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Telecommunications Engineering — Applications

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Thoughts on the Possibility of Damage of High-Voltage Electrical Insulation below the so-called Inception Voltage: The Historical Background – Part I

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Abstract

Partial discharges (PD) may cause damage to high-voltage (h.-v.) electrical insulation and eventually breakdown. It is known, however, that sudden breakdowns occurred in industrial insulations after only a few months in service, although they had passed the suggested international specifications tests. In this paper, we investigate the possibility of damage of an h.-v. insulation even below the inception voltage, giving the historical background which led to certain thoughts. References to previous work are given and a differential equation is proposed regarding the possibility of having charging phenomena below the inception voltage.

Keywords

Partial discharges, high voltage insulation, cavities, inception voltage, leakage currents

Introduction

PD may cause significant damage to the h.-v. insulation [1], [2]. PD may start from asperities on the electrodes, from enclosed voids, from fissures and/or from enclosed foreign particles [3]. Numerous publications tackled the question of the relation between PD parameters and insulation damage [4]–[7].

Although a voluminous amount of research has been performed on the questions of insulation damage and PD, no particular attention was given to possible charging events below inception voltage. However, such events were held responsible (at least partly) for the failure of insulation equipment back in the fifties and the sixties of the last century [8]-[11]. Such incidents were reported, regarding big electrical machines as well as high voltage switches that failed abruptly, although they passed all tests the international technical committees were suggesting [8]. Which were these incidents? In the 1950’s one major US manufacturer produced and sold large rotating machines with cast polymer insulation. At that time all available diagnostic techniques suggested that there should be no problem at all from low leakage currents. Surprisingly enough, these rotating machines failed while in service in a few months. Another occasion of impressive failure was registered when another US manufacturer producing 15 kV class vacuum switches, reported that, although all normal tests at that time were done, unexplained erosion of cast epoxy insulation occurred in these switches, only after a few years in service. Such were the incidents that led to the exploration of the below inception regime of charging phenomena [12]. Scientific evidence of "something" happening below inception was provided by Filippini [13], who suggested that treeing propagation followed growth along current paths. Furthermore, Brancato [14] indicated the possibility of relating current below inception with temperature rise. In his own words, "perhaps the most exciting but speculative project is the development of techniques to determine temperature rise of void surfaces due to partial discharge. ... electrical aging may in reality be a chemical reaction in voids induced by the deposition of energy. This deposition is expended in the raising of the temperature of the walls of the void, in creation of ozone and possibly nascent oxygen which tend to oxidize the surface chemical reactions which in the presence of water components form nitric or nitrous acids which deteriorate the void surfaces and finally mechanical erosion by the resulting ion stream impinging on the void". In the same publication, Brancato also pointed out that measuring or sensing techniques may not be adequate for all classes of dielectric materials or to all aging environments and/or the inadequate sensitivity of some instruments to detect changes. Recent papers point out to the slow decline of inception voltage with time [15]. Is this also an indication of charging phenomena below the so-called inception? Would such phenomena play a role regarding the decrease/decline of inception voltage?

Hints about possible damaging events below inception voltage were discussed in a brief report by E. Brancato back in 1991 [16]. Previous work on air gaps with a non-uniform electrode arrangement suggested that such charging events were possible [17]-[20]. To the best of our knowledge, until now there are indications of possible charging effects below inception voltage but a definite proof is missing.

It is the purpose of the present paper to offer the historical background of the approach regarding charging events below the inception voltage and to explore a bit further the events below inception. An equation, which was proposed many years ago by Bruning, is discussed.

On the Problem of Inception Voltage – Historical Background

Inception voltage is called the lowest voltage under a.c. conditions, at which repetitive PD of a specified magnitude in successive cycles are observed, as the applied voltage increases [21]. Above the inception level, an insulation may deteriorate depending on the magnitude of the imposed voltage. Things become more blurred when an insulation is subjected to an applied voltage which is lower than the extinction voltage (according to the seminal publication by Kelen [21], the extinction voltage is the voltage at which discharges of a specified magnitude will recur when an alternating voltage, which exceeds the discharge-inception voltage, is reduced).

In his important paper, Bruning and colleagues [9], pointed out that unexpected insulation failures occurred despite the fact that the insulation was operating below the inception voltage. In this doctoral thesis, Bruning [8] pointed out that there were problems in tackling and understanding the basics of current-voltage relationships for new insulating materials and/or new devices. For example, the design failure of epoxy insulators, which used the application of criteria for porcelain discharge onset, did not sufficiently characterized low current performance with contamination. On another occasion, there was a lack of fundamental current vs. voltage analytical model for the design of a new type of transformer windings. In many cases of transformer failures, discharge testing did not indicate low level pre-discharge activities with operation. Problems also arose with underground cables, where aging effects, exacerbated by the presence of water, may give higher discharge currents which are below the level which can be satisfactorily measured. Bruning speculated that low level discharge currents cause a destructive local temperature effect. Problems related to the above questions were revealed in the USA with electrical machines, cables and high-voltage switches, which failed unexpectedly although all of them passed the required tests prescribed by the international technical committees.

All the above point to the fact that there is a need for a fresh approach for this problem, an approach which may give a possible solution to charging effects below inception. Efforts have been undertaken in Bruning's seminal publications [8], [9], where questions such as the following were put:

a) what is the insulation leakage current-voltage characteristic?

b) what is the effect of such a leakage current?

Efforts were also undertaken in some publications, albeit with a different insulating material and a much simpler electrode arrangement [17]-[20]. In those papers, indications were presented that effects below the so-called inception level may exist. Moreover, experiments performed in polyethylene samples with enclosed cavities, indicated that at relatively low voltages sharp current waveforms were detected. This indicates sudden streamer PD mechanism in enclosed cavities. In previous years, comments regarding the relation between such sudden PD waveforms and events at or below the inception level were offered. It was speculated that there may be sudden bursts related to local rising of temperature in a cavity [22]-[26].

Possible Relation Between PD Events at Inception Voltage and Charging Events below Inception

Bruning and colleagues [8], [9], [27] proposed an equation describing the quasi-steady state for current flow

$$\nabla^2 V + \nabla V \bullet \nabla s / s = 0 \qquad (1)$$

where, ∇ is the gradient and ∇^2 is the Laplace operator expressed as a function of the location, V is the local voltage and s the local conductivity of the fluid (in our case air). They also proposed that it would be plausible to state that the local air temperature is related to the local power dissipation which is leakage current times the local voltage gradient. This being true, the local electrical conductivity is related to the local temperature. The question was as to whether such an equation was leading to a burst or sudden PD pulse even below inception. Would this be possible?

In fact the above equation was characterized as the "thermal model" in Bruning’s Ph. D. Thesis [8]. It suggests a thermal model of gaseous conduction which under certain conditions of limited diffusion rate of ionized species, low radiant energy loss, and low thermal conductance, a diffuse current flow may generate a diffuse conduction process. Similar pulseless regimes were suggested in [28]. Furthermore, the same direction of research, without however being so specific, was pointed out in [29], [30], where pseudoglow regimes were observed. It may well be that the current not indicated on a conventional PD detector is a current below the detection level.

More in detail, if one assumes that in the gas there is a dissipative current flow, using classical notation,

$$\nabla V \bullet J = 0 \tag{2}$$

$$J = sE \tag{3}$$

$$\nabla \bullet sE = 0\text{, but } E = \nabla V \tag{4}$$

and consequently,

$$\nabla^2 V + \nabla V \bullet \nabla s / s = 0 \tag{5}$$

The above equation, in the case of a constant conductivity s, reduces to the well known Laplace/Poisson equation. However, for a gaseous conduction process, where the there is a partial variable ionization as J varies with time and position, we have finally Eq. (5).

As was noted in a previous paper [27], solution of the distributed – perhaps pulseless current flow – then proceeds from ionization determined from both Saha’s equation and the heat balance determining the local temperature. The complexity of the transport processes have not permitted ab initio calculations. However, approximations indicate a variation of current density and field strengths, which indicate the possibility of current below the detection level. Whether the continuous thermal conduction model arises from true continuous conduction or from pulses too short to be detectable by conventional PD detectors, it is a question in need of an answer. It is interesting to note, however, that sudden bursts of pulses at or below the so-called inception voltage were observed recently, not only in conventional polymers but also – albeit less frequently – in nanocomposites [31], [32].

Research by Bruning and colleagues [9], [10] indicated that damage observed below inception was very similar to the damage above inception. In these papers, indications were offered that chemical changes below inception were similar to those noted above inception. Such indications gave strong ground for suggesting that "something" goes on below the inception voltage. Chemical changes that indicate chemical deterioration below inception imply the existence of charging phenomena that may render shorter the lifetime of the insulation. Charging effects below the inception voltage may imply that there is no voltage below which no deterioration takes place. More precisely, it is known that the lifetime L (time to failure) is given by the formula

$$L = c(V - V_0)^{-k} \qquad (6)$$

where, V is the applied voltage, V_0 is the voltage below which no deterioration takes place and k is a constant. k, V_0, and c are constants depending on the insulation material (it should be noted that original form of Eq. (6), referred to in [33], was

$$L = (A - \alpha)^{k}(V - \alpha A)^{-k}$$

where, L is life in minutes, A is the 1 min strength, α is a material constant, k is another material constant and V is the applied voltage). However, if one assumes that there is damage below the inception voltage, then

$$V_0 = 0 \qquad (7)$$

and Eq. (6) becomes

$$L = cV^{-k} \qquad (8)$$

As was noted in [9], "most equipment designers use this empirical relation without having settled the fundamental question as to whether $V_0 = 0$ or not, since empirical experiments in reasonable time periods cannot distinguish between the two forms", i.e. that of Eq. (6) from that of Eq. (8). Ambiguities regarding Eq. (6) still remain to this day, especially if one looks at insulation lifetime models [34]. The question of whether V0 = 0 is also relevant to the sensitivity of PD detector as well as to the thickness of the examined insulation, deserves to be further explored. It was reported before, that scaling laws exist, i.e. a thicker insulation requires a more sensitive PD detector [35], [36]. Needless to say that the sensitivity of a PD detector determines the inception voltage of either an insulating material or a full insulation system, or in the words of one of the most distinguished researchers of the good old generation, E. Brancato, "... electric stresses in the absence of internal discharges can cause changes in material properties. Some ascribe the changes to electrochemical reactions, while others express the suspicion that the observed changes are really caused by partial discharges but the corona detecting system is too insensitive" [37].

From the above it is indicated that, although there is not yet a universal name to it, "something" must occur below the inception voltage. Whether this "something" can be referred to as "charging phenomenon" or can be manifested as "signal", is not yet clear. Moreover, if one sees the more practical questions and if one tackles the problems of the role of antioxidants in cable insulation, one may say that antioxidants are incorporated to prevent premature degradation during extrusion, but the role of the residual antioxidant on insulation response to aging stresses has not yet been quantified, especially in voltages below the inception level [38].

Conclusion

The present paper is an introduction to the problem of possible charging effects below the so-called inception voltage. The historical background of an approach – different from the usual approaches – is given as well as the indications that charging phenomena below inception may exist. Below inception sudden pulses were observed with an electrode arrangement of point-plane with air as insulating material. It is speculated that minute abnormalities on the cavity surface may act as emission sites and thus provoke small charging phenomena not easily detected by normal conventional PD detectors. An equation regarding the current flow in a cavity was given and commented upon. In a future publication, a solution of the said differential equation will be given together with appropriate comments.

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A Planar Delta–Cross Shaped Loop Antenna: Analysis and Simulation – The 2 WL Case

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Abstract

A planar Delta–Cross shaped loop antenna is proposed. The presentation includes results from an analytic study of the radiation pattern, as well as, from a simulation study for both the electric and radiation characteristics: input impedance, standing wave ratio, radiation pattern and directivity. The loop was initially shaped as 4 non-overlapping equilateral triangles on a plane, symmetrically oriented around a common vertex, center fed at one triangle base. In order to improve the antenna characteristics, its shape was then modified by equally changing the triangle base angle–while keeping the loop length constant and equal to 2 wavelengths WL. In this way, the final antenna loop was shaped with 4 isosceles triangles. The analytical and simulated results for the radiation pattern were found to be in good agreement. Furthermore, a comparison with antenna's dipole counterpart characteristics showed a much better performance of the proposed antenna.

Keywords

Cross loop antenna, delta elements, analysis, simulation, improvement

Introduction

The cross loop antenna consisting of four delta elements was examined as a prototype antenna during preparation of an EECE diploma thesis [1]. The main available tools for its study were the antenna theory [2], the [RadPat4W] computer program for antenna patterns [3] the [RICHWIRE] simulation program [4] and the mini-Suite of software tools [5]. Its simple plane figure of double symmetry with respect to two axes which means easy geometrical representation for the theoretical consideration of its radiation pattern as well as for the simulation and easy construction, was the basic reason for this proposal. The initial antenna consists of four equilateral triangles with side length λ/6 and almost coincident their four vertices. Thus, the total length of the antenna is 2λ. The feed source was at the middle of the base of one of the triangles as it is shown in Fig. 1.

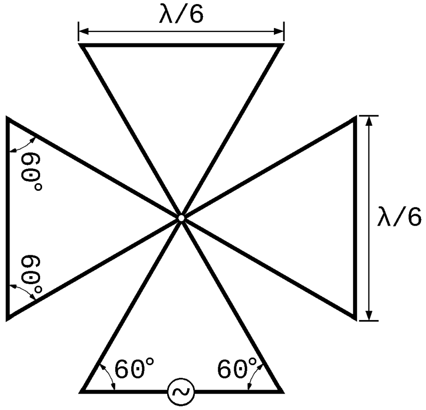

Fig. 1: Planar Delta–Cross Shaped Loop antenna

Then, the antenna was modified only with respect to the base angles of the triangles, keeping constant the triangle perimeter equal to λ/2, resulting a cross antenna of four isosceles triangles. The angle was varied between 48° and 78°, in order to improve both of its electrical and radiative characteristics and the one with 48° angle was selected as the improved Delta–Cross Shaped Loop antenna.

Analysis

The initial antenna was analytical studied considering standing waves, that is, sinusoidal, current distribution in a parallel wire transmission line. Since the perimeter of each equilateral triangle is λ/2, the total antenna length is equal to 2λ and it corresponds to a properly formed short circuited transmission line. However, the study was carried out in a 5λ/2 piece of open circuited transmission line, formed properly as in Fig. 2, since the available formula of equation (1) concerns open circuited two parallel wired transmission lines

$$\dot{I}(\ell) = \dot{I}\,\sin\left(\beta\left(h - |\ell|\right)\right) \qquad (1)$$

with

$$-h \leqslant \ell \leqslant +h \quad \text{where } h = \frac{5}{4}\lambda\ .$$

The above current distribution (1) was used to evaluate the radiation pattern of the antenna through the relations

$$\bar{\mathbb{E}} = e^{i\beta R_{k_r}}\,\dot{PF}\begin{bmatrix}\underset{\shortmid}{\ell}_\theta\\ \underset{\shortmid}{\ell}_\varphi\end{bmatrix} \qquad (2)$$

$$\dot{PF} = \int_{\ell_A}^{\ell_T} \dot{I}(\ell)\,e^{i\beta\underset{\shortmid}{\ell}_r\ell}\,d\ell \qquad (3)$$

According to the basic standing wave theory: i) the direction of current changes per λ/2 segment, ii) between two successive standing wave nodes the current phase remains the same and iii) if a source is between two successive standing waves the current direction does not changes. These principles were applied at the properly bended 2-wire transmission line of Fig 2, keeping in mind that the Kirchhoff laws must be simultaneously satisfied.

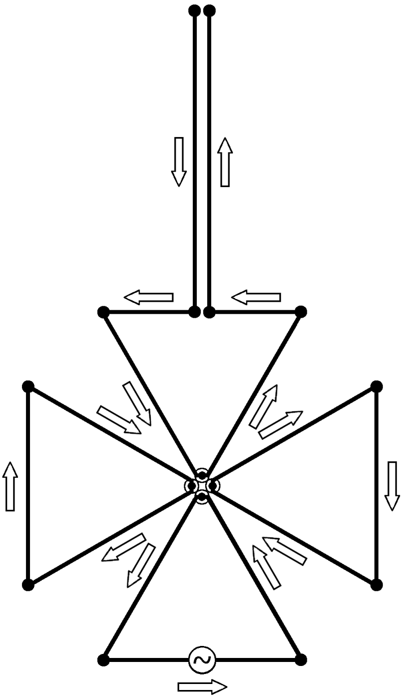

Fig. 2: 5λ/2 properly bended 2-wire transmission line

The double arrows indicate the direction of $\dot{I}\vec{\ell}_{\iota}$ product for every one segment, and the dotted circles at the almost coincident vertices of the four equilateral triangles correspond to a zero in the current distribution.

The two parallel λ/4 segments are almost coincident with opposite currents, so they are mutually canceled as for the radiation and they are excluded from further study. Thus, the remaining segments form the desired antenna, with total length 2λ and a current maximum at the source, as it is shown in Fig. 3.

For every one segment 0-12, of Fig. 3, we had to determine four quantities: the length of its starting point ℓ_A, the length of its end point ℓ_T, the position vector of its center $\vec{R}_k$, as if they were part of the corresponding line of 2λ length, and its unit direction vector $\vec{\ell}_{\iota}$, with its direction to be in all segments from ℓ_A to ℓ_T. The planar antenna was arranged on yOz as it is shown in Fig. 4, along with all the $\vec{R}_k$ position vectors as they were determined by the relation

$$\vec{R}_{k_\nu} = \vec{OA}_\nu - \ell_{A_\nu}\vec{\ell}_{\iota\nu} \qquad (4)$$

and Tab. 1 contains all the above mentioned geometrical quantities.

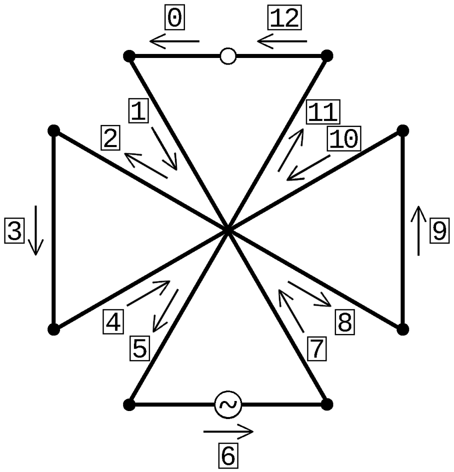

Fig. 3: 13 segments

Then through (1)-(3), that is, after the evaluation of the definite integral for the Pattern Factor $\dot{PF}$ [2], [6] the radiation pattern of all the 13 segments was formulated and according to the law of superposition the total radiation pattern is given by

$$\bar{\mathbb{E}} = \sum_{\nu=0}^{12} \begin{bmatrix} \dot{\mathbb{E}}_{\nu\theta} \\ \dot{\mathbb{E}}_{\nu\varphi} \end{bmatrix} = \begin{bmatrix} \dot{\mathbb{E}}_{\theta} \\ \dot{\mathbb{E}}_{\varphi} \end{bmatrix} = \dot{\mathbb{E}}_{\theta} \underset{|}{\vec{\theta}} + \dot{\mathbb{E}}_{\varphi} \underset{|}{\vec{\varphi}} = \qquad (5)$$
$$= (\mathbb{E}_{\theta_R} + i\mathbb{E}_{\theta_I}) \underset{|}{\vec{\theta}} + (\mathbb{E}_{\varphi_R} + i\mathbb{E}_{\varphi_I}) \underset{|}{\vec{\varphi}}$$

which, after a lot of symbolic manipulation where the real parts are mutually eliminated, leads to a more simplified expression

$$\bar{\mathbb{E}} = \begin{bmatrix} \dot{\mathbb{E}}_{\theta} \\ \dot{\mathbb{E}}_{\varphi} \end{bmatrix} = i\,(\mathbb{E}_{\theta_I} \underset{|}{\vec{\theta}} + \mathbb{E}_{\varphi_I} \underset{|}{\vec{\varphi}}) \qquad (6)$$

and by the symmetry of the geometry radiation patterns of 0th, 12th and 6th wire are combined, as well as the five (5) couples: 1, 7 – 2, 8 – 3, 9 – 4, 10 and 5, 11 as it is obvious from Tab. 1. Thus, the total radiation pattern is

$$\bar{\mathbb{E}} = \bar{\mathbb{E}}_{0,12,6} + \bar{\mathbb{E}}_{1,7} + \bar{\mathbb{E}}_{2,8} + \qquad (7)$$
$$+ \bar{\mathbb{E}}_{3,9} + \bar{\mathbb{E}}_{4,10} + \bar{\mathbb{E}}_{5,11}$$

Simulation

The simulation process was carried out in terms of [RICHWIRE] program. The center frequency was 1111 [MHz] where the wavelength is $\lambda = 0.27$ [m] and the wire radius was 1 [mm]. We studied the antenna characteristics both electric and electromagnetic (SWR, Input Impedance, Directivity, Radiation Pattern) in the range [600, 1300] MHz around the center frequency with a 10 [MHz] step.

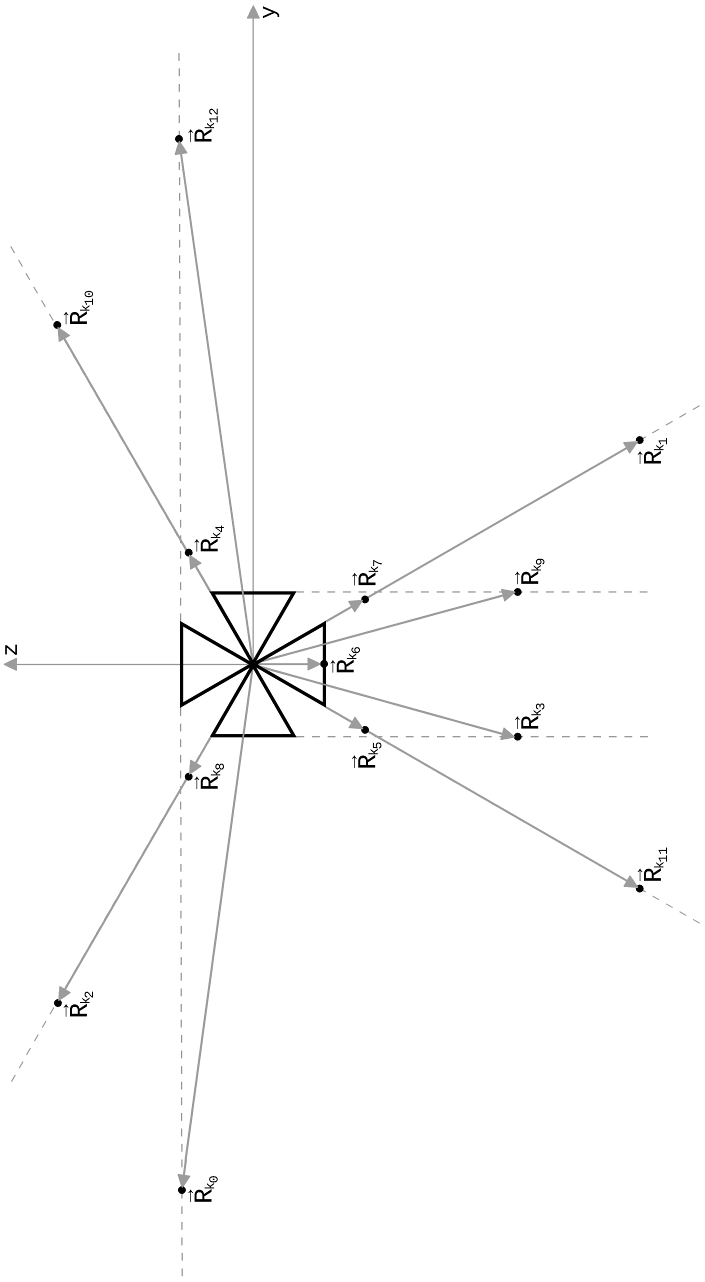

Fig. 4: 13 position vectors

Tab. 1: Geometrical Data

#	ℓ_A	ℓ_T	$\vec{R}_k$		βR_{k_r}
			$\vec{y}_{\prime}$	$\vec{z}_{\prime}$	
0	$-\lambda$	$-\frac{11}{12}\lambda$	$-\lambda$	$\frac{\sqrt{3}}{12}\lambda$	$-2\pi\sin\theta\sin\varphi+\frac{\sqrt{3}\pi}{6}\cos\theta$
1	$-\frac{11}{12}\lambda$	$-\frac{9}{12}\lambda$	$\frac{3}{8}\lambda$	$-\frac{3\sqrt{3}}{8}\lambda$	$\frac{3\pi}{4}\sin\theta\sin\varphi-\frac{3\sqrt{3}\pi}{4}\cos\theta$
2	$-\frac{9}{12}\lambda$	$-\frac{7}{12}\lambda$	$-\frac{3\sqrt{3}}{8}\lambda$	$\frac{3}{8}\lambda$	$-\frac{3\sqrt{3}\pi}{4}\sin\theta\sin\varphi+\frac{3\pi}{4}\cos\theta$
3	$-\frac{7}{12}\lambda$	$-\frac{5}{12}\lambda$	$-\frac{\sqrt{3}}{12}\lambda$	$-\frac{\lambda}{2}$	$-\frac{\sqrt{3}\pi}{6}\sin\theta\sin\varphi-\pi\cos\theta$
4	$-\frac{5}{12}\lambda$	$-\frac{3}{12}\lambda$	$\frac{\sqrt{3}}{8}\lambda$	$\frac{\lambda}{8}$	$\frac{\sqrt{3}\pi}{4}\sin\theta\sin\varphi+\frac{\pi}{4}\cos\theta$
5	$-\frac{3}{12}\lambda$	$-\frac{\lambda}{12}$	$-\frac{\lambda}{8}$	$-\frac{\sqrt{3}}{8}\lambda$	$-\frac{\pi}{4}\sin\theta\sin\varphi-\frac{\sqrt{3}\pi}{4}\cos\theta$
6	$-\frac{\lambda}{12}$	$\frac{\lambda}{12}$	0	$-\frac{\sqrt{3}}{12}\lambda$	$-\frac{\sqrt{3}\pi}{6}\cos\theta$
7	$\frac{\lambda}{12}$	$\frac{3}{12}\lambda$	$\frac{\lambda}{8}$	$-\frac{\sqrt{3}}{8}\lambda$	$\frac{\pi}{4}\sin\theta\sin\varphi-\frac{\sqrt{3}\pi}{4}\cos\theta$
8	$\frac{3}{12}\lambda$	$\frac{5}{12}\lambda$	$-\frac{\sqrt{3}}{8}\lambda$	$\frac{\lambda}{8}$	$-\frac{\sqrt{3}\pi}{4}\sin\theta\sin\varphi+\frac{\pi}{4}\cos\theta$
9	$\frac{5}{12}\lambda$	$\frac{7}{12}\lambda$	$\frac{\sqrt{3}}{12}\lambda$	$-\frac{\lambda}{2}$	$\frac{\sqrt{3}\pi}{6}\sin\theta\sin\varphi-\pi\cos\theta$
10	$\frac{7}{12}\lambda$	$\frac{9}{12}\lambda$	$\frac{3\sqrt{3}}{8}\lambda$	$\frac{3}{8}\lambda$	$\frac{3\sqrt{3}\pi}{4}\sin\theta\sin\varphi+\frac{3\pi}{4}\cos\theta$
11	$\frac{9}{12}\lambda$	$\frac{11}{12}\lambda$	$-\frac{3}{8}\lambda$	$-\frac{3\sqrt{3}}{8}\lambda$	$-\frac{3\pi}{4}\sin\theta\sin\varphi-\frac{3\sqrt{3}\pi}{4}\cos\theta$
12	$\frac{11}{12}\lambda$	λ	λ	$\frac{\sqrt{3}}{12}\lambda$	$2\pi\sin\theta\sin\varphi+\frac{\sqrt{3}\pi}{6}\cos\theta$

#	$\vec{\ell}_i$		ℓ_{r_i}	ℓ_{θ_i}	ℓ_{φ_i}
	$\vec{y}_i$	$\vec{z}_i$			
0	-1	0	$-\sin\theta\sin\varphi$	$-\cos\theta\sin\varphi$	$-\cos\varphi$
1	$\frac{1}{2}$	$-\frac{\sqrt{3}}{2}$	$\frac{1}{2}\sin\theta\sin\varphi-\frac{\sqrt{3}}{2}\cos\theta$	$\frac{1}{2}\cos\theta\sin\varphi+\frac{\sqrt{3}}{2}\sin\theta$	$\frac{1}{2}\cos\varphi$
2	$-\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	$-\frac{\sqrt{3}}{2}\sin\theta\sin\varphi+\frac{1}{2}\cos\theta$	$-\frac{\sqrt{3}}{2}\cos\theta\sin\varphi-\frac{1}{2}\sin\theta$	$-\frac{\sqrt{3}}{2}\cos\varphi$
3	0	-1	$-\cos\theta$	$\sin\theta$	0
4	$\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	$\frac{\sqrt{3}}{2}\sin\theta\sin\varphi+\frac{1}{2}\cos\theta$	$\frac{\sqrt{3}}{2}\cos\theta\sin\varphi-\frac{1}{2}\sin\theta$	$\frac{\sqrt{3}}{2}\cos\varphi$
5	$-\frac{1}{2}$	$-\frac{\sqrt{3}}{2}$	$-\frac{1}{2}\sin\theta\sin\varphi-\frac{\sqrt{3}}{2}\cos\theta$	$-\frac{1}{2}\cos\theta\sin\varphi+\frac{\sqrt{3}}{2}\sin\theta$	$-\frac{1}{2}\cos\varphi$
6	1	0	$\sin\theta\sin\varphi$	$\cos\theta\sin\varphi$	$\cos\varphi$
7	$-\frac{1}{2}$	$\frac{\sqrt{3}}{2}$	$-\frac{1}{2}\sin\theta\sin\varphi+\frac{\sqrt{3}}{2}\cos\theta$	$-\frac{1}{2}\cos\theta\sin\varphi-\frac{\sqrt{3}}{2}\sin\theta$	$-\frac{1}{2}\cos\varphi$
8	$\frac{\sqrt{3}}{2}$	$-\frac{1}{2}$	$\frac{\sqrt{3}}{2}\sin\theta\sin\varphi-\frac{1}{2}\cos\theta$	$\frac{\sqrt{3}}{2}\cos\theta\sin\varphi+\frac{1}{2}\sin\theta$	$\frac{\sqrt{3}}{2}\cos\varphi$
9	0	1	$\cos\theta$	$-\sin\theta$	0
10	$-\frac{\sqrt{3}}{2}$	$-\frac{1}{2}$	$-\frac{\sqrt{3}}{2}\sin\theta\sin\varphi-\frac{1}{2}\cos\theta$	$-\frac{\sqrt{3}}{2}\cos\theta\sin\varphi+\frac{1}{2}\sin\theta$	$-\frac{\sqrt{3}}{2}\cos\varphi$
11	$\frac{1}{2}$	$\frac{\sqrt{3}}{2}$	$\frac{1}{2}\sin\theta\sin\varphi+\frac{\sqrt{3}}{2}\cos\theta$	$\frac{1}{2}\cos\theta\sin\varphi-\frac{\sqrt{3}}{2}\sin\theta$	$\frac{1}{2}\cos\varphi$
12	-1	0	$-\sin\theta\sin\varphi$	$-\cos\theta\sin\varphi$	$-\cos\varphi$

The total number of 96 segments for the whole antenna, where all sides had equal number of points, was selected for the simulation, after the investigation for 13, 24, 48, 72, 96, 120, 144, 168, 192, 216, 240 segments. The above mentioned characteristics remained almost constant after this number of 96 segments. An appropriate computer program was developed in Fortran to create the input file with antenna geometry for [RICHWIRE].

A very good agreement between simulated and analytical produced radiation patterns is shown in Fig. 5 for the three main planes in 1111 [MHz], although there is a point for discussion here. A closer examination, after 7 years from the initial work [1], of what was really compared in Fig. 5, proved that the analytical patterns illustrated corresponds to rather an upper bound of the absolute radiation pattern since it results from the sum of the 13 absolute radiation patterns and not from the total absolute radiation pattern.

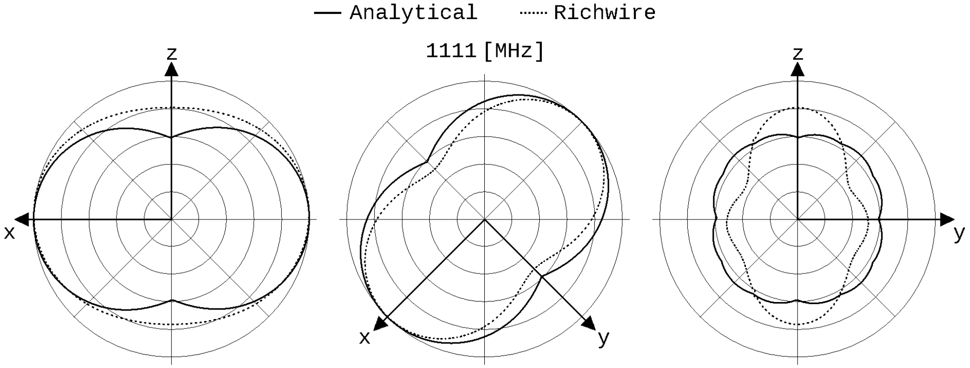

Fig. 5: Radiation patterns in 1111 [MHz]

Furthermore, the simulation model, as it is shown in Fig. 6, consists inevitable not in four equal delta elements but in four truncated ones, as care must be taken

a) to avoid the overlapping of the wires in a future construction and

b) to reduce the strong coupling caused by the proximity effect.

Thus, the minimum permitted square region with side (2a+a/10), where "a" is the used wire radius, was removed from the center intersection point of the four delta elements, while in the same time, in order to achieve the connection of the neighboring sides, the base angles of every element are slightly greater that 60°, and the total length of such formed element was slightly greater than the initial λ/2.

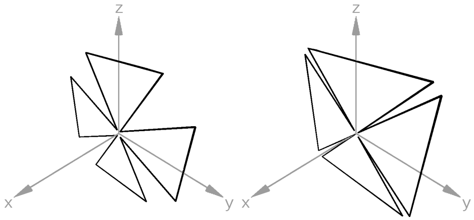

Fig. 6: Simulation models

Extremely high values of Standing Wave Ratio [SWR] in 1111 [MHz] for the three characteristic impedances 50, 75 and 300 [Ω] as it is shown in Fig. 7, made clear the need for further research on the antenna's geometry.

The antenna was modified only with respect to the base angles for constant delta perimeter, resulting a Delta–Cross Loop antenna of four isosceles triangles. A computer program was also developed in Fortran producing the corresponding input data for [RICHWIRE].

The investigation was performed from the value of 48° for the base angles to 78° in step of 1° at the frequency of 1111 [MHz]. The best performance was noticed between 48° and 52° and the model, shown in Fig. 8, with 48° base angles was selected.

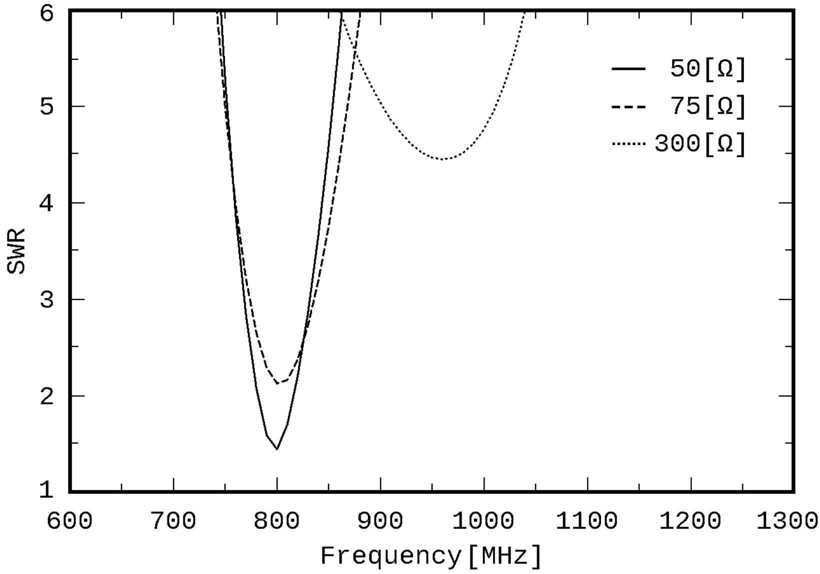

Fig. 7: Standing Wave Ratio against frequency

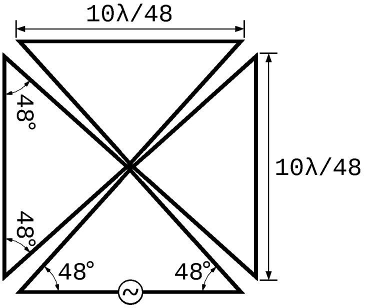

Fig. 8: Improved antenna

In Figs. 9 – 13 SWR, Input Impedance [Z_{inp}] as Input Resistance R_{inp} and Input Reactance X_{inp} in [Ω] and Directivity D in [dB] of the improved antenna together with that of the initial one and of 2λ dipole, are shown respectively. Fig. 12 shows a properly selected window of the total frequency range for the Input Impedance in order to clarify the improvement of the modified antenna. In Figs. 14 – 15 a comparison of the radiation patterns of the three antennas is given at five frequencies in the three main planes zOx, xOy and yOz. In Fig. 16 the 3D analytical radiation pattern at 1111 [MHz] and in Fig. 17 the corresponding 3D patterns in all frequencies are shown.

Conclusion

Although, the agreement of results between simulation and analysis was very good, the characteristics of the initial antenna were not satisfactory. An improvement process was needed and the research was here limited to the change of the base angles only to the rather small range of –12°, +18° around the initial 60° base angle. Thus, the improved antenna had the best performance about 100 MHz lower of the desired frequency of 1111 [MHz], as it is shown in Figs. 9 – 13. The SWR for the 50 [Ω] characteristic impedance has its best value closer to 1111 [MHz] while the initial antenna and the 2λ dipole of equivalent length had a relative small value of SWR at about 800 [MHz] (Fig. 9). It is also obvious that the Input Impedance as well as Directivity is relatively stable and slightly better for the improved antenna and much better from the initial one (Figs. 10 – 13). Corresponding values for SWR, Input Impedance and Directivity for the three antennas are given in Tab. 2.

The radiation pattern of the improved antenna is closer to that of a centered fed sinusoidal λ/2 dipole, avoiding the dispersion of radiation in multiple directions of the rather long 2λ dipole antenna (Figs. 14 – 15, 17).

Tab. 1: SWR, D, Z_{inp}

	SWR	D [dB]	Z_{inp} [Ω]
1111 [MHz]			
60°	43.7	2.49	40 – i 287
2λ	26.1	4.09	577 – i 647
48°	6.55	3.10	70 + i 127
800 [MHz]			
60°	1.44	2.61	36 + i 5
2λ	2.55	3.21	88 – i 52
48°	42.7	2.30	24 – i 219
1010 [MHz]			
60°	29.6	2.85	1297 + i 485
2λ	20.4	3.74	993 + i 168
48°	1.26	2.90	40 + i 3

An extensive investigation concerning the analytical determination of the antenna radiation pattern and its normalized absolute values is in the immediate future plans of the authors in order to achieve the clarification of its relation with the one produced by simulation.

A wider range of the base angle variation or the variation of the total length of each delta element are some design ideas for a future research work. Nevertheless, the final step is, without doubt, the construction and measurement of the proposed antenna together with the comparison of the corresponding results.

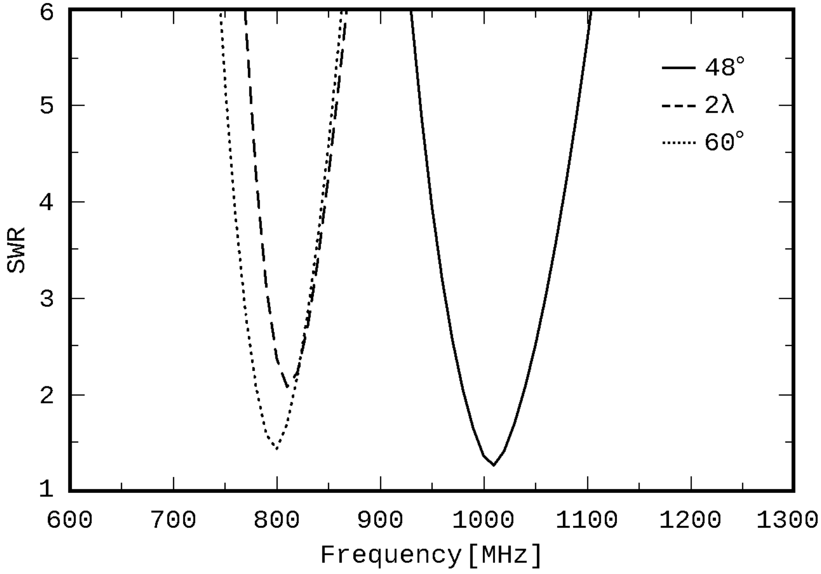

Fig. 9: SWR for improved-48°, 2λ and initial-60° antenna

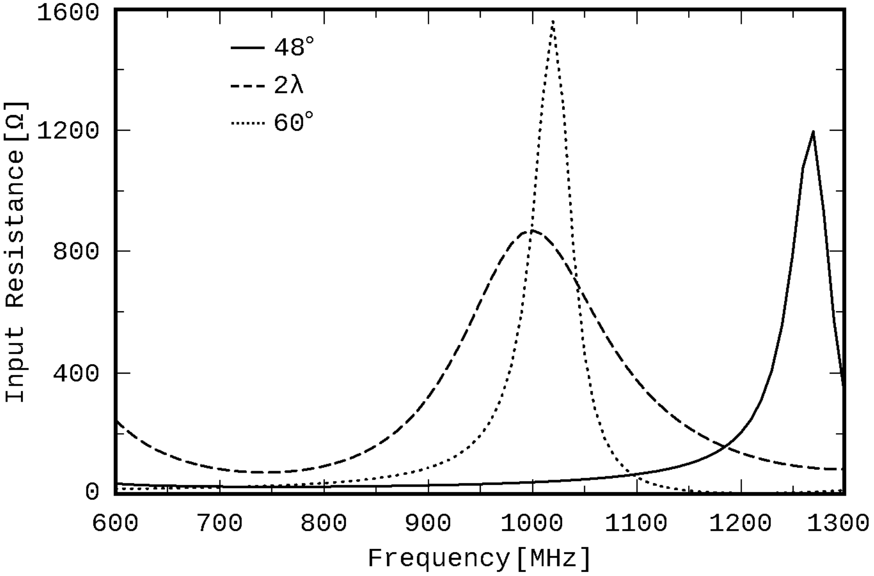

Fig. 10: R_{inp} for improved-48°, 2λ and initial-60° antenna

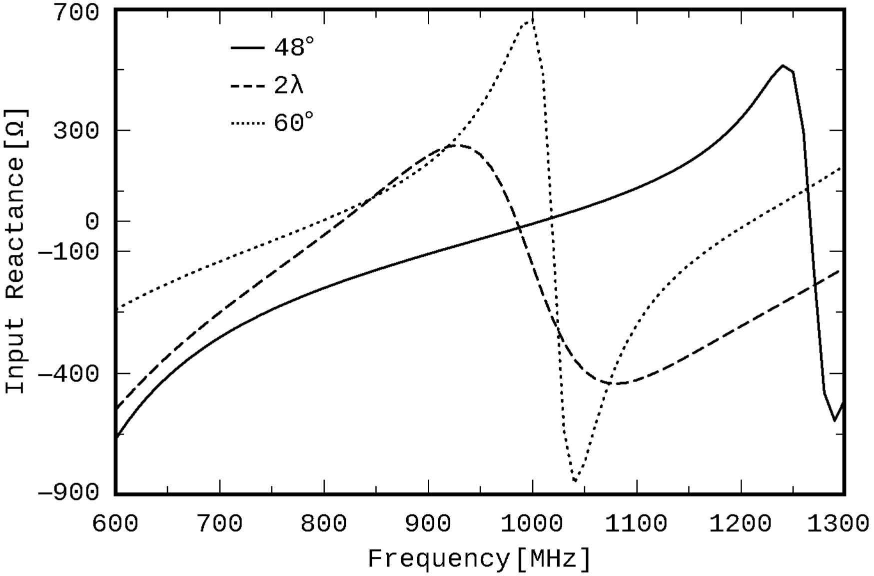

Fig. 11: X_{inp} for improved-48°, 2λ and initial-60° antenna

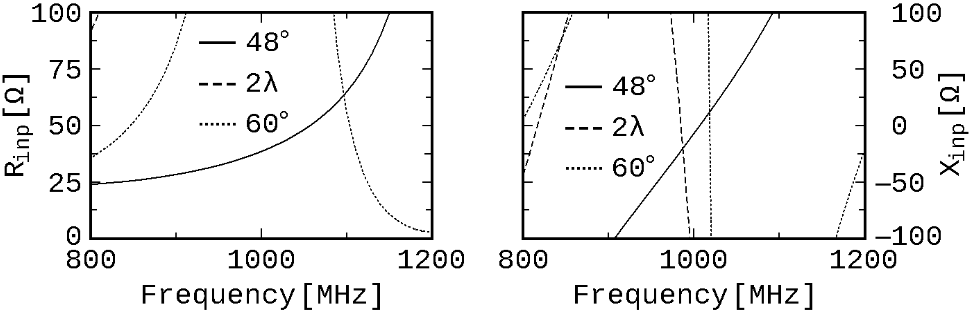

Fig. 12: R_{inp}, X_{inp} for the three antennas in [800, 1200] MHz

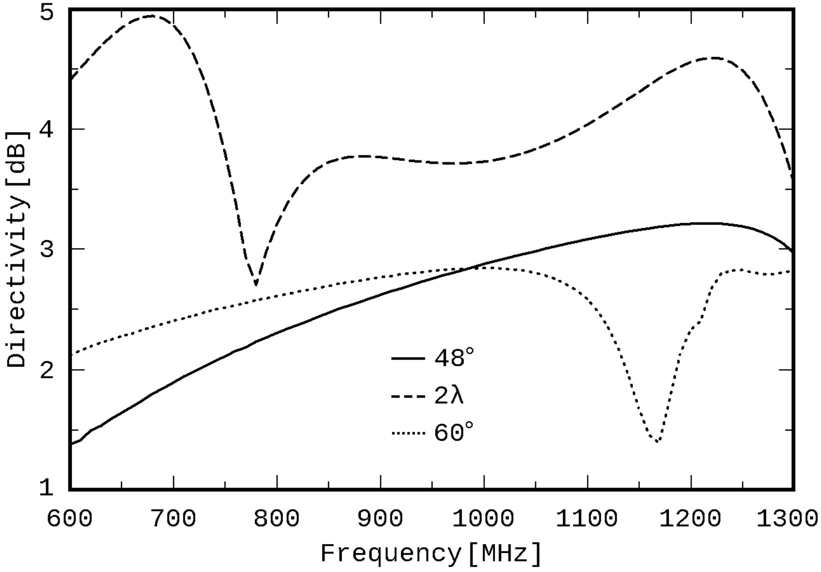

Fig. 13: Directivity of the three antennas

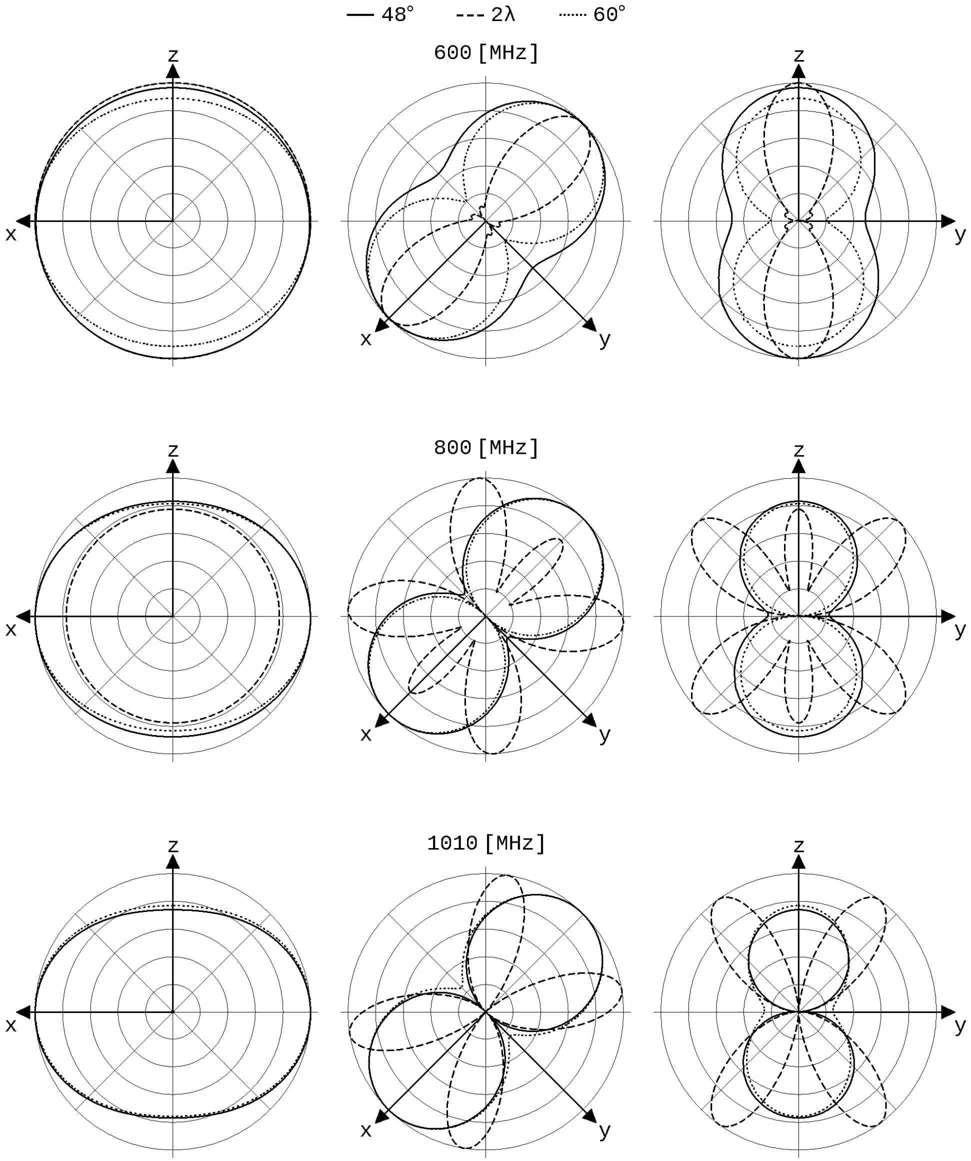

Fig. 14: Radiation patterns at 600, 800 and 1010 [MHz]

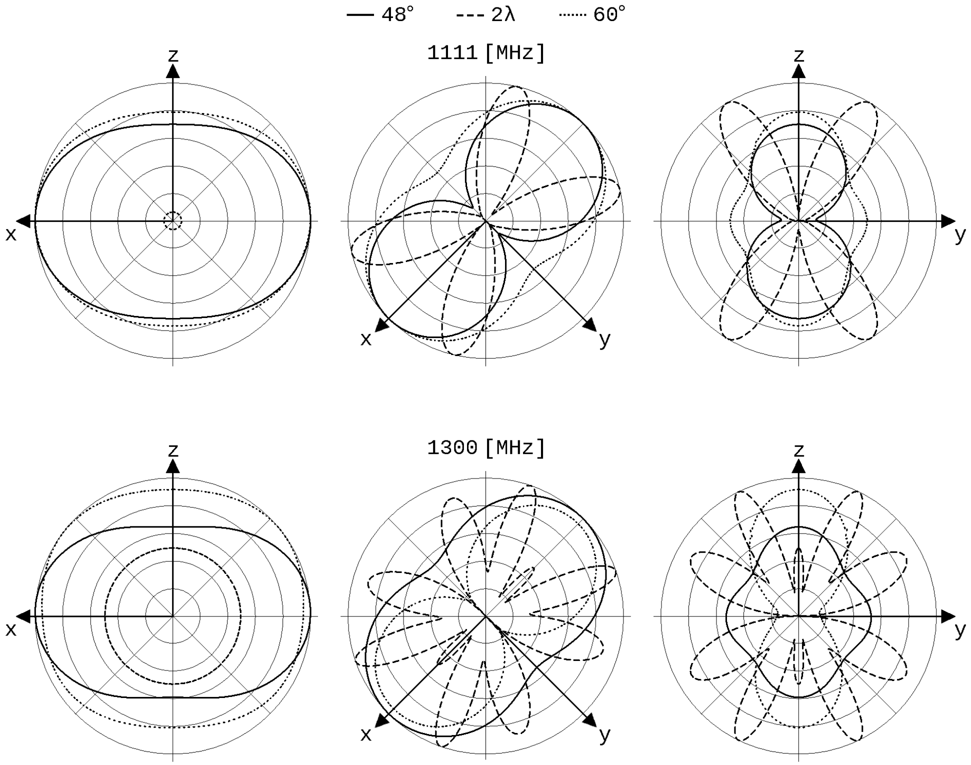

Fig. 15: Radiation patterns at 1111 and 1300 [MHz]

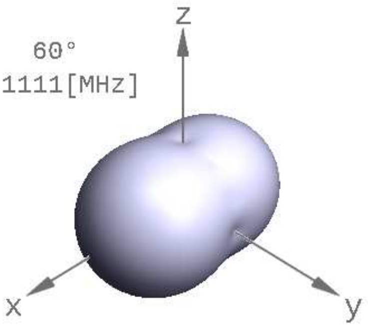

Fig. 16: 3D Analytical Radiation Pattern

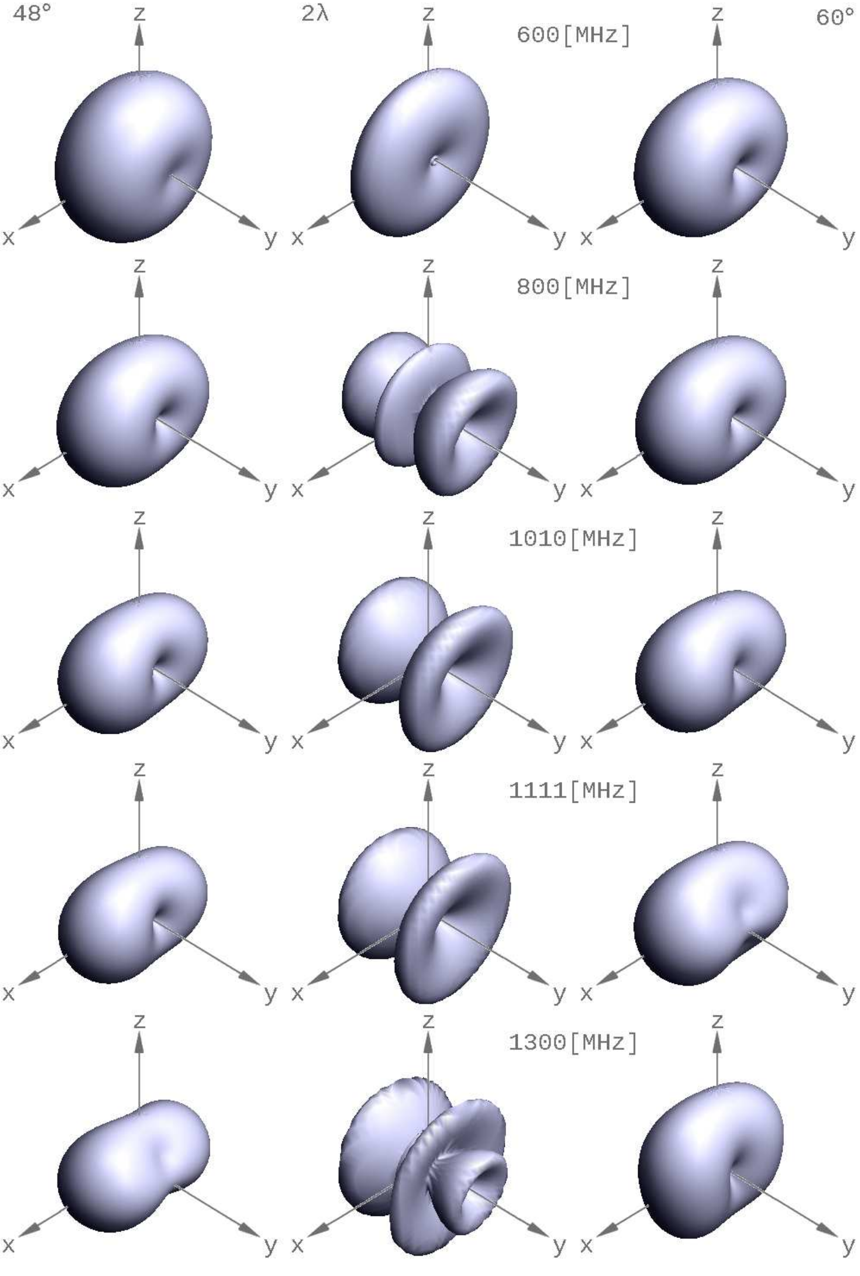

Fig. 17: 3D Simulated Radiation Patterns

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Nikolitsa Yannopoulou, Issue 1, Year 1, p. 15

Petros Zimourtopoulos, Issue 1, Year 1, p. 15

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FRONT COVER VIGNETTE

A faded synthesis of an anthemion rooted in a meandros

The thirteen-leaf is a symbol for a life tree leaf.
"Herakles and Kerberos", ca. 530–500 BC,
by Paseas, the Kerberos Painter,
Museum of Fine Arts, Boston.

www.mfa.org/collections/object/plate-153852

The simple meandros is a symbol for eternal immortality.
"Warrior with a phiale", ca. 480–460 BC,
by Berliner Maler,
Museo Archeologico Regionale "Antonio Salinas" di Palermo.

commons.wikimedia.org/wiki/File:Warrior_MAR_Palermo_NI2134.jpg