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EVALUATION OF INDUCTANCE WITH ELECTRICAL WIRES

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Abstract

In this paper proved the possibility of developing passive electronic inductive elements based replace metal wire that is wound inductor, the wire is made of electret. The relative permeability of the electret $\varepsilon_S \approx 10\ 000$, several orders of magnitude greater than the permeability of conventional insulation materials, $\varepsilon_i < 10$, resulting current in the wire acquires properties bias current. The essence of innovation is to replace the source of of magnetic induction flow that pervades the core of the coil. According to the theory of electrodynamics, current bias, in contrast to conduction current, generated no movement of charge along the wire, but the change of the charge in the local volume. Equivalence bias current and conduction current is manifested in the possibility of forming a magnetic field. The flow through magnetic induction coil core regardless of the current it generates, creates voltage at its ends.

The paper also shows the numeric characteristics that determine the effective frequency range, specified the reason why electric a wire with $\varepsilon_i < 10$ can not generate magnetic flux through the core and serve as a passive reactive component.

Keywords

Inductance; coil; transformer; high-frequency microelectronics; electricity.

Introduction

Research topic relates to the field of electronic production, especially high basic components of electrical circuits. Although the technology of manufacturing monolithic integrated circuits reached 20 nm separation levels proposed in this paper, the ideas will improve their functionality by replacing the active inductances miniature passive inductor, construction of which involves the replacement of metallic conductor on electret.

Theory, ways to implement the coils and their design enough known [1, 2, 3] and detailed in scientific literature since the work of Michael Faraday (1791-1867), (Michael Faraday. Experimantal Researches in Electricity, that published in three volumes in the period from 1839 to 1855 years). Side surface of the metal conductor is usually coated with insulating material to isolate the coil circle apart. Permittivity insulating material $\varepsilon < 5$, commensurate with the magnitude of the dielectric constant of dry air $\varepsilon = 1$. Wire, wound on the carcass cylindrical, conical, toroidal, or other form of lateral surface in one or in several layers.

Analytical calculation coefficient of self-induction L (inductance) for different variants of geometric forms coils wound metal wire, fully presented in the book [2] in which to practice with sufficient fullness describes methods of analysis and are given the appropriate formulas. Specific design inductors are protected by many patents, for example, [3, 4]. Analysis of the morphology of existing inductors indicate that they are only in form but not in substance, differ from one another. Their differences are dictated only change the size and terms of use, which limits their functional versatility. In addition, the conduction current flowing through the wires, causing thermal energy losses and imposes restrictions on the value of real quality factor coils, not exceeding Q <200, even in the case of conductors with silver or gold, with the greatest relative conductivity.

The study aims to the disclosure of the processes of transformation of physical quantities in the dielectric inductor (DCI) calculation of their characteristics, confirming the possibility of implementing the proposed idea.

1. 1. Theoretical study.

Consider first the processes in idealized inductor. The mechanism of occurrence voltage rather simple and schematic submitted following successive transformations of physical quantities, Fig. 1. The current external source *i(t),* that flows through coil turns, creates a magnetic flux *Φ(t)* and the latter, penetrating the core of the coil, it leads to voltage *u(t)* according to Faraday's law [8, p. 17]

$$u = \frac{d\hat{O}}{dt} \tag{1}$$

where *u* – the voltage at the ends of inductors

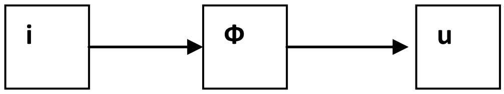

Fig. 1. - The transformation of physical quantities in the inductor

Prove the possibility of developing dielectric inductors. For this we consider construct, fig. 2, in which the wire «1», that wound on a skeleton of coil «3», and made of electret, the relative dielectric constant of which, $\varepsilon_c \approx 10\ 000$, several orders of magnitude higher than the dielectric constant of air or insulating wire «2», $\varepsilon_d < 10$, that isolates turns of each other.

1.1. According to Maxwell's equations [1, 8],

$$rot\vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}, \qquad rot\vec{E} = -\frac{\partial \vec{B}}{\partial t}, \tag{2}$$

where (H, B), (E, D) – modules vectors of tension and induction respectively magnetic and electric fields. The relationship between the vectors (2) determined by the material parameters ε, σ, μ of the environment

$$\overline{D} = \varepsilon_a \overline{E}, \quad \overline{J} = \sigma \overline{E}, \quad \overline{B} = \mu_a \overline{H}, \tag{3}$$

where ε_a (Φ/м), σ, (Sim / m) μ_a (H / m) – absolute permeability values corresponding vectors $\overline{H}$ (À / m), $\overline{E}$ (V / m) electromagnetic field in the dielectric, conductor and magnetic environment.

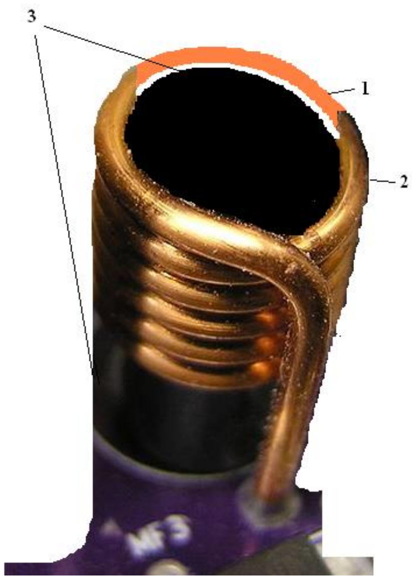

Fig. 2 - Dielectric inductor 1 - ferroelectric wire; 2 - dielectric insulation; 3 - magnetic conductive frame.

Classical Electrodynamics equation (2), (3) show that at each point in space vortices source $rot\vec{H}$ of the magnetic field may be not only the conduction current density $\vec{j}$, and the density and displacement currents – $\partial\vec{D}/\partial t$. The current displacement, in contrast to conduction current is not associated with the movement of noses elementary charge, but resulting changes of the electric induction time. Another significant difference between the currents is that the current conduction may not vary in time, in which case it generates a constant magnetic field, which does not depend on time. However, a constant electric field can not generate a variable and not constant magnetic field. Thus, one could argue that the inductor can be created not only a metal wire, and wire and dielectric having a high dielectric constant ε_s where there is a flow of electric displacement field, directed along the axis of the wire. However, with increasing frequency displacement current only grow, and the current conduction, because of the inertia of real particles and skin effect will diminish. Flow bias current trajectory in turns creates a magnetic flux in the core , which is a source of electromotive force of Faraday (1). Thus, the circuit changes, Fig. 1, reflects the work of inductors that wound as a metal and dielectric wire. The difference between the idealized process is the conversion of the electric induction flux in the flux of magnetic induction, Fig. 1, takes place in an environment with: $\sigma \to \mu$ for metallic conductor; $\varepsilon \to \mu$ in dielectric coil.

It should make a remark that equation (2) describe the relationship between the vectors in separate point of space, but not difficult to prove the relationship flows vectors of electromagnetic field induction vectors with values in some of its points. This should specify the problem by asking morphology inductors and electrical parameters of its components.

1.2. We know that in a linear environment, the current flowing through the inductor generates in plane crossing its core S flux of magnetic induction

$$\hat{O} = \iint_S \overline{B} d\overline{s} \qquad (4)$$

indirect source of which is current *i(t),* which is defined as flux of the current density. The value of this stream for a linear environment directly proportional to the turns of the coil current.

$$\hat{O}(t) = L * i(t) \qquad (5)$$

where L – main parameter that in the theory electrical circuits was named the coefficient of self-induction (or inductance). Its value depends on the design features coil: geometric dimensions and electrical parameters of carcass wire insulation shell and core.

Component equation idealized inductors obtained by substituting (5) into (1)

$$u = L * \frac{di}{dt}; \quad i = \frac{1}{L} * \int_{-\infty}^{t} u dt = i(0) + \frac{1}{L} * \int_{0}^{t} u dt \qquad (6)$$

where *i(0)* – constant of integration which characterizes the stocks distributed in space reactive energy of the magnetic field on time t=0. Current *i(0)* specifies the initial conditions for the solution of the problem of transient in electrical circuit with the coil inductance. Within descriptors classical theory of electrical circuits equation (6) is postulated as the thesis is seen as imperative law.

Given that the nature of the current component equations (6) is not established, it is believed that the classical theory of electrical circuits. as the theory of electromagnetic field, also not denied using bias current to generate dielectric inductors.

1.2. Consider the basic properties of the electret from the perspective of their use as substances with which it is proposed to produce wire inductors. Nomenclature of chemical compounds that are characterized by relative permittivity that a thousand times greater than the dielectric conductivity of air, every day is increasing, as, indeed, and the scope of their application. To the electrets include: Rochelle salt –$NaKC_4H_4O_6 \cdot 4H_2O$; barium titanate – BaTiO3; triglycine sulfate – $(CH_2NH_2CO{*}OH)_3H_2SO_4$; potassium dihydrogen phosphate – KH_2PO_4; gadolinium molybdate – $Gd_2(MoO_4)_3$; fluorine beryllates – $(NH_4)_2BeF_4$; lithium niobate – $LiNbO_3$ etc. Electrets properties and their possible application areas attract the attention of manufacturers of electronic devices and are the subject of many research scientists. [5, 6], http://www.terver.ru/segnetoelektriki.php . Electret allowed to develop its properties unique micro capacitors. For the same values of capacitors capacity size at least an order of magnitude were less than electrolytic capacitors that are made in metal cans up to 20 cm in height.

Microstructure electret material, like a mosaic composed of domains - domains with different directions of polarization of electric dipoles. In the absence of an external electric field overall dielectric dipole moment is not shown. But under the influence of an external electric field is the reorientation of dipole moments of domains in a direction that is correlated with the field lines. As a result, the total electric field domain will support specific orientation and after the termination of extraneous field. Thus, the electret wire dipole reorientation charges around a fixed point of rotation without moving them, as in the metal along the wire. The lack of reciprocal compensation direction dipole fields leads to a sharp increase in the electric field inside the electret wire. This electric field increases by several orders of magnitude, so that the relative permittivity of the field, for example, to reach Rochelle salt $\varepsilon_{max} \approx 10^4$.

Electrets properties change significantly depending on the parameters of the environment. In particular, the solid physical state of each ferroelectric characterized by temperature, above which its unique properties disappear and it becomes normal dielectric properties of $\varepsilon_d < 10$. This temperature was called "Curie point". For some electrets, there is not only the upper but also the lower limit of the temperature range within which there is intense polarization domains. For example, Rochelle salt has two Curie points (—18 and +24)^{0}C. Similar properties characterized compounds having isomorphic with Rochelle salt microstructure. In addition, when approaching the Curie points, a sharp increase in heat capacity electrets, that accompanied by a change in its electrical parameters. Arguably, inductors with wire electret, like ferroelectric capacitors find wide use in the art instrument engineering and environmental monitoring.

2. The principle of operation

2.1. *Convert vector flow induction in the coil inductance*

To understand the principle of the dielectric coils find out the difference between the coils, which wound idealized ferroelectric ($\varepsilon \rightarrow \infty$) and idealized dielectric ($\varepsilon \rightarrow \infty$) wire.

For this we use the model of quasi-stationary electromagnetic field in which is possible to use formula (1), (5), (6). Considering the conversion of physical quantities, Fig. 1, it should be noted that in different environments, these changes occur on different paths. In the idealized case, this difference is manifested in the way of guidance flow vectors induce electric and magnetic fields in relation to the axis of symmetry coils and the axis of symmetry of wire, which this coil is wound.

In the coil that is wound idealized ferroelectric Fig. 3, an electric field is applied to the ends of the coil, Fig. 3a, within each coil wire has the ability to change its direction as a result of active ferroelectric polarization domains and, ideally, the flow of electric displacement field inside the wire N directed along the trajectory spiral coil, Fig. 3b.

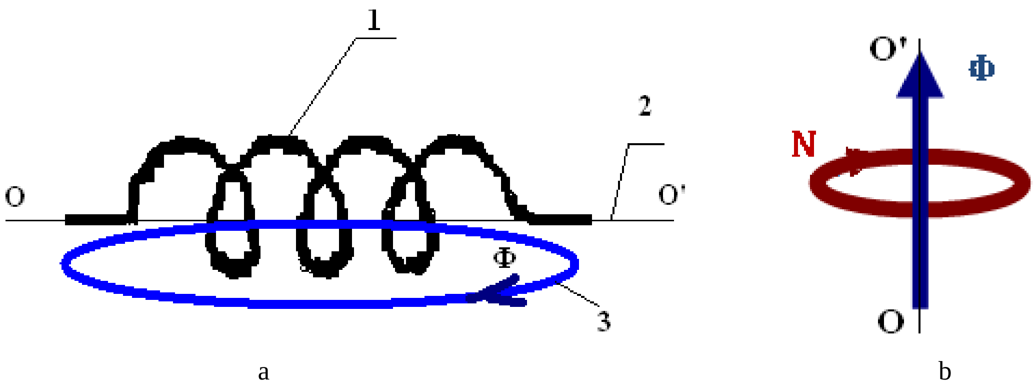

Fig. 3 - ferroelectric coil, a - the orientation of the magnetic flux Φ (3) to the axis (2) coils (1); b - flow conversion circuit of the electric and magnetic induction.

Its time for a change in the formula (2) and is the source of magnetic flux Φ. These flows N and Φ are mutually perpendicular and therefore flux Φ "3" is directed inside the coils axis parallel to its "2".

In the coil, Fig. 4, wound idealized dielectric with $\varepsilon_d = 1$, an electric field is applied to the ends of the coil, Fig. 4a, within each coil wire has the ability to change its direction due strictly related domains like "vacuum" does not respond to an external electric field, and therefore such a coils electric field oriented parallel to the axis OO '"2" , Fig. 4b. This flux of magnetic induction F, will circulate in the to the transverse plane. Power lines are like arrows magnetic compass around the conductor, which simulates the inductor.

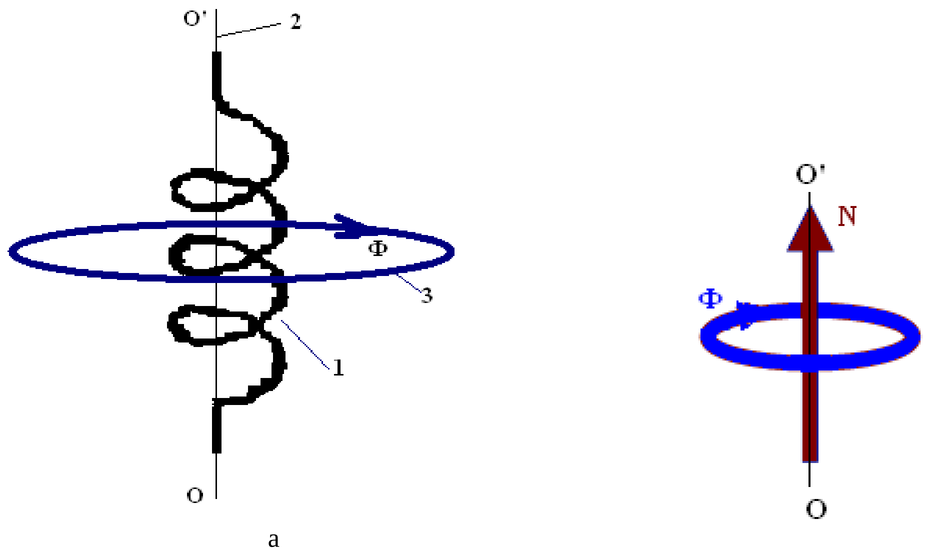

Fig. 4 - Dielectric coil, a - the orientation of the magnetic flux Φ (3) to the axis (2) (1); b - flow conversion circuit of the electric and magnetic induction.

3. Comparative characteristics

To determine the performance characteristics of coil and comparative analysis we write Maxwell's equations for complex amplitudes of harmonic oscillations. In view of (3) equation (2) have the form

$$rot\dot{H} = \sigma \dot{E} + j\omega\varepsilon_a \dot{E}, \qquad rot\dot{E} = -j\omega\mu_a \dot{H} \qquad (7)$$

where ω – cyclic frequency harmonic oscillation of the electric field.

Using these equations solve a number of tasks that allow you to perform a comparative analysis of the properties of inductors that are made of metal and wire electret.

Task 1. Find current value *I*, a copper conductor, the dimensions of which: length *l*=100 m; diameter wire ∅ = 1 mm, – if applied to the ends of the wire voltage U=10 V, the specific conductivity of copper $\sigma = 5{,}7 \cdot 10^7$ Sim/m.

Solution 1. Conductor resistance [1, p 34] is defined as

$$R = \frac{1}{\sigma}\frac{d\ell}{ds}$$

for a homogeneous environment conductor

$$R = \frac{\ell}{\sigma S} = 2.234 \quad Om$$

and conduction current

$$I = \frac{U}{R} = \frac{10}{2.234} = 4.477 \quad A$$

independent from the frequency.

Find the value of bias current in ferroelectric electric wire. Its dimensions are: length *l*=100 m; diameter ∅ = 1 mm, – if applied to the ends of the wire voltage U=10 V, the relative permittivity of ferroelectrics $\varepsilon_S = 10^4$.

Solution 2. Module reactance ferroelectrics for a homogeneous dielectric environments is frequency-dependent magnitude

$$X = \frac{1}{\omega\varepsilon_a}\frac{d\ell}{ds} = \frac{\ell}{\omega\varepsilon_a s} \, Om,$$

the tracker which is shown in Fig. 5.

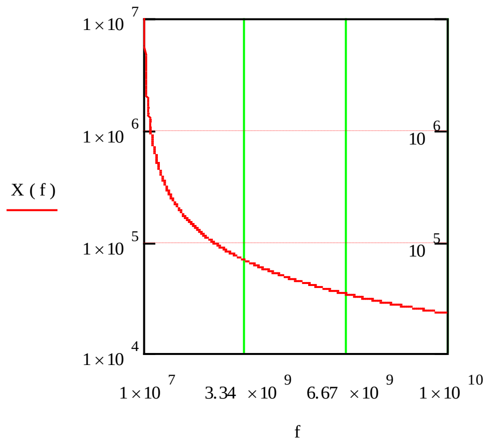

Fig. 5 - reactance ferroelectric dielectric wire

Thus, the current module ferroelectric electric wire in the frequency range 10 MHz ... 10 GHz

$$I_s = \frac{U}{X},$$

as expected, increases with increasing frequency, Fig. 6

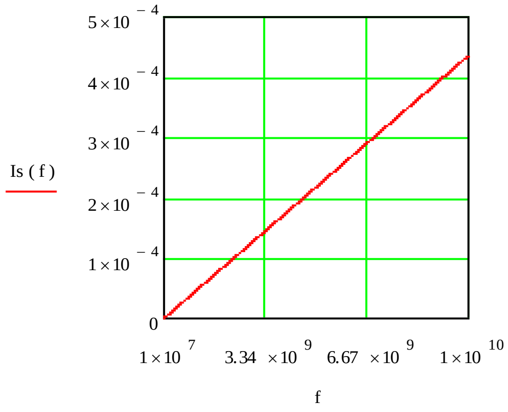

Fig. 6

Task 3. The coil is made of ferroelectric electric wire. The length of the wire - l = 100 m; ferroelectric diameter wire - ∅ = 1 mm. Wire covered with insulating varnish thickness in Δ = 0,02 mm. Determine the voltage on the coil in the frequency range (10 MHz ... 10 GHz) sinusoidal current shift.

Solution 3. Define inductance coil. Coefficient of self-induction solenoid coil with an idealized electret (ε → ∞) can be calculated by the formula determining the inductance coil with a metal conductor, because, in terms of the external manifestations of their actions, as noted earlier, are equivalent. According to [2, p. 247]

$$L = \frac{\mu_0}{4\pi} Ô\, w^2 d \;\; Ãí \;, \qquad (8)$$

where $\mu_0 = \frac{4\pi}{10^7}\frac{H}{m}$ – магнітна проникність вакууму;

w – number of turns coil;

d – diameter coil;

Φ(α) – a quantity whose value depends on α = a/d, that is, a value - up to d - diameter coil ([2], Tab. 6-1);

The number of turns of the winding w can be defined as based on the length of "a" coil (w_a) and on the basis of length *"l"* of the wire - (w_l)

$$w_a = \frac{a}{\varnothing}; \qquad w_\ell = \frac{\ell}{\pi d}.$$

In the general case w

$$w = \min(w_a, w_\ell)$$

but based on the economic feasibility of the size of coil must be matched to the size of the conductor, which this coil is wound.

$$w_a = w_\ell; \quad \pi d a = \ell\varnothing \qquad (9)$$

It follows from (9) coil design allows random choice only 3 of the 4 design parameters. Since the bias current calculation was carried out at fixed values of diameter d ferroelectric wire coil, its length

$$a = \frac{\ell\varnothing}{n\pi d}$$

we can determine from (8) averaged for a given diameter d n- layers inductor, Fig. 7

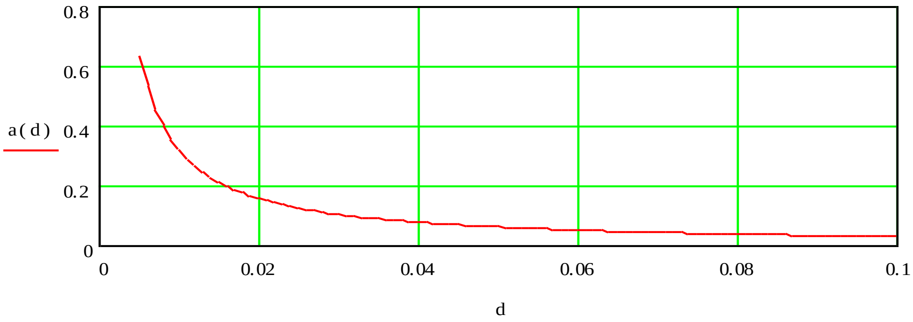

Fig. 7. - Coherence ferroelectric coil sizes

So for ten layers coil that has a diameter d = 1,8 cm and length a=18 cm, number of turns

Таким чином, для десятишарової котушки при діаметрі котушки d=1,8 см, і довжині см кількість витків $w \approx 800$, and the value Φ(10) = 0,946. The results make it possible to calculate the required inductance (8) coil L = 15,17 uH. and the frequency dependence of the module voltage Us on the coil, according to (6), Fig. 8.

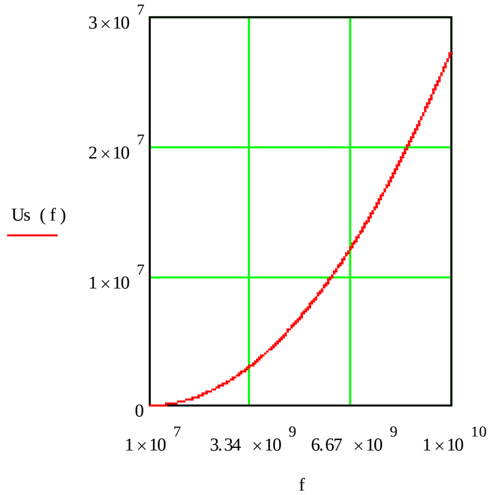

Fig. 8. - Frequency dependence module of voltage to the ferroelectric coil

Analyzing the results, it should be noted that the increase in coil voltage is due to two factors: the increase in the frequency and increase the current shift in the frequency range indicated in Fig. 6. This effect is in essence equivalent resonance voltage in sequential circuit whereby the voltage on the reactive components increases the quality factor times relative to the input voltage circuit.

Task 4. To define the frequency at which the dielectric and metal coil have the same resistance on the module.

Solution 4. If the inductor is made of copper, for which the value of specific conductivity σ = 5,65*10^7 S/m, then the bias current for the same density as the conduction current density must fulfill the conditions $\sigma = \omega \varepsilon_{as}$, to determine the frequency of oscillation external voltage on the inductor, which would provide the same flow (4) magnetic induction flowing through the coil core

$$f = \frac{\sigma}{2\pi\varepsilon_{as}} = \frac{5,65 * 10^7}{2\pi(36\pi)^{-1}10^{-9}10^4} \approx 10^{14}\ \tilde{A}\ddot{o}$$

where ε_{as} – absolute permittivity of ferroelectrics.

Permissible dimensions coil at this frequency should be at least an order of magnitude less than the the length electromagnetic wave

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8}{10^{14}} = 3 \cdot 10^{-6}\ m$$

ie not exceed 30 microns that meets modern technological level nano- and microelectronics. It is clear that with a decrease in the frequency of these dimensions can be increased to values which satisfy the conditions of quasi-stationary electromagnetic field and provide electromagnetic compatibility of inductors.

Conclusion

The paper proposed construction inductors, the principle of which is based on the use electret as material from which the winding is wound coils and provided theoretical justification efficiency design. For have been involved elements of the theory of electromagnetic field theory of electrical circuits, reduced physical and chemical properties of substances that can be used for manufacturing ferroelectric wire inductors. There were conducted numerical calculation of frequency characteristics that confirm performance of proposed designs inductance and illustrate its properties in different frequency bands.

The use of this design in technology development monolithic integrated circuits to considerably improve technical and economic indicators. First of all, it - reducing energy losses due to the significant increase of merit, cheaper materials and expansion of functional properties.

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AUTOMATION NEWS

New ISA Standards Committee to Improve SCADA Systems

Supervisory control and data acquisition (SCADA) systems have long served a vital monitoring and control function throughout process industries. Some argue, in fact, that the Industrial Internet of Things (IIoT) is essentially the already common SCADA infrastructure. And with growing IIoT relevance and popularity in industry, as well as the cybersecurity concerns that come with it, there is also a need for standardization around those SCADA systems.

With that in mind, ISA’s Standards & Practices (S&P) board has approved a new committee to develop standards and technical reports geared toward improving the overall reliability of SCADA system design, installation, integration and operation for such process industries as oil and gas, water and wastewater, and power.

“With the increased connectivity of the wide range of devices used to monitor and control our environment, SCADA systems are becoming a more important part of today’s control infrastructure,” said Ian Verhappen, S&P board member and senior project manager of automation at CIMA. “SCADA is so ubiquitous, but everyone does it their own way. But there are a lot of general principles that all of them use, and that is what we’ll try to capture, and what we’ll try to document.”

Initially proposed a couple years ago by Greg Lehmann and Ram Ramachandran, when the idea for the SCADA committee came up again, ISA decided to survey the automation community, where they got overwhelming support. “We had 80+ people responding, and over 80 percent said go for it,” said Verhappen, who led the survey and analysis for the S&P board. Several of the survey respondents also indicated that they’d like to help out with the standards, he added, which of course is key for getting the standards done.

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