ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

POLYETHYLENE PIPELINE DETECTION AND VISUALIZATION USING THE METHOD OF AUXILIARY SOURCES

M.Sc. THESIS

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POLİETİLEN BORU HATTININ EŞDEĞER KAYNAKLAR YÖNTEMİ İLE TESPİT EDİLEBİLİRLİĞİ

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Ömer Faruk GÜNER, a M.Sc. student of ITU Informatics Institute student ID 705161013 successfully defended the thesis entitled “POLYETHYLENE PIPELINE DETECTION AND VISUALIZATION USING THE METHOD OF AUXILIARY SOURCES”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To My Family

FOREWORD

I have been working in the research and development departments of different companies. I have been receiving tasks for the last four years in Turkey's one of the biggest natural gas distribution company İGDAŞ as research and development engineer and pressure reducing and metering station maintenance engineer. During this duty, I took part in many different projects to improve the company's position. The most important project I was focusing on was the location of our buried pipelines without excavation and mapping coordinates. In line with this goal, we conducted field studies with the products of many companies. Although we have achieved some positive results as a result of these studies, we have always prioritized further studies on different methodologies.

I would like to thank my thesis advisors, Asst. Prof. Dr. Sebahattin EKERand Assoc. Prof. Dr. Vasil TABATADZEfor their support and assistance during this study.

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August 2019 ÖMER FARUK GÜNER
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TABLE OF CONTENTS

Page

ABBREVIATIONS

PE : Polyethylene
PL : Pipeline
RS : Remote Sensing
EM : Electromagnetic
MAS : Method of Auxiliary Resources
AS :Auxiliary Sources
SFS : Scattered Field Singularities

LIST OF FIGURES

Page

POLYETHYLENE PIPELINE DETECTION AND VISUALIZATION USING THE METHOD OF AUXILIARY SOURCES

SUMMARY

In Istanbul and many other cities, underground networks like water, natural gas is used to deliver a range of services to households and industries. It is inevitable for the metropolitan cities to operate the infrastructure system without any problems.

Pipelines maintaining and upgrading are the most important undertakings for distribution companies. Excavation work is required to reach the pipe for possible maintenance works that may occur on the pipelines.To avoid unnecessary holes dug in wrong places and excavator damage to pipeline, before invasive works, it is normally required that excavators should obtain record information from distributing company to identify what is buried where.

However, the mapping information supplied by distributing companies is often of limited use as asset records are usually inaccurate and incomplete. Although the coordinate information of the pipelines recorded by the distribution companies does not vary in x and y, the depth coordinates of the pipelines change over time due to the superstructure studies.This changing depth information carries the risk of damaging the pipelines if there is no current data in the next excavation.In drilling-like works, uncontrolled gas outlets or fire may occur at high pressure with perforation, tearing, breaking in the natural gas distribution network. For this reason, the security of life, property, and environment and the natural gas supply of residential, commercial, and industrial establishments are endangered and may cause big material losses for our country.

Thus distribution companies have to conducted using sensor devices, such as ground-penetrating radar (GPR) to avoid damage to pipelines. As the results of many field tests could not be obtained from the devices, it was decided to research a different method.

In this thesis, the detection of polyethylene pipes of different diameters buried underground will be investigated by using the Method of Auxiliary Sources.

POLİETİLEN BORU HATTININ EŞDEĞER KAYNAKLAR YÖNTEMİ İLE TESPİT EDİLEBİLİRLİĞİ

ÖZET

İstanbul ve diğer pek çok şehirde, su, doğal gaz gibi yer altı şebekelerini ev sahiplerine ve sektörlere çeşitli hizmetler sunmak için alt yapı sistemleri kullanılmaktadır. Bu hizmetlerin kesintisiz ve güvenli şekilde sağlanması ve altyapı sistemlerinin sorunsuz bir şekilde çalıştırılması kaçınılmazdır. Ülkemizde altyapı şebekeleri büyük bir ivmeyle gelişmeye devam etmektedir. Türkiye genelinde sadece doğal gaz dağıtım sistemi yaklaşık 138 bin kilometreden daha fazla bir uzunluğa ulaşmıştır.

Şehirlerdeki altyapı şebekelerinin gelişim, genişleme ve yenileme faaliyetlerindeki artış altyapı hizmeti işletmeciliği açısından bazı tehlike ve riskleri de beraberinde getirmektedir. Altyapı hizmeti işletmeciliğinin en önemli önceliği ise boru hatlarının bakımı ve işletme hizmetinin geliştirilmesidir. Boru hatları üzerinde meydana gelebilecek olası bakım işleri için boruya ulaşmak için en bilindik yöntem ise kazı çalışmasıdır. Bu yöntem aynı zamanda işletme açısından karşılaşılabilecek en büyük risk olan doğal gaz boru hattı hasarı riskini de taşımaktadır. Kazı kaynaklı hasarlar doğal gaz dağıtım sektörü için kronik bir sorundur. Meydana gelebilecek bu tarz hasarlar can, mal ve çevre emniyetini de büyük ölçüde tehlikeye düşürmektedir. Ayrıca bu hasarlar altyapı hizmetlerini aksatması nedeniyle aynı zamanda müşterilere verilen hizmetin de kesintiye uğramasına sebep olmaktadır. Türkiye'de izinsiz ve kontrolsüz kazı sayısı her geçen gün artmaktadır ve bu durumun sonuçları ise şebekelerde delinme, yırtılma, kırılma ile birlikte meydana çıkan yüksek basınçta kontrolsüz gaz çıkışları ve buna dayalı yangınlar meydana gelebilmektedir. Bu nedenle can, mal ve çevre emniyeti ile konut, ticari ve endüstriyel sanayi kuruluşlarının doğal gaz arzı tehlikeye girmekte ayrıca ülkemiz için de büyük maddi kayıplara sebebiyet verebilmektedir.

Kazı çalışmalarını yapmadan önce kazı çukurlarının yanlış yerlerde yapılmasını ve ekskavatörün boru hattına zarar vermesini önlemek için, kazı çalışmalarından önce, ekskavatörlerin çalışma planını ayarlamada dağıtıcı şirketin kayıt altına aldığı altyapı koordinat bilgilerini referans alarak çalışmayı yapması gerekmektedir. Ancak, dağıtım şirketleri tarafından sağlanan haritalama kayıtları düzenli aralıklar ile güncelleme istediği için çoğu zaman sınırlı kullanımdadır. Dağıtım şirketleri tarafından kaydedilen boru hatlarının koordinat bilgileri x ve y eksenlerinde değişiklik göstermese de, boru hatlarının derinlik koordinatları yapılan kazı çalışmaları ve yol çalışmaları nedeniyle zaman içerisinde derinlik yani z koordinat bilgileri değişmektedir. Bu değişimleri sürekli olarak güncel tutmak ve takip etmek ise son derece zor bir iştir.

Bu nedenle dağıtım şirketleri, boru hatlarına zarar gelmemesi için yer altı radarı (GPR) gibi sensör cihazları kullanarak kazı çalışmaları yapmalıdır. Yer altı Radarı günümüzde bilinen ismiyle (GPR: Ground Penetrating Radar), yüzeyin üzerinden

düşük derinlikleri incelemek için kullanılan yüksek frekanslı elektromanyetik dalgalar ile çalışan cihazlardır. Düşük derinlik tanımı jeoteknik araştırmalar için kullanıldığında 0 ile 3 metre arası derinlikler genelde jeoteknik araştırmalar için yeterli olmamaktadır. Fakat şehir içi yer altı şebekeleri için 3 metre derinliğe nüfuz eden yer radarları yeterli görülmektedir.

GPR cihazlarının içinde bulunan alıcı veya verici antenler bulunmakta olup bazı cihazlarda ise hem alıcı hem verici antenin birlikte olduğu anten kutusu bulunmaktadır. Antenlerin görevlerini tanımlarsak verici anten yer yüzeyinden yer altına doğru yüksek frekanslara sahip kısa sinyaller halinde dalgalar göndermektedir. Bu gönderilen dalgalar yerin altında bulunan bir cisme veya di-elektrik sabiti içinde mevcut bulunduğu katman içerisindeki farklı katman sınırları ile temas ettiğinde, bu yüzeylerden gelen farklı varyasyonlardaki dalgaları alıcı anten sayesinde tespit edip kayıt altına alır.

Güncel piyasada bulunan GPR cihazları ile yapmış olduğumuz saha testleri neticesinde çelik boruların tespiti polietilen borulara nazaran iyi sonuçlar vermektedir. Fakat altyapısı karışık olan bölgelerde yaptığımız çalışmalarda boru hatlarını ve diğer altyapı varlıklarını birbirinden ayırma ve tespit etme noktasında problemler yaşanmıştır. Farklı bir teknoloji olan polietilen boru hatlarına yönelik akustik tabanlı çalışan polietilen boru dedektörü saha ortamında uygulanmış olup güzel neticeler vermiştir. Fakat tespit süreci oldukça uzun olduğu için isteklerimizi tam olarak sağlayamamıştır. Yapılan birçok saha çalışmaları neticesinde tatmin edici sonuçlar elde edemediğimiz için farklı metotlar üzerinde araştırma yapılması gündeme gelmiştir. Çelik hatların tespitine yönelik birçok cihaz ile yaptığımız saha testleri sonucunda polietilen boru hatlarının tespitine nazaran daha olumlu sonuçlar aldığımız için çalışmanın önceliği polietilen boruların tespit edilebilirliği konusuna çevrilmiştir. Çalışmanın ilerleyen dönemlerinde ise bütün altyapı varlıklarının tespitine yönelik bir çalışma planlanmaktadır. Çalışma kapsamında farklı metotlar araştırılmış olup eşdeğer kaynaklar yöntemi ile altyapı sistemlerimizde genellikle en çok kullanmış olduğumuz polietilen boru tipleri tespit edilmiştir. Polietilen boru hatlarımızın derinlikleri en az 0.5 metre en fazla ise 1.5 metre olarak seçilmiştir. Boru hatlarının çapları ise sırası ile Ø32 mm, Ø63 mm ve Ø125 mm olarak seçilmiştir. Ortam şartları ise toprak nemliliğinin dielektrik katsayısına doğrudan etki etmesinden dolayı öncelik olarak kuru toprak üzerinde çalışma yapılmıştır. Kullandığımız yöntem olan eşdeğer kaynaklar yöntemi (MAS) ise, belirli bir diferansiyel denklem için sınır probleminin çözümünü ve bu denklemin temel veya diğer tekil çözeltileri açısından genişleterek çözümü bulma yöntemidir. Özellikle karmaşık şekilli ve dolgulu gövdeler üzerine 2D ve 3D saçılma problemlerine uygulanan bir yöntemdir.

Eşdeğer kaynaklar yöntemi farklı durumlar için uzak ve yakın alanlar, yarı-statikten yarı-optiğe kadar geniş frekans bandında sayısal simülasyonlarla analiz edebilmemizi sağlamaktadır. Ayrıca eşdeğer kaynaklar yöntemi karmaşık saçılma problemlerini inceleme ve elektromanyetik ve hafif dalga bandında çeşitli fiziksel olayları görselleştirme konusundaki etkinliği de gösterilmiştir. Çalışma kapsamında polietilen borunun kendisine ait rezonans frekans aralığı taranmış olup seçilen aralıklarda meydana gelen grafiklerdeki tepe noktaları frekans aralıkları küçültülerek incelenmiştir. Elde edilen rezonans frekansı sayesinde farklı derinliklerde bulunan farklı kalınlıklardaki polietilen boruların tespit edilebilirliği incelenmiştir. Ayrıca yüzeye dik olarak gönderilen kaynak açıları değiştirilerek farklı açılardan gönderilmiş olup eşdeğer kaynaklar yöntemi ile yer altında bulunan polietilen boruların tespiti sağlanmıştır.

1.INTRODUCTION

The auxiliary source is a method that is based on the distribution of singularities. With this method, the basic functions found in scattering objects are concentrated by the property of the analytical progress of a scattered field.As a result, the collision coefficient was determined and proved by the sequencing technology to solve the external and internalproblems of the electrodynamics.

1.1Purpose of the Thesis

Investigation of infrastructure using electromagnetic radiation to detect infrastructure systems buried in the soil is a very typical problem.It is widely used in the detection and mapping of infrastructure systems with different material properties and different transmission lines that are underground with electromagnetic waves.

In cities such as Istanbul, where the infrastructure is dense and complicated in terms of transmission lines, it is really difficult to detect the pipes by a non-destructive testing method.To find and distinguish between transmission lines such as natural gas, water, fiber optic, electrical cables within the Istanbul infrastructure employingthe non-destructive testing method and tried to differentiate them from each other has been tried and obtained fast and healthy data.

For this reason, the resonance frequency of a pipeline made of polyethylene material was determined by using a different method, and the detectability of the pipe was investigated by using a source sent from outside without excavation.

1.2 Literature Review

The mathematical explanation of the auxiliary sources method was made by Georgian mathematicians (Kupradze, Vekua). Besides, there are many studies by these authors about scattered areas. Georgian mathematicians V. Kupradze, I. Vekua, and M. Aleksidze have proved varying differential equations and boundary conditions. They also applied these concepts to the solution of certain boundary problems.In Field *D*mentioned in the following sections, for randomly closed auxiliary surface, it has been proven that the solution is discarded into the real with the increasing number of auxiliary sources.

Some authors see such an approach only as a mathematical way of finding a solution to the physical problem and have not exemplified any physical meaning. Convergence and stability depend on the correct selection of ancillary parameters that exemplify physical meaning. Therefore, MAS's modern algorithm has been developed as a numerical method for solving boundary problems of mathematical physics.

2. PROBLEM STATEMENT

Firstly measure the all reflected field in the points on all sides of first source location after that setup frequency characteristics of the polyethylene pipeline. The reflected field will be added to the polarization of the wave field and processing of the polyethylene pipeline axis.

The main aim is discovering to polyethylene pipelines inside the ground.

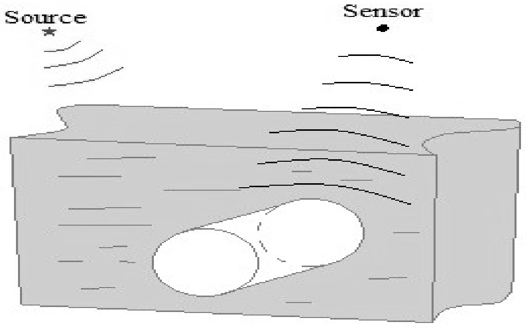


Figure 2.1 : Problem statement.

The electromagnetic wave was used to investigate the soil. At certain frequencies, we thought that the empty spaces in the ground behave as resonators. The measured reflectance thus has to have peaks point for the resonance frequencies to the polyethylene pipe resonances. All features of polyethylene pipe system; dimension, coordinate and direction of the pipelines, as well as the permeability and conductivity of the pipelines, have to include the reflected area. We obtain different cases of pipelines positions and sizes also use different source locationtoacquire some statistical regularity.

With this study, we will discuss the solution of different dimensions Ø 32mm, Ø 63mm, Ø 125mm cylindrical shape polyethylene the pipelines are underground and parallel to the surface axis. Also EM field point use source in different positions above the ground.

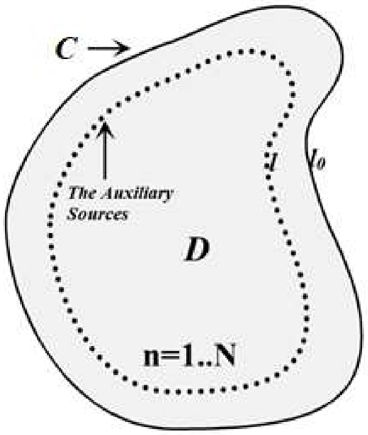
2.1 Meaning of The Method of Auxiliary Resources

The Method of Auxiliary Sources (MAS) is a numerical technique for analysis of electromagnetic radiation and scattering problems.

MAS can explain an external scattering problem :

The sources of the scattered field are selected as separate sources such as Hertzian dipoles and line currents. These spread fields are given in closed-form expressions. The auxiliary sources are placed on an auxiliary surface and placed in the scatter. Allow the auxiliary resources to be disseminated in the free space. Their excitations are then determined by matching the boundary condition on the surface of the scattering. Thus we can resolve the linear system of equations in this way.

Consider object perfectly conductor scatterer with surface C. Incident field excites current on the C, and we get the scattered field. To find the scattered field, we have to determine currents excited on the surface. For this, we have to require boundary condition satisfaction on The scatterer's surface.



$$E_z = E_z^i + E_z^s = 0$$

Figure 2.2: Total electric field.

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2.2 Theoretical Part About Method of Auxiliary Resources

Let us explain the meaning of this method in a two-dimensional plane. In the field *D*, if we select the closed *L* boundary and these *N* auxiliary sources with unknown complex coefficients defined by the basic solutions of the Helmholtz equation, the scattered field of *D* can be searched as the sum of the total fields.

$$U=\sum_{n=0}^{N} a_n H_0(kR_n) \tag{2.1}$$

where

$$R_n=\sqrt{(x-x_n)^2+(y-y_n)^2} \tag{2.2}$$

x , y is thepoint of examination coordinates

x_n, y_n given in the general formula are the coordinates of the auxiliary resources (2.2). H_0 represents the cylindrical Hankel function. Each member of the formula in (2.1) satisfies the Helmholtz wave equation and the radiation state. It means inphysically replacing the field of the continuous surface by the field of the auxiliary sources on *l*.

Let us assume that this disintegration is excited by the field U^i withtime dependence of $e^{-i\omega t}$, the aim is discoveringthe scattered field $U^S(x,y,z)$ which satisfies Helmholtz equation

$$\Delta U^S(x,y,z) + k^2 U^S(x,y,z) = 0 \tag{2.3}$$

the infinity radiation condition and boundary condition:

$$W\{US(x,y,z) - Ui(x,y,z)\}=0,\ M(x,y,z)\in S \tag{2.4}$$

W is now the operator of boundary conditions. An auxiliary surface is inserted into the area D. On this surface, *σ* is evenly distributed to several points.

$$r_n\left\{x_n, y_n, z_n\right\}_{n=1}^{\infty} \in \sigma \tag{2.5}$$

Let;

$$\{U_n(|\vec{r}_n - \vec{r}\,|)\}_{n=1}^{\infty} \tag{2.6}$$

The Helmholtz equation may have basic solutions in which SF is represented. Functions are:

$$U(|\vec{r}_n - \vec{r}\,|) = H_0^{(1)}\left(k\sqrt{(x_n - x)^2 + (y_n - y)^2}\right) \quad \text{2-D} \tag{2.7}$$

$$U(|\vec{r}_n - \vec{r}\,|) = \frac{e^{ik|\vec{r}_n - \vec{r}|}}{|\vec{r}_n - \vec{r}\,|} \qquad \text{3-D} \tag{2.8}$$

and

$$|\vec{r}_n - \vec{r}\,| = \sqrt{(x_n - x)^2 + (y_n - y)^2 + (z_n - z)^2} \quad ; \quad M(x_n, y_n, z_n) \in \sigma \tag{2.9}$$

The system of function mention in (2.6) is stated as the basic solution of the Helmholtz equation. This equation can define the properties of the field (electric field, magnetic field, or field potentials) independently and completely on the surface. Using the first N functions of the system in question, all SF functions on the surface S have j_n coefficients, where the basic solutions can be represented by a linear combination of appropriate coefficients (2.10).

$$U^i(x, y, z)\,|_S \approx \sum_{n=1}^{N} j_n U(|\vec{r}_n - \vec{r}\,|)\,|_S \tag{2.10}$$

The approach solution out of boundary problem is:

$$\tilde{U}^S(x, y, z) = \sum_{n=1}^{N} j_n U(|\vec{r}_n - \vec{r}\,|) \tag{2.11}$$

Then,

$$U^{S}(x,y,z)\,\text{with}\,N\to\infty. \tag{2.12}$$

This is the general concept of MAS introduced by Kupradze.

In a dielectric scatter, the SF should be with the field in the body. Two auxiliary surfaces should be selected on both sides of the main surface *S*.

However, for the convergence of the computation line to proceed, contour *l* must be subtracted from contour *l0* but not approached. Regarding dielectric objects, the regions should also be determined in the *D* region. Therefore, it is convenient to select the electric Hertz vector as the desired function in every homogeneous part of the space and present it as follows.

$$U_1=\sum_{n=0}^{N}a_nH_0(kR_n)\qquad R_n\notin D \tag{2.13}$$

$$U_2=\sum_{n=0}^{N}b_nH_0(kR_n)\qquad R_n\in D \tag{2.14}$$

The magnetic fields and electrical fields components can be exploredwhit the known correlations. The coefficients a_n and b_n can be determined by unknown complex boundary conditions.

The choice of the technique of determining the values of a_n and b_n with unknown coefficients will become the main issue after selecting the basic functions.

If we now examine the part of the polyethylene pipeline mean that the surface among *S* and *S0*. Surfaces with dielectrics complex permittivity losses. $\varepsilon_c=(\varepsilon',\varepsilon'')$. The area above the surface and inside the PE pipeline permittivity which ε_0, μ_0.

We can think about the S plane part of the surface, the mass of the cylindrical PE pipeline *S0* is placed (Figure 2.3). EM wave,whichincludes time-harmonic $\vec{E}_{inc}$, $\vec{H}_{inc}$ affect to *S* surface. The purpose in this section is to detectreflected field which $\vec{E}^{out}$,

$\vec{H}^{out}$ above the area, the field among surface and polyethylene pipeline $\vec{E}^{bet}$, $\vec{H}^{bet}$ and area inside layer in $\vec{E}^{in}$, $\vec{H}^{in}$.

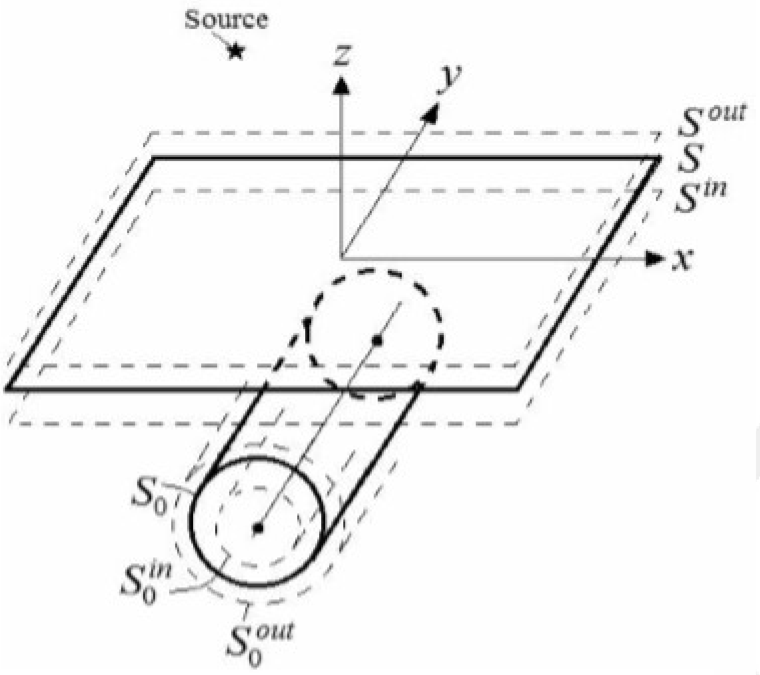

Figure 2.3 : Source and pe pipeline.

The problem which is pipeline detection resolved with using the MAS. We define the inner with S^{in} and outer S^{out}. The selected auxiliary surfaces must be parallel to the S surface, and they must be placed at equal intervals on the S surface. The auxiliary surfaces which S_0^{in} and S_0^{out} are must build inner and outer of the polyethylene pipeline Figure (2.3). It points to the equivalent joint points for both sides on the ground flat surfaces and the cylindrical polyethylene pipeline called M and N.

Also,examine all aspects of the scattering EM fields, we select polarizations and two vertical hertz dipoles as auxiliary sources.

Green function:

$$\vec{G}_E^{\tau}\left(\vec{r},\vec{r}',\varepsilon\right)=\frac{e^{i\sqrt{\varepsilon}k_0\left|\vec{r}-\vec{r}'\right|}}{4\pi\omega\varepsilon_0\varepsilon}\left\{\begin{array}{l}\left(\dfrac{k_0\sqrt{\varepsilon}}{\left|\vec{r}-\vec{r}'\right|^2}+i\dfrac{1}{\left|\vec{r}-\vec{r}'\right|^3}\right)\left[\dfrac{3\left(\vec{r}-\vec{r}'\right)\cdot\vec{\tau}}{\left|\vec{r}-\vec{r}'\right|^2}\left(\vec{r}-\vec{r}'\right)-\vec{\tau}\right]\\-i\dfrac{k_0^2\varepsilon}{\left|\vec{r}-\vec{r}'\right|^3}\left(\left(\vec{r}-\vec{r}'\right)\times\left(\left(\vec{r}-\vec{r}'\right)\times\vec{\tau}\right)\right)\end{array}\right\}$$

$$\vec{G}_H^{\tau}\left(\vec{r},\vec{r}',\varepsilon_c\right)=\frac{e^{i\sqrt{\varepsilon_c}k_0\left|\vec{r}-\vec{r}'\right|}}{4\pi}\left(\frac{1}{\left|\vec{r}-\vec{r}'\right|^3}-i\frac{k_0\sqrt{\varepsilon_c}}{\left|\vec{r}-\vec{r}'\right|^2}\right)\left(\vec{\tau}\times\left(\vec{r}-\vec{r}'\right)\right)$$

The polarization vectors come from the tangent vectors of the main surface and the PE pipeline surface.

The total areaon the surface include $\vec{E}_{inc}\left(\vec{r}\right)$, $\vec{H}_{inc}\left(\vec{r}\right)$. And the same area also has reflected $\vec{E}_{S^{in}}\left(\vec{r}\right)$, $\vec{H}_{S^{in}}\left(\vec{r}\right)$.

The reflected is defined by the auxiliary sources deploy on thearea S_0^{in}. The area between S and S_0 also include $\vec{E}_{S^{out}}\left(\vec{r}\right)$, $\vec{H}_{S^{out}}\left(\vec{r}\right)$ fields. The fields reflected the surface is $\vec{E}_{S_0^{in}}\left(\vec{r}\right)$, $\vec{H}_{S_0^{in}}\left(\vec{r}\right)$. The fields are located on S^{out} and S_0^{in} have been identified concerning auxiliary sources.

So;

$$\vec{E}^{in}\left(\vec{r}\right)=\vec{E}_{S_0^{out}}\left(\vec{r}\right),\quad \vec{E}^{out}\left(\vec{r}\right)=\vec{E}^{inc}\left(\vec{r}\right)+\vec{E}_{S^{in}}\left(\vec{r}\right),$$

$$\vec{H}^{in}\left(\vec{r}\right)=\vec{H}_{S_0^{out}}\left(\vec{r}\right),\quad \vec{H}^{out}\left(\vec{r}\right)=\vec{H}^{inc}\left(\vec{r}\right)+\vec{H}_{S^{in}}\left(\vec{r}\right),$$

$$\vec{H}^{bet}\left(\vec{r}\right)=\vec{H}_{S^{out}}\left(\vec{r}\right)+\vec{H}_{S_0^{in}}\left(\vec{r}\right),\quad \vec{E}^{bet}\left(\vec{r}\right)=\vec{E}_{S^{out}}\left(\vec{r}\right)+\vec{E}_{S_0^{in}}\left(\vec{r}\right),$$

The auxiliary surfaces fields.

$\vec{E}_{S^{in}}\left(\vec{r}\right)$, $\vec{H}_{S^{in}}\left(\vec{r}\right)$, $\vec{E}_{S^{out}}\left(\vec{r}\right)$, $\vec{H}_{S^{out}}\left(\vec{r}\right)$, $\vec{E}_{S_0^{in}}\left(\vec{r}\right)$, $\vec{H}_{S_0^{in}}\left(\vec{r}\right)$, $\vec{E}_{S_0^{out}}\left(\vec{r}\right)$, $\vec{H}_{S_0^{out}}\left(\vec{r}\right)$

These functions are expressed like:

$$\vec{E}_{S^{in}}\left(\vec{r}\right)=\sum_{n=1}^{N}a_n{}^1G_E(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{N}a_n{}^2G_E(\vec{r},\vec{r}',\varepsilon)$$
$$\vec{E}_{S_0{}^{in}}\left(\vec{r}\right)=\sum_{n=1}^{M}c_n{}^1G_E(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{M}c_n{}^2G_E(\vec{r},\vec{r}',\varepsilon)$$

$$\vec{H}_{S^{in}}\left(\vec{r}\right)=\sum_{n=1}^{N}a_n{}^1G_H(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{N}a_n{}^2G_H(\vec{r},\vec{r}',\varepsilon)$$
$$\vec{H}_{S_0{}^{in}}\left(\vec{r}\right)=\sum_{n=1}^{M}c_n{}^1G_H(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{M}c_n{}^2G_H(\vec{r},\vec{r}',\varepsilon)$$

$$\vec{E}_{S^{out}}\left(\vec{r}\right)=\sum_{n=1}^{N}b_n{}^1G_E(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{N}b_n{}^2G_E(\vec{r},\vec{r}',\varepsilon)$$
$$\vec{E}_{S_0{}^{out}}\left(\vec{r}\right)=\sum_{n=1}^{M}d_n{}^1G_E(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{M}d_n{}^2G_E(\vec{r},\vec{r}',\varepsilon)$$

$$\vec{H}_{S^{out}}\left(\vec{r}\right)=\sum_{n=1}^{N}b_n{}^1G_H(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{N}b_n{}^2G_H(\vec{r},\vec{r}',\varepsilon)$$
$$\vec{H}_{S_0{}^{out}}\left(\vec{r}\right)=\sum_{n=1}^{M}d_n{}^1G_H(\vec{r},\vec{r}',\varepsilon)+\sum_{n=1}^{M}d_n{}^2G_H(\vec{r},\vec{r}',\varepsilon)$$

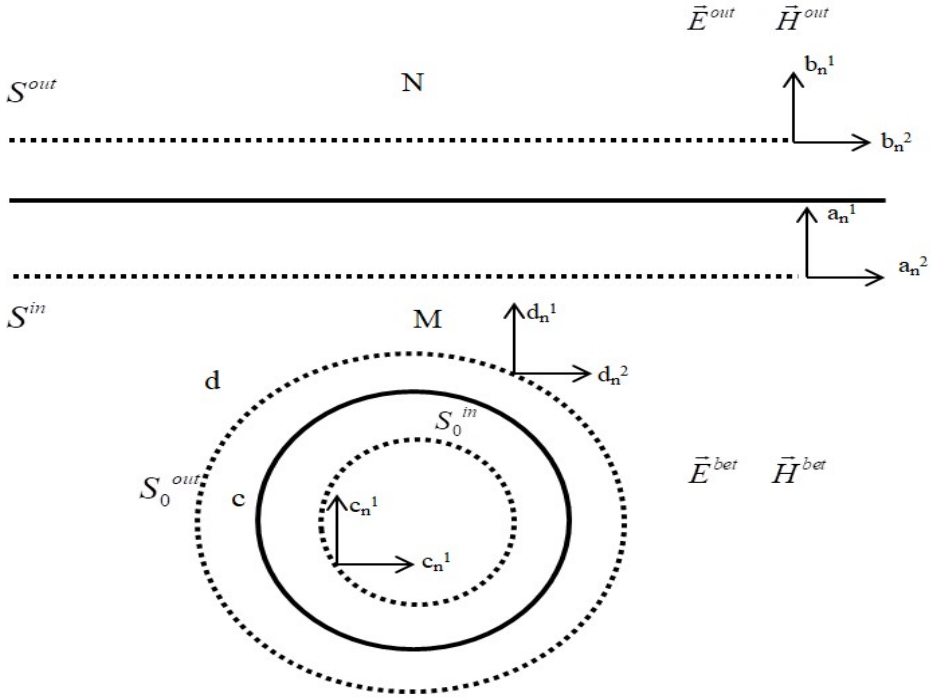

Figure 2.4 : The geometry of the auxiliary surfaces fields.

The unknown complex amplitudes can be used to find boundary conditions. Tangent components of magnetic field and alsoelectric field must be continuous along the PE pipeline and surface:

$$\begin{cases} \vec{E}^{out}\left(\vec{r}_m\right)\cdot\vec{x}=\vec{E}^{bet}\left(\vec{r}_m\right)\cdot\vec{x} \\ \vec{E}^{out}\left(\vec{r}_m\right)\cdot\vec{y}=\vec{E}^{bet}\left(\vec{r}_m\right)\cdot\vec{y} \\ \vec{E}^{bet}\left(\vec{r}_{0,n}\right)\cdot\vec{\vartheta}_n=\vec{E}^{in}\left(\vec{r}_{0,n}\right)\cdot\vec{\vartheta}_n \\ \vec{E}^{bet}\left(\vec{r}_{0,n}\right)\cdot\vec{y}=\vec{E}^{in}\left(\vec{r}_{0,n}\right)\cdot\vec{y} \end{cases} \begin{cases} \vec{H}^{out}\left(\vec{r}_m\right)\cdot\vec{x}=\vec{H}^{bet}\left(\vec{r}_m\right)\cdot\vec{x} \\ \vec{H}^{out}\left(\vec{r}_m\right)\cdot\vec{y}=\vec{H}^{bet}\left(\vec{r}_m\right)\cdot\vec{y} \\ \vec{H}^{bet}\left(\vec{r}_{0,n}\right)\cdot\vec{\vartheta}_n=\vec{H}^{in}\left(\vec{r}_{0,n}\right)\cdot\vec{\vartheta}_n \\ \vec{H}^{bet}\left(\vec{r}_{0,n}\right)\cdot\vec{y}=\vec{H}^{in}\left(\vec{r}_{0,n}\right)\cdot\vec{y}. \end{cases}$$

The boundary conditions symbolize the system of linear algebraic equations concerning the coefficients.

For;

“**a**”a_n^1, a_n^2

“**b**”b_n^1, b_n^2

“**c**”c_n^1, c_n^2

“**d**” d_n^1, d_n^2.

By resolve this system, we found the unknown amplitudes.

3. NUMERICAL SIMULATIONS AND RESULTS

We have created a user-friendly program package for performing numerical experiments with the mathematical algorithm mentioned above. With this program package, we have gained the ability to select ground and polyethylene pipeline parameters, welding position, and other parameters to calculate field distributions. We can create frequency properties for different situations, and we can compare the results with each other. The principal idea of these experiments is to formulate the methodology of the given problem. The User-Friendly Program provides the ability to administratesome parameters; configure the problem with material characteristics (cylindrical polyethylene pipeline), select the type of source, the frequency range of the EM wave and the reflected area.

If can we compose a library of these properties, we can compute the measurement results with the values we have previously determined in the library. In this way, we can easily decide that the polyethylene pipeline that we searched for by real experiment is in the soil. The program package we have created allows us to examine the dynamics in the 3D field. It is also possible to create a wider library by making additional calculations for all infrastructure assets.

First of all, it is necessary to obtain the resonance frequency of the polyethylene pipe to perform this study. To find the resonance frequency of the polyethylene pipe, firstly, the frequency range was scanned between 1.90 and 2.10.

The graph obtained by scanning the frequency range 1.90 to 2.10 is as shown in Figure 3.1.

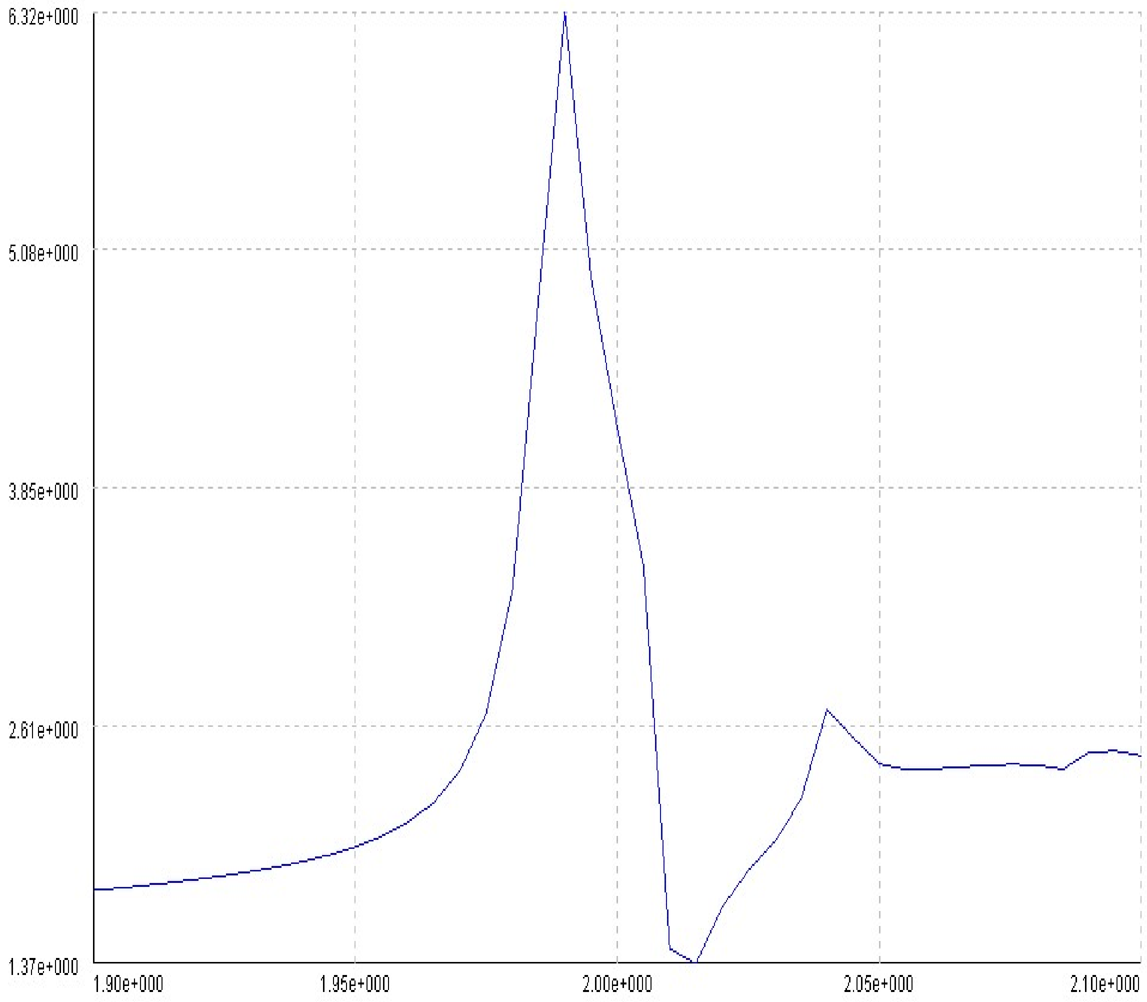

Figure 3.1 : Result ofthe frequency range (1.90 - 2.10).

To find the exact value of the remarkable peak in the 1.90 - 2.10 frequency range we have scanned, the frequency search range has been further reduced and scanned from the new values of 1.95 to 2.05.

The graph obtained as a result of the scanning of the frequency range 1.95 to 2.05 in Figure 3.2.

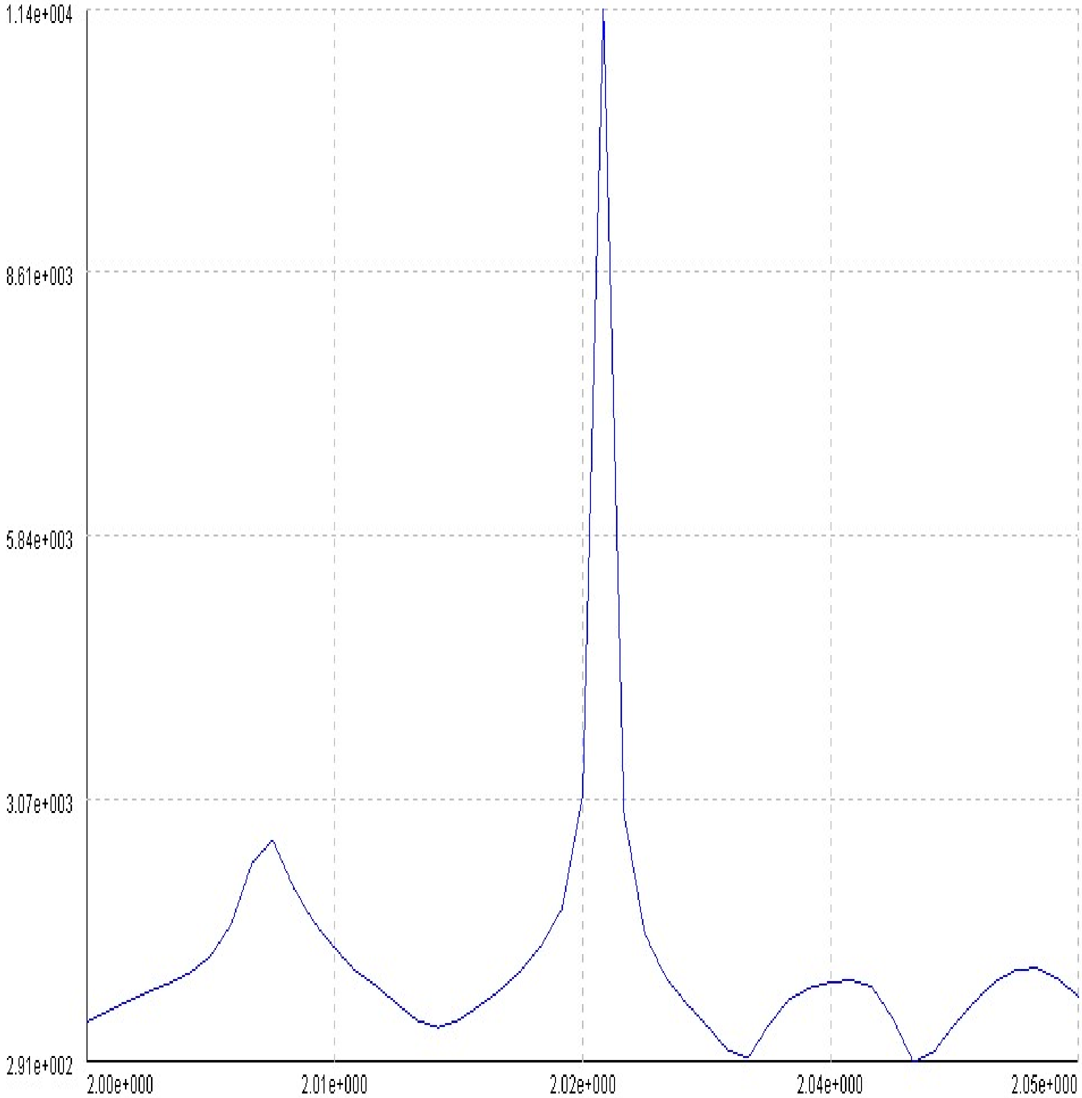

Figure 3.2: Result of the frequency range (1.95-2.05).

It was seen that the peaks have almost the same value in the graph obtained at the end of two measurements. For this reason, the frequency search range for the peak value is reduced, and Figure 3.3 is obtained.

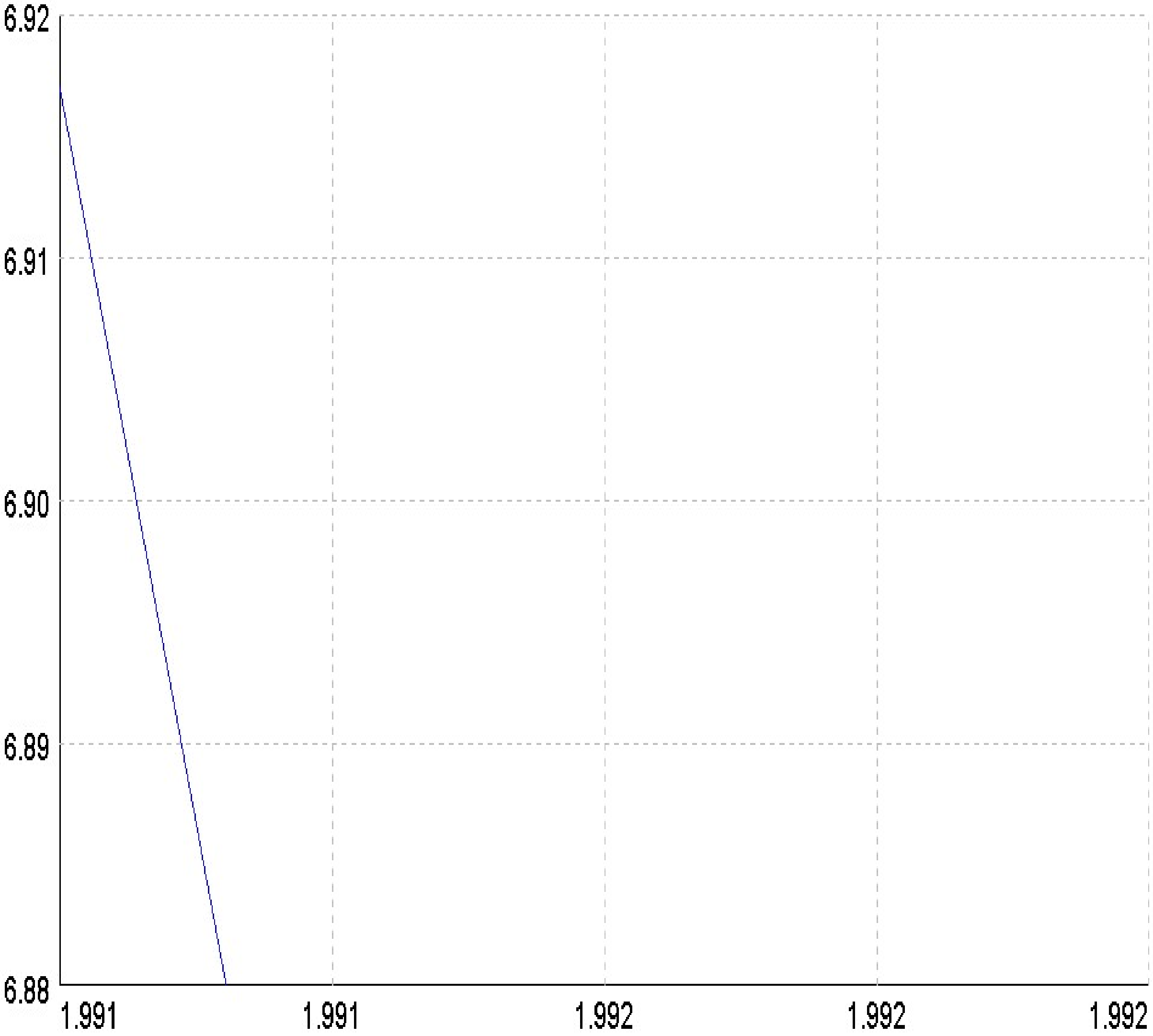

Figure 3.3 : Peak value (1.911).

The peak value is 1.991, which is the natural resonance frequency of our polyethylene pipeline.

For this value, the detectability of polyethylene pipelines in different sizes was investigated. Besides, the results obtained when the resource used is positioned at different angles.

3.1 Investigation of The Detectability of PE Pipelines With Frequency 1,991

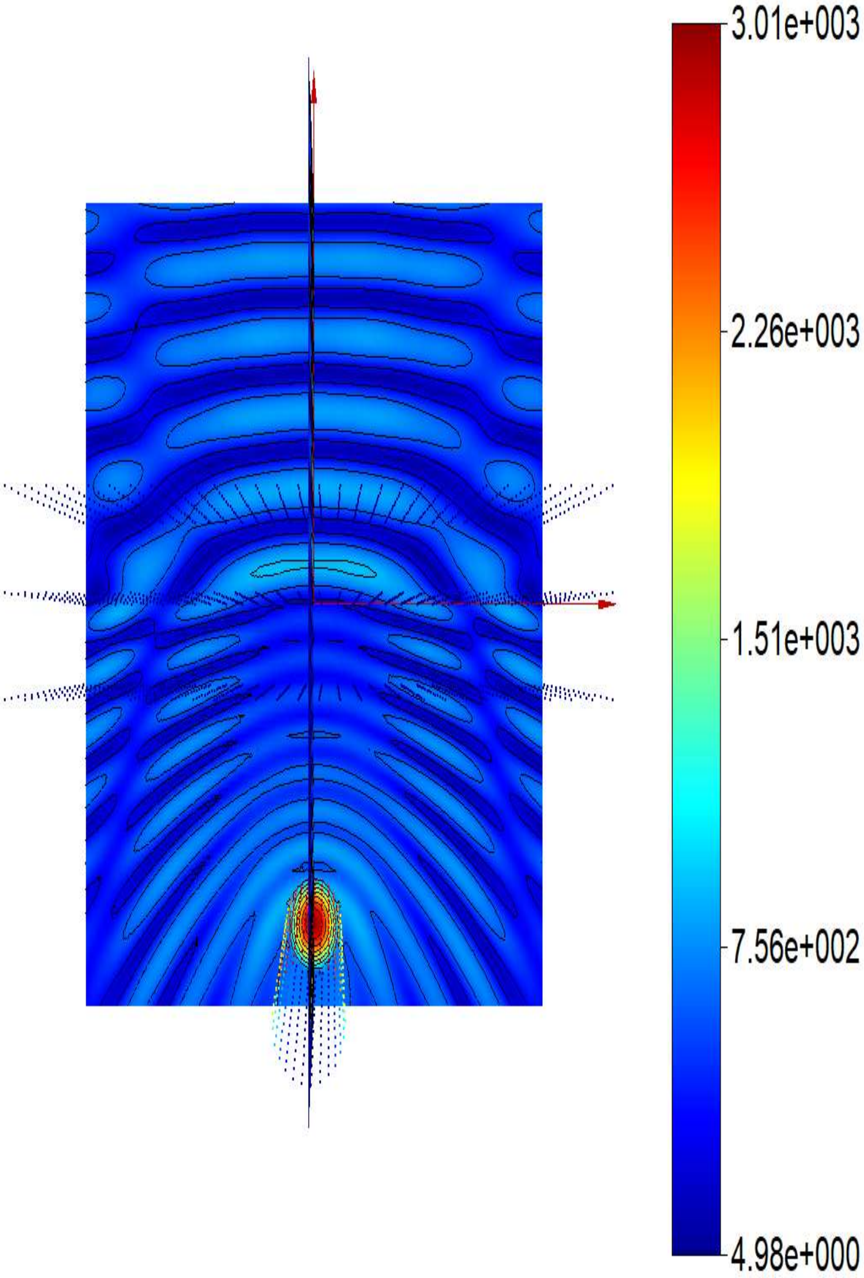

Figure 3.4 :1 meter depth Ø32mm PE X-Z coordinate.

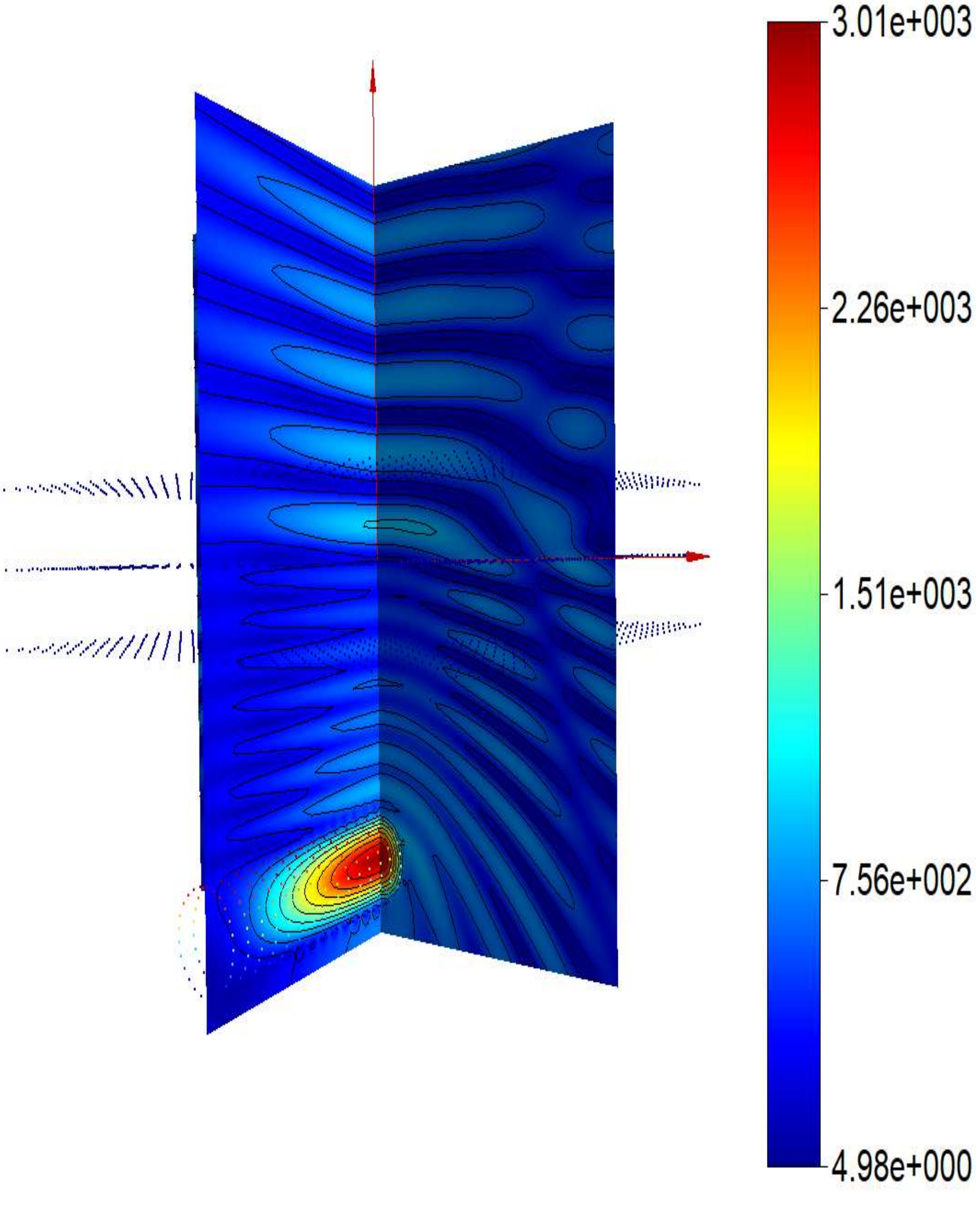

Figure 3.5 : 1 meter depth Ø32mm PE X-Y coordinate.

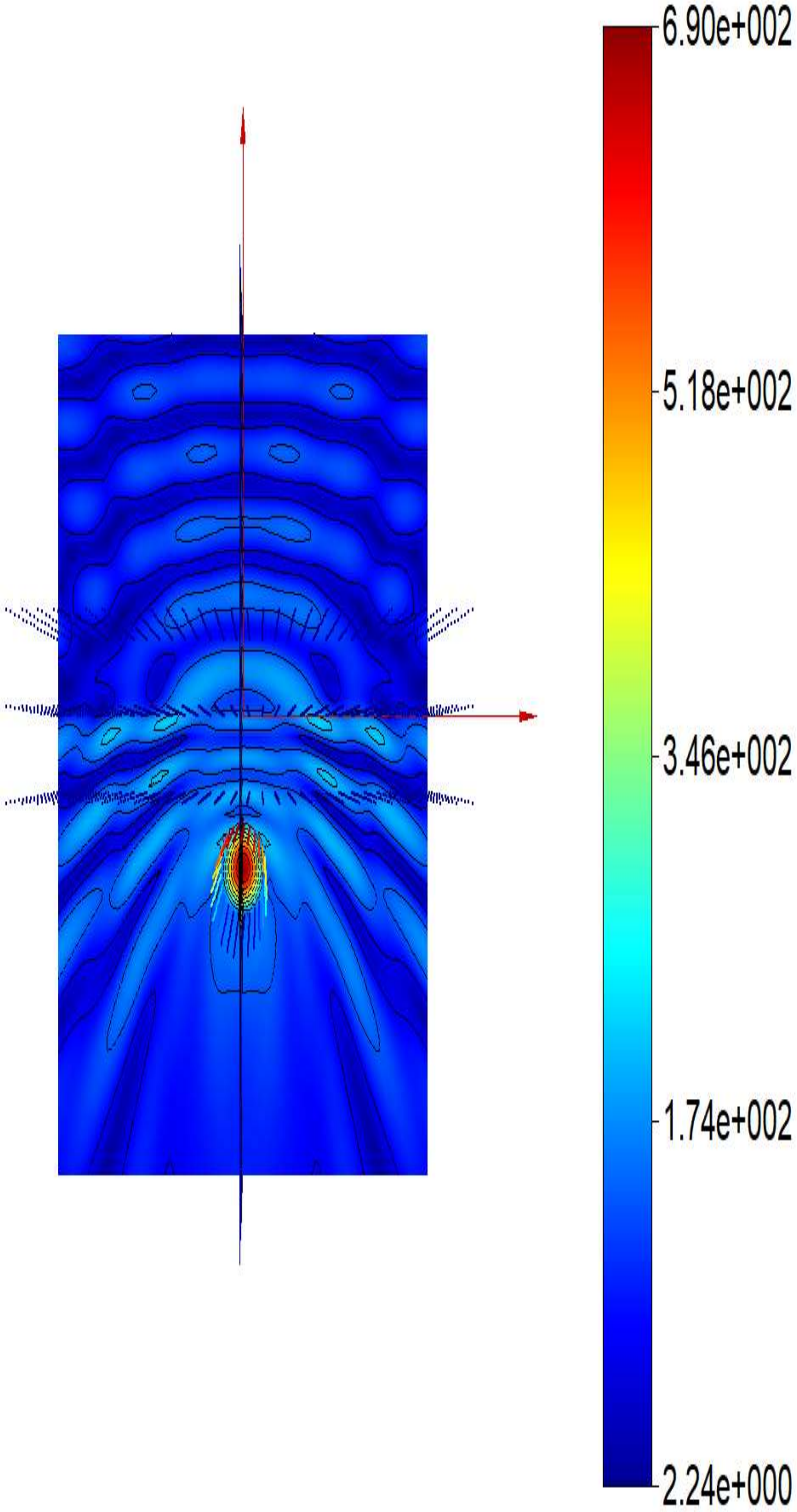

Figure 3.6 : 1 meter depth Ø63mm PE X-Z coordinate.

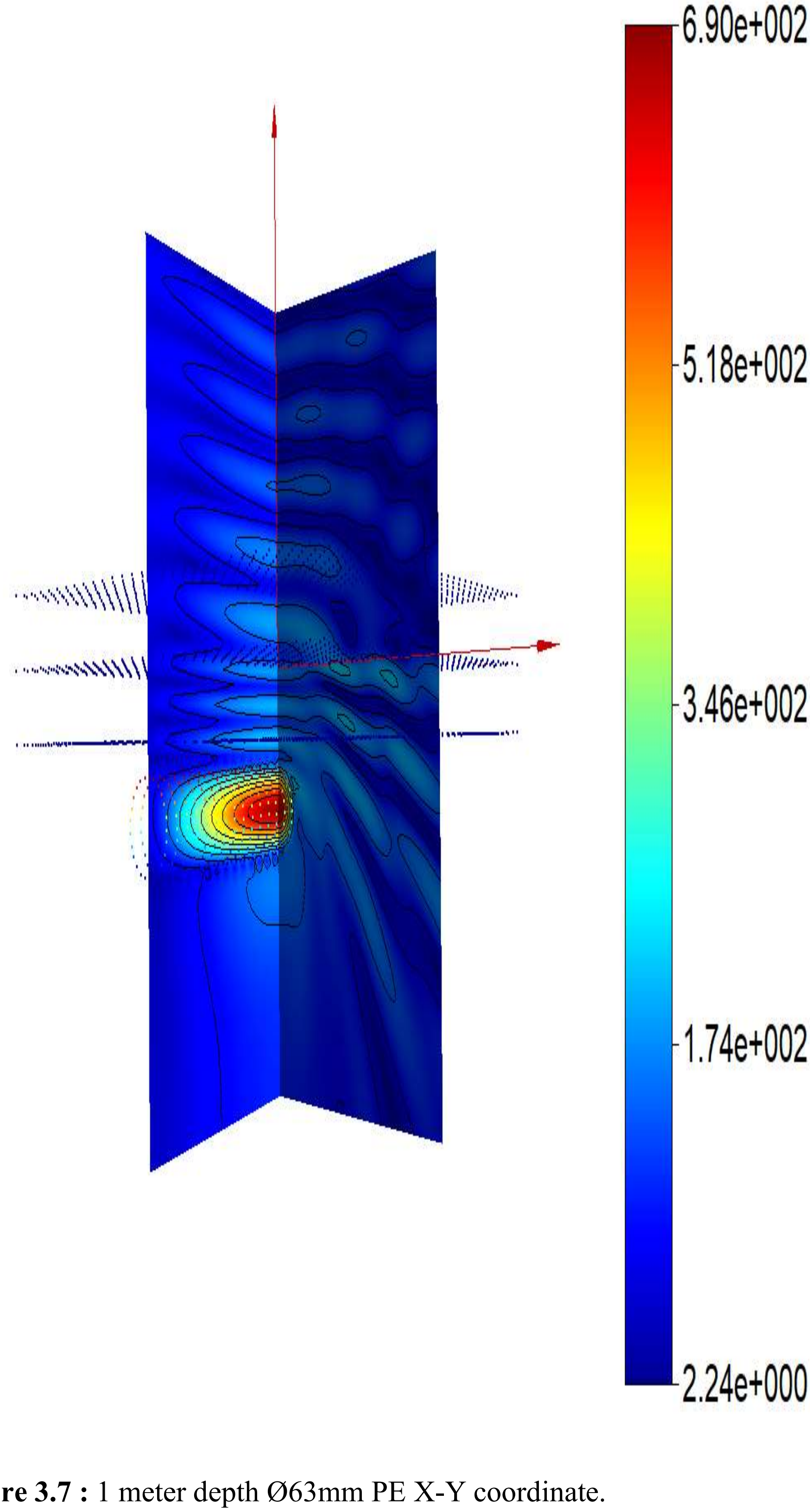

Figure 3.7 : 1 meter depth Ø63mm PE X-Y coordinate.

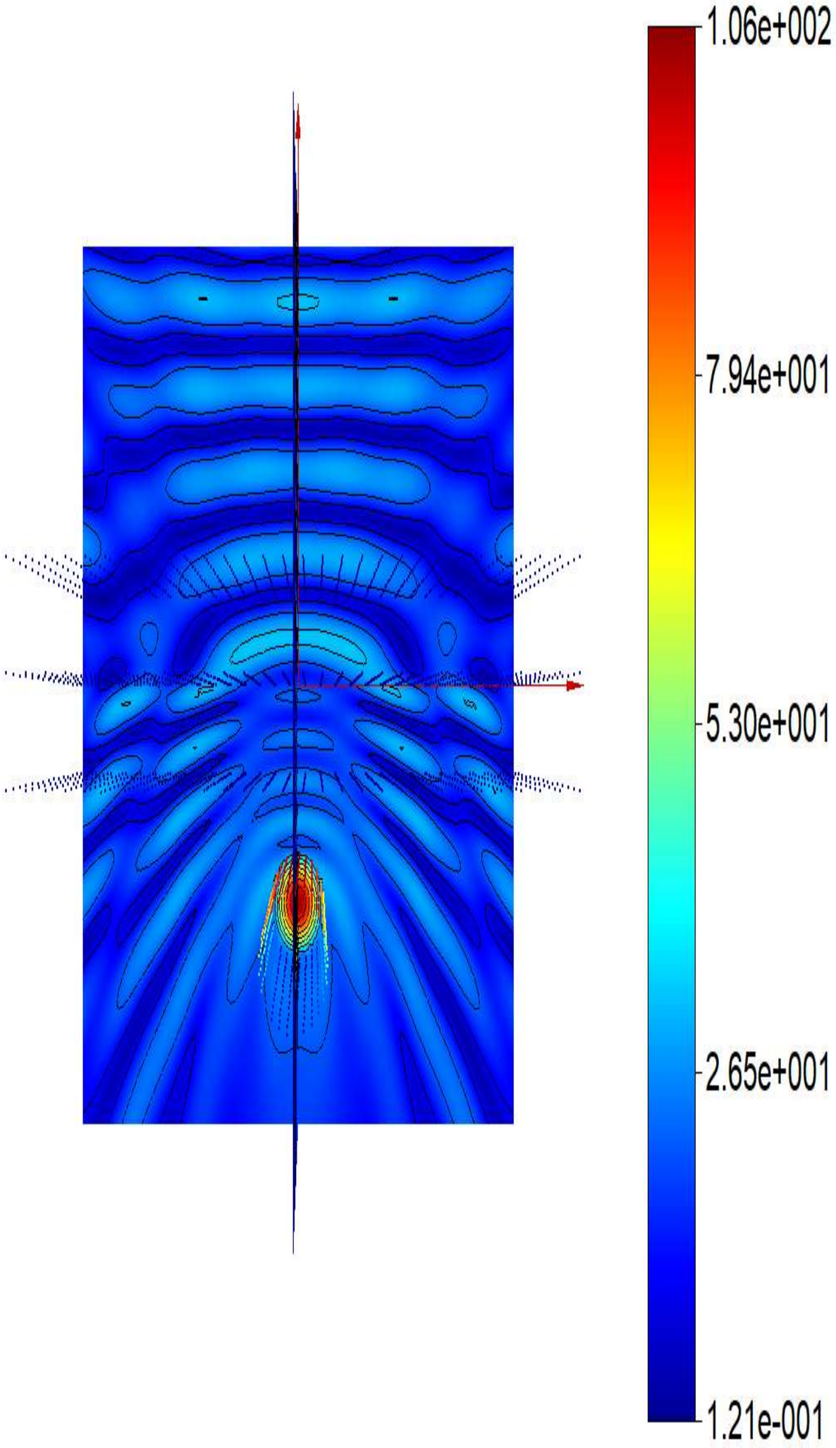

Figure 3.8 : 1 meter depth Ø125mm PE X-Z coordinate.

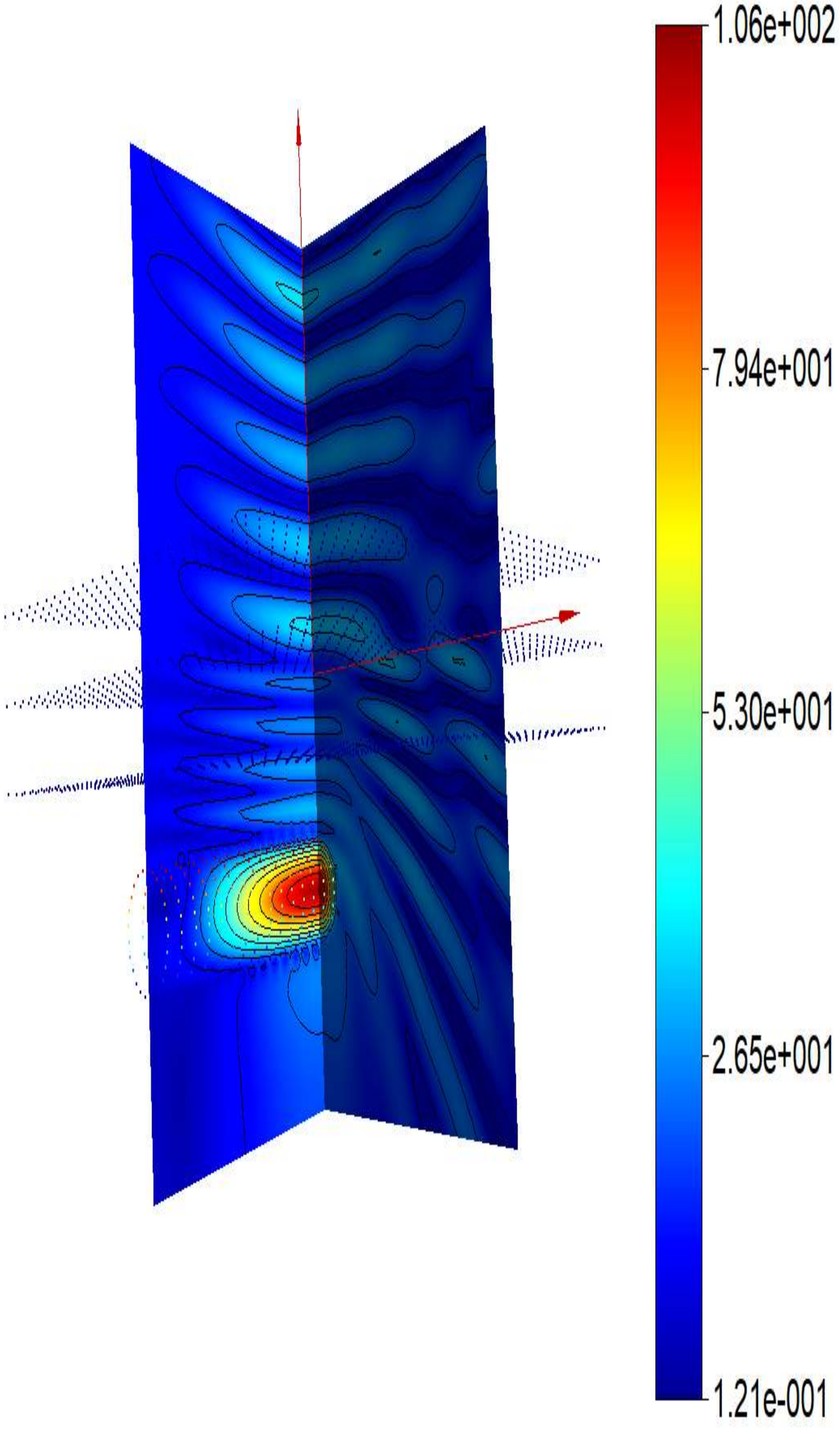

Figure 3.9 : 1 meter depth Ø125mm PE X-Y coordinate.

3.2 Investigation of The Detectability of PE Pipeline at 1.5 Meter Depths and Different Source Location

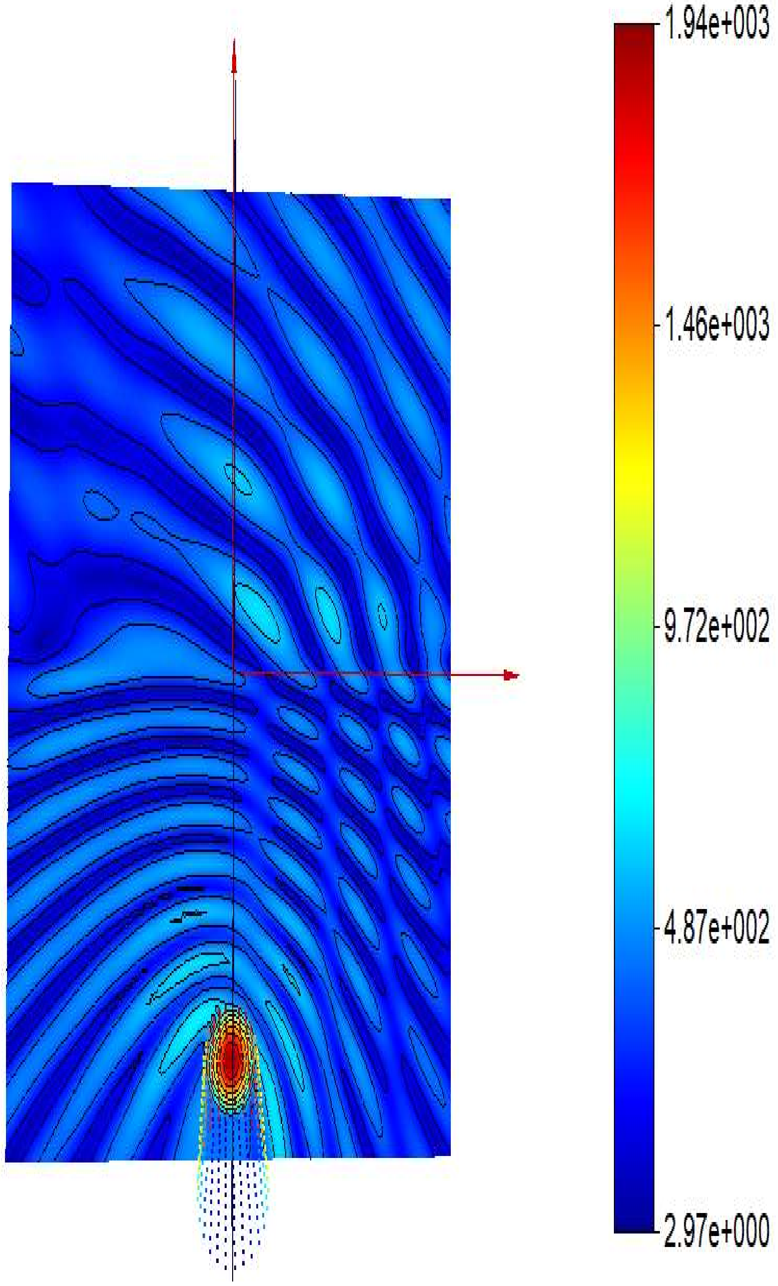

Figure 3.10 : 1.5 meter depth Ø32mm PE source on the right X-Z coordinate.

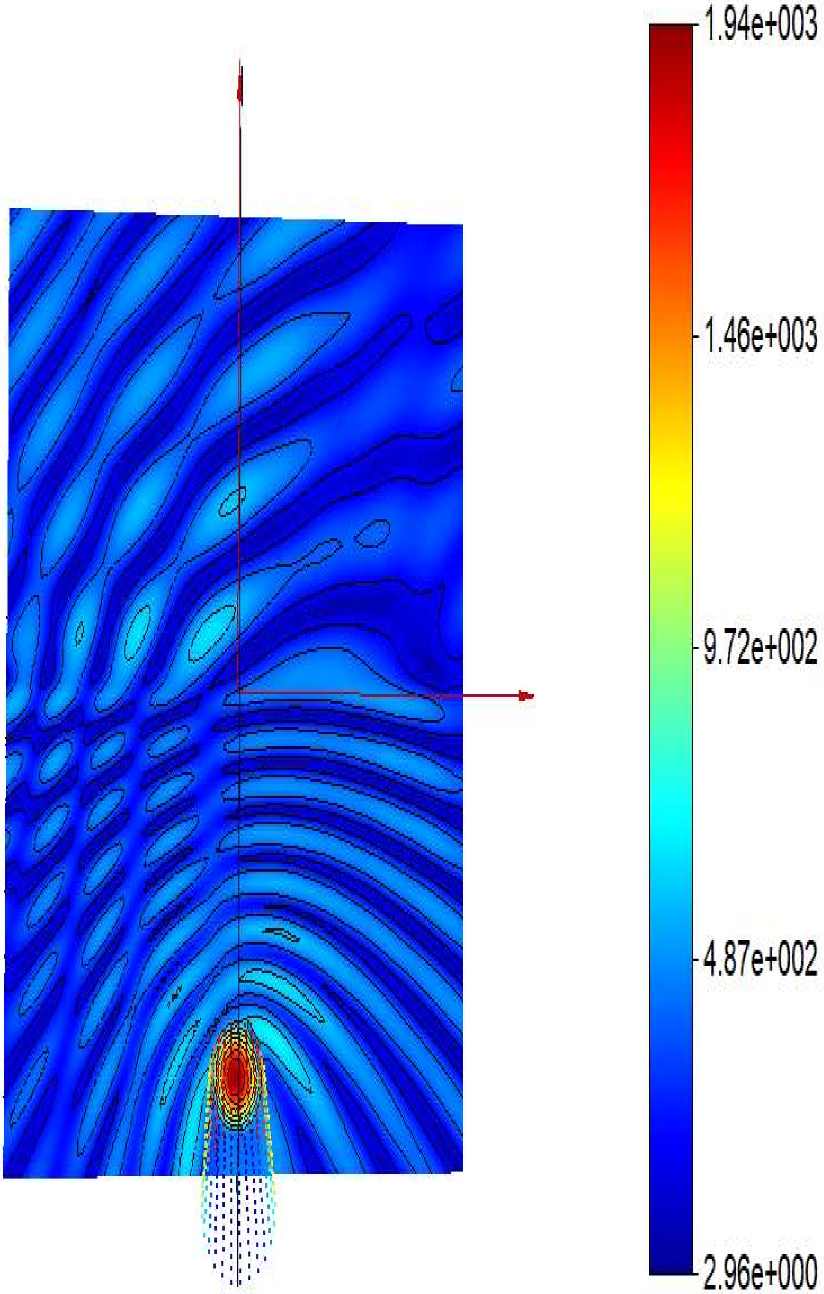

Figure 3.11 : 1.5 meter depth Ø32mm PE source on left X-Z coordinate.

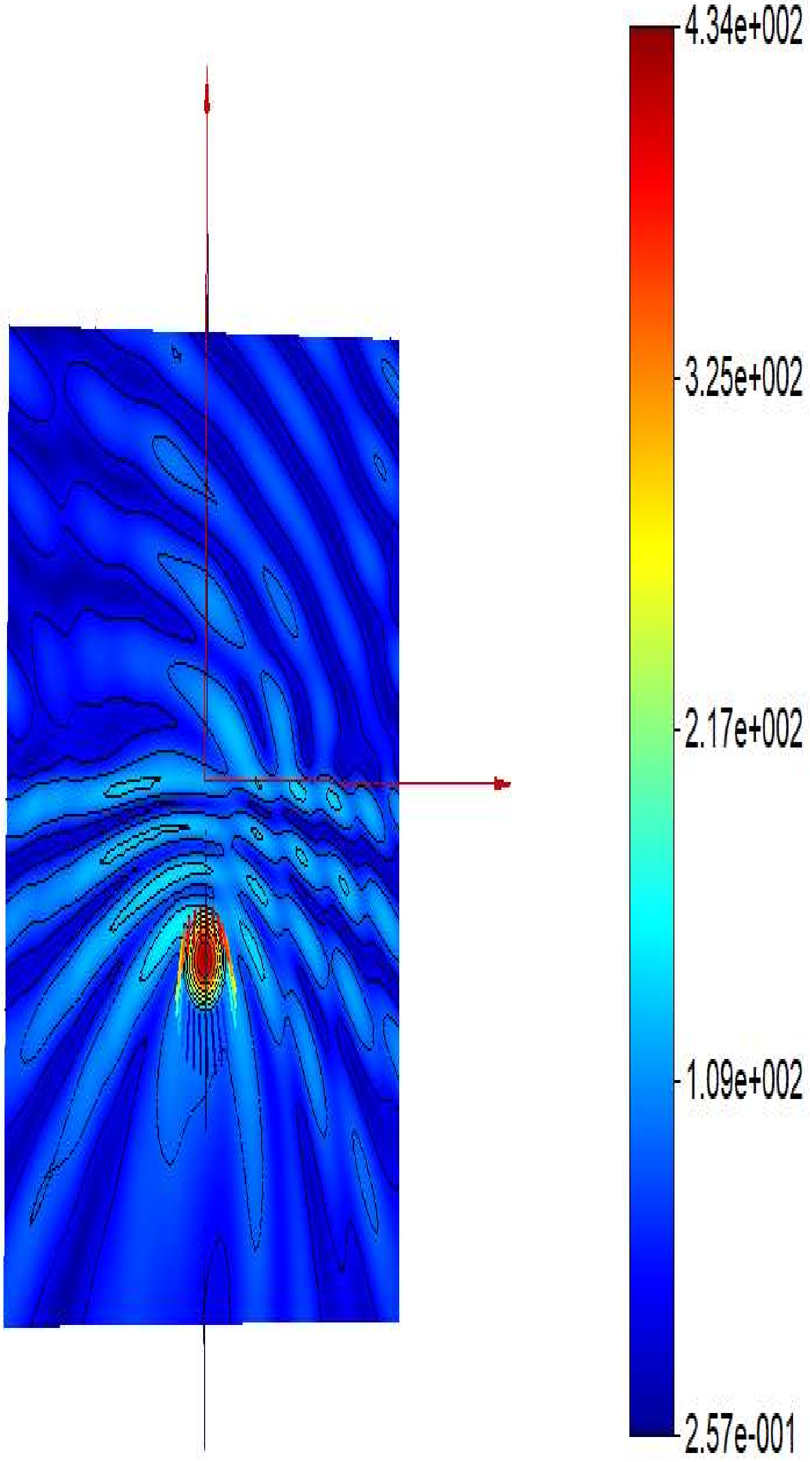

Figure 3.12 : 1.5 meter depth Ø63 mm PE source on the right X-Z coordinate.

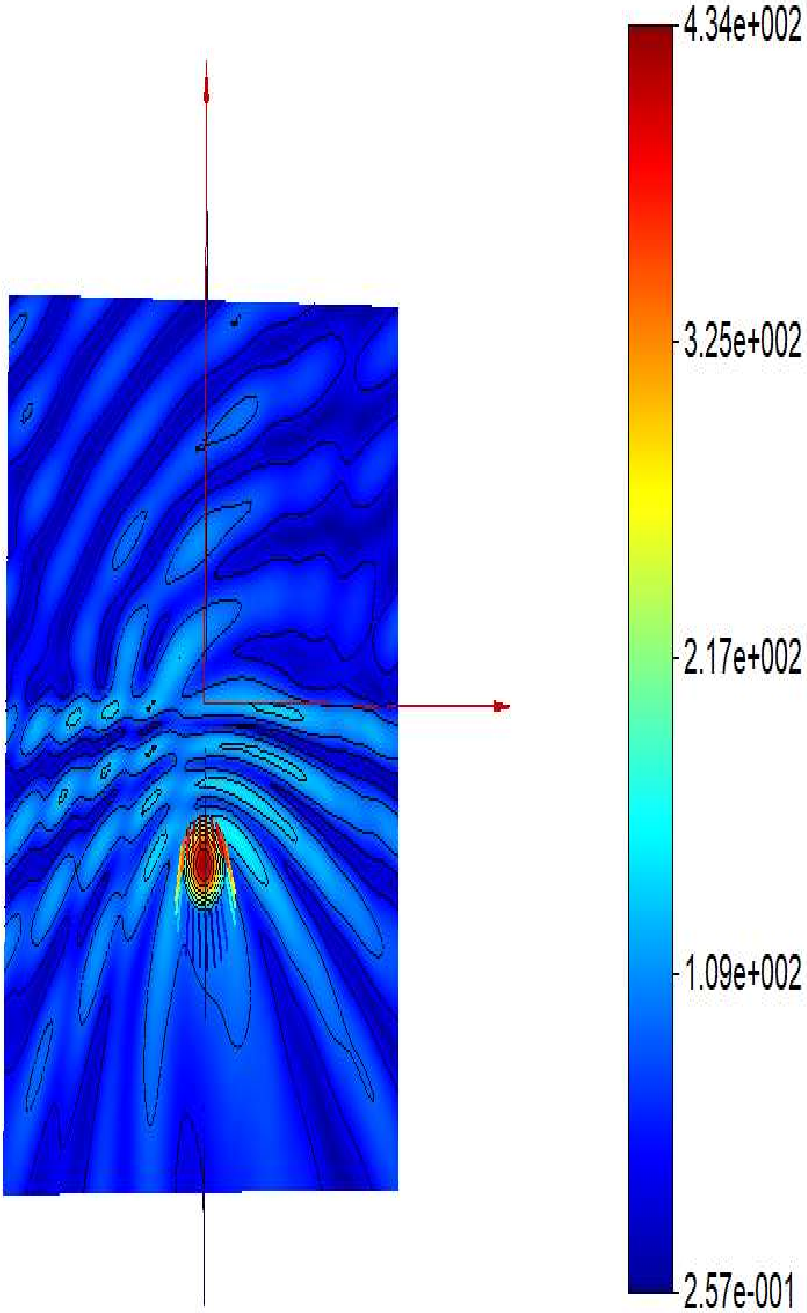

Figure 3.13 : 1.5 meter depth Ø63 mm PE source on left X-Z coordinate.

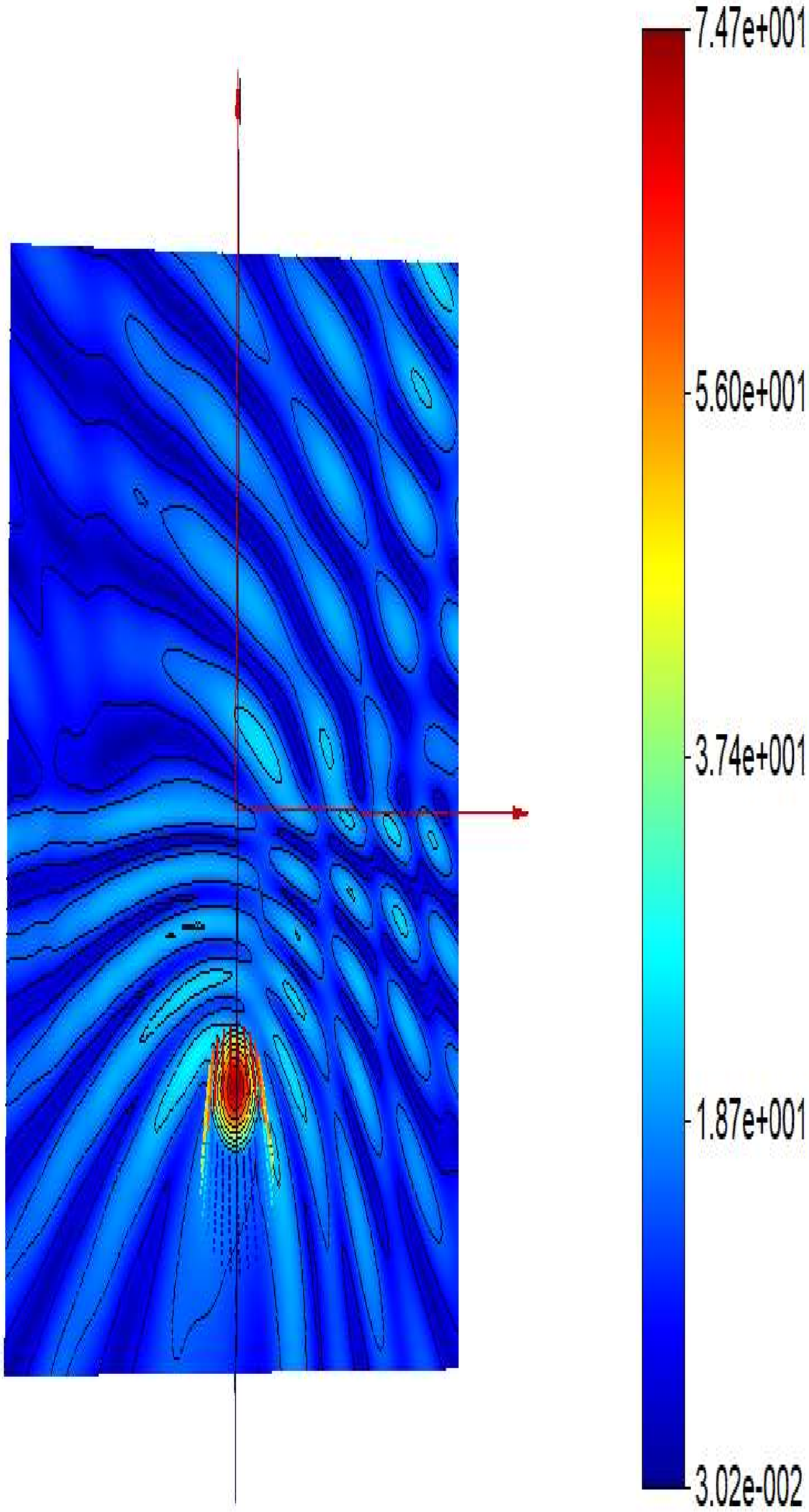

Figure 3.14 : 1.5 meter depth Ø125 mm PE source on the right X-Z coordinate.

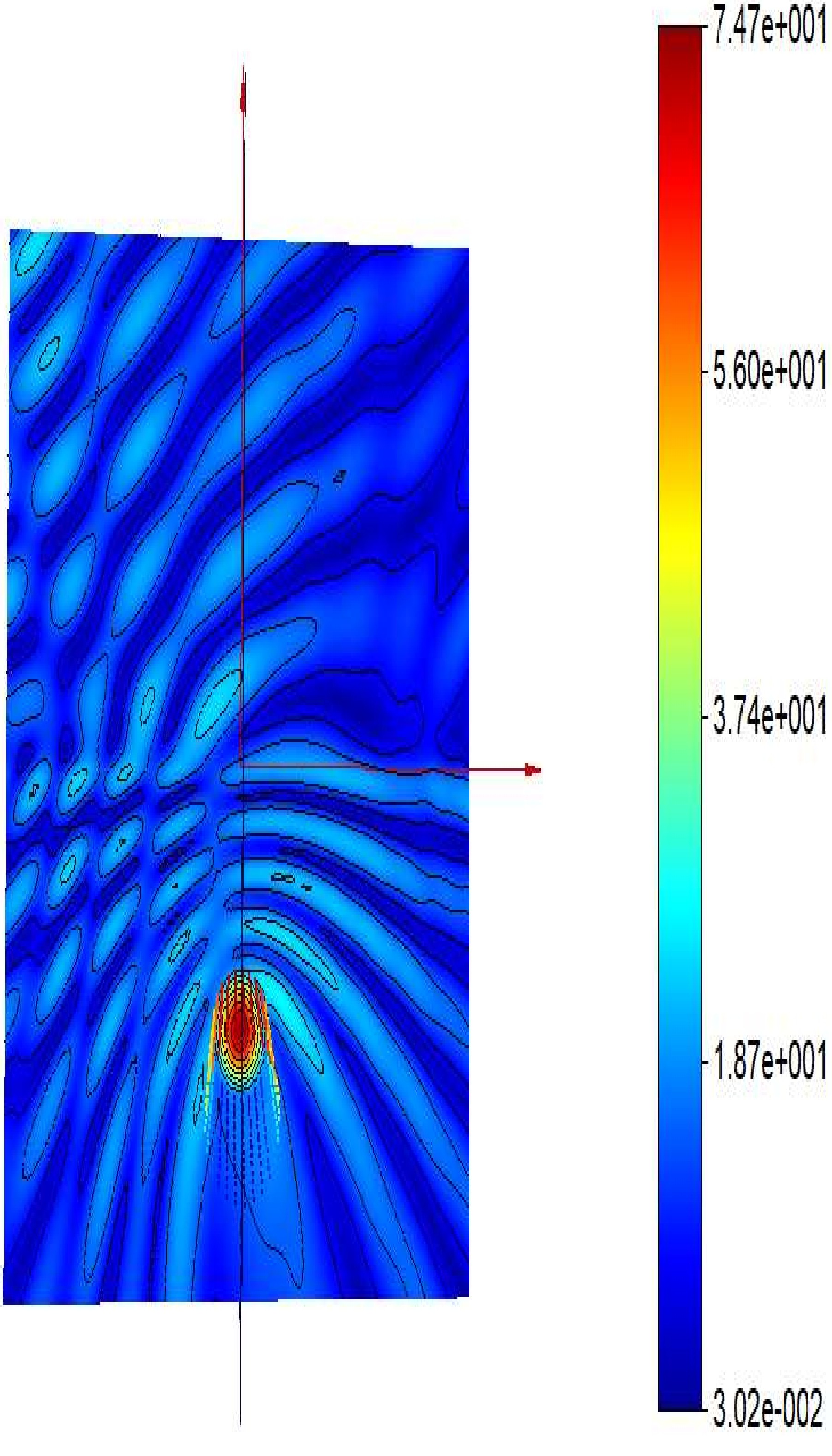

Figure 3.15 : 1.5 meter depth Ø125 mm PE source on left X-Z coordinate.

4. CONCLUSIONS AND FUTURE WORK

In this study, resonant properties of polyethylene pipelines of different sizes (Ø32mm, Ø63mm, Ø125mm) and different depths (1 - 1.5 m) in dry soil were investigated.The main objective of the study was to determine the presence, size, and direction of the polyethylene pipeline in dry soil by using electromagnetic wave radiation with MAS. In this case, some numerical results have been proposed for the source to show different polarizations.With this program, we changed the radius and depth coordinates of the polyethylene pipeline, and we calculated the soil conductivity and the frequency characteristic for different conditions according to the environment we selected.

As a result of this study, it is aimed to find buried polyethylene pipelines in the first step and to develop studies on other infrastructure transmission lines as the second step. By determining the characteristics of all underground assets related to infrastructure systems, it is aimed to create a large library by making measurements in different soil conditions and different soil levels.

If we create a library of infrastructure systems with different characteristics that we obtain under different conditions, we can use this information for a real field experiment.The frequency characteristics of the infrastructure assets to be performed in the actual experiment will be measured and compared with the library data we obtained. After this comparison, we can determine which features are closer to the simulated one and decide whether the infrastructure systems we are looking for are in the ground or what direction.

In this way, we want to ensure that our infrastructure systems which are in a complicated situation can be detected by undamaged detection.

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