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Conception and experimentation of Innovative Minerals and Metals Detector by Exploiting of Electromagnetic Waves Emitted and Received by Helical Antenna

This paper discusses the simulation and experimentation of innovative minerals and metals detector to improve the performances of old systems. Indeed, actual detectors are limited concerning depth, sensitivity and selectivity. We propose here to implant helical antenna on shell points of two coils to boost detection process by increasing directivity gain and reflexion coefficient. The system uses the principle of electromagnetic induction and beat frequency oscillator (BFO) and contains search coil to detect metals and minerals at appropriate range and gives an auditory and vibratory indication once the element is detected. The search coil forms part of an LC oscillation circuit linked to added helical antenna. The activation frequency of the LC oscillator is primarily determined by the value of involved inductor and capacitor to recover the large gamme of frequencies and detect more kind of materials.

Keywords : *Minerals detector, Electromagnetic waves, Antennas, Oscillators, Reflexion.*

1. INTRODUCTION

The metals detection and minerals sensors are widely used in many fields such as industry [1, 2]. Many efforts have been devoted to improve the depth, sensitivity and selectivity but until the moment it is fruitless. Foreign materials are not only metal but also wood, ceramics [3] and germs [4] so that various met–hods are envisaged to detect these materials which are not detectable by using metals sensors. The detection for metals pieces is important [5] in food industry as the same in others fields. Above that detection may adopt X-ray [6], light [7] and exploiting of Telescope. Generally there are many methods like Very low frequency (VLF), Pulse induction (PI), Beat-frequency oscillation (BFO), and Resonant-frequency oscillators RFO. Basically there are many configurations of coils: Concentric, Mono, Imaging, Double-D and 2box. The size of a magnetic field depends on the size of a coil. Therefore, larger search coils generally detect deeper than smaller search ones. Many factors affect quality of detector: Depth, Sensitivity, Discrimination, Ground balance, Coil types. In this work we propose to innovate BFO oscillator by adding helical antenna to improve anticipated studies [8]. It is awesome for geophysics to discover a wide family of minerals [9] as it constitutes the core of smart and newer technology. To establish the process of detection and discrimi–nation we should have a huge knowledge about materials properties [10]. For sample the reflection coefficient is very important [11] to increase selectivity. Refer to literature [12] emission and reflection of electromagnetic wave permit to determine nature of metal and mineral. By accurate analysis of measurement data we get appropriate identification [13], we notice that the quality of process depends on the principle of metals and minerals detection [14]. In summary, we optimize directivity gain to increase the depth and confirm that helical antenna reinforce sensitivity and selectivity due suitable tuning.

2. EXPERIMENTAL DISPOSITIF DESIGN

We base on a Beat Frequency Oscillator (BFO) shown in the block diagram (Figure 1) for materials detection. It is among oldest detection methods and its operation is quite simple. Thus the first oscillator contains the search coil as part of its resonant circuit. Its frequency depends upon the search coil's inductance as well as the value of a variable capacitor, which is also a part of that resonant circuit. We tuned this oscillator to a frequency that it converges to the same as the frequency of the second oscillator to obtain low difference that considerates as reference state. When a material is around the search coil, its inductance changes, therefore the oscillator frequency changes as well. Signals from both oscillators are fed to a mixer whose output consists of several frequencies and the difference between the two generates the harmonic frequencies. Only the difference frequency is within the human hearing range thereat we use a speaker to notice success detection. Using the variable capacitor connected to the first oscillator we can set and adjust frequency difference and inductances for an adequate process. To achieve higher difference frequencies, we need to use oscillators with higher frequencies. Doing

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this, however, oscillator stability inconvenient is raised, so we have to strike a balance between stability and higher frequency to reach the best performances. It is privileged due simple construction but influenced by medium noises that affect detector quality. Referring to colpitts oscillators techniques we innovate the detector by inserting helical antenna on shell points in which LC dipole is connected to both oscillators to resolve disadvantages evoked previously. The schematics could be depicted as follow:

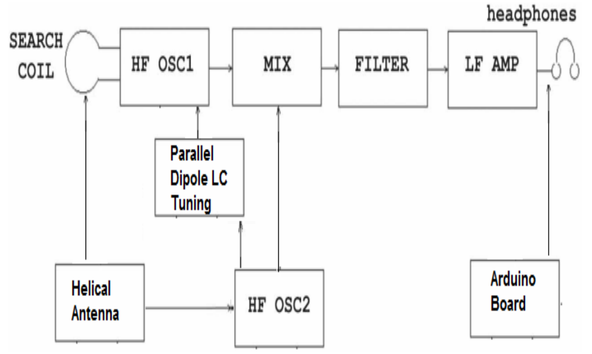

Figure 1. Detector description schematic.

The Oscillator makes a frequency change when some metal is near the detector coil. The signal is send to a multiplexer. The circuit uses a quite filter to generate the tone or others signs as indication. Above, we provide the system by microprocessor μC mounted in Arduino board with an LCD to make reading so easy. Moreover, we can manage, and discriminate changes of magnetic properties ranges of frequencies [15-16]. The electric circuit in which we show the added part is given below:

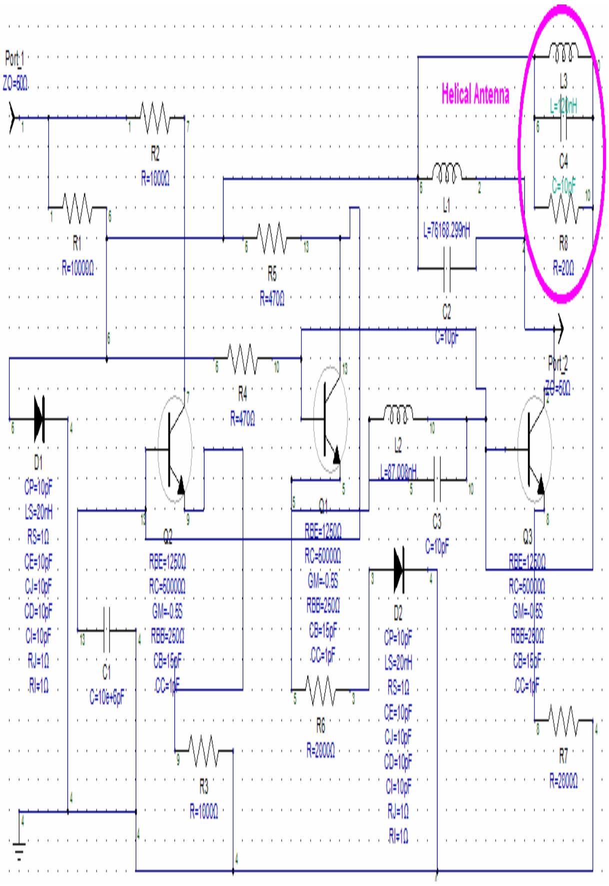

Figure 2. Detector prototype schematic.

The developed device contains two loops as BFO oscillator. We connect helical antenna to shell points in the reason to increase directivity and sensitivity. Depend on voltage variation Arduino board mentions about detected mineral or metal. As evoked Microcontroller (μC) and acquisition instruments could be used to analyze a signal given by our circuit and determine the specimen. Thereon the difference of frequency is important especially while we are tuning to detect different materials. The receiver antenna is averaging the incoming signal all the time, and indicate the existence of object by suitable tones and vibrations. This type works in areas with iron content and others grounds. The buffer as speaker indicates the kind of detected material either ferrous and nonferrous metal, and make different output of it. An appropriate capacitor is used on the loudspeaker to ensure the flows of current changes from generated signal [17]. The prototype can be installed simply and move anywhere as shown below:

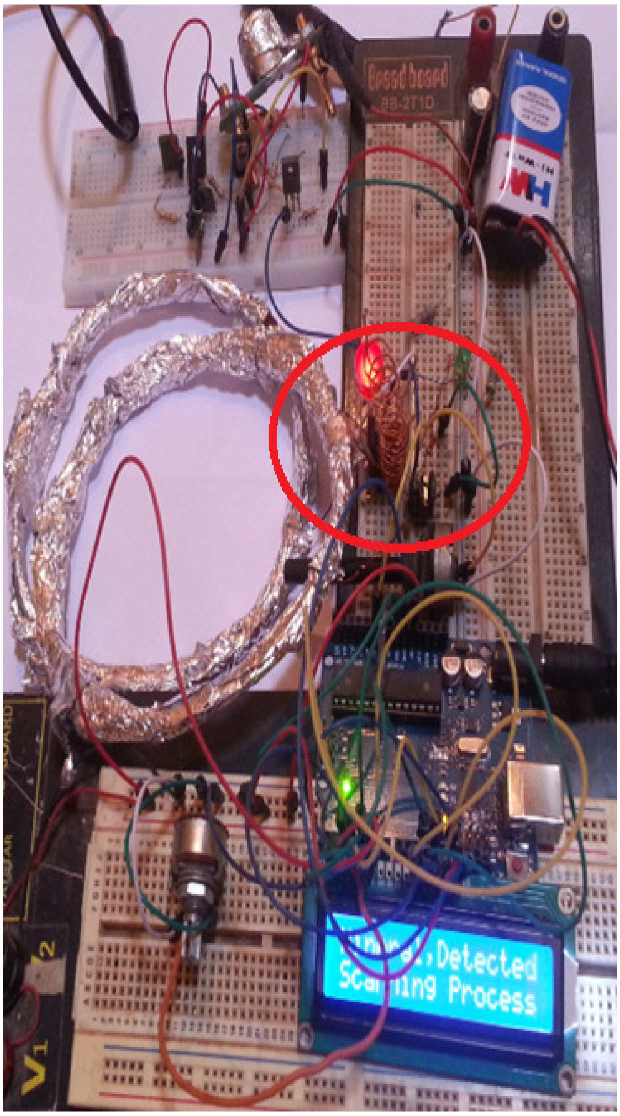

Figure 3. Detector fabrication.

3. RESULTS AND DISCUSSIONS

The innovation consists to add adequate antenna to boost emitting and reception of electromagnetic waves. Refer to literature there are many patch antennas but helical antenna is characterized by many advantages that we give in this table:

Table 1.Helical antenna characteristics

Advantages	Disadvantages
Simple construction	Feed problems
More directive	Bad matching impedance
High sensitivity	Acute resonance

Such antennas have been used for many applications for samples RFID devices, MF-HF-SW receivers, Aircraft receiver and UFH transmitters so it looks suitable for minerals detectors. During process of detection we base on electromagnetic waves emission and reception. The dimensions are very important, especially to improve directive gain. Using CST software we give here antennas simulations of both loop antenna used in old systems of detection and the helical antenna that we have implemented. The advantage of helical antenna is that when its circumference reaches the order of wavelength, it radiates with the maximum power density in the direction of its axis so more directive in axial mode than loop antenna as confirmed by the following simulations:

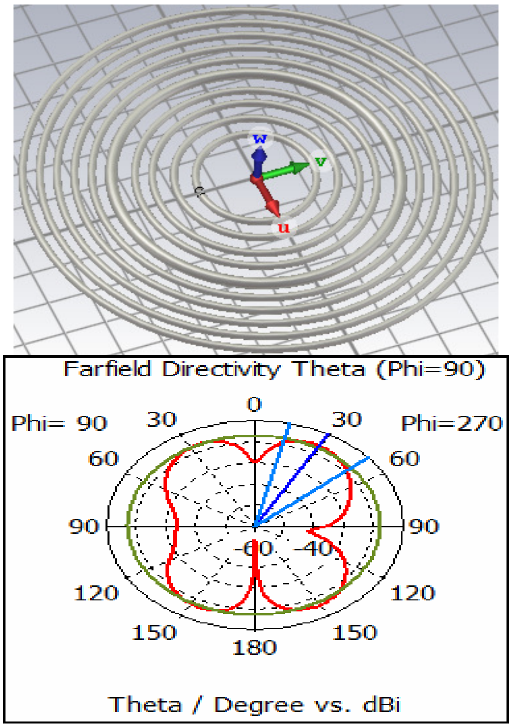

Figure 4. Loop antenna directivity simulation.

From comparison between loop antenna used in old BFO detector and the inserted helical antenna we remark that the last one has many advantages resumed in the performances below:

Table 2. Helical and loop performances comparison for F=4MHz.

Parameter	Equation	Loop Antenna	Helical Antenna
AngleWidth (deg)	ΔA	75	68
Axial Ratio	AR	0	2.1
Gain (dBi)	G	2.4	3.5
Efficiency (%)	η	65	78

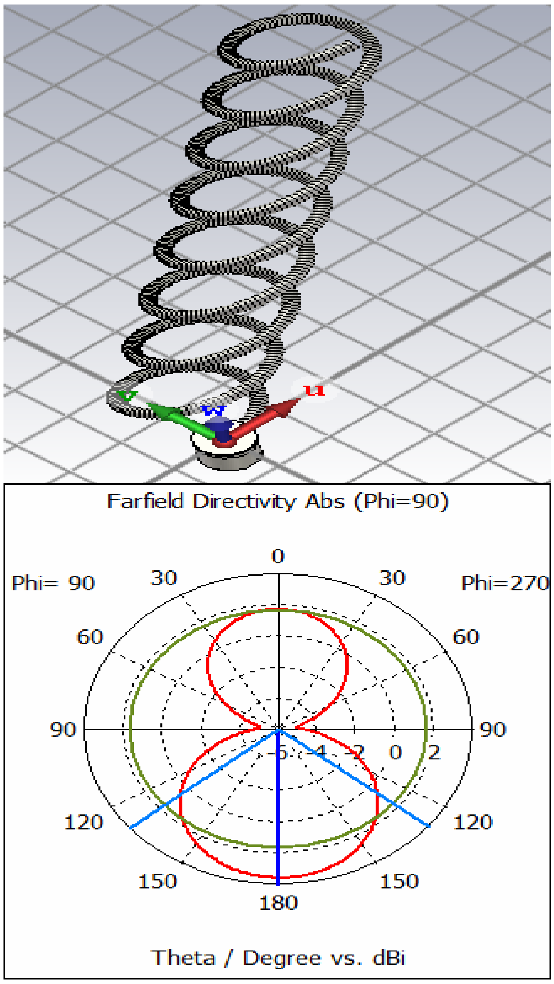

Figure 5. Helical antenna directivity simulation.

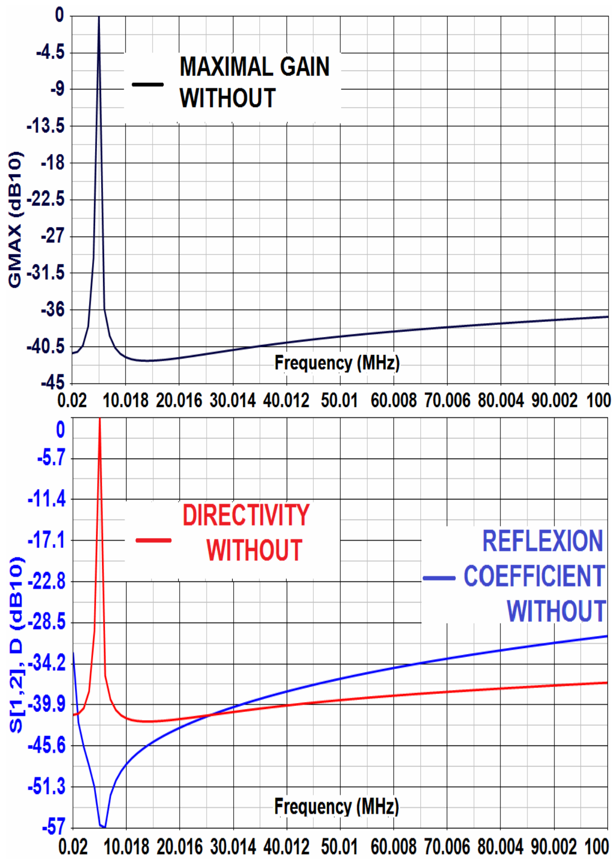

Figure 6. Simulations without helical antenna.

To establish accurate simulation of our device we have used ADS and GENESYS software's thanks to their flexibility and reliability for complex circuit. The implantation of helical antenna is justified after many training about its performances under CST studio and so far inspired from other sources [18]. We resume results of simulations by curves below:

These newer results due helical antenna are shown by the following graphics:

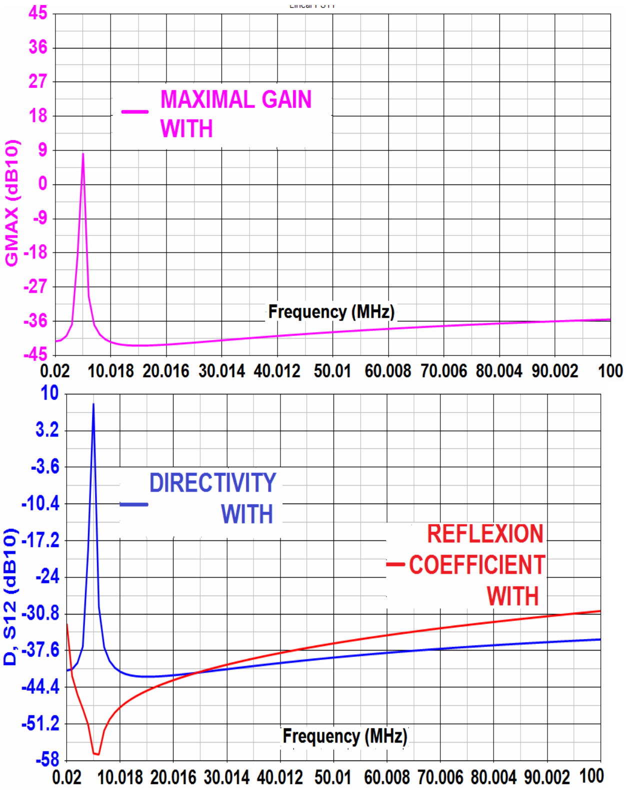

Figure 7. Simulations with inserting of helical antenna.

The comparisons of performances are depicted by the table below:

Table 3. Performances comparison at 4 MHz.

Parameter	Without Helical Antenna	With Helical Antenna
AngleWidth (MHz)	4	2.4
Directivity (dB10)	0.2	8
MAXIMAL GAIN Gmax (Db10)	0.1	8.9
Reflexion Coefficient (dB10)	-57	-58

After providing detector circuit by helical antenna it has a positive effect on voltage fluctuations thereon the sensitivity is ameliorated. Above that, we have simulated the detector under ISIS proteus and PSPICE to compare the response of circuit to impulses due existing of metal or mineral around. Rely to graphical comparison it is fruitful to add helical antenna on shell points as illustrated by the circuit below.

For a given impulse the circuit behave with a different sensitivity if helical antenna and while excluded from. Each frequency leads to an amplitude and we distinguish different response and amplitude. Thereby helical antenna is more directive and sensitive than the loop antenna.The specimen is characterized by the properties that determine the range to tune about while its detection. We illustrate by the tables below the effect of frequency range on detector performances especially depth and sensitivity as we illustrate by following tables:

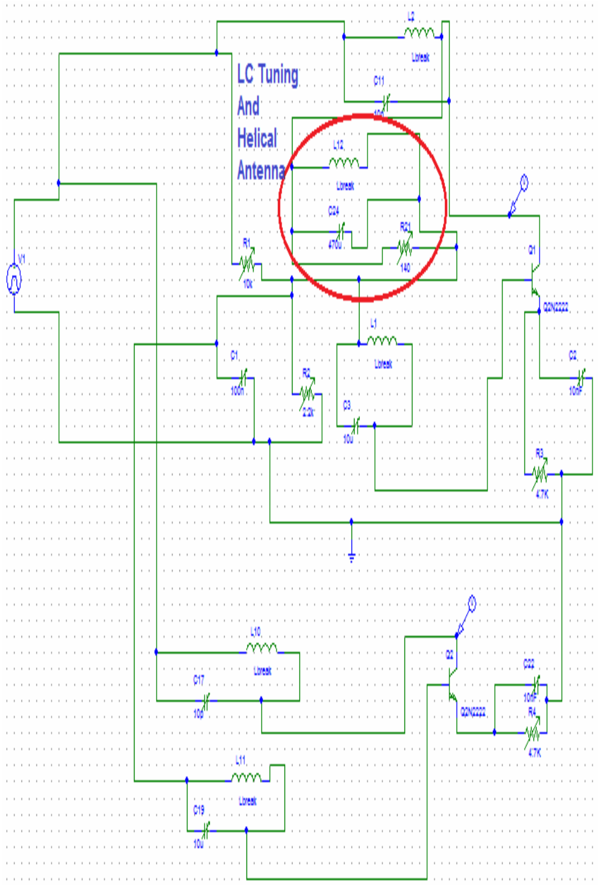

Figure 8. Simulation circuit of sensitivity under PsPice.

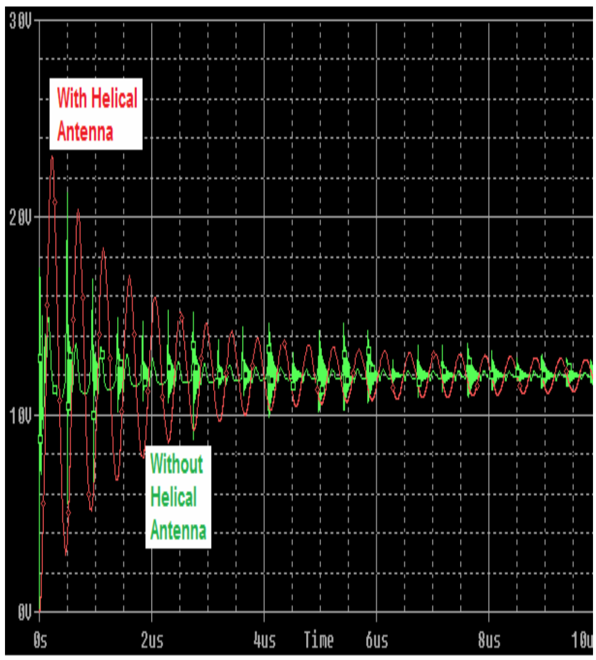

Figure 9. Evolution of voltage sensitivity .

Table 4. Experimentation results for F= 600 KHz.

Metal / Mineral	Cu	Fe	Ag	Al	Zn	Pb
Sensitivity without (V)	0.4	1	0.2	0.1	0.04	0.06
Sensitivity with (V)	0.7	1.8	0.5	0.3	0.12	0.14
Depth without (cm)	16.2	24.5	12	13.2	8	11
Depth with (cm)	28.4	36	17.6	22	14	17

Table 5. Experimentation results for F= 800 KHz.

Metal / Mineral	Cu	Fe	Ag	Al	Zn	Pb
Sensitivity without (V)	0.64	0.7	0.43	0.092	0.06	0.048
Sensitivity with (V)	0.94	1.43	0.66	0.16	0.64	0.08
Depth without (cm)	17.9	21.2	13.8	10.2	10	8.7
Depth with (cm)	31.1	32	17.6	17.4	16.2	14.2

Table 6. Experimentation results for F= 1MHz.

Metal / Mineral	Cu	Fe	Ag	Al	Zn	Pb
Sensitivity without (V)	0.87	0.58	0.76	0.072	0.08	0.01
Sensitivity with (V)	1.08	1.2	1.06	0.14	0.97	0.063
Depth without (cm)	20.1	18	15.7	8.6	12.6	6.58
Depth with (cm)	33.2	26.4	21.6	14.5	19.87	12.3

By analyzing these results the range of frequency has a huge effect on material detection due its reso–nance frequency. The magnetic properties are very important to make the detection process easy for elements. The utilization of coils as antennas describe both the proximity of the metal as well as its type. By tuning the frequency we charge the emitting coil that creates a magnetic field and flows towards the aim specimen then back into receiver antenna and read it by the circuit. These electromagnetic waves are reac–ting nearby metals and minerals that create its_own electromagnetic field and flows opposite to the field created by the antennas. By result we notice decrease of original circuit inductance. All different kinds of metal detectors behave with this change of charge and inductance in some way, but we will focus more on how that is specifically done in a beat frequency oscillator (BFO). The operation of this metal detector type is keeping inductance of one antenna as coil constant. The inductance nearby the goal substance is compared to that of the first coil. The difference is then translated into an audio output that changes relative to the value of the difference in inductances. The coil with an inductance held constant is called the reference coil, while the coil that detects metal is called the search coil. The detector depends on the difference between the inductances of the two coils to function correctly. The added antenna and LC dipole on shell points is to boost the difference and evitate losses and external perturbation for more accuracy. Every measurement device should be calibrated before first use. Empirically, it is almost impossible for both coils to have identical inductances, but it can be close enough so that any change in inductance is readily noticed through the audio output. For a suitable detector we should get a perfection of either depth, sensitivity and selectivity around the resonance frequency or detection range. For our system this condition is reached as we can see in comparison to old systems and the improvement is realized as we can illustrate by the following tables:

Table 7. Comparison for iron detection.

	Fe			
Frequency (KHz)	Depth Old BFO (cm)	Depth Recent Work (cm)	Sensitivity Old BFO (V)	Sensitivity Recent work (V)
600	24.5	36	1	1.8
800	21.2	32	0.7	1.43
1000	18	26.4	0.58	1.2

Table 8. Comparison for copper detection.

	Cu			
Frequency (KHz)	Depth Old BFO (cm)	Depth Recent Work (cm)	Sensitivity Old BFO (V)	Sensitivity Recent work (V)
600	16.2	28.4	0.4	0.7
800	17.9	31.1	0.64	0.94
1000	20.1	33.2	0.87	1.08

Table 9. Comparison for silver detection.

	Ag			
Frequency (KHz)	Depth Old BFO (cm)	Depth Recent Work (cm)	Sensitivity Old BFO (V)	Sensitivity Recent work (V)
600	12	17.6	0.2	0.5
800	13.8	18.7	0.43	0.66
1000	15.7	21.6	0.76	1.06

To see how is the evolution of depth varies with the frequency for each material range we represents it in function of frequency it seems obviously that iron is against copper and silver that are also different about the manner of increasing and the cause is resonance frequency, moreover we can study many parameters ([19,20]). The comparisons between old BFO metals detector and the recent detector are shown in figure 10.

Refer to curves the iron has quite detection for low range of frequencies (<800 KHz) thank to important depth that reaches 36cm and the sensitivity for the recent detector becomes more than 1V. When the frequency increase 2_MHz we note that sensitivity is weak otherwise the depth is still important but above of 4MHz both are less than values of accepted perfor–mances and the detector is unable to detect this element.

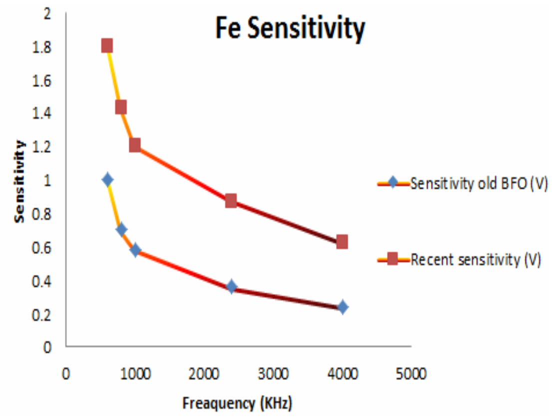

Figure 10. Iron response comparison for old and recent detector.

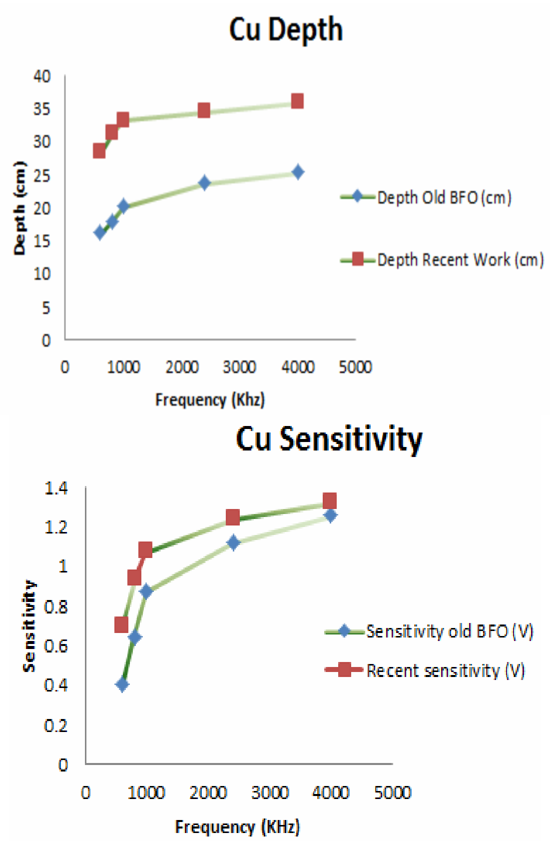

Figure 11. Copper response comparison for old and recent detector.

For the case of middle range the copper is an example. Indeed, for low frequencies we remark wide difference for the depth otherwise sensitivity is the same between two detectors. When we have tendency into the middle exactly about 2.4MHz we distinguish the difference between old and recent detector and the copper is detected easily with there is depth more than 30cm and sensitivity of 1.2V. For high frequencies not good cause of sensitivity saturation against the silver element.

By examination of silver performances evolution we find that its response is awesome for high fre–quencies that are in order of 4MHz.Thus the sensitivity is not accepted for low frequencies and the depth is still increasing for middle range. In summary the depth and sensitivity characteristics are ameliorated thank to recent work. For the iron the resonance frequency is low (600_KHz) so its performances decreasing with increasing of frequency. However, the copper response exists in the middle range which is around 2.4MHz. Above that, simillars materials to the silver are detected for high frequency at order of 4MHz .Thereon each material is characterized by its range of detection rely to its content and resonance frequency. Based on these comparisons the developed detector is provided by more directive gain that it improves the depth of detection. Each material has a special frequency that we should tune about during discovering its intrinsic properties [21,22,23]. For the first time to detect the substance the harmonic has important amplitude that amortised by scanning so far. Thereby we measure the fluctuation of voltage as sensitivity, which is different such as the case of ferrous ones and nonferrous substances.

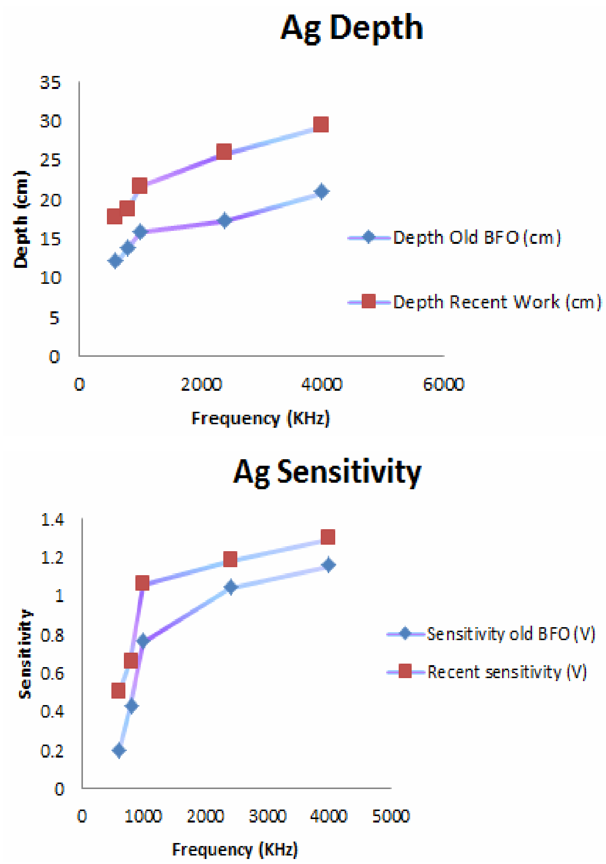

Figure 12. Silver response comparison for old and recent detector.

4. CONCLUSION

The helical antenna resolves the performances shortage of detectors, especially depth and sensitivity. Indeed, as found by measurement the helical antenna is characterized by adequate directivity and thin angle-width thereon it improves depth of detection and selectivity. Moreover, the new inductance of system ensures good sensitivity. After building and testing, it was found that our detector was more efficient. In fact, adding helical antenna reinforces the power of electromagnetic waves in the goal direction. Other advantages are simplicity to build the presented detector and move anywhere due small size. The different shapes of coils and antennas permit oscillators with high performances, such as the recent work in which we added helical antenna on shell points and tuning components for more adjusting and give suitable alternative for materials detection.

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КОНЦЕПЦИЈА И ЕКСПЕРИМЕНТ СА ИНОВАТИВНИМ ДЕТЕКТОРОМ МИНЕРАЛА И МЕТАЛА ИСПИТИВАЊЕМ ЕЛЕКТРОМАГНЕТНИХ ТАЛАСА КОЈЕ ЕМИТУЈЕ И ПРИМА ХЕЛИКОИДНА АНТЕНА

А.Мриј, А.Е.Бакали, Ј.Фоши

Рад приказује симулацију и експеримент изведен помоћу иновативног детектора минерала и метала у циљу побољшања перформанси старог система. Постојећи детектори имају ограничења у погледу дубине, осетљивости и селективности. У раду се предлаже уградња хеликоидне антене на тачкама омотача два калема да би се процес детекције унапредио појачањем учинка директивности и коефицијента рефлексије.

Систем користи принцип електромагнетне инду–кције и осцилатор бита фреквенције и има калем детектор који детектује минерале и метале у одређеном опсегу и даје аудитивне и вибрационе индикације када се елемент открије. Калем детектор чини део осцилаторног ЛЦ кола повезаног са додатом хеликоидном антеном. Фреквенцију активирања ЛЦ осцилатора одређују индуктор и кондензатор који повећавају вредност фреквенције и тако се открива већи број материјала.