Corresponding Member of the Academy of Sciences of the USSR K. B. Karandeev and L. Ya. Mizyuk

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Abstract

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GEOPHYSICS

Corresponding Member of the Academy of Sciences of the USSR K. B. Karandeev and L. Ya. Mizyuk

ON THE PRINCIPLES OF DESIGNING GEOPHYSICAL APPARATUS FOR ELECTRICAL PROSPECTING BY THE METHOD OF RECORDING FREQUENCY CHARACTERISTICS

To obtain sufficiently complete information about a geoelectrical section, multifrequency electrical prospecting is used [1,2]. Existing apparatus provides for measuring the amplitude and phase, or the active and reactive components of the signal, successively at a number of fixed frequencies lying in the range approximately from 25–40 Hz to 7–12 kHz.

Measurements in multifrequency electrical prospecting essentially reduce to recording, point by point, the frequency amplitude-phase characteristics or only the amplitude characteristics of a certain four-terminal network (see Fig. 1), whose input terminals *ab* are the terminals of the exciter of the electromagnetic field (an ungrounded loop, a grounded loop at the ends of a long cable, a magnetic dipole-frame), and whose output terminals *cd* are the terminals of a receiving frame or electric dipole. The parameters of such a four-terminal network depend on the electrical properties of the strata of rocks composing the section near the observation point.

Successive measurements at separate frequencies make it possible to use highly selective amplifiers in multifrequency prospecting. This provides high noise immunity of the apparatus and makes it possible to work with very weak signals, in particular at a considerable distance from the field sources, when the normal field almost does not hinder the manifestation of anomalous signals.

However, the sequence of measurements at all operating frequencies is a substantial drawback of multifrequency electrical prospecting, not only ruling out the possibility of work in motion, but also sharply reducing the productivity of geophysical surveying.

Low-frequency electrical prospecting by the field-transient method, successfully tested in the ground version in 1959 by Yu. V. Yakubovsky, is free of this drawback. In the field-transient method the same four-terminal network is studied by its transient characteristics, which, unlike frequency characteristics, are

Fig. 1

Figure 1: Fig. 1

recorded in one operation*. For this purpose, in the frame that excites the field, a current step is produced—for example, its very rapid switching-off (fractions of a millisecond)**—and the curve of the transient process is recorded by means of the receiving frame. The normal field is absent in this case, and therefore the anomalous effects appear in pure form, which is a serious advantage of the method.

Along with such important merits, the method of recording transient characteristics also has a substantial drawback—low noise immunity, since in order to obtain the curve of the transient process it is necessary to pass a broad frequency spectrum and therefore at the output of the receiving frame

* The difference between the methods of recording frequency and transient characteristics consists essentially in the fact that in the first of them signals of different frequencies act on the object under study successively, and in the second simultaneously.

** It should be noted that obtaining in the generator frame or loop a sufficiently powerful current pulse with a steep front presents considerable technical difficulties.

it is necessary to include a wide-band amplifier. This limits the practical possibilities of implementing the method, especially in airborne electrical prospecting, where, owing to the vibration of an airplane or helicopter, the noise level is very high. By using the principles of signal accumulation, one can weaken the action of random factors and thereby increase the noise immunity of the circuit. In this case, however, one of the important advantages of the method is lost—high productivity.

The question arises whether it is possible to combine the advantages of the transient-characteristics method (high productivity) and of the multifrequency electrical prospecting method (high noise immunity).

Fig. 1

The well-known method of recording frequency characteristics with the aid of generators of rocking frequency (sweep generators) could substantially increase the productivity of multifrequency electrical prospecting. However, in its usual version it is necessary to use a wide-band amplifier. To obtain high noise immunity in such a method of recording frequency characteristics, it would be necessary, simultaneously with the change in the frequency of the exciting field, also to change the tuning of the selective amplifier connected at the output of the receiving loop. With a sufficiently rapid change in frequency, such a procedure would make it possible to carry out multifrequency electrical prospecting from moving objects, in particular from an airplane or helicopter.

Periodic change in the frequency of the exciting field in time does not cause technical difficulties. It is evidently considerably more difficult to provide tracking retuning of the selective amplifier. With its high selectivity, even a small detuning of the amplifier can introduce large errors into the frequency (especially phase) characteristics of the object.

The usual methods of retuning a selective amplifier over a frequency range (changing the capacitances of resonant circuits, changing photoresistances in quasi-resonant *RC*-amplifiers, controlling a reactance tube, applying the heterodyne method of signal reception with electrical control of the heterodyne frequency, etc.) require that the signal controlling the frequency retuning of the generator and amplifier have one and the same form. This requirement is not easy to satisfy, since the generator and amplifier may be separated by a large distance (from several kilometers in a grounded-loop circuit to several tens of kilometers in airborne electrical prospecting). When transmitting the control signal over a special communication channel, very stringent requirements would have to be imposed on the system for maintaining exact synchronism and identity of the form of the control voltages.

The problem of creating a highly selective amplifier with tracking tuning, varying synchronously with the change in the frequency of the exciting field, is considerably simplified if the measuring circuit is based on

principle of synchronous rectification. If the reference (commutating) signal significantly exceeds the interference, then the controlled rectifier (synchronous detector), together with the low-pass filter connected at its output, has, as is known (3, 4), very high selectivity. At the same time it is automatically retuned as the frequency of the reference voltage changes and therefore does not require additional control signals of special form. For $U_o \gg U_c$, the rectified voltage at the output of the controlled rectifier is proportional to the active component $U_c \cos \varphi$, where φ is the phase angle between the signal U_c and the reference voltage U_o.

To obtain the frequency response in a Cartesian coordinate system, it would be sufficient to determine the dependence of the active and reactive components on frequency, i.e., to use two controlled rectifiers in which the reference voltages must be shifted relative to one another by 90°. To obtain the frequency-phase response in a polar coordinate system, as is usually done, it is necessary to carry out a coordinate transformation. This can be done by means of a circuit operating on the principle of frequency conversion. If the DC voltages corresponding to the active and reactive components of the signal are converted into AC voltages of frequency Ω in such a way that there is a phase shift of $\pi/2$ between them, then, by summing the signals after the converters, we obtain a voltage of frequency Ω, the modulus and phase angle of which exactly correspond to the vector of the measured signal. Applying this principle to the construction of measuring apparatus, one can draw up the block diagram of a device for aerial electrical prospecting by the method of recording frequency characteristics, shown in Fig. 1.

The loop P_1, which excites the electromagnetic field, is supplied from a sinusoidal audio-frequency voltage generator ZG through a power amplifier UM. The frequency of the audio generator is varied periodically in time according to a linear law by means of the control circuit US from $f_{\min}$ to $f_{\max}$. The voltage taken from the receiving loop P_2, after preliminary amplification by the broadband amplifier U, is fed to two controlled rectifiers UV_1 and UV_2, which form the basis of the measuring circuit. The reference voltage required for operation of the rectifiers is supplied to the measuring device through the reference-signal transmission channel KOS directly from the ZG. The reference-voltage transmission channel may be either a cable line or radio communication. After demodulation, which is necessary when radio communication is used, the reference voltage is applied to the quadrature phase splitter KFR_1, which gives at its output two voltages shifted with respect to each other by 90°. As quadrature splitters operating in a frequency range, use may be made, for example, of circuits with a logarithmic dependence of phase on frequency (5), phase-shifting circuits of the tracking type, etc. After two-sided limiting in the limiting amplifiers UO_1 and UO_2, introduced to eliminate the influence of variations in the level of the reference signal, the voltages U_o and jU_o are applied to UV_1 and UV_2.

The DC voltages at the output of the low-pass filters $FNCh_1$ and $FNCh_2$ are proportional respectively to the active and reactive components of the signal. If the reference voltages significantly exceed the interference, which is easy to achieve, then the selectivity of the controlled rectifiers with single-link RC circuits in the $FNCh$ is equivalent to the selectivity of resonant circuits with a high quality factor determined by the time constant of the $FNCh_i$ circuits. By increasing the time constants of the $FNCh$, one can ensure a large equivalent quality factor and, consequently, high noise immunity of the circuit.

The DC voltages after $FNCh_1$ and $FNCh_2$ are converted by means of the converters Pr_1 and Pr_2 into AC voltages of fixed frequency Ω. In order that the AC voltages at the output of the conver–

[[unclear: beginning of word]]···were located in quadrature from the auxiliary generator $I(\Omega)$, through the quadrature phase shifter KFR_2, to Pr_1 and Pr_2, reference voltages U_o and jU_o are supplied. The alternating voltages, fed to the input of the summing circuit CC, with frequency Ω, proportional to the active and reactive components of the signal and shifted in phase relative to one another by 90°, give at the output of CC the complete vector, whose modulus is proportional to the modulus of the measured signal, while the phase angle relative to U_o is equal to the phase angle of the signal relative to U_o. After amplification by a selective amplifier $\varphi(\Omega)$, the measured signal is supplied to the amplitude A and phase φ recorders.

If the sweep speed (paper motion) of the voltmeter A and the phase meter φ is coordinated with the rate of change of the frequency of ZG, then, as the latter is varied from $f_{\min}$ to $f_{\max}$, the amplitude-frequency and phase-frequency characteristics of the geo-electrical section under study will be recorded. By using a faster-acting device for recording, for example an electronic oscilloscope with a photographic attachment that records each of the successive cycles of frequency change on separate frames, it is possible to obtain frequency characteristics in motion, in particular in airborne electrical prospecting.

Experimental verification has shown that the circuit described, while ensuring absolutely rigorous synchronism between the frequencies of the excited field and the tuning of the measuring device, has high selectivity, does not require a control signal of special form, and therefore can serve as the basis for high-productivity and noise-resistant equipment for electrical prospecting by the method of taking frequency characteristics.

Institute of Automation and Electrometry
Siberian Branch of the Academy of Sciences of the USSR

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Note: Figure translations are in progress. See original paper for figures.