Wireless passive sensor for crack detection exploiting RFID technology

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Abstract: This paper presents concept of passive, wireless sensor based on RFID technology for detection of cracks in ceramic parts, plates and equipment. Main objectives of this work were to develop as cheap as possible, quantitative sensor without any power source that would be also extremely simple and has possibly long lifecycle. This type of sensor could be used in Structural Health Monitoring, in tasks connected with crack detection in concrete structures (special ceramic specimens embedded in structure) and another tasks related to detection of damages in any ceramic parts (bulletproof vest plates, ceramic bearing, insulator in power engineering). In this paper we present technical concept of sensor, investigations on planar coil calculation, entire system simulation, prototypes that check manufacturing possibilities.

Keywords: wireless sensor, RFID, planar coil designing, SHM, concrete structure, ceramic crack detection

1. Introduction

The increasing interest in designing of wireless and battery-free sensors is one of the most significant trends within the subject of Structural Health Monitoring (SHM) in recent researches. Wireless Sensor Networks (WSN) offers almost endless opportunities, both in the tasks related to monitoring condition of structures, and another tasks connected with collecting of environmental information such as temperature, brightness, sound and vibration [2]. Wireless sensors are successfully implemented in many of practical applications such as environmental conditions monitoring, agricultural monitoring, vital sign monitoring in medicine, many of military applications, like DARPA's for instance [3]. Base difference between concrete examples of applied wireless sensor is the way of powering. There are two possibilities to solve this problem. First and already well developed approach is the power source connected to sensor (generally this is a battery). These type of sensors are well described in many papers such [2,4]. The second approach is generally more complicated, and stands numerous challenges against inventor. In this case the power is supplied to sensor from outside through ambient-power scavenging, from temperature difference using Peltier effect, solar energy, mechanical energy from vibrations by using of piezo-elements, and most of all directly from reader by using of magnetic coupling with reader [5]. It is obvious that sensor, that is both wireless and battery-free has advantages of this two groups of sensor. On the one hand it has almost endless lifetime and no needs for additional space for battery, on the other hand there is no needs for wire connection, it could be placed anywhere in places with difficult access, also on moving elements.

Preferably chosen technology by designing of wireless sensor is RFID (Radio Frequency Identification) in various forms and concepts. There are papers referred using of "1-bit only transponder" called EAS [1], well known as application in anti-theft devices in shops. Often there are threshold sensors that change its state by defined conditions. That are for instant low-cost temperature sensor, used in goods distribution tasks changing its state by transition of temperature below 0° C [6], displacement sensor using changing in backscattered signal response due to metal element closing to sensor transponder [6, 7], fluid level sensor, that could be used in restaurant applications (it uses the fact that water detunes tag antenna stuck on the glass, therefore when glass is empty the signal is readable) [6]. To this group belongs also low-cost corrosion sensor designed to detect corrosion in reinforced concrete structures [8–10]. The second group is represented by WISP (Wireless Identification and Sensing Platform), which are sensors connected with RFID transponder circuit and powered from reader [11]. Many papers describe WISP sensors such a WISP light sensor [12], sensors used in System for Human Activity Recognition and Prediction (SHARP) [13], wireless strain monitoring system called WISDOM (Wireless Distributed Strain Sensing for Structural Health Monitoring) [14]. There are also similar solutions, such self-powered temperature sensor [15] that satisfies the assumptions of WISP technology, but is not defined by that name.

In this short introduction it is signalized the most important recently researches and developments within the subject of wireless sensors used today and them application area. It is easy noticeable that designed sensor must be simply, low-cost, low-powered and must provide the opportunity to be ubiquity. Obvious there is many of wireless sensors presented above, there is still lack of such solution that is widely used in SHM application. This paper presents a concept that could fulfill specified market area and has great chance to be ubiquity.

2. Sensor concept

As was mentioned above a construction of designed sensor should be as simple as possible. Following requirements are: minimal cost of proposed sensor, practically endless lifetime (which excludes using of battery), possibility to place sensor on ceramic parts in almost arbitrary environment, in difficult accessible locations as well. There is strong demand for this type of sensor, both in SHM area, and in tasks connected with machine state monitoring.

In order to satisfy these requirements, a sensor with following operating principle has been designed. Firstly, will be discussed a concept of sensor that could be placed on flat parts, for instance ceramic plate putted into bulletproof vest. The main concept was to develop threshold sensor, changing its state by appearance of crack damage.

Therefore, the sensor has form of simple resonant circuit connected with RFID chip. The role of inductance element of the circuit plays a planar coil printed directly on ceramic elements. The role of capacitance elements plays, depending on frequency range of system, additional SMD capacitors or capacitor integrated with RFID chip internal circuit. The sensor system designed like that is tuned to determine resonant frequency (operating frequency), according to frequency of standard commercially available RFID reader. When crack occurs, tracks which forms planar coil become interrupted, there is no more backscattered signal in RFID reader, and thus we can conclude that ceramic part is damaged. Summarized, we can conclude that the sensor is in fact RFID transponder with specific form and role. This concept is somewhat similar to sensor for steel reinforced concrete presented in [9], however the role of susceptible element plays there a role of connection between two capacitors, lead outside sensor housing, effectively removing second capacitor in case of corrosion, what cause changing in resonant frequency of circuit. In our concept the susceptible element is in fact track that form planar coil.

As can be seen, this concept of sensor fulfilled almost all posted stipulation. Only costs are made by cost of simply RFID chip (depends on manufacturer it amounts about few dollars) and printed tracks – we have decided to use thick-film technology, screen printing that belongs to this technology is well-known and inexpensive method of application conductive inks (following [16]). The sensor could be placed at almost every flat ceramic part by its manufacturing, or later (the only requirement is connected to surface roughness). Its simplicity is also strong site of this concept – there is not any power source that could be discharged, loss of backscattered signal clearly indicates that damage has occurred. The lifetime of whole construction is only limited by lifetime of integrated circuit of RFID chip that is theoretically endless. Next advantage is fact that there is no need to place sensor in visible position. Depending on reader's range, it could be interrogated from up to 1 meter and more, independently what is between sensor (transponder) and reader. Only limitations result from presence of metal parts in near field of sensor that could change magnetic field around theme and thus limit read range of reader.

The crack damage sensor designed this way could be attractive for industry, military and construction application. It is simply, low-cost, has almost endless lifetime and thus has great chance to be ubiquitous. This type of proposed sensor could be used in many type of different application related to Structural Health Monitoring (SHM), maintenance of machines that contain ceramic parts, military application.

The first and probably most significant application is using this sensor in maintenance of concrete structure. There is strong demand for sensor that allows to prevent propagation of cracking damages in this kind of structure, due to their rapid recognition. We could manufacture ceramic plates and stick theme on the concrete building elements in the most endangered places, or even embedded theme into concrete during construction. Using of RFID technology allow us to avoid necessity of placing sensor in visible places, it could be placed for instance under plaster or another outer layer of the facade. Once placed sensor could be examined at certain times, depending on different application (for instance once a week), unlimited number of times, for many years. The lack of backscattered signal in RFID reader gives clearly information, that crack in structure has occurred and that whole construction is in danger. To achieve even more effectiveness, there is possibility to use stress-sensitive ceramic material for plate, what gives possibility to avoid crack even before its occurring.

The second area of application could be maintenance of ceramic plates placed in bulletproof vest. This type of plates must be fully functional in order to comply its role. Even small crack damage could be hazardous for soldiers, that using bulletproof vest. Therefore these plates require frequent revision. Equipment of every plate in crack damage sensor could significantly reduce time of revision, due to avoidance of taking out every plate. There are also many different areas, depending only on needs, where this type of sensor could be used. Immediately coming to mind is maintenance of insulators in power engineering and maintenance of becoming more popular ceramic bearing. These areas of using, however, require more investigations.

3. Physical phenomena, simulations and prototypes

In first investigations carried out on this concept sensor we would to check the possibility to printing planar coil at any type of ceramic elements, recognize limitations, choose the best method of manufacturing process, choose the best method to calculate planar coil's self-induction and simulate operating principles of entire system. This knowledge will be important by process of designing and manufacturing of working sensor prototypes.

Due to the fact that it is intended to place sensor on any ceramic parts, we decided to use silver conducting ink for planar coil. There are many papers that report successful using of silver ink to fabrication printed RFID applications [17, 18]. Accordingly to chosen material, we used screen printing application method, as was mentioned above. The designed system could work at LF or HF frequency (125 kHz and 13.56 MHz respectively, standardized frequencies for RFID systems). Concrete sensor will work at specified frequency, depends on environmental conditions and concrete application requirements.

First we must consider some effects that could be important for designing of planar coil for RFID transponder. There are skin effect, current crowding effect, resistance of planar coil related to sheet resistance of conductive ink and inductance of planar coil. Some of these phenomena need to be checked once for specified conditions, like for instance operating frequency, another become significant in entire designing process. Below there is short description of these phenomena, that could be helpful in designing process of RFID transponder on any substrate, not only ceramic.

3.1. Skin effect

According to [19] the skin effect "is the tendency of high frequency current to concentrate near the outer edge, or surface, of a conductor, instead of flowing uniformly over the entire cross sectional area of the conductor". This effect increases according to growth of frequency, causes decreases of current density inside the conductor. This effect occurs due to Faraday's law applied to high frequency conductive tracks. The result of skin effect is called "skin depth", which states thickness of conductive tracks in which approximately 63 % of all current flows. Practically we assumed that at higher frequencies, there is no reason to increasing track thickness, because flowing current is limited by skin depth, described with following equation:

$$\delta = \sqrt{\frac{1}{\pi \cdot \mu \cdot f \cdot \sigma_e}} \tag{1}$$

where μ is permeability, σ_e is conductivity of silver ink and f is operating frequency.

As Leung reported [20] "the skin effect is negligible for the printed coils at 13.56 MHz". After substituting values related to our assuming

$$\left(\begin{array}{l} \mu = 4\pi \cdot 10^{-7} \dfrac{N}{A^2}, \quad \rho_e = 1.6 \cdot 10^6 \dfrac{S}{m}, \\ f = 13.56\, MHz \end{array} \right)$$

[18], we considered that value of skin depth is 108 µm. Average thickness of screen printed track is 25 µm, which confirms that skin effect is negligible, particularly by using of silver conductive ink at HF and we will consider no more at this phenomenon.

3.2. Current crowding effect

The current crowding effect (called also as proximity effect) is connected with increasing effective resistance above its DC value at higher frequencies in conductive traces placed close to each other, especially in application such planar coil inductors, due to eddy currents induced inside of traces [21]. This effect is difficult to precise analysis; however there is an equation, allowed us to approximately define the boundary frequency, when it becomes significant:

$$f_{\lim} = \frac{3.1\, P\, R_{sheet}}{2\pi\mu_0 W^2} \tag{2}$$

where P is sum of track and internal width and W is track width as shown in picture (fig. 1), more information about R_{sheet} is posted below. Therefore trace sheet resistance is not exactly known before manufacturing first prototypes, what is subject of this paper, result of solving this equation will be mentioned in results.

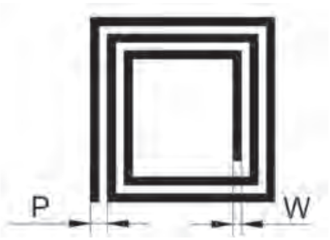


Fig. 1. Track width and sum of track and internal width
Rys. 1. Szerokość ścieżki oraz suma szerokości przerwy między ścieżkami i ścieżki

3.3. Resistance

Track resistance has significant influence for quality factor of resonance circuit. Resistance of produced tracks depends on conductive ink, method of manufacturing and material of substrate. Producers of standard conductive ink give information about trace sheet resistance (measured in Ohm/square) by standardized average trace thickness of 25 µm, printed on LTCC substrate. In our investigation we checked trace resistance of conductive ink applied on ceramic substrate that was not designed especially for electronic tasks. In this case apparently insignificant parts of manufacturing process become important. For obtainment of trace sheet resistance we have measured total resistance of prototype traces and using equation:

$$R_{sheet} = \frac{R_t \cdot W}{L} \tag{3}$$

where R_t is total resistance, W is track width and L is track length, we have received real value of trace resistance for chosen manufacturing method and type of substrate. This investigation was necessary, due to much lower value of conductance in silver-ink printed tracks, compare to standard etched copper tracks.

3.4. Inductance

The subject of planar coil inductors lies in area of great interest for many years. There are many of papers describing approximating formulas allow us to calculate inductance of planar, especially square-shaped inductor [22–26]. We decided to check usefulness of chosen equation and method of prediction coil inductance, by designing our prototypes. First equation was given by Wheeler in 1928 (following [23]):

$$L_{Wh} \approx \frac{45 \cdot \mu_0 \cdot n^2 \cdot a^2}{22\, r - 14\, a} \tag{4}$$

where n is the number of turn in coil, r is the half-width of the square coil and a is the distance from the centre of the inductor to the middle of the windings, as shown in (fig. 2).

In this paper [23] was given also modified Wheeler equation differing to original only with constant 45 changed to 33:

$$L_{Wh(Mod)} \approx \frac{33 \cdot \mu_0 \cdot n^2 \cdot a^2}{22\, r - 14\, a} \tag{5}$$

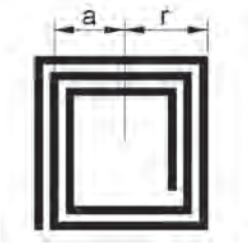


Fig. 2. Variables a and r presented on square shaped *coil*
Rys. 2. Zmienne *a* i *r* pokazane na cewce kwadratowej

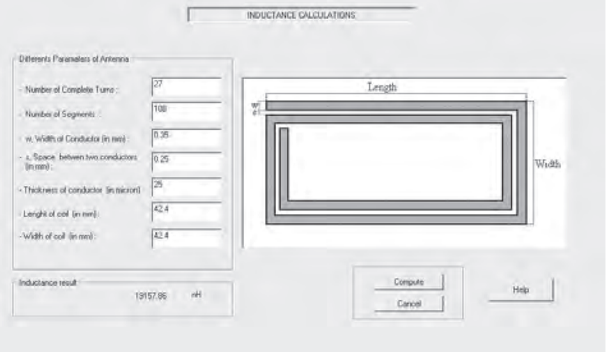
Another equation named Grover method was given at [24]:

$$L_{Grov} = \sum_{j=1}^{s} L_j + M \tag{6}$$

where s is the number of segments, M is the mutual inductance between each segments and L_j is the self inductance of each segment given by [25]:

$$L_j = 0.002l\left(\ln\left(\frac{2l}{w+t}\right) + 0.50049 + \frac{w+t}{3l}\right) \tag{7}$$

where l, w and t are track length, width and thickness respectively. This equation was applied to antenna design tool, developed by ST Microelectronic (fig. 3).



Differents Parameters of Antenna

- Number of Complete Turns : 27
- Number of Segments : 108
- w, Width of Conductor (in mm) : 0.35
- s, Space between two conductors (in mm) : 0.25
- Thickness of conductor (in micron) 25
- Lenght of coil (in mm) : 42.4
- Width of coil (in mm) : 42.4

Inductance result

19157.86 nH

Fig. 3. ST Microelectronic tool calculating inductance of planar coil

Rys. 3. Narzędzie firmy ST Microelectronic obliczające indukcyjność cewki planarnej

In ERES materials [26] about coils we found approximately equation related to planar inductor printed on foil (35 µm thick):

$$L = nD_m\left(nK_1 + K_2\right) \tag{8}$$

where n is the number of turns, D_m is the calculation diameter of coil differing for each coil shape, as shown in fig. 4 (according to [26]), K_1 and K_2 are constants taken from graphs posted in [26] – (figs. 5 and 6).

We also developed a simulation of planar inductor in COMSOL Multiphysics, approximating planar square-shaped inductor as several concentric squares differing only length of the side. Inductance depends mainly on quantity of magnetic flux lines flowing through inductor, thus leading design variable is coil shape and dimensions. The tracks of inductor are approximate as one dimension (length only) conductive lines embedded in 3D space. This model of planar coil is both close to reality and should state good approximation, as well as relatively fast in the calculations for computer (fig. 7 and 8).

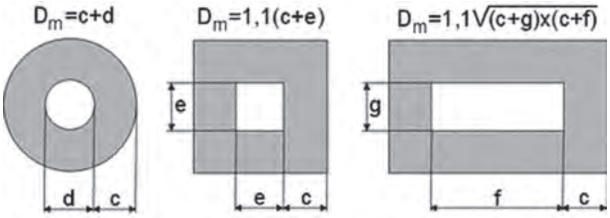


Fig. 4. Difference in coil diameter calculation due to its shape

Rys. 4. Zmiany w sposobie obliczania wymiarów cewek ze względu na ich kształt

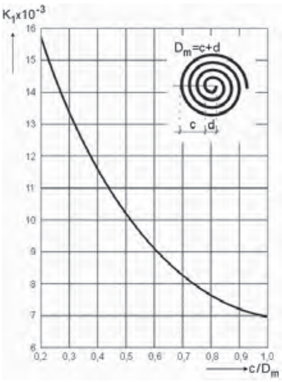


Fig. 5. Calculation of K_1 constant

Rys. 5. Obliczenia stałej K_1

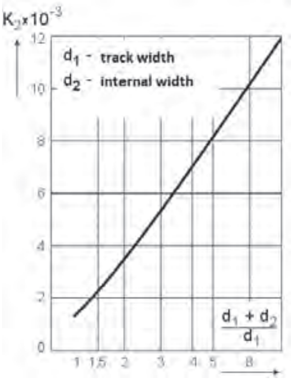


Fig. 6. Calculation of K_2 constant

Rys. 6. Obliczenia stałej K_2

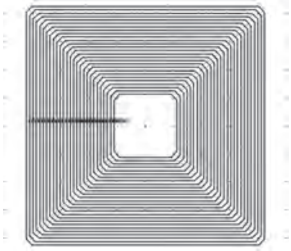


Fig. 7. Model of square shaped planar coil

Rys. 7. Model kwadratowej cewki planarnej

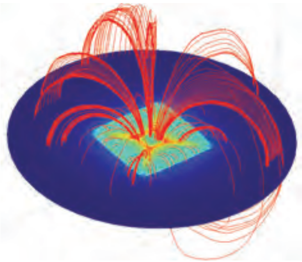


Fig. 8. Simulation of magnetix flux in planar coil embedded in 3D space

Rys. 8. Symulacja strumienia magnetycznego w cewce planarnej w przestrzeni 3D

After manufacturing some prototypes we measured real inductance of coils by using RLC Bridge model 41R produced by CHY company. We compared all results (from theoretical equation, simulation and measurement of real prototypes), receiving information for future investigation, which way of planar coil designing is the best and closest to reality.

3.5. Operating principle simulation

Using CST Microwave Studio we simulated the entire system. We developed model of planar coil embedded in air space that is as close as possible to reality. In preparing of system environment we have used lumped capacitive element and discrete port to excitation entire structure. Designed system is prepared for work with operating frequency 13.56 MHz. Assuming, that internal capacitance value of real RFID chip provided by ST Microelectronic (M24LR64-R model), that we intend to use, is about

27.5 pF, we could calculate needed inductance for achieving determined frequency, transforming simple, well known equation:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{9}$$

to:

$$L = \frac{1}{4\pi^2 C f^2} \tag{10}$$

After substitution we became value of inductance about 5.01 µH. We done preliminary design of planar coil, computed initially value of inductance with help of described above antenna design tool, assuming that introduced modifications, like for instances rounded corners of planar coil tracks, could change slightly final value of inductance. We tested value of S11 parameter measured on discrete port and investigated impact of occurring damage to changing in resonant response entire system.

3.6. Planar coil prototypes

We developed several of planar coil inductors at ceramic substrate from fireplace ceramic-glass called ROBAX in the form of small square (50 × 50 mm). To manufactured planar coil we used glassy conductor silver ink, what allow us to soldering SMT elements, additive capacitors for instance. Connection between coil traces was produced by help of polymer-based silver conductor ink, due the fact, that resist layer was also from polymer-based ink (using of glassy resistive inks resulted in surface cracking of substrate material).

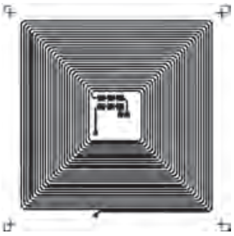


Fig. 9. CAD-project of second prototype

Rys. 9. Projekt CAD drugiego prototypu

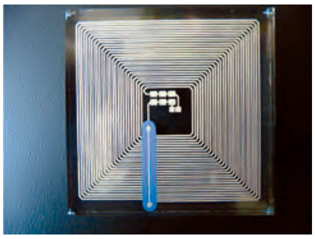


Fig. 10. Second prototype after manufacturing process

Rys. 10. Drugi prototyp po procesie produkcji

Tab. 1. Basic data related to prototype coils

Tab. 1. Podstawowe dane cewek prototypowych

Prototype	1	2
Track length	3838 mm	2894 mm
Track width	0.225 mm	0.35 mm
Internal width	0.225 mm	0.25 mm
Side length	42.4 mm	42.4 mm
Number of turns	36	27
Average track resistance	430 Ω	46 Ω
Average inductance	33.72 µH	18.62 µH

There are two main prototypes which could serve as examples to compare with equations and digital model. There were also earlier prototypes that allow us to investigate some of screen printing method principles related to entire ceramic substrate. Concerns connected with filling of conductive ink after printing have been allayed. By annealing the tracks rather shrink. The adhesion to substrate material was also very good. There were also some problems with resistive ink, which was described above.

Concerning again at two prototypes, there is some technical and physical data of printed coils (tab. 1) and also pictures that show physical model of them (fig. 9 and 10).

4. Results and discussion

We manufactured two following prototypes of planar coil. In comparison above, easy noticeable difference is the average track resistance. After substituting values to formula (3), we obtain quite different real value of trace sheet resistance about 25.2 mΩ and 5.5 mΩ for first and second prototype of coil respectively. This significant distinction outcomes from application of some improvements in manufacturing method by production of second prototype. After notice some features of fabrication conductive traces on ROBAX substrate, like for instance shrinkage of traces by annealing, we decided to developing model with wider tracks, using of screen with larger mesh factor (initial concerns about spillage of tracks by annealing have been canceled), backed with thicker foil, which affected on more accurate mapping of screen traces on substrate, due to thicker tracks (in first prototype we noticed some constrictions in tracks, probably due to local loss of thickness). Trace sheet resistance is value of great importance, through its straightforward impact to real resistance of track and therefore indirectly for quality factor of coil (the lower the resistance, the higher the quality factor), which is significant for all resonance circuit.

After obtaining final value of trace sheet resistance, we could consider on current crowding effect in planar coil. Using equation (2), we obtain value of frequency, at which the current crowding effect becomes significant, impacts on increasing of tracks resistance. It is interesting that by our manufacturing methods, achieved trace sheet resistance and track thickness, this frequency is about 10.58 MHz, by assuming operating frequency 13.56 MHz. That is the signal that current crowding effect must be taken into account, by designing of planar coil intended for similar tasks, like this type of crack damage sensor.

The main results of our investigations was checking of usefulness of different designing and calculating method for planar coil inductance, in relation to designing of planar coil printed on any ceramic substrate. Below in tab. 2 were posted results of coil calculations by using methods described above in comparison to real values of inductance, measured by RLC bridge:

By analyzing of these results we concluded that all of approximating methods of coil inductance calculations give values greater than measured value in prototype. The nearest to reality is Grover Method applied in ST Microelectronic antenna design tool and it was chosen to developing of next prototypes of sensor. Other methods

Tab. 2. Values of inductance received from different equations and measured in prototype coils

Tab. 2. Wartości indukcyjności otrzymane z różnych wzorów i zmierzone w cewkach prototypowych

Real inductance	33.72 µH	18.62 µH
Simulation in Comsol	37.62 µH	21.40 µH
Grover Method	33.95 µH	19.15 µH
Method from ERES materials	37.98 µH	21.49 µH
Wheeler equation	46.47 µH	26.53 µH
Modified Wheeler equation	36.14 µH	20.63 µH

(simulation in Comsol, method from ERES materials) are similar and give values a few microhenries greater than real, they are helpful by preliminary calculations. Considering on Comsol simulation, it is useful because of possibility to calculating another values connected with RFID system design (mutual inductance, coupling coefficient), what will be described in the next papers. The Wheeler equation is one of the first methods to calculating planar coil inductance and nowadays it can be treated as historical, its difference in calculated value is greatest, it could be useful only in forecast of inductance value order of magnitude. The modified Wheeler formula is more useful, its error is similar to earlier described method (ERES and Comsol).

The second of main results in our investigations was simulation of entire system, carried out to checking supposed operating principles, which assume that occurring crack damage and interruption of track, lead to changes in impedance (thus in RFID reader tuned to specified operating frequency, there is lack of backscattered signal). First we had checked S11 parameter of undamaged system presented in fig. 11. We had investigated this parameter in frequency range, that we supposed resonant peak (10–15 MHz). By analyzing obtained results, we concluded that system has resonance in 13.46 MHz (fig. 13). Slightly displacement of resonant peak is caused by some changes in planar coil inductance compared to assumed value (due to simplifications in preliminary calculations). More interesting, however, is the simulation where crack occurs. We parameterized length of damage that resulted in four cases (undamaged planar coil by length zero, damage on one, two and three tracks) (fig. 12). Width of crack damage was constant and amounts 0.1 mm. By analyzing results there is clearly visible that resonant peak was significantly displaced (fig. 14) by occurring of crack damage. There is the leading result of our investigations. By displacement of the resonant peak, there is no more backscattered signal in RFID reader, thus we can conclude that our assumption related to operating principle was correct. Interesting phenomena is low impact of increasing number of interrupted tracks for resonance frequency. There is a great difference in value of undamaged coil impedance compare to coil with one track interrupted, but further damages do not impact so much. This phenomenon requires more investigations. There is admittedly some question connected with the result, for instance different place and amplitude of resonant peak of undamaged system compared to first simulation or significant difference in amplitude values, however we supposed that is the reason of simulation uncertainty and lack of precision. The leading operating principle was shown with this simulation.

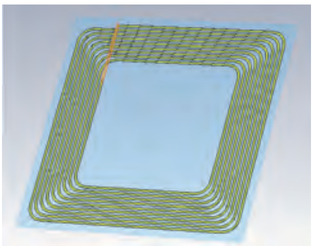


Fig. 11. Simulation of undamaged coil

Rys. 11. Symulacja cewki nieuszkodzonej

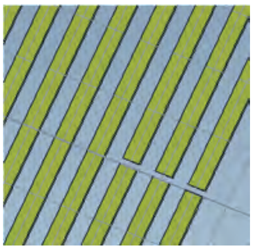


Fig. 12. Simulation of planar coil with interrupted tracks

Rys. 12. Symulacja cewki planarnej z przerwanymi ścieżkami

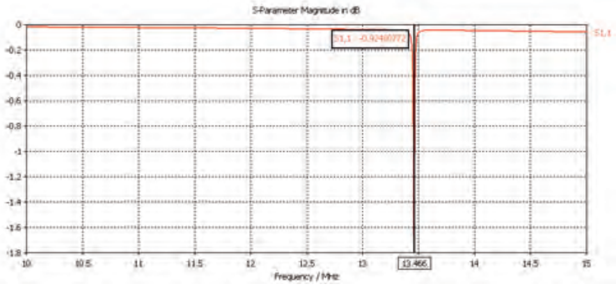


Fig. 13. S11 parameter with resonant peak of undamaged coil

Rys. 13. Parametr S11 z pikiem rezonansowym cewki nieuszkodzonej

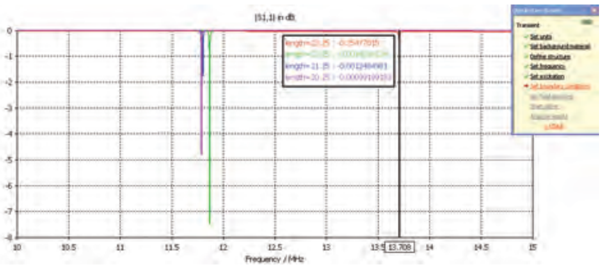


Fig. 14. Difference in S11 parameter and occurring of resonant peak due to tracks damages

Rys. 14. Różnica w parametrze S11 na skutek pojawienia się uszkodzenia

5. Conclusion

In our investigations we examined different methods of planar coil designing, both in the way of simulation, as well as inductance calculation. There Grover Method was chosen, as the best method to calculating inductance of planar coil printing on ROBAX substrate. We also developed appropriate components of manufacturing process, including screen mesh size, thickness of backed foil, method to connect inner and outer planar coil tracks. Our investigations resulted also in significant decreasing of track sheet resistance that now corresponds to value given by producers of silver ink. In this occasion it becomes clearly that current crowding effect is important phenomenon by designing of planar coil with similar characteristics and must be consider by designer. We developed also complete simulation of described system, checking the impact of crack damage, which interrupted tracks of planar coil, to its impedance, thus its resonant response. These preliminary investigations show possibility to developing crack damage sensor, which concept was also described here. This type of sensor has great chance for success on SHM and maintenance market. By the low cost per unit, especially due to the cost efficiency manufacturing method and simple operating principle, there is possibility to selling large number of units.

Next step will be designing of RFID system, working at specified operating frequency, with transponder manufactured directly on any ceramic elements. We will also investigate useful of such system in concrete structure monitoring and another tasks connected with maintenance of systems including ceramic parts. Parallel we would to develop more simulations, in order to find response for new question, that have appeared by preliminary simulation and to even better understanding of entire system.

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Bezprzewodowy pasywny czujnik uszkodzeń wykorzystujący technologię RFID

Streszczenie: Artykuł ten opisuje koncepcję pasywnego, bezprzewodowego czujnika opartego na technologii RFID, służącego do detekcji pęknięć w elementach, płytkach i urządzeniach ceramicznych. Głównym celem badań było opracowanie taniego progowego czujnika bez żadnego źródła zasilania, o prostej zasadzie działania i możliwie długiej żywotności. Taki typ czujnika mógłby być używany w monitoringu stanu konstrukcji, w zadaniach związanych z detekcją pęknięć w strukturach żelbetowych (specjalne próbki ceramiczne umieszczone w konstrukcji) i innych zadaniach związanych z detekcją uszkodzeń elementów ceramicznych (płytki umieszczane w kamizelkach kuloodpornych, łożyska ceramiczne, izolatory w energetyce). Poniżej zaprezentowano pierwszą fazę badań (koncepcję czujnika, wybór sposobu zaprojektowania i obliczeń indukcyjności cewki planarnej, symulacja zasady działania, wytworzenie prototypów w celu sprawdzenia możliwości produkcyjnych).

Słowa kluczowe: czujnik bezprzewodowy, RFID, projektowanie cewek planarnych, SHM, konstrukcje żelbetowe, detekcja pęknięć w ceramice

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