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Calculation of the Parameters of a Broadband Active Magnetic Antenna*

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A method of calculating the parameters of a broadband active magnetic antenna with field feedback that make it possible to obtain a minimum sensitivity threshold level in a given frequency band is considered and the antenna amplifier requirements that ensure stability are determined.

One method of designing magnetic antennas that enable one to obtain a frequency-independent conversion factor G_0 over a broad frequency band with a low sensitivity threshold H_t is to employ field feedback.

The purpose of this paper is *to derive refined recommendations for designing such antennas which contain an amplifier with a complex frequency-dependent gain* $\dot{k}_U = k_U e^{-i\varphi}$.

The equivalent circuit of the antenna is shown in the figure, where MR is the magnetic receiver which converts the magnetic field energy at the antenna into an electrical signal.

It follows from this circuit that the antenna conversion factor will be

$$G = -i\omega\bar{\tau}_1 \dot{k}_U G_0 / J(\omega), \tag{1}$$

where $G_0 = Mn_1(-1)^p/\tau_1$; $J(\omega) = 1 - \omega^2/\omega_r^2 - \omega\bar{\tau}_1\dot{k}_U + i\omega L_1/R_{in} + \bar{Y}_{in}R_e$; $R_e = r_1 + R_{fb}\omega^2\tau_1^2$; M is the specific magnetic moment of the magnetic receiver; MR; $\bar{\tau}_1 = \tau_1 \exp(i \arg \tau_1) = L_1\dot{k}_c/k_T(r_2 + R_{fb} = i\omega L_2)$; $k_c = k_c \exp(ip\pi)$ is the gain between the primary winding of the magnetic receiver (n_1 turns) and having n_2 turns of the feedback winding ($p = 0$ or 1 depending on the relative phasing of the windings); $k_T = n_1/n_2$; $\bar{Y}_{in} = i\omega C_{in} + 1/R_{in}$ is the input admittance of the amplifier; $\omega r^{-2} = L_1C$; $C = C_1 + C_{in}$.

It is possible to achieve a frequency-independent conversion factor by selecting appropriate values of k_U, R_{fb} and k_T. In this case it is usual to proceed from the acceptable nonuniformity α_n of the conversion factor at the low frequency of the operating frequency band, which in this case we treat as the maximum permissible value [1, 2]. As a result, we obtain the inequality

$$\frac{R_{fb}k_T}{k_c} \le \omega_n L_1 k_U \left(\sqrt{A^2 - \left(1 - \frac{1}{\alpha_n^2}\right)\left(1 - \frac{\omega_n^2}{\omega_r^2}\right)} + A \right) \Big/ \left(1 - \frac{\omega_n^2}{\omega_r^2}\right) \tag{2}$$

($A = Cr_1 \cos\varphi(\omega_n) + (1 - \omega_n^2/\omega_r^2)\sin\varphi(\omega_n)$) which only in a special case ($\varphi(\omega_n) = 0$) will be identical with the expression given in [1, 2].

The condition limiting the decrease of the left-hand side of Eq. (2) is the need for the resulting system to be stable under feedback. To analyze the feedback, let us write Eq. (1) in the form

$$G = G_0 W(i\omega)/(1 + W(i\omega)) ,$$

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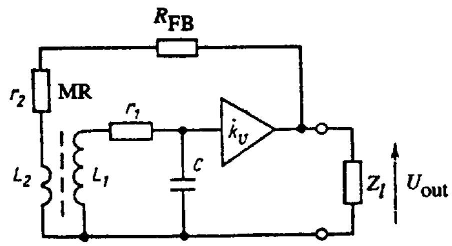

where $W(i\omega) = -i\omega\bar{\tau}_1\dot{k}_U/(1-\frac{\omega^2}{\omega_r^2}+i\omega\frac{L_1}{R_{in}}+\bar{Y}R_e)$, and for $|i\omega C| \gg 1/R_{in}$ arg $W(i\omega) \approx -\frac{\pi}{2}-\varphi-\text{arctg}\frac{R_e\omega C}{1-\omega^2/\omega_r^2}+\pi p$.

In accordance with Nyquists' criterion, the stability of the system will depend on the behavior of the holograph of $W(i\omega)$ in the complex plane (1, i) which is largely determined by the change in the phase characteristic of the amplifier.

The sensitivity threshold of this antenna can be determined, as in [3], by the functional

$$H_d = \sqrt{\int_{f_l}^{f_u} P_n \, df} \, / G_0 \,, \tag{3}$$

where P_n is the spectral noise power density at the antenna output whose source includes the thermal noise of the resistance of the antenna coil as well as the resistance R_{fb} and the noise introduced by the amplifier.

If such noise is taken into account by introducing into the amplifier circuit correlated noise current and voltage sources with spectral power densities i_n^2 and e_n^2, respectively [4], then

$$P_n = k_U^2 Y(\omega)/|J(\omega)|^2 \,, \tag{4}$$

where $Y(\omega)=4kTR_e+e_n^2((1-\frac{\omega^2}{\omega_{r_0}^2})^2+\ \omega^2R_e^2C_1^2)+i_n^2(R_e^2+\omega^2L_1^2)+2e_n\,i_n\,R_e\left[((1-\frac{\omega^2}{\omega_{r_0}^2})\ -\ i\omega C_1R_e)(R_e+i\omega L_1)\gamma\right]$,

k is Boltzmann's constant; T [K] is the absolute temperature, $\omega_{r0}^{-2} = L_1C_1$; and γ is the correlation coefficient between e_n and i_n [4].

It is possible to obtain an approximate estimate of Eq. (3) starting from the fact that the denominator in Eq. (4) $J(i\omega) = -i\omega\bar{\tau}_1\dot{k}_U$ in the operating frequency range. Then

$$H_{appx} \approx \sqrt{\int_{f_l}^{f_u} \frac{Y(\omega)}{\omega^2} \, df} \, / Mn_1 \,,$$

and, in the special case when R_{fb} is so large that the inequality

$$R_{fb} \gg \omega^2 L_1^2 k_{fb}^2 / k_T^2 \tag{5}$$

holds, H_{appx} in Eq. (3) will be independent of R_{fb}.

This enables us to separate the processes of selecting the parameters of the magnetic receiver, the amplifier, and the feedback circuit. In particular, for an amplifier having given noise parameters, the first stage may include selecting the number of windings of the magnetic receiver so as to minimize functional (3). The limiting factor in this case will be the natural resonant frequency ω_r which must obviously exceed 0.7-0.8 ω_u, since otherwise the second and subsequent resonance will appear in the passband and will distort the linearity of the AFR $G(f)$.

From the number of windings obtained we can determine M, L_1, while the multiplier $R_{fb}k_Tk_c^{-1}$, can be determined from the given value of G_0, while Eq. (5) can be employed to determine k_T, R_{fb}, and, consequently, n_2.

The required amplifier gain at low frequencies can be found from Eq. (2). The stability conditions determine the requirements imposed on amplifier nonuniformity and the phase characteristic outside the frequency band.

Conclusion. When inequality (5) cannot be satisfied, the algorithm given above cannot be used In this case, the calculation can be carried out by means of successive approximations, i.e., by a successive inspection of several versions. As our first approximation we can take the number of turns that enables us, as in [5], to obtain $\omega L_1 = e_{in} i_{in}^{-1}$ at a frequency $\omega = \omega_0 = \sqrt{\omega_u \omega_l}$.

REFERENCES

1. Vakul'skiy, A.A. et al. Apparatura dlya aerogeofizicheskoy razvedki magnitnym i elektromagnitnym informatsionnymi kanalami (Airborne Geophysical Prospecting Equipment Employing Magnetic and Electromagnetic Data Channels), Naukova Dumka Press, Kiev, 1985.
2. Gontar, I.M., L. Ya. Mizyuk and R.V. Prots'. Otbor i Peredacha Informatsii, No. 68, 1983.
3. Panin, V.V. and B.M. Stepanov. Izmereniye impul'snykh magnitnykh i elektricheskikh poley (Measurement of Pulsed Magnetic and Electric Fields), Energoatomizdat Press, Moscow, 1987.
4. Gromov, V.I. and A. Ye. Mioshinskiy. Otbor i Peredacha Informatsii, No. 71, 1985.
5. Shcherbakov, V.A. Issledovaniya v oblasti metrologii slabykh peremennykh magnitnykh i elektricheskikh poley (Metrological Studies of Weak Variable Magnetic and Electric Fields), Trudy VNIIM im D.I. Mendeleyev, 1985.