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PRECISE HIGH Q-FACTOR DOUBLE LOOP SELF-ADAPTING AMPLIFIER

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Abstract: High precision, high Q-factor and small phase shift of output with input voltages in the case of an angular frequency change within broad limits is described in the paper. New tuned amplifier is grounded on the self-adapting principle of operation. Dynamics analysis of a double loop, non-linear modulating system is grounded on the usage of the generalized method of linearization by the describing function.
Keywords: tuned amplifier, self-adapting system, method of linearization

1 INTRODUCTION

Single tuned, double tuned and band pass amplifiers are widespread in radio engineering, automatic control, communication etc. The main requirement to these amplifiers is provision a high Q-factor. Special demands are put forward in measurement and instrumentation. These demands are small settling time and static multiplication error. We cannot use a negative feedback system concept for minimization a multiplication error. A non-homogenous G-plan is grasped as a frequency error, which is reduced in 1+ $k\beta$ times, where k-is a gain of amplifier, β is negative feedback factor. This fact causes extension of a bandwidth of an amplitude-frequency band and reducing of Q-factor. Only one way exist for provision simultaneously a high Q-factor and a small multiplication error: this way is grounded on borrowed from cybernetic engineering the self-adapting method.

2 PRINCIPLE OF OPERATION

The mechanism of acting of a double loop self-adapting tuned amplifier is grounded on the property of a resonance and some quasi-resonance amplifiers: a phase-frequency locus (P-plan) cross abscissa axes at resonance frequency [1]. We measure a phase shift of output with input voltages and use this phase shift for control a resonance or quasi-resonance network to obtain the zero phase shift. The operation of control may be carried out in analog or digital form by change of parameters of a resonance network's elements: a capacitor or an inductor.

Zero phase shift of output with input voltages provides simplification the problem of an amplitude error minimization. We may use an ordinary subtractor for comparison input with the portion of output signals. The last is an output signal of precise voltage divider with an attenuation factor equals to the amplifier's gain in initial conditions. So, we use two loops: the first for a phase shift minimization, and the second for minimization a multiplication error.

3 DYNAMICS AND STATIC ANALYSIS

It is impossible to use the standard method of conversion of a multi-loop system to a single-loop configuration: a double loop amplifier is non-linear, non-stationary system. There is only one way for dynamic analysis: to consider each loop as independent. It is possible, if a greater time constant of the loop for correction a phase shift is greater in many times (minimum in 10 times) than a same parameter for the second loop that provide correction of an amplitude error. It is reasonable to use for dynamics analysis in both cases the generalized method of linearization by the describing function.
Application of the Generalized Method of Linearization by the Describing Function GMLDF is grounded on the following assumptions.

1. We consider envelopes of signals instead real signals in a close loop system.

$$A(t)\sin(\omega t+\varphi) \leftrightarrow A(t) \quad (1)$$

This assumption permits to regard such essentially non-linear elements as amplitude and phase detectors or rectifier, as linear units. Moreover, this fact permits to reduce in two times the order of resonance network's differential equation by the usage the concept of shorten transfer functions.

2. A Controlled Element CE with a transfer function y=(k'+zk")x we substitute by cascade connected an Adder ADD and a Non-Linear Element NE that may be described by the 2nd power polynomial:

$$y=k(x+z+a)^2 \approx 2kax+2kzx, \text{ if } k'=2ka,\ k''=2k. \qquad (2)$$

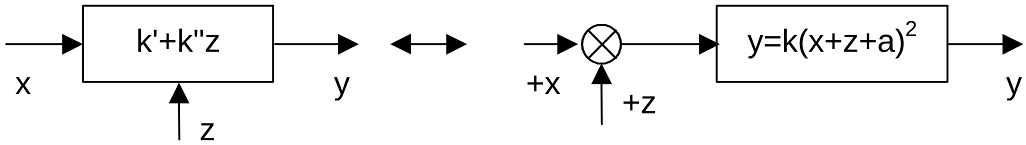

Figure 1.

3. An automatically controlled switch we substitute by an ordinary subtractor

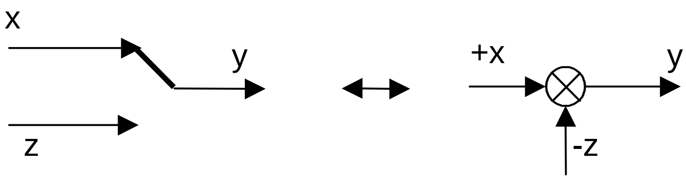

Figure 2.

A self-adapting system's block diagram after transformation has the following configuration Fig.3

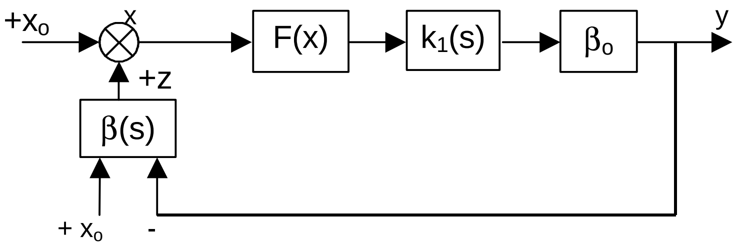

Figure 3.

Let's consider two cases: a non-linear element transfer function is symmetrical and non-symmetrical with respect to the origin of coordinate.
Case 1.

$y=F(x)$, (3)

$z=\beta(s)[x_o-yk_1(s)]$, (4)

$x=x_o+z$, (5)

$k_1(s)=k(s)\beta_o$, (6)

$x=x_o+\beta(s)x_o-yk_1(s)\beta(s)=x_o+\beta(s)x_o-F(x)k_1(s)\beta(s)$, (7)

$x+k_1(s)\beta(s)F(x)=[1+\beta(s)]x_o$, (8)

If $F(x)=k_{max}x$, $x+k_1(s)\beta(s)\, k_{max}x=0$

$a_n s^n + a_{n-1}s^{n-1} + \ldots + a_o=0$, the Routh - Gurwitz test may be used.

If $F(x)= q(A)x$, $q=\frac{1}{2\pi}\int_0^{2\pi} F(A\sin\psi)d\psi$, (9)

$s=j\omega$, (10)

$a_n (j\omega)^n + a_{n-1} (j\omega)^{n-1} + \ldots + a_o=0$, $a_o = k_{max}$ (11)

$Re(A,\omega)+jIm(A,\omega)=-1$, (12)

$Re(A,\omega)=-1$, $Im(A,\omega)=0$, (13)

and we determine A, ω. If A>0 a system is unstable and it is possible to observe stable oscillations. If A <0, a system is stable, a=0 is the boundary of stability. If ω>0, we have a periodical term in signals, if ω<0, we have monotonic convergent process.

Suppose now that asymmetry is caused by an input signal with the constant amplitude x_0. As we consider envelopes of signals, this means that applied an input signal cause appearance of direct components of all signals in the closed-loop system. A factor of linrarization now is a function of A and x_0 (case 2). A direct component of a non-linear element's input signal we obtain in result of solution algebraic equations for static: s=0. The next order of operations is repeated.

Let's go to consideration a static equation for **the loop for correction a phase shift.** We shall consider two modifications: proportional and proportional + integral feedback control system.

Proportional Feedback Control System. The block diagram is shown in Fig. 4 and consists of the forward branch and the backward branch. The forward branch includes a tuned amplifier 1 with controlled phase sift of output with input voltages. A phase shift, strictly say, is parameter of sinusoidal signals, and cannot be used for transient. The resonance amplifier may be considered as second order element with respect to immediate signals, or as a first order operator block with respect to envelopes of these signals, and as a non-inertial operator block with respect to signal that change capacitance, or inductance. More correct is to add a time delete, or first order operator block, but a time constant, in majority cases, is negligible in comparison of low frequency filter's time constant.

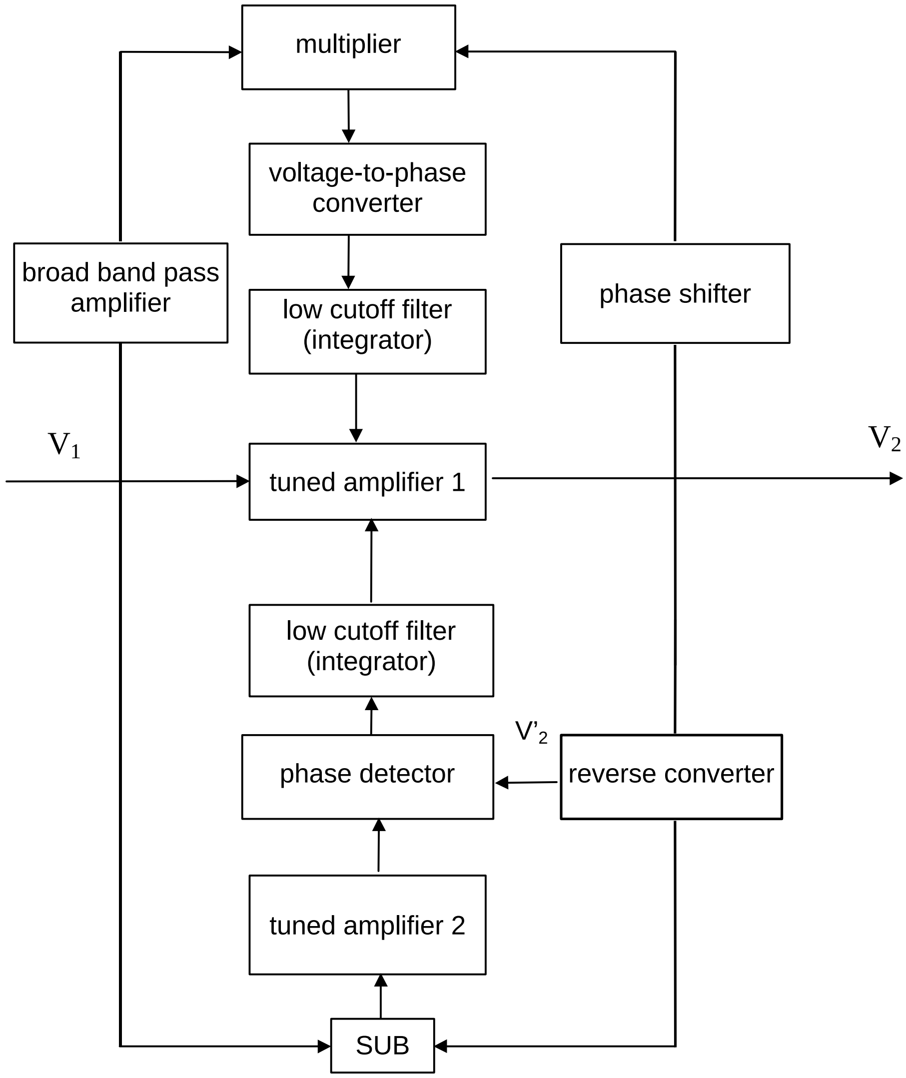

Figure 4.

The correcting circuit is a phase-meter. One possible modification of a phase-meter is represented in Fig. 5. The product of two sinusoidal signals is proportional to cosine of a phase shift between these signals. If one signal is sifted by phase shifter on the angle $\pi/2$, the product is proportional to sine of this angle, or, for small angles, directly proportional to a phase angle. The correcting circuit consists of a Broad Band Pass Amplifier BBA, a $\pi/2$-Phase Shifter PS, a Multiplier M, a Voltage-to-Phase Converter VPHC that converts a direct component DC of a product to a signal, which control parameter of a resonance network of a tuned amplifier, and change a phase shift. This signal acts via a low frequency filter, or an integrator. A structural block diagram of the loop for correction a phase error is shown in Fig. 5.

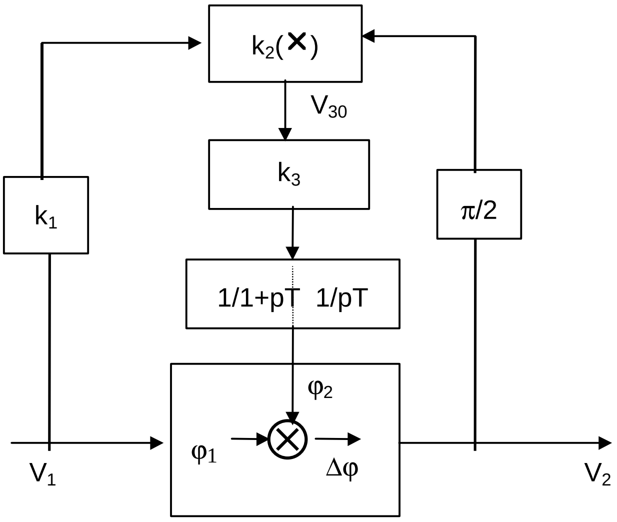

Figure 5.

Mathematical description of processes in the loop for correction a phase error is:

$$\Delta\varphi = \varphi_1 - \varphi_2,$$

$$\varphi_1 = 2Q\frac{\Delta\omega}{\omega_0}.$$

$$V_3 = k_1 k_2 V_1 V_2 e^{+j\pi/2},$$

$$V_2 = k' V_1,$$

$$\varphi_2 = k_3 V_{30}. \qquad (14)$$

An output voltage of multiplier equals:

$$V_3 = k_1 k_2 V_{m1}\cos(w_0 + \Delta w)t \times V_{m2}\cos[(w_0 + \Delta w)t + \Delta j + \frac{p}{2}] =$$
$$= \frac{k_1 k_2 V_{m1} V_{m2}}{2}\left\{\cos(\Delta j + \frac{p}{2}) + \cos[(w_0 + \Delta w)t + \Delta j + \frac{p}{2}]\right\} \qquad (15)$$

A direct component of this voltage and a static equation is:

$$V_{30} = k_1 k_2 k' V_1^2 \sin\Delta j \approx k_1 k_2 k' V_1^2 \Delta j,$$

$$j_2 = k_3 V_{30} = k_1 k_2 k' V_1^2 \Delta j,$$

$$\Delta j = 2Q\frac{\Delta w}{w_0} - k_1 k_2 k' V_1^2 \Delta j, \qquad (16)$$

$$\Delta j = \frac{2Q\frac{\Delta w}{w_0}}{1 + k_1 k_2 k' V_1^2}.$$

The last formula illustrates that a phase error, caused by an input signal’s frequency instability, is inversely proportional to the correcting circuit’s gain, and may be very small even in the case of a frequency variation within broad limits.

Proportional + Integral Feedback Control System. This modification of the loop for correction a phase error provides a static error theoretically equals to zero by the usage of an integrator. Mathematical description is following:

$$\varphi_2 = \frac{V_{30}k_3}{p}, \qquad \frac{d\varphi_2}{dt} = V_{30}k_3, \qquad \varphi_2 = V_{30}k_3 t$$
$$\Delta\varphi = \frac{2Q\dfrac{\Delta\omega}{\omega_0}}{1 + k_1 k_2 k_3 k' V_1^2 t}. \qquad (17)$$

In static t→∞, Δφ→0.

The Loop for correction an amplitude error has two standard modifications Fig. 6 and Fig. 7. Static equations and multiplication errors have standard form.

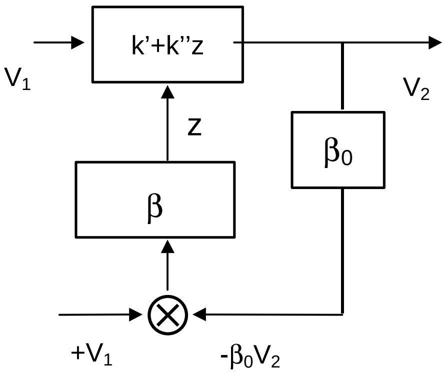

Figure 6.

Proportional Feedback Control System

$$V_2 = \frac{k' + k''\beta V_1}{1 + k''\beta\beta_0 V_1} V_1,$$
$$\frac{\Delta k}{k} = \frac{\dfrac{\Delta k'}{k'}}{1 + k''\beta\beta_0 V_1}. \qquad (18)$$

Proportional + Integral Feedback Control System

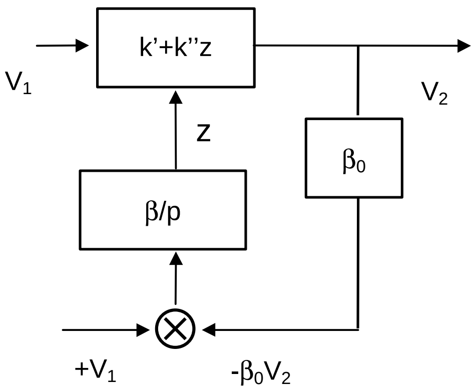

Figure 7.

$$V_2 = \frac{V_1}{\beta_0 + Ce^{-\beta\beta_o k'' t}}.$$ In static t→∞, Δφ→0,

or, in the other words, a static error equals to zero. Practically this error depends on the backward branch resolution.

Data of the double loop self-adapting amplifier, which was used in a high accuracy permeameter for measurement characteristics of hard magnetic materials with ferromagnetic Hall-effect sensors, are the following:

4 SUMMERY

a resonance frequency with high stability electro- acoustic resonance network	200 Hz
an admitted frequency instability	10%
a Q-factor	350
a total error	0.1%

REFERENCE

[1] Ñ.Ã. Òàðàíîâ Ñàìîíàñòðàèâàþùèåñÿ èçìåðèòåëüíûå ïðèáîðû, Íàóêîâà Äóìêà, Êèåâ 1981

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