system proceeds when the multi well plate is inside the VOI with the substances on it. After many measurements and experiments we successfully reach the best shape of the applicator antenna which either responds electrically and mechanically to the demands of the VOI. Also, it allows the maximum possible energy to the plate and avoid auto-oscillations tendency when the Q factor of the solenoid is too high.

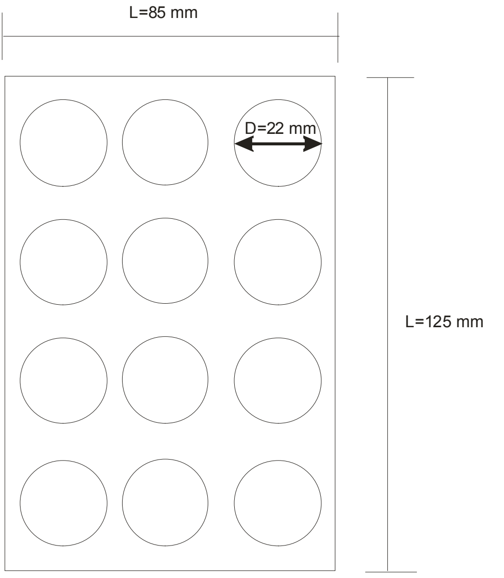



**Fig. 2.Shape and dimensions of twelve multiwell plate**

**4. Experimental approach**

Radiation field around the antenna was measured taking into account the limitations of the device we used. At a distance of 15cm, the value reached the limit of the measuring device (800 V/m). At the same distance around the antenna, we constantly measure the value of 280V/m. In the center, behind the antenna, the field is 300V/m. If we use a reflector, the measurement results do not change due to the low value that stands for radiation resistance under 1 ohm.

In the center, at 15 cm from one side of the solenoid, we have measured using an electric field probe the values from table 1. This variation is due to the modification of the RF power in the period of the calibration process at the frequency of13.56MHz.

**Table 1. The field values in front of antenna, at 15 cm[3-Pa]**

| Level (dB) | Distance (cm) | Indication of own indicator | Field intensity(V/m) |
|---|---|---|---|
| 0 | 15 | 5 (max) | 800 |
| -1 | 15 | 4,5 | 580 |
| -2 | 15 | 3,5 | 534 |
| -3 | 15 | 3 | 482 |
| -6 | 15 | 2,4 | 303 |

For accurate measurements inside the VOI we are searching for the electric component of the field this being much easier to be evaluated. The electric field is 377 times stronger than the magnetic component due to the intrinsic impedance of the air. Along the twelve wells, the EM field (see table 2) is expressed in percentage.

**Table 2.Values of the electro magnetic field, expressedas a percentage of VOI point, measured. [3-Pa]**

| | Line 1 | Line 2 | Line 3 |
|---|---|---|---|
| Column 1 | 0.35 | 0.5 | 0.42 |
| Column 2 | 0.81 | 0.87 | 0.75 |
| Column 3 | 1.12 | 1.05 | 1.09 |
| Column 4 | 0.96 | 1-VOI | 1 |

Next set of measurements where made keeping constant the RF power but varying the distance, along the focalline. The variation of field intensity with the distance is presented in table 3.

**Table3.Values of the electromagnetic field outside antenna, varying with the distance, measured on the center line**

| Level (dB) | Distance (cm) | Indication of own indicator | Field intensity (V/m) |
|---|---|---|---|
| 0 | 0 | 5 (max) | 3150 |
| 0 | 9 | 5 | 1000 |
| 0 | 15 | 5 | 800 |
| 0 | 20 | 5 | 360 |
| 0 | 25 | 5 | 240 |

Correlating the values from table 3with the ones from table 4, it results that the maximum value of electric field inside the VOI is3150V/m. The maximum value of the electric field will be a reference (1-VOI) to normalized all others values. This normalization approach lids to the results from table 2. The real value in V/m are shown in Table 4. This normalization makes the interpretation of the result easier for medical point of view by avoiding electric units like volt and making easier the positioning of the plate. The positioning is made manually and the technician is looking for these normalized value that must full fil the demands in terms of the minimum threshold value with respect of the cancer treatment scheme.

**Table 4. Values of electro magnetic field inside antenna, in all wells**

| | Line 1 | Line 2 | Line 3 |
|---|---|---|---|
| Column 1 | 1102.5 V/m | 1575 V/m | 1323 V/m |
| Column 2 | 2551.5 V/m | 2740 V/m | 2362.5 V/m |
| Column 3 | 3528 V/m | 3307.5 V/m | 3433.5 V/m |
| Column 4 | 3094 V/m | 3150 V/m | 3150 V/m |

Basically, the results from table 2 is the most important indicator of the distribution of the electromagnetic field in each cell of the multi well plate. The values from table 4 applied to the twelve well plate with cell culture allowing an accurately characterization of the field before the expouser. In this way the behavior of the sample is predictable and the exposure time limit computable.

Thanks to the trans-match block from figure one the system can match the output of the RF generator to the load (the solenoid) for almost any frequency in a broadband approach. In this way we can broden the spectrum of the treatment. To demonstrate the efficiency of the trans-match against commonly methods that are using only one frequency we offer, in table 5, the VSWR (Voltage Standing Wave Ratio). This parameter stands for the evaluation of the matching between the load and the generator. An ideal value for VSWR is one but here in this circumstances a value around 3 is excellent. This is because for VSWR = 3 approximately half of the RF power will be transfer to the load. This is excellent in these circumstances taking into account the Q factor of the solenoid.

**Table 5.Variation of VSWR with the frequency, measured in VOI, in order to establish the bandwidth of the system**

| Frequency | Wavelength | VSWR | Field intensity |
|---|---|---|---|
| 4,8 MHz | 62,5 m | >25 | N/A |
| 5 MHz | 60 m | 1,4 | 4800 V/m |
| 10 MHz | 30 m | 2,1 | 4200 V/m |
| 13,56 MHz | 22 m | 3,5 | 3150 V/m |
| 15 MHz | 20 m | 3,7 | 3150 V/m |
| 20 MHz | 15 m | 4,7 | 3150 V/m |
| 25 MHz | 12 m | 5 | 3150 V/m |
| 30 MHz | 10 m | 8,6 | 1500 V/m |

This table reveals the true band width of the system, sampled by the probe in the VOI (volume of interest). We note that the antenna calibration becomes more difficult with the increasing of the frequency. For lower frequencies, the calibration becomes easier and may even transfer more energy to the load.

Since the results obtained from the Institute of Oncology Research Laboratory cell lines were obtained at levels comparable to the standard,we do not consider necessary the increase of the power any further. This proves the efficiency of the trans-match and the decreasing of the RF power, against the common systems for a green environment. Also, the approach avoiding the overheating tendency of the RF generator and the VOI enclosure. The broadband frequency range from 5 MHz to 25 MHz is large enough to increase the spectrum of the treatment and its successful rate. The validation of the results using other laboratory equipments (oscilloscope and spectrum analyzer) has been done also as a secondary approach that follows the same rules. The visualisation of the signal with the current probe and the voltage probe was one of the intermediary approach that help a lot in tuning the system. In order to improve the results, the signal was visualized using an oscilloscope LeCroy Wave Runner 204Xl (2GHz, 4ch, 5GSample/ s).

**The key element is its probes:**

- A voltage probe across the antenna coil-DTMF312-600V peak
- A current probe-30LeCroyCP031- measured at the entrance loop antenna coil

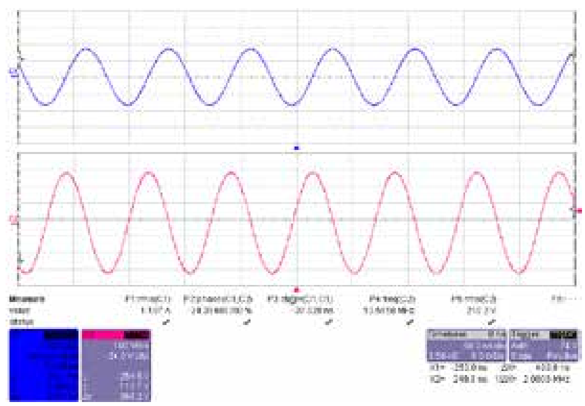
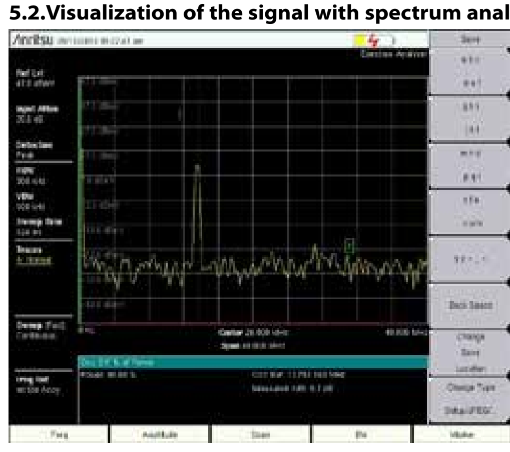


**Figure 3.The signal, visualised with the voltage and current probes, at 3150 V/m**

We can observe that the signal at the test frequency – 13.56 MHz is maintaining its good aspect, without distortion and at a 90 degrees phase shift difference. As one can see the maintaining of the sinusoidal shape of the current in spite of the reactance behavior of the load is the key factor in the tuning process. This shape allows the tuning procedure to attain VSWR<3 and the 50% of the energy to be transferred to the plate in 12 different points. The purity of the RF signal is the goal from the spectrum perspective and figure 5.2. No dispersion of the energy is allowed in the spectrum but only over the require frequency.

**5.2.Visualization of the signal with spectrum analyzer**



## 6. Conclusions

Following the design requirements, the created system is fully defined.

- We defined the bandwidth that can be used in research laboratories,
- We have characterized completely the electromagnetic field inside antenna in all points of interest, according with wells' geometry,
- We find that the antenna is in fact an applicator, with minimum efficiency in the far field zone, so the maximum power is attained inside (in near field zone), in the VOI,
- Although the theory states that the electromagnetic field inside a multiloop antenna is constant, we have demonstrated that this distribution is not uniform. The electromagnetic field distribution inside is essential for assessing its effects on a functionalized nanostructure,
- Also, through the measurements we have made we shown that our system allows a wide frequency band (5-25 MHz), compared to other existing systems that allow only a single frequency (13.56 MHz ) with a great impact over the spectrum of the treatment and over the rate of success.

**ACKNOWLEDGEMENT:**

This paper is supported by the Sectoral Operational Programme Human Resources Development POSDRU/159/1.5/S/137516 financed from the European Social Fund and by the Romanian Government.

**REFERENCES**

• [Ch-1] Cheol Yong Yang, Seong Ha Lee, and Woon Geun Yang, New Multiple Loop Antenna Design for 13.56 MHz RFID Reader, PIERS Proceedings, Moscow, Russia, Page 586 August 19–23, 2012 | • [Pa-02] The Radio Frequency System Dedicated to the Study of Carbon Nanotubes Behaviour in RF Field, D.PANTIS1,2,3, N.CRISAN1 , C. BRAICU 4,M.BORDA1, Tom 58(72), Fascicola 1, 2013 Scientific Bulletin of the Politehnica University of Timisoara - Transactions on Electronics and Communications | • [St-3] Stutzman, W. L. and G. A. Thiele, Antenna Theory and Design, 68–76, John Wiley & Sons, 1998. | [Na-4] Natalia Nikolova, Cylindrical Antennas-Classical Theoretical Models, Antentop 01 2011 | De Publisher Igor Grigorov Pg 5-24 |