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Transmitter & Receiver Coil Design for Open Area Concealed Weapon Detection System

TRANSMITTER AND RECEIVER COIL DESIGN FOR OPEN AREA CONCEALED WEAPON DETECTION SYSTEM

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ABSTRACT

Individuals carrying guns, knives and other weapon type metal objects are a threat to general public safety and thus the detection of such weapons is a priority in airports, schools and military checkpoints etc. Conventional metal detectors and image scanners, typically, are unable to distinguish between different types of threat and non-threat metal objects and or lack the ability to detect threat items in large areas. The accurate and fast detection of threat metal objects in a crowded open area environment is the aim of this work. The optimum design of transmitter and receiver coils, which are arranged in an array structure, is an important aspect of an effective large area metal detection system. Transmitter and receiver coils arrays, proposed in this paper, reduce the occurrence of hotspots (area of high sensitivity) or dead zones (area of low sensitivity) and have been modelled and analysed in Opera 3D electromagnetic simulation software. The results are being used to build a multi-zone transmitter and receiver coil array for large open area concealed weapon detection system. Thus, the system is expected to be suited for use in corridor entrances in airports, apartments, schools, colleges and military checkpoints etc.

Keywords Coils, Metal weapon detection, Modelling and simulations

1 INTRODUCTION

Violent crimes involving metal weapons have increased in recent years [1]. In order to screen individual people for concealed weapons, metal detectors are widely used in many locations such as airports, sporting events, government buildings, schools and other high security establishments. The research to build a robust metal weapon detection system has identified problems in the screening of people for metal weapons. Firstly, currently available equipment detects all metal objects without deciphering between different types of threat or non-threat metal objects, leading to false alarms [2]. Secondly, congestion in dealing with large numbers of people, is created by the inability of systems to process multi-users [3]. Thirdly, screening systems do not generally identify the location of weapons on an individual, so full manual searches are required. It is therefore necessary to build an open area Concealed Weapon Detection (CWD) system that can accurately locate and identify one or multiple weapons in a large crowd of people. The design of the transmitter and receiver coil is the key to successful illumination and detection of metal objects in an open area detection system.

This paper identifies problems with the design of a transmitter and receiver for Open Area Concealed Weapon Detection (OACWD) systems and proposes experimental evidence to eliminate these problems.

2 COIL DESIGN

The CWD model is based on pulse Electro Magnetic Induction (EMI) technology [4], where a metal target is illuminated by pulsed current, and as the current is switched off, a secondary magnetic field is generated around the metal object. A secondary current on the surface of the metal object can then be sensed by a receiver coil and analysed to determine the object type. The principle of metal detection is shown in figure 1; decay current time of a metal object is shown in fig. 2. Previous research in metal detection has identified the secondary current decay time to be a unique property of a metal object which is dependant on the shape, magnetic and electrical properties [5]. Decay current time constant is used as an object signature to classify different type of metals in the metal detection space.

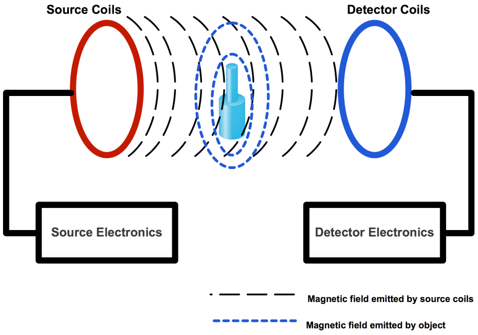


Figure 1: Principle of metal detection

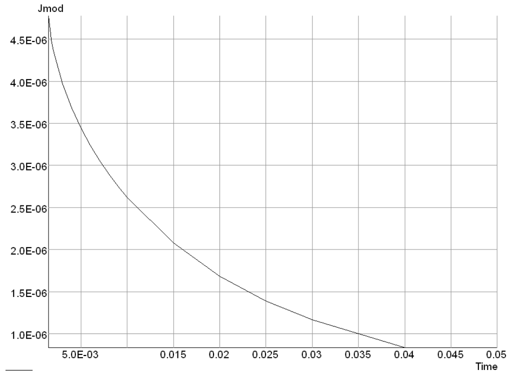


Figure 2: Eddy current decay time of metal

Electromagnetic investigation of materials by means of systems using coils has been available for many years. These systems have been used in activities such as exploration for minerals ores, searches for military purposes, treasure hunting, food testing for metal particles and searches for weapons at airports and other high-risk installations [6]. Current metal detectors used in airports and other high-risk installations are designed on the principle of EMI technology. In these systems, transmitter coils are arranged on one side and a mirror image pair of receiver coil arrays on the opposite site of the portal. The two coil arrays are laid out at different angles to achieve polarization diversity. It is thought that the use of matched mirror-image arrangement improves performance, however, careful examination of these detectors reveals that 'hot spots' arise when the field of one coil array is unusually strong in a given location, while the field of another coil is at some typical value for that distance [6]. Tight bundling of the coil causes the hot spots and also an unnecessary increase in both intra-winding capacitance and coil inductance, both of which significantly increase the response time and hence reduces the sensitivity to small objects such as wristwatch or key etc. The reduction of hot spots and dead zones is the key to the design of an OACWD system. The effects of hot spots are avoided by distributing transmit and receive coils in multiple zone array in a detection space.

Open large area detection space creates challenges for the design of transmitter and receiver coils for the CWD system. The following challenges were identified in the design of a OACWD system is described below.

Firstly, relatively uniform horizontal magnetic field intensity needs to be generated to aid in target detection [7]. Secondly, magnetic field intensity needs to be uniform in height improving detection sensitivity. Thirdly, fewer components and wires are required to produce the system design at a lower cost. Fourth, increased bandwidth for the transmitter for a given sensitivity is required to improve the target classification potential and accuracy. Fifth, a need to avoid cross talk with suitably placed magnetic field receivers, enhancing sensor sensitivity and construction simplicity.

The above-mentioned aspects were considered for the design of coils for an OACWD system. Two different types of coils are used in the current CWD systems. A transmitter coil is used for the illumination of metal target and receiver coil captures the secondary signal from the target in detection space. Important coil parameters taken into considerations in this model are shape, number of windings, internal diameter, resistance and inductance of the coil.

2 .1 DETECTION SPACE

The detection space is defined as the area where metal objects are searched in order to identify threat and non-threat metal objects [8]. A model of the OACWD system is shown in figure 3; the detection space is divided into several zones; arrangement of the transmitter and receiver coils in different detection zones makes it easier to locate metal weapons. The receiver coil is placed within the perimeter of transmitter coil and separated by 25 cm from each other. A switch in the control circuit board is used to enable pulsed current through the transmitter coil. Transmitter coil is activated at different times in different zones. Hence the field is a zone is not affected by the fields from adjacent zones. Therefore, metal objects are detected independently, and individually identified in each zone, enabling variations in the effectiveness of zones to be taken in account.

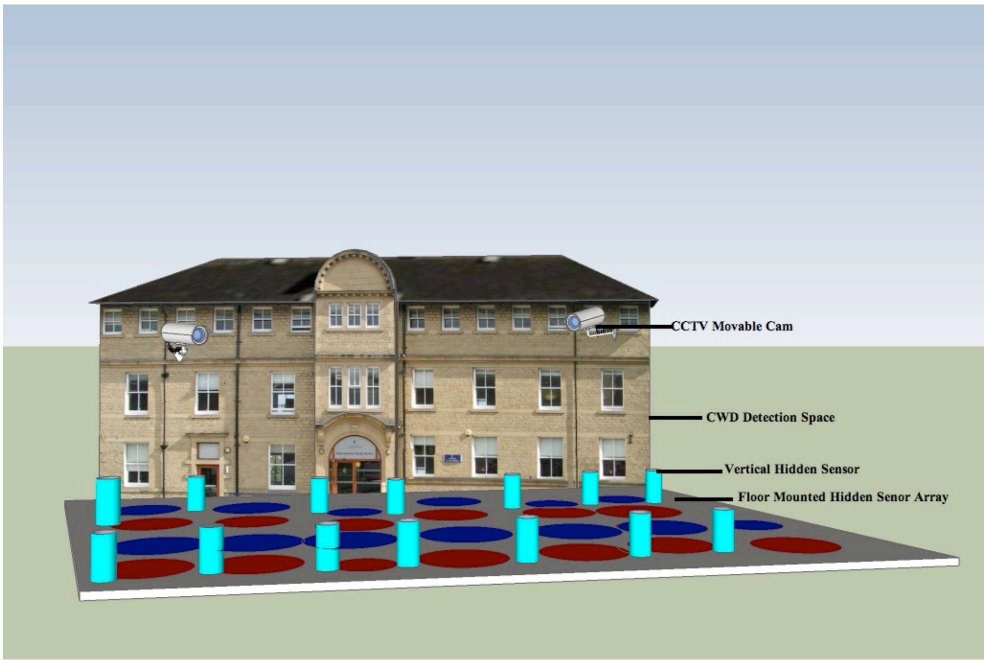


Figure 3: Metal detection in open large area detection space

Sensitivity at floor level is a persistent and difficult problem in OACWD system design; receive signals are often influenced by the coupling effect from transmitter coils array on the floor. A bucking coil is therefore attached to the receiver coil to eliminate the coupling effect of transmitter coil during the switch on period in a particular zone. The wall/post sensor coil, shown in fig 3, is used to capture the height of metal objects in detection space. The zone-array detection space is integrated with CCTV monitoring in order to develop a tracking system for real time monitoring of threat metal objects by a remote operator. An alarm is created when the person is carrying a threat metal object in a zone and subsequently video tracking system is activated to track the individual, in real time. However, the detail of the video tracking system integration with zone array system is beyond the scope of this paper.

2 .2 TRANMITTER COIL DESIGN

A multi-zone coil design provides unmatched illumination of potential threat items such as guns, knives and other flat and rod shaped weapons regardless of location and orientation in the detection space. The new coil structure reduces hotspots with shorter transmitter time constants. The transmitter and receiver pair modelled in Opera 3D is shown in fig. 4.

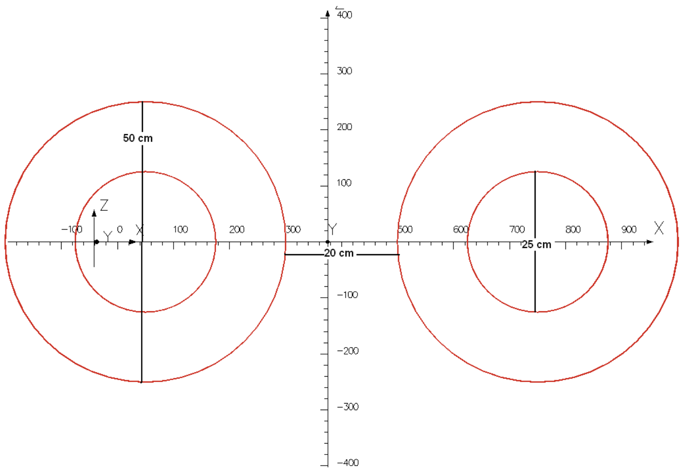


Figure 4: Physical characteristics of transmitter and receiver coils in two zones

A solenoid shaped transmitter coil effectively illuminates the zone in the detection space; fig. 5 shows the magnetic field distribution from the transmitter coil during switched on period. It was observed from fig. 5 that the field strength is high around the edges of the transmitter coil, hence placement of receiver coil inside the perimeter of transmitter coil is not affected by mutual coupling between the coils. The field strength of the transmitter coil diverges vertically with increase in distance from transmitter coil and illuminates the zone effectively. The transmitter coil is made of 0.5 mm copper wire, wound 20 times to form a solenoid shape. The physical characteristics of transmitter coil are shown in table 1.

Material	Copper
No of Turns	20
Conductivity	5.88E+7 S/m
Permeability	1
Internal Diameter	0.5 mm
Outer Diameter	50 cm
Off time	After 10 microsecond of analysis

Table 1: Transmitter coil characteristics

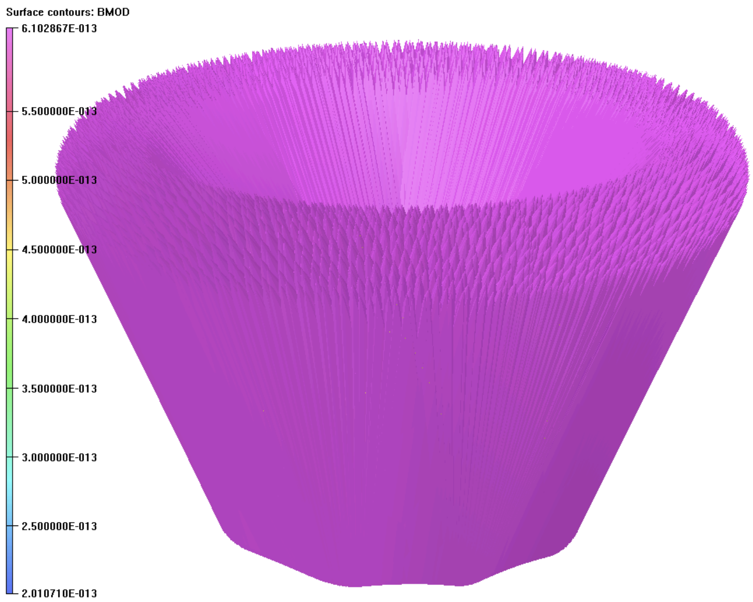


Figure 5: 3D magnetic flux distribution of transmitter coil in a zone

A large diameter transmitter coil is used for the generation of higher magnetic field strength in a zone; the transmitter generates transient magnetic field by the application of a 10 ms pulsed current. In order to view field strength and current densities over the coil, the outer regions of both transmitter and receiver coils are meshed with air regions and shown in fig. 6.

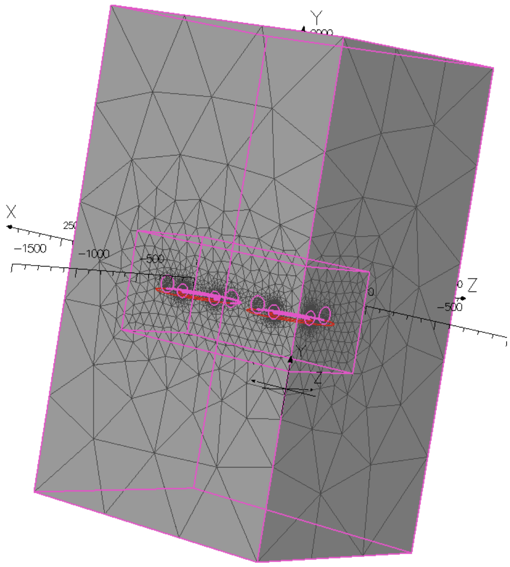
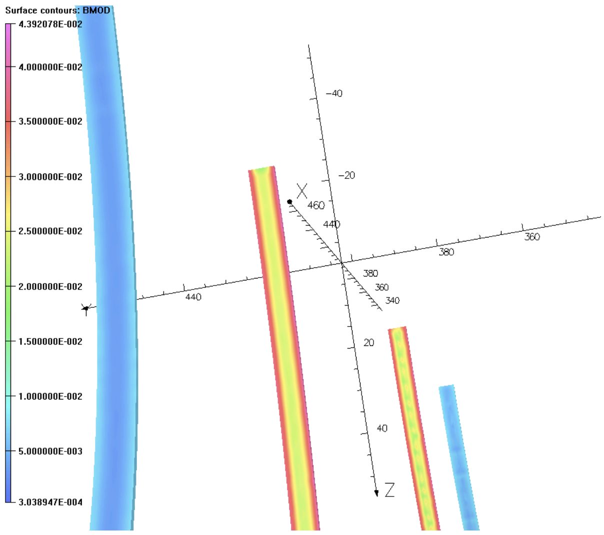


Figure 6: Meshed air regions around the transmitter and receiver coil array

Each transmitter coil is designed with two high-speed electronic switches to minimize inductance and reduce coupling and operate in parallel with other transmitter control pulse operations. The magnetic field strength after 5 ms of analysis is shown in fig. 7; it is observed the field strength is higher on the edges of coils and quickly spreads to middle of the coil after 100 ms of analysis as shown in fig. 10.



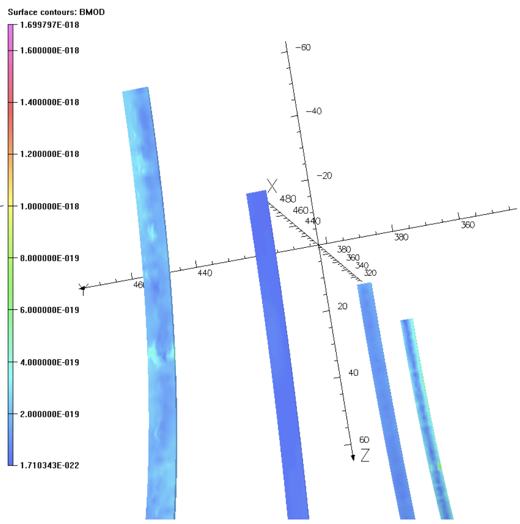


Figure 7: Field strength after 5 microseconds of analysis

Figure 8: Field strength after 20 microseconds of analysis

Increasing the number of turns in the transmitter minimizes the power loss and reducing the magnitude of pulse current, which in turn reduces the heating effect. However, increasing the number of turns to a maximum decreases the diameter of the transmitter coil, which in effect increases coil resistance. Therefore for optimum strength, 20 turns of coils wound to form the transmitter is proposed in this model.

It is a challenge to reduce current to absolute zero and minimize background noise at the end of transmission pulse in multi zone open area detection system. Hence, a 20 cm bucking coil with 160 turns is currently being designed to place between transmitter and receiver coils to reduce environmental noise in the system. The external circuit in Opera 3D is modelled with an high resistance switch to force current towards zero and the transmitter was switched off at 10 ms of analysis. It is seen from fig. 9 that field strength of the transmitter coil is reduced to zero after the transmitter coil was switched off after 10 ms of the analysis.

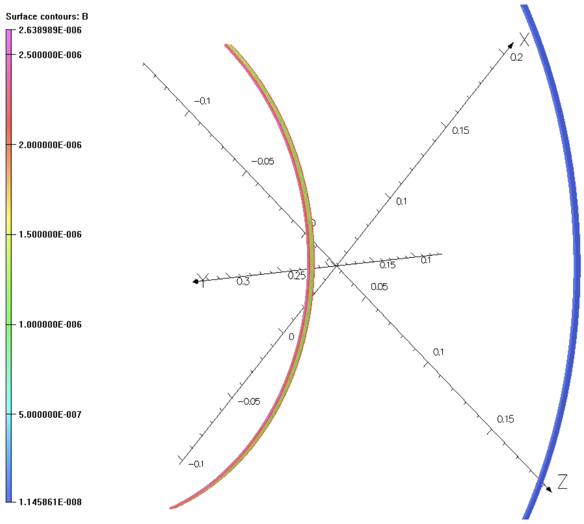


Figure 9: Field strength after 10 microseconds of analysis

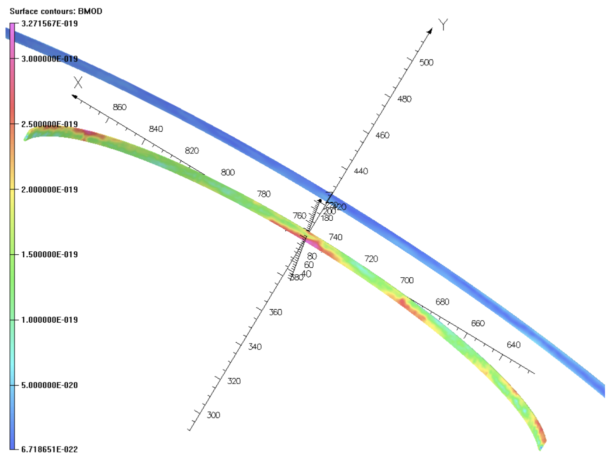


Figure 10: Field strength after 100 milliseconds of analysis

2 .3 RECEIVER COIL DESIGN

Eddy current decay time of a metal object depends on the shape, size and electrical properties of the metal. Small metal items have smaller decay times than large metal object. Hence a receiver coil needs to be made with smaller diameter and higher numbers of turns of wire to detect small metal objects. The placement of sensors in the floor and in walls reduces blind spots in the detection space. Each zone is illuminated, uniformly over the detection space, aiding the detection of metal objects. Table 2 shows the physical and electrical characteristics of the receiver coil.

Material	Copper
No of Turns	40
Conductivity	5.88E+7 S/m
Permeability	1
Internal Diameter	0.40 mm
Outer Diameter	25 cm
On time	After 10 microseconds

Table 2: Receiver coil characteristics

The size of a coil influences the detection depth and sensitivity; a smaller coil is more sensitive to smaller targets but achieves less depth and vice versa. The number of windings in a coil affects strength of the magnetic field as the theoretically field strength is proportional to the square of number of turns; doubling the number of turns results is four times the field strength. However, the increase in windings results higher coil resistance, and more parasitic capacitance, which limits the amount of 'on' current and thus the field strength [9]. Hence, a coil of larger internal diameter is used to lower the resistance of the coil [10]. Increasing the number of turns of coils increases parasitic capacitance, which tends to limit dI/dt during turn off of transmitter, again reducing the transient field strength dB/dt.

The stored energy of the coil is kept as low as possible to detect small and fast conducting metal objects. The energy is stored in three ways; first the magnetism, which favours large value. Secondly the inductance, which is very low in an open air cored inductor, third and most importantly, the capacitance, which has no effect other than to slow down the rate of decay of magnetic field [6]. The capacitance is produced by the proximity of conductors in the coil, which are only separated by thickness of the insulating varnish, so a significant improvement was obtained by insulating the wire with a PVC sleeve. Greater gains are obtained by winding the coil, with extra insulation, in a neat manner so that the inside turns are as far away from the outside turn as possible.

From fig. 11, it was found that the field strength of transmitter coil is not reduced to zero after the current was switched off immediately after 10 ms and rather it continues up to 5 ms after transmitter was switched off in the coil. It is a problem inherent in the design of the transmitter and receiver coil array where the high kick-back voltage of the transmitter coil temporarily 'blinds' the receiver from amplifying metal target signals near the turn off time of the transmitter [7]. The transmitter is an impulse excitation to the receiver coil, and as such, the receiver coil has a decay voltage proportional to its inductance. Since receiver coils have many turns for increased sensitivity they have large inductances. The large decay voltage persists for 5 ms after the transmitter was switched off and masks the signal from metal targets.

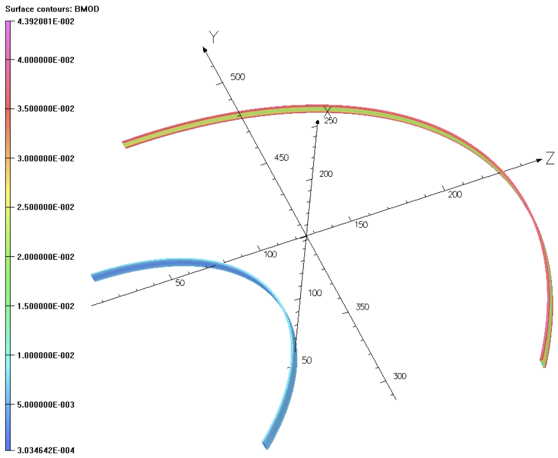


Figure 11: Field strength of transmitter coil at 11 microseconds

A new method to sense metal signatures closer to the transmitter turn-off time is proposed as follows. For a given transmitter receiver coil configuration, it is necessary that the receiver coil needs to be effectively invisible during transmitter turn-off transient. One way to achieve this is to minimize the inductance of the receiver coil during this critical time, which is achieved by breaking the conventional multiple turn receiver coil into individual wire segments so that the current is not able to flow in a loop during transmitter turn off transient [7]. The inductance of individual wire segments is in parallel during the transmitter turn off time and hence, is very small compared to a multiple turn coil.

The field strength of the receiver coil, 30 ms after the transmitter is switched off, is shown in fig.12; it is seen that the field strength is uniform on the inner surface of the coil. The uniformity of the field strength in the receiver coil is utilized to gather signals from metals uniformly in all directions in the zone in an OACWD system.

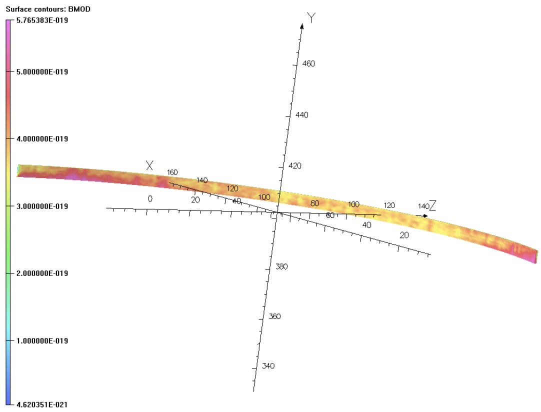


Figure 12: Field strength of receiver coil at 30 microseconds

3 CONCLUSIONS

In the design of a metal detection system, it is important to consider the interaction of the transmit and receive coil arrays very carefully. The sensitivity to metal objects and generated noise is ultimately determined by the complex interaction of excitation of the object and reception of resulting signals. Performance is determined not only by the strength of the excitation field, or by the effective sensitivity field of the receiver coil, or even by the product of the two strengths. The signal induced in the receiver coil, by the metal object, at a given point is calculated by a series of vector operations. Firstly, the magnetic excitation field is calculated at the location of interest. Next, the sensitivity field of the receive coil is calculated for the point of interest. The sensitivity field is a vector field, calculated from the receive coil geometry by exactly the same algorithm that is used to calculate the excitation field of the transmitter coil.

The important criteria for the design of a multi-zone transmitter/receiver coil array was analyzed in this paper. A model of two transmitter and receiver coils was designed and tested for hot spots and dead zones in the multi-zone OACWD system. The magnetic field and current density of the coils were analyzed in both during transmitter switch on and off times. A physical model of transmitter and receiver array is currently being developed, using the above analysis in this paper, for an OACWD system.

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