Longitudinal Electrical Near-field generated by a Tapered Coax and studied with a Piezoelectric Film coupled with an Optical Probe

Sébastien Euphrasie, Pascal Vairac, Bernard Cretin

LONGITUDINAL ELECTRICAL NEAR-FIELD GENERATED BY A TAPERED COAX AND STUDIED WITH A PIEZOELECTRIC FILM COUPLED WITH AN OPTICAL PROBE

S. Euphrasie, P. Vairac, B. Cretin

FEMTO-ST Institute, department LPMO,
UMR 6174 CNRS-UFC-ENSMM-UTBM
32 avenue de l'Observatoire, 25044 Besançon Cedex, France
Tel: (+33) 3.81.85.39.20, Fax: (+33).3.81.85.39.98
E-mail: sebastien.euphrasie@femto-st.fr

Abstract. We investigated the influence of using a conical end on the longitudinal electrical near-field generated by a coaxial cable. Simulations with Finite Integration Technique show that this influence greatly varies along the longitudinal axis. Experimental measurements were also carried out. To that purpose, we designed a new set-up to measure the electrical field in one direction with a spatial resolution of 100 microns in this direction, with nearly no perturbation by the other components of the field. This set-up uses a piezoelectric sintered PZT film and a heterodyne laser probe.

***Keywords**:* near-field, tapered coax, electrical field sensor

1. INTRODUCTION

One can find in the literature coaxial cables, with or without the central conductor protruding, used as antennas to measure electrical near-field [1-3]. Depending on the length of the protruding connector or even the shape of the cable's apex, the sensitivity to the longitudinal electrical field can greatly vary. As far as we know, no study has been carried out concerning this topic. In optics, it is known that using a radial polarization – therefore the electromagnetic field is akin to the one in coaxial cables – in a sharpened fibre allows creating a longitudinal evanescent field [4]. Although there are several wavelengths in the fibre's core, which is not the case with classical electrical propagation in coaxial cables, the issue is similar and a conical extremity should increase the longitudinal electrical field generated by a coax.

Therefore we decided to study the influence of having a cone, ending or not the coaxial cable, on the longitudinal electrical near-field. Since emitting and receiving is akin in an antenna, our study concentrates on the emitting issue. We used "large" coaxial cables since it was easier to work with; but, as the problem can easily be scaled down, this study can be applied to MEMS, in particular to the structures developed in reference [5]. In order not to mix two different issues, we did not use the tip effect by sharpening the inner conductor as in reference [1]. Of course, the two effects can be combined to increase the sensitivity of the probe.

Simulations using a commercial software based on Finite Integration Technique (FIT) – CST Microwave Studio – were carried out to compare several cases, including different shapes of the cone. Their presentation will constitute the next part of this article. Then we will present the experimental set-up: first the different coaxial cables used as emitting antenna, then the sensor we designed to measure the electrical field along one axis with a spatial resolution of about 100 microns. The last part will concern the results.

2 SIMULATIONS

The simulations were carried out with CST Microwave Studio, a commercial software using Finite Integration Technique (FIT) and the Perfect Boundary Approximation (PBA^{TM}) [6-7]. The FIT can be seen as a generalization of the FDTD (Finite Difference Time Domain) method. It discretizes the integral form of Maxwell's equations, rather than the differential one, on a pair of dual interlaced discretization grids. The PBA^{TM} permits to avoid the disadvantage of the staircase approximation of complex boundaries.

Figure 1 shows the evolution of the longitudinal electrical field along with the distance z from the end of the coaxial cable, for different shapes. The radius of the external conductor is 30 mm, the internal one is 0.5 mm and the frequency is 50 MHz. To insure that there is no tip effect at the end of the outer conductor, a small ring of metal has been added in the case of the shapes "cone30_R30_r05" (the length of the cone is 30 mm) and "expo1" (see figure 1 for its shape). The power at the port is 1 W. Figure 1 clearly shows that having a cone-shaped end increases the value of the longitudinal field "near" the coaxial cable (z < 0.8 mm in our case). The benefit decreases as the distance increases and, after some distance, the longitudinal field magnitude is lesser with a conical end. Of course, in that case, a conical shape still has a better spatial resolution, but that is not the topic of this article. At the frequency of 50 MHz, whichever conical shape gives about the same longitudinal field. On the contrary, when the frequency is higher and the wavelength nears the dimensions of the cable, the shape is critical. The shape expo 1 gives the best result (i.e. higher field near the apex) followed by the cone with an angle about 45°. Removing the ring preventing the tip effect hardly changes the results for expo1 and improves cone30_R30_r05 so that the field is similar to expo1's. The conical shape with an angle about 45° will be used for the other simulations and experiments because of its simplicity.

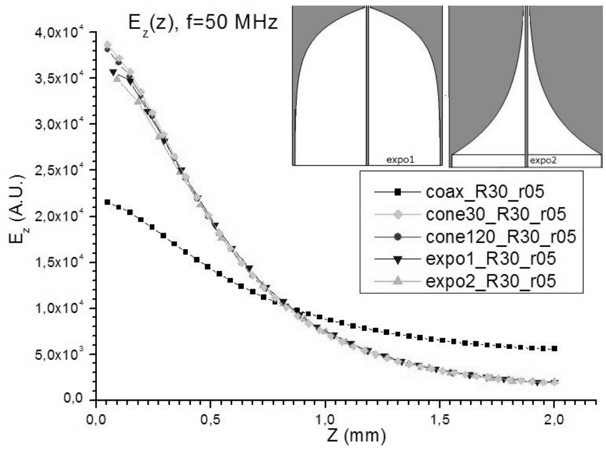

Figure 1: Simulation of the longitudinal electrical field Ez versus the distance z from the end of the cable for different shapes at a frequency of 50 MHz. The radius of the outer conductor is 30mm and the inner's one is 0.5mm. The angle of "cone30" is about 45° and 14° for "cone120". The view of the shapes "expo1" and "expo2" is inserted.

The influence of the length of the protruding part of the inner conductor has also been simulated. In figure 2, the longitudinal field E_z has been plotted against the distance z from the end of the central conductor, for different lengths of the protuberance (p = 0 mm, 5 mm and 10 mm). Once again, the radius of the external conductor is 30mm, the internal one is 0.5 mm, the angle is about 45° and the frequency is 50 MHz. Figure 2 shows that having a protuberance slightly decreases the longitudinal field near the end of the cable, i.e. when the cone-shape increases it. The same study at higher frequencies shows the same results. We will therefore not use a protruding inner conductor for the following simulations and experiments.

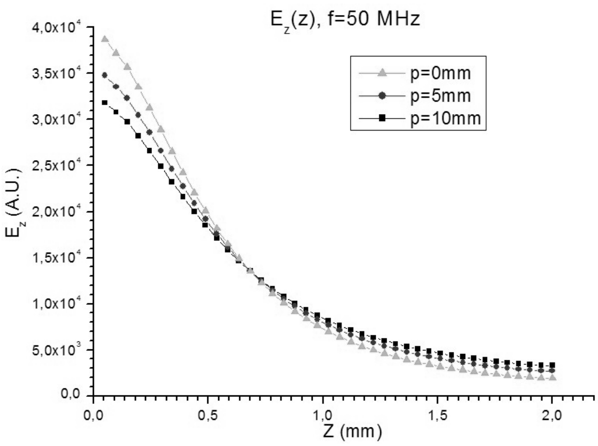

Figure 2: Simulation of the longitudinal electrical field E_z versus the distance z from the end of the cable for different protruding length of the inner conductor at a frequency of 50 MHz.

3. EXPERIMENTS

In the experimental set-up, we used two coaxial cables as emitting antennas and designed a sensor to measure the electrical field along one axis with a spatial resolution of about 100 microns. The coaxial cables were quite "large" – the outer radius was 26 mm and the inner conductor had a radius of 0.85 mm – in order to have a better spatial resolution compared to the dimensions of the coaxial cables. The dielectric was made of PVC, drilled in the centre to insert a copper wire and coated with silver paint to make the outer conductor. One coax was cone-shaped with an angle of 45° and the other one was not tapered. Both of them were connected to a classical coaxial cable with a tapered coaxial transition made likewise and ending with a BNC connexion (cf. fig. 3).

In order to measure the longitudinal electrical field E_z, we chose to convert it in displacement with a piezoelectric element and to measure the movement with a home-made heterodyne probe [8, 9]. In optimal conditions, the sensitivity of the probe is 2 fm / $\sqrt{Hz}$. One of the advantages is that it is a non-contact method without any wire transmitting the information that can be interfered with. Details about this sensor will be given elsewhere.

The piezoelectric element must not be a mono-crystal so that the other components of the field do not induce a displacement. The displacement δ can be expressed - without clamping effect – as:

$$\delta = d_{33} \cdot E_{3ext} / \varepsilon_r \cdot t \tag{1}$$

where E_{3ext} the field in the air (along the axis 3 which is the polarization axis of the ceramic), d_{33} is a piezoelectric coefficient of the ceramic, ε_r its relative dielectric constant and t its thickness.

The spatial resolution of this sensor is given by its dimensions. Since the displacement is proportional to the thickness, a compromise must be made for t. We fabricated a 100 µm thick PZT element with a square shape of 1mm x 1mm, glued on 200 µm thick Si cantilever, with MEMS techniques. The cantilever was then glued to a set-up with two micrometric translations and two micrometric rotations so that the PZT orthogonally reflects the probe's laser beam. The previously presented coaxial cables were mounted using three micrometric translation stages for x-y-z displacements and the three rotations could be adjusted and blocked manually with screws. They were the moving part of the experimental set-up. A low frequency generator was used as a power supply for the antennas and for the lock-in detection (cf. fig. 3).

Considering a piezoelectric coefficient d_{33} of 290 pm/V, a relative dielectric constant ε_r of 735, the displacement should be 4.10^{-17} m for E_{3ext} = 1V/m. In our case, the probe has a sensitivity of 5. 10^5 V/m, which gives 2.10^{-11}V for E_{3ext} = 1V/m. Considering that in these conditions, with the synchronous detection, the noise is about 20 nV, the threshold of detection of the electrical field in the air is around 1KV/m. In particular by changing the optics, it can be greatly enhanced but it is enough for our experiments. Note that because of parasitic mechanical resonances, which can increase the sensitivity of our sensor, a calibration must be done for quantitative measurement. Since we used our sensor only to compare two antennas, this calibration has not been undergone.

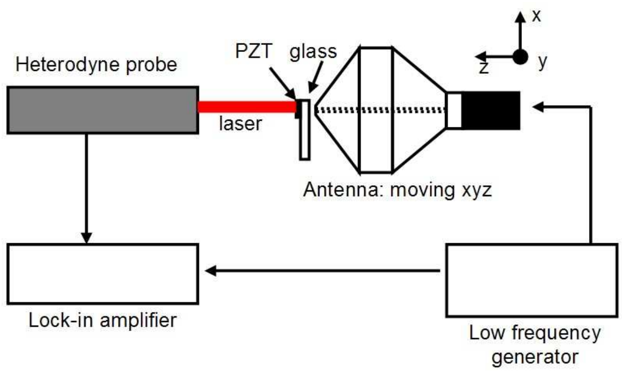

Figure 3: Experimental set-up

The voltage supplied by the generator to the antennas was 10 Vpp at 25 KHz. The antennas were centred compared to the piezoelectric element and were moved along the longitudinal axis z. Origin of the axis was taken in the centre of the piezoelectric element.

4. RESULTS

In figure 4, experimental results and simulations are plotted together. The simulations used a lossy dielectric (polyimide: $\varepsilon_r = 3.5$, tangent delta = 0.003). Since there was no calibration, the simulations were re-scaled, both with the same factor. The experiment and simulation fit well together for the cone-shaped coaxial cable. Although that is not the case with the non-tapered coax, we observe the same tendency as in the simulations: the longitudinal field E_Z is greater with a cone-shaped coax when measured near the end of the cable (distance z less than about 1 mm); farther it is smaller.

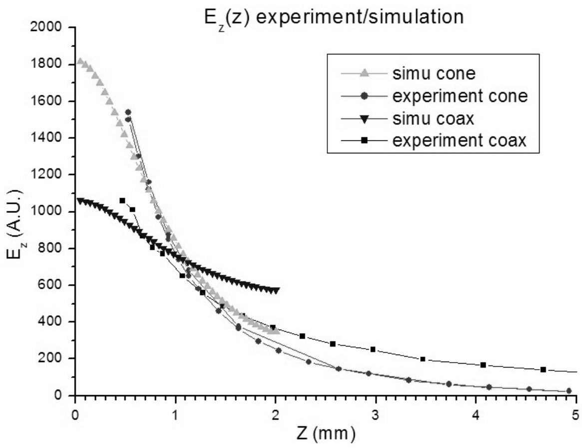

Figure 4: Comparison of experimental and simulation results for the longitudinal electrical field for the cone-shaped and the non-tapered coaxial cables versus the distance z from the end of the cable.

CONCLUSIONS

We investigated the influence of using a conical end on the longitudinal electrical near-field generated by a large coaxial cable. To that purpose we designed a new set-up to measure the electrical field in one direction with a spatial resolution of 100 microns in this direction, with nearly no perturbation by the other components of the field. Simulations and experiments agreed to the fact that the nearer to the end of the cable the more advantageous is the cone-shape but, farther a certain limit, the non-tapered shape is better to sense the longitudinal electrical field, without taking into account the spatial resolution. Therefore, for this application, the cone-shape is not always the best and one must consider the distance of work to determine the best shape.

ACKNOWLEDGEMENT

The authors would like to acknowledge the help of Gwladys Lengaigne for SU8 gluing, Sylvain Ballandras, Ludovic Gauthier-Manuel, David Vernier, Jean-Claude Baudouy and Pierre Berthelot.

REFERENCES

[1] A. Kramer, F. Keilmann, B. Knoll and R. Guckenberger, "The coaxial tip as a nano-antenna for scanning near-field microwave transmission microscopy", Micron, vol. 27, Issue 6, pp. 413-417, 1996

[2] F. Lafon, F. De-daran, J. Dupois, "Near Field Immunity cartography method to characterize an IC to fields radiated by an ESD", ICONIC 2005 UPC, Barcelona, Spain, 8th − 10th June 2005

[3] M. Q. Feng, Y. Jin Kim, H. C. Rhim, and L. Jofre, "Identification of Electromagnetic Properties of Fiber Reinforced Polymer and Concrete for Nondestructive Evaluation", ICONIC 2005 UPC, Barcelona, Spain, 8th − 10th June 2005

[4] E. Descrovi, L. Vaccaro, W. Nakagawa, L. Aeschimann, U. Staufer, and H. P. Herzig, "Collection of transverse and longitudinal fields by means of apertureless nanoprobes with different metal coating characteristics", Applied Physics Letters, vol. 85, no 22, pp. 5340-5342, 2004

[5] B. T. Rosner, T. Bork, V. Agrawal and D. W. van der Weide, "Microfabricated silicon coaxial field sensors for near-field scanning optical and microwave microscopy", Sensors and Actuators A: Physical, vol. 102, Issues 1-2, pp. 185-194, 2002

[6] B. Krietenstein, R. Schuhmann, P. Thoma, and T.Weiland, "The Perfect Boundary Approximation technique facing the challenge of high precision field computation", in Proceedings of the XIX International Linear Accelerator Conference (LINAC'98), Chicago, USA, pp. 860-862, 1998

[7] L. Lau, I. Munteanul, F. Demming, and M. Walter, "3D EM in South East Asia - state of the art and future perspective", 200 Asia-Pacific Conference on Applied Electromagnetism Proceedings, Johor Bahru, Johor, MALAYSIA, December 20-21, 2005

[8] B. Cretin, P.Vairac, "Multiple-reflection beams for simplified heterodyne interferometers" EUROPTO, Francfort, June 20-23, 1994, published in SPIE Vol. 2248, "Optical Measurement for the Process Industries", pp. 399-406, 1994

[9] P. Vairac, B. Cretin, "New structures for heterodyne interferometric probes using double-pass", Optics Communications 132, pp. 19-23, 1996