

Geophone Equivalent Circuit for Simulation Tasks in Spice Packages

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Introduction. In modern electronic equipment the inductive seismic receivers (geophones) are the most widespread as sensors for registration of seismic signals. In developing seismic receiving devices, the most significant attention is paid to input amplifiers, which are directly connected to the geophones. Depending on the type of seismic research it is necessary to allocate specific ranges of input frequencies. For filtration and frequency response form correction to geophone is adding additional circuits. Therefore, the work of the geophone should be considered in conjunction with the input cascades of the seismic waves receiver.

The main part. The main parameters from the documentation of geophones are analyzed and parameters for the assess of created model adequacy are selected. The analysis was carried out on an example of the model GS-ONE produced by Geospace (USA). The structure of the geophone and the principle of electromechanical analogies for equivalent circuit creating are considered. The equivalent circuit, taking into account parasitic parameters, and the measuring and calculating methods of the scheme elements are given. The influence on the work of the geophone of the shunt resistance connected to the output geophone terminals is considered. The calculation of the circuit elements according to the following method is carried out on the example of the GS-ONE geophone, the amplitude and phase frequency responses as the results of simulation in the package of NI Multisim are introduced. The simulation results are assessed according to their similarity with geophone parameters from documentation.

Conclusions. The accuracy of the given model is increased compared to known models [1,2] due to the consideration of the presence of the output geophone branch in the form of inductance coil and its parasitic parameters. This method can be used for equivalent circuit parameters calculation and for modeling in electronic simulation packages. The model does not take into account absolutely all processes in geophone, which leads to deviation in the amplitude values of amplitude frequency response to 8% and the deviation of phase frequency response to 2 degrees. However, further additions to the model will complicate its use in engineering practice and from this point of view it is not expedient.

Key words: geophone; seismic signals; equivalent circuit; simulation in SPICE packages

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Introduction

Several types of seismic waves, namely, longitudinal, transverse, and surface waves of the Rayleigh and Love propagated in the surface layer of the Earth. Any disturbance on the surface will be followed by the emergence of mixed type waves. The sources of seismic fluctuations could be registered and identified by recording the availability and energy of shear. The registration of seismic oscillations is used for the search for minerals [1], the warning about the landslides ascension [2], and in the means of perimeter protection [3]. Different accelerometers by the principle of action and by the physical effects underlying their work are used to register and evaluate the surface waves parameters [4]. There are piezoelectric accelerometers [5], MEMS accelerometers [6], inductive geosensors [7]. Due to the low cost and high sensitivity, the inductive type is

the most widely used seismometers (the geophones). A geophone is an electromechanical converter that registers the soil shear. The registration of soil movement should be carried out the relative "unmoved" ground. So as this condition is impossible, for these purposes in the geophones the inertia of the mass, suspended by the spring suspension to the device body, is used. When moving the soil, the mass retains its position in space due to the spring suspension, and the body repeats the fluctuations of the ground [8].

To transform the mechanical vibrations into electrical is used the principle of electromagnetic induction. The cylindrical coil used as a hanging mass on the suspension, inside the coil placed a permanent magnet attached to the body, which creates a radial magnetic field (Fig. 1 b). With the soil displacement, the geophone body with the magnet moves along with it while the coil stays immobile, as a result, an electric

current produced in the coil. Structurally, the geophone consists of two coils with counter winding, located in the magnetic field of a permanent magnet (Fig. 1). Such connection of coils ensures the adding of the EMF caused by the displacement of the coil and the subtraction of the EMF induced by external sources to suppress the common-mode interference.

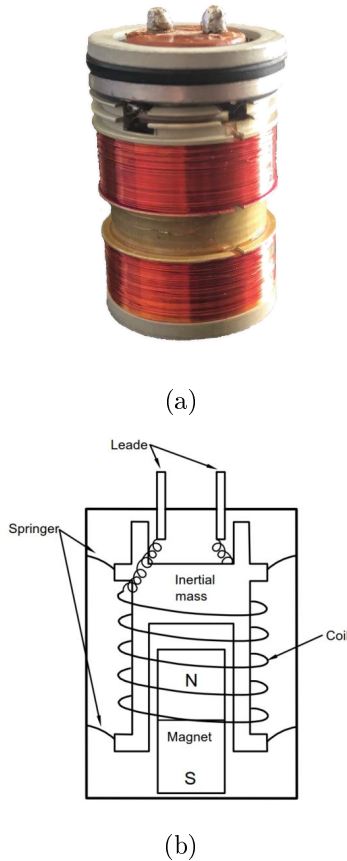


Fig. 1. a) geophone without a casing; b) simplified scheme of the geophone

In [9], were made calculations of seismograms at the geophone output. As can be seen from the materials of the publication, the following method can be used to obtain seismograms of signals suitable for the task of processing seismograms. In developing seismic receiving devices, the most significant attention paid to input amplifiers with directly connected inductive geophones. Depending on the type of seismic research it is necessary to allocate specific ranges of input frequencies. For filtration and frequency response form correction to geophone is adding additional circuits. Therefore, the work of the geophone should be considered in conjunction with the input cascades of the seismic waves receiver.

In [10], obtained an equivalent geophone circuit for simulation in SPICE packages. The given circuit is very simplified and takes into account only the presence of mechanical vibrational system, without the presence of the inductance coil for the transformation of mechanical energy into electrical. In [11], the output coil replaced by active resistance, and there is no explicit method for calculating the elements of the circuit. This study, though, provides a workable model, but it needs to refine for obtaining adequate results.

The purpose of this article is the development of a geophone equivalent circuit for simulation in SPICE packages, which combines mechanical and electrical branches, and the methodology for calculating its parameters. It allows simulating the seismic signal receiving system taking into account the influence of the geophone output elements parasitic parameters and provides an opportunity to accelerate the development of systems with its use.

1 The main material

The sensitivity and phase shift characteristics for GS-ONE geophones (Geospace Technologies production) [10] shown in Fig. 2 a, b.

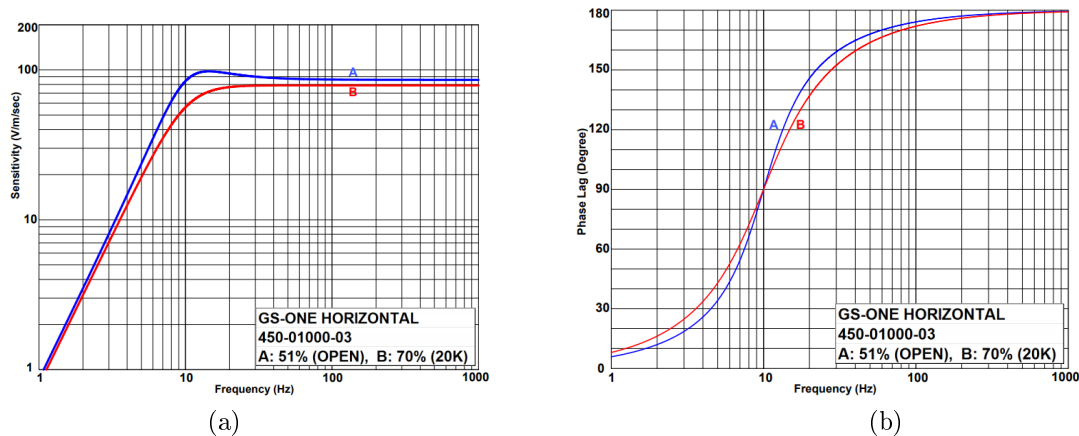


Рис. 2. a) GS-ONE geophone sensitivity; b) GS-ONE geophone phase shift

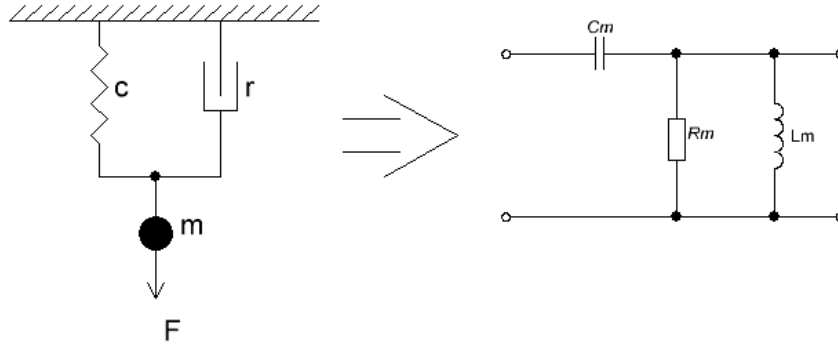


Рис. 3. Transformation the mechanical branch to an electrical one.

It should be paid particular attention to the fact that the graphs of sensitivity and phase shift of the geophone (Fig. 2 a, b) have two curves. The curve A (blue) corresponds to the sensor with the open output (without load) and curve B (red) – with the addition of output shunt resistor 20 kOm. This configuration of the sensor is optimal since it allows us to get the maximally flat amplitude frequency response. On these figures, the presence of resonance at a frequency of 10 Hz is visible. This resonance has a mechanical source and is determined by the coil mass and the spring stiffness. In designing a system with geophones, it should ensure that the resonance frequency located below the lower limit of working range. In geophones the output voltage $V(t)$ at the open output is proportional to the shear rate of the body $e(t)$:

$$e(t) = K \cdot V(t), \quad (1)$$

where K is a geophone gain coefficient. Below the resonant frequency, the output signal is proportional to the third derivative of the body shift [11].

To construct a geophone equivalent circuit, we use the principle of electromechanical analogy. It suggests the possibility of mechanical system introducing as an electronic circuit using the identity of the equations describing the behavior of these systems [12].

Description of oscillations in the electrical system:

$$C \frac{\partial u}{\partial t} + \frac{1}{R} U + \frac{1}{L} \int U dt = i. \quad (2)$$

Description of oscillations in the mechanical system:

$$m \frac{\partial v}{\partial t} + rv + \frac{1}{c} \int v dt = f. \quad (3)$$

As is seen from (??) and (??), the presentations of oscillations in the mechanical and electrical system are similar, with the exception of their coefficients: L, R, C – inductance, resistance, capacitance; m, r, c – mass, a coefficient of friction, flexibility; The functions U, v , and i, f coincide.

Based on these conditions, we will have the opportunity to consider the mechanical system in the

form of electrical with some replacements shown in Table 1.

Табл. 1 The electrical and mechanical parameters compliance

mass (m)	capacitance (C)
coefficient of friction (r)	conductance (G)
flexibility (c)	inductance (L)
velocity (v)	voltage (U)
force (f)	current (i)

We will depict the mechanical system of the geophone and the corresponding electric branch using data from Table 1 (Fig. 3), where R_m, L_m, C_m are parameters of equivalent replacement circuit of the geophone.

Since the geophone is an electromechanical converter, it is necessary to add some elements responsible for the transformation from mechanical to electrical energy in the equivalent circuit. Two coils connected in series are such constructive elements.

The gain coefficient is one of the main parameters of the geophone, working in terms of electromechanical analogies, it corresponds to the transformation magnitude of forces and velocities. The transformer T_m corresponds to the implementation of this function (Fig. 4).

Where R_k, C_k is the parasitic coil parameters, R_{sh} – shunt resistance which is added to the geophone to increase the damping rate and the uniformity of the frequency response.

Method of the equivalent circuit parameters calculation

To find the parameters of the equivalent circuit, it is necessary at first to determine all mechanical parameters of the geophone oscillating system: suspension flexibility and Q-factor. The values of the moving mass, the resonant frequency and the damping factor can be founded in the geophone documentation.

The flexibility of a spring suspension calculated according to the formula:

$$c = \frac{1}{m(2\pi)^2 f_{res}^2}, \quad (4)$$

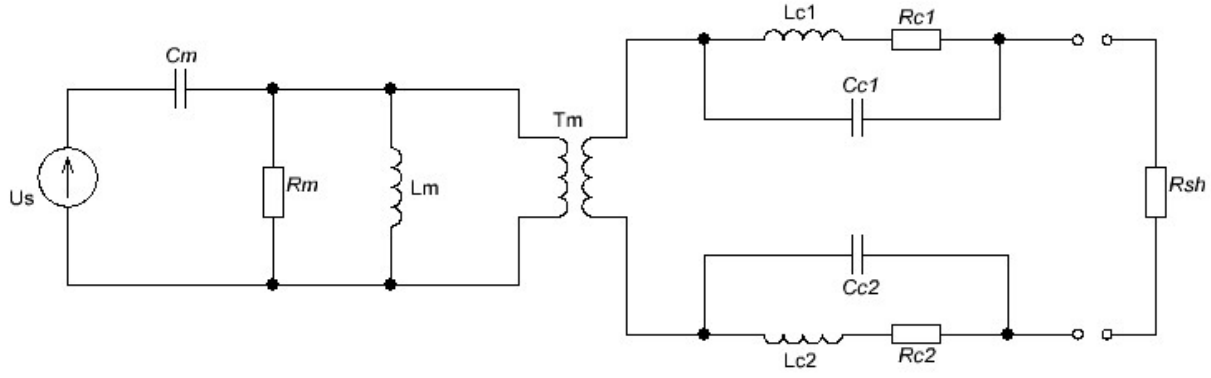


Рис. 4. Geophone equivalent circuit

where m is moving mass, f_{res} is mechanical resonant frequency.

The Q-factor of the mechanical branch can be calculated using the damping factor:

$$Q = \frac{1}{2\xi}. \quad (5)$$

For find the resistance of the mechanical branch, it is required to move from mechanical to electrical quantities following Table 1.

$$m \rightarrow C_m, \quad c \rightarrow L_m$$

The mechanical branch equivalent circuit (Fig. 3) is a parallel oscillatory circuit, so we can apply the formula for calculating the contour resistance through the Q-factor.

$$R_m = \frac{Q}{\sqrt{\frac{C_m}{L_m}}} \quad (6)$$

For voltage transformation (in a mechanical system of velocities) an ideal transformer is used with a transformation coefficient K which equals the inversed to the sensitivity of the unloaded geophone magnitude v , information on sensitivity also given in the documentation.

$$K = 1/v \quad (7)$$

For find the parameters of output branches, it is necessary to measure the values of the inductance and capacitance of the geophone coil, and it is expedient to use an RLC-meter. It should note that for real accurate measurements it is necessary to immobilize the geophone and to use the smallest possible measurement limits on the measuring device. The geophone output coils have a series connection, and they are completely identical, so it becomes possible to get their value using the following formulas.

Coil resistances:

$$R_{c1} = R_{c2} = \frac{R_c}{2}. \quad (8)$$

Coil inductances:

$$L_{c1} = L_{c2} = \frac{L_c}{2}. \quad (9)$$

Coil capacitances:

$$C_{c1} = C_{c2} = 2C_c. \quad (10)$$

2 The experimental part

The initial data for equivalent circuit parameters calculations given on the example of two models of geophones, GS-ONE, and GS11-D (Table 2):

Табл. 2 Data for replacement circuit parameters calculations

Parameter	GS-ONE	GS11-D
m – moving mass	14 g	23.6 g
f_{res} – resonant frequency	10 Hz	4,5 Hz
ξ – damping factor (without shunt)	0,48-0,54	0,34
v – sensitivity (without shunt)	85,8 V/m/s	32 V/m/s
ξ – damping factor (with a shunt)	0,7	0,7
v – sensitivity (with a shunt)	78,7 V/m/s	26,18 V/m/s
R_k – coil resistance	1800 Ohm	380 Ohm

We perform calculations for geophones GS - ONE:

1) The flexibility of the spring suspension: x

$$c = \frac{1}{m(2\pi)^2 f_{res}^2} = 0.018 \text{ m/H}$$

2) Q-factor of the mechanical branch:

$$Q = \frac{1}{2\xi} = 0,98$$

3) Then it is necessary to make a transformation from mechanical values to electrical ones:

$$m = 0.014 \text{ kg} \rightarrow C_m = 0.014 \text{ F}$$

$$c = 0.018^m / H \rightarrow L_m = 0.018 \text{ H}$$

3) The value R_m we will find using values of quality Q and L_m, C_m :

$$R_m = \frac{Q}{\sqrt{\frac{C_m}{L_m}}} = 0.882 \text{ Ohm}$$

4) Transformation coefficient of T_m :

$$K = 1/v = \frac{1}{85,8}$$

5) Coil resistances:

$$R_{c1} = R_{c2} = \frac{R_c}{2} = 900 \text{ Ohm}$$

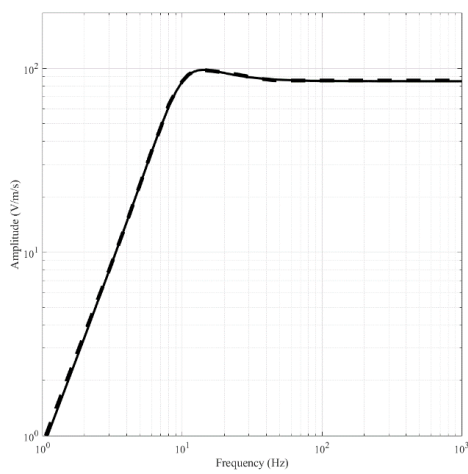
6) Coil inductances:

$$L_{c1} = L_{c2} = \frac{L_c}{2} = 70 \text{ mH}$$

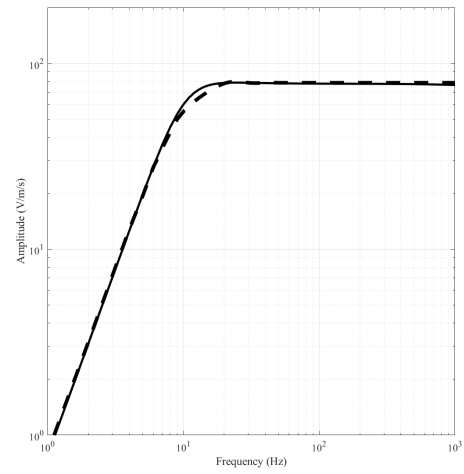
7) Coil capacitances:

$$C_{c1} = C_{c2} = 2C_c = 100 \text{ mF}$$

The amplitude frequency response of geophone without load shows in Fig. 5 a, and amplitude frequency response of geophone with the load of shunting resistor 20 kOhm (according to the manufacturer's recommendation) presented in Fig. 5 b.

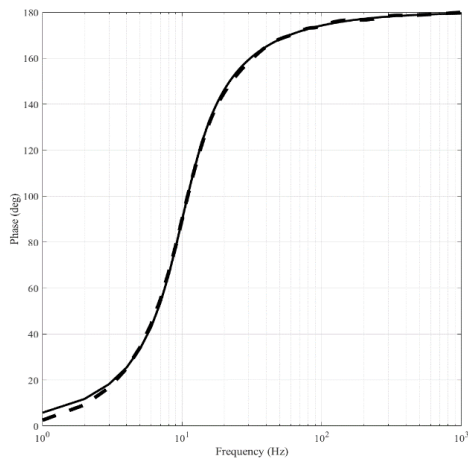


(a)

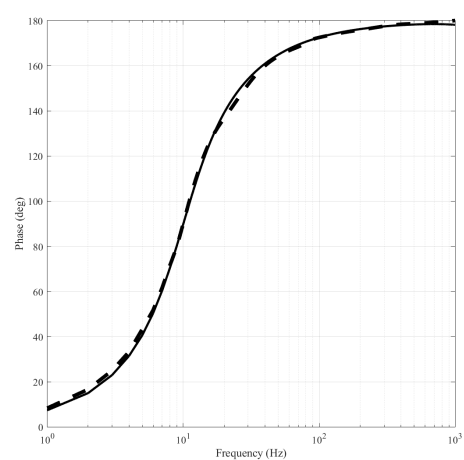


(b)

Рис. 5. The comparison of geophone characteristics and simulation results (dashed line – data from the datasheet of the geophone, solid line – results): a) amplitude frequency response of geophone without load; b) amplitude frequency response of geophone with a load



(a)



(b)

Рис. 6. The comparison of geophone characteristics and simulation results (dashed line – data from the datasheet of the geophone, solid line – results): a) phase frequency response of geophone without load; b) phase frequency response of geophone with the load

The phase frequency response of geophone without load presented in Fig. 6 a, and the phase frequency response of geophone with a load of shunting resistor 20 kOhm presented in Fig. 6 b.

As is seen, the coincidence of experimental data and data presented in the documentation is entirely satisfactory. The maximum deviation of the geophone amplitude frequency response is equal to 8%. The maximum variation of the geophone phase frequency response is equal to 2 degrees. As to the position of the resonant frequencies of the geophone, they coincide entirely.

Conclusions

1. The calculation method for the equivalent scheme of geophone on the basis of the electromechanical analogies principle is given. The order of measurement and calculation of model elements is shown. The calculation of the circuit elements according to the following method is carried out on the example of the GS-ONE geophone, the amplitude and phase frequency responses as the results of simulation in the package of NI Multisim are introduced.
2. The accuracy of the given model is increased compared to known models [13, 14] due to the consideration of the presence of the output geophone branch in the form of inductance coil and its parasitic parameters.
3. This method can be used for equivalent circuit parameters calculation and for modeling in electronic simulation packages and also can be recommended for engineering practice use.
4. The model does not take into account absolutely all processes in geophone, which leads to deviation in the amplitude values of amplitude frequency response to 8% and the deviation of phase frequency response to 2 degrees. However, further additions to the model will complicate its use in engineering practice and from this point of view it is not expedient.

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Схема заміщення геофона для задач моделювання в SPICE пакетах

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Вступ. У сучасній техніці при реєстрації сейсмічних сигналів у якості давача найбільше поширення отримали індуктивні сейсмореймачі (геофони). При розробці апаратури прийому сейсмічних сигналів найбільшу увагу приділяють вхідним підсилювачам, до яких безпосередньо підключається геофон. Так як, в залежності від типу сейсмічного дослідження необхідно виділяти певні діапазони вхідних частот до геофонів додаються ланки фільтрації і корекції форми АЧХ та ФЧХ геофону. Тому робота геофону повинна розглядатися в комплексі з вхідними каскадами приймача сейсмічних хвиль.

Основна частина. Було проаналізовано основні параметри геофонів, що наводяться у документації на виріб, виділенні основні параметри, за якими буде оцінюватися адекватність створеної моделі. Аналіз проводився на прикладі моделі GS-ONE виробництва компанії Geospace (USA). Розглянуто будову геофона та принцип електромеханічних аналогій для створення схеми заміщення. Приведена схема заміщення з урахуванням

паразитних параметрів та методика вимірювання і розрахунку елементів схеми. Розглянуто вплив шунтуючого опору, підключеного до вихідних клем геофона, на роботу геофона. Проведено розрахунок елементів схеми по наведеній методиці на прикладі геофона GS-ONE, представлено графіки АЧХ та ФЧХ, отриманні в результаті моделювання у пакеті NI Multisim. Оцінено результати моделювання за їх відповідністю до аналогічних, наведених у документації на геофон.

Висновки. У даній моделі підвищена точність у порівнянні з відомими моделями [1,2] завдяки врахуванню наявності вихідної ланки геофона у вигляді котушки індуктивності та її паразитних параметрів. Розроблена методика може застосовуватися для розрахунку параметрів схеми заміщення геофона та використання в пакетах моделювання електронних схем. Модель не враховує абсолютно усіх процесів, що проходять у геофоні, що призводить до відхилення в показниках амплітуди у АЧХ перетворювача до 8%, а відхилення ФЧХ до 2-х градусів. Проте подальше доповнення моделі ускладнить її використання в інженерній практиці і з цієї точки зору не є доцільним.

Ключові слова: геофон; сейсмічні сигнали; еквівалентна схема; моделювання в SPICE пакетах

Схема замещения геофона для задач моделирования в SPICE пакетах

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Одним из направлений современной техники является аппаратура регистрации сейсмических сигналов. В качестве датчиков таких сигналов используют индуктивные сейсмоприемники – геофоны. При разработке аппаратуры приема сейсмических сигналов наибольшее внимание уделяется входным усилителям. Работа геофона рассматривается в комплексе с входными каскадами приемника сейсмических волн. Была предложена схема замещения геофона для учета влияния паразитных параметров для получения возможности моделирования в SPICE пакетах. Приведенная схема дает возможность ускорить разработку системы регистрации. Проведена проверка адекватности полученной схемы путем проверки сходимости экспериментальных данных и данных, приведенных в документации на геофон.

Ключевые слова: геофон; сейсмические сигналы; эквивалентная схема; моделирование в SPICE пакетах