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AN ADJUSTABLE CONSTANT PHASE SHIFTING NETWORK INDEPENDENT OF FREQUENCY

by
C. A. KARYBAKAS
(Laboratory of Electronics University of Thessaloniki)
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Abstract: *A curcuit which is capable to produce a constant but adjustable phase shift irrespective of frequency of the input signal is proposed. The operation of the circuit is based mainly on a* 90° *phase shifting network which is proposed here. The constant phase shift of* 90° *is achieved by a voltage dependent resistor (VDR) put in the feedback path of a differentiator. The dynamic resistance of this nonlinear element is controlled by feedback action so that the gain remains constant in spite of frequency variation. The circuit can give flat frequency response over a band of one and a half decade but has a slow time response to a step frequency change, as it contains filtering networks with large time costants.*

1. PRINCIPLE OF THE CIRCUIT

The principle of the circuit is explained by the block diagram of fig. 1. If the input voltage is $\upsilon_i = A\sin\omega t$ and constants K_1 and K_2 are chosen to be

$$\begin{aligned} K_1 &= \cos\varphi \\ K_2 &= \sin\varphi \end{aligned} \tag{1}$$

then the output υ_0 from the adder will be

$$\upsilon_0 = A\cos\varphi\sin\omega t + A\sin\varphi\cos\omega t = A\sin(\omega t + \varphi) \tag{2}$$

The 90° phase shifter 2,3,5 which is needed for the production of the $\cos\omega t$ term is a constant gain differentiator shown in fig. 1 in dotted lines. The frequency transfer function of a differentiator constructed hy an operational amplifier is

$$G(j\omega) = -jRC\omega \tag{3}$$

where C is the value of input capacitor, R is the value of feedback resistance and ω is the input signal frequency. This linear differentiator produces a constant phase of —90°, in all frequencies, while its gain is proportional to frequency ω. However, as a constant gain differentiator, which is needed for this circuit, is not feasible with linear means, it is proposed here the use of a voltage depended resistor (VDR) put in the feedback path of the operational amplifier. Thus, the VDR acts as a variable resistance which can be controlled by feedback action and can compensate the variation of gain with respect to frequency. Hence, the overall gain of the differentiator remains constant. With a large enough value of gain K, the input and output signal amplitudes of the circuit is nearly equal and therefore the overall gain is

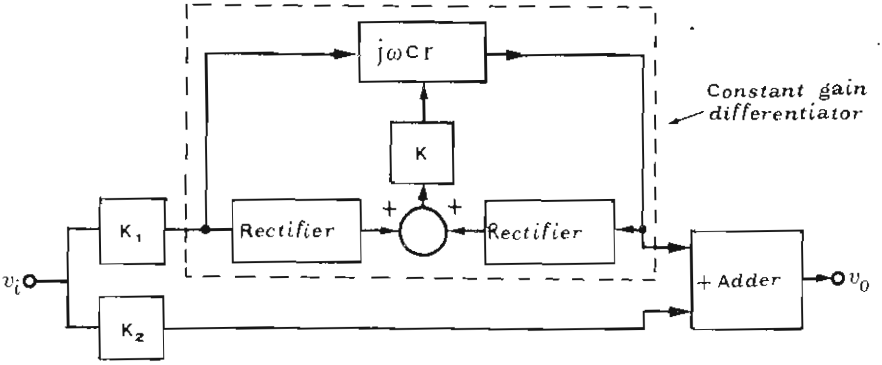


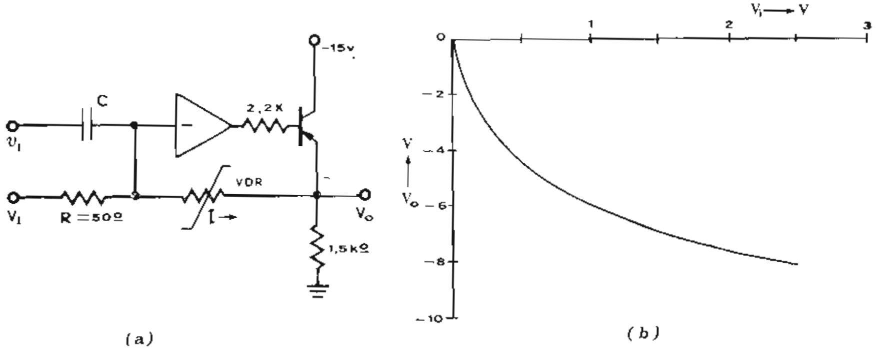
Fig. 1. Block diagram explaining the principle of the contstant phase shifting circuit.

$$\omega Cr \cong 1 \tag{4}$$

The above relation means that the dynamic resistance r is inversely proportional to frequency ω.

2. STATIC GAIN CHARACTERISTIC OF THE DIFFERENTIATOR

In fig. 2 (a) the used differentiator with a VDR in the feedback path is shown. The extra voltage V_i is needed to bias the circuit and brink the operating point to the desired place on the static curve. The measured voltage gain characteristic $V_0 = f(V_i)$ of the circuit is shown in fig. 2 (b).



(a) (b)

Fig. 2. The nonlinear differentiator (a) and it's static characteristic (b).

The volt-ampere relation of a VDR, as it is known 1,4, can be approximately described by equation

$$I = \beta V^{\alpha} \tag{5}$$

where β and α are parameters characterizing each resistor. Coefficient β is nearly constant, while the nonlinearity index α increases with increasing voltage V. For the particular VDR used in the experiment, α is equal to unity for low voltages. For the circuit of fig. 2 (a) one has

$$I = \beta \mid V_0 \mid^{\alpha}, \; V_i > 0 \tag{6}$$

Since $I = V_i / R$, the static input-output characteristic is

$$V_i = \beta R \mid V_0 \mid^{\alpha}, \; V_i > 0 \tag{7}$$

where it is sign $V_i = -\,\mathrm{sign} V_0$. For $V_i > 0$ it follows that

$$V_0 = -\left(\frac{V_i}{\beta R}\right)^{\frac{1}{\alpha}} \tag{8}$$

From eqns (6) and (8) one takes for $V_i > 0$

$$\frac{dI}{dV_0} = \alpha\beta \mid V_0 \mid^{\alpha-1} = \alpha\beta\left(\frac{V_i}{\beta R}\right)^{\frac{\alpha-1}{\alpha}} \tag{9}$$

Hence, the dynamic resistance of the circuit, as a function of input bias voltage V_i, is

$$r = \frac{dV_0}{dI} = \frac{1}{\alpha\beta}\left(\frac{V_i}{\beta R}\right)^{\frac{1-\alpha}{\alpha}} \tag{10}$$

For small bias voltage V_i, where $\alpha = 1$, the above equation becomes

$$r = \frac{1}{\alpha\beta} = r_0 \tag{11}$$

Thus eq. (10) can be written as

$$r = r_0\left(\frac{V_i}{\beta R}\right)^{\frac{1-\alpha}{\alpha}} \tag{12}$$

3. FREQUENCY LIMITATION OF THE CIRCUIT

Essentially, the performance of the overall phase shifting circuit is determined by the differentiator. Therefore, the frequency range where the differentiator has constant gain is the useful frequency range. In this range the whole network gives a constant phase shift.

The incremental small signal gain of the differentiator is

$$A = \omega C r = \omega C r_0\left(\frac{V_i}{\beta R}\right)^{\frac{1-\alpha}{\alpha}} \tag{13}$$

The above relation shows the dependence of incremental gain on the external bias voltage V_i. For small bias voltage ($\alpha = 1$), eq. (13) becomes

$$A = \omega C r_0 = A_{max} \tag{14}$$

and gives the expression of the maximum gain for a constant frequency signal. The gain A of the differentiator, for large values of V_i (say $V_{i\,max}$), is given by eq. (13). Therefore, the ratio of maximum to minimum gains of the circuit from eqns (13) and (14), for a constant frequency signal, is

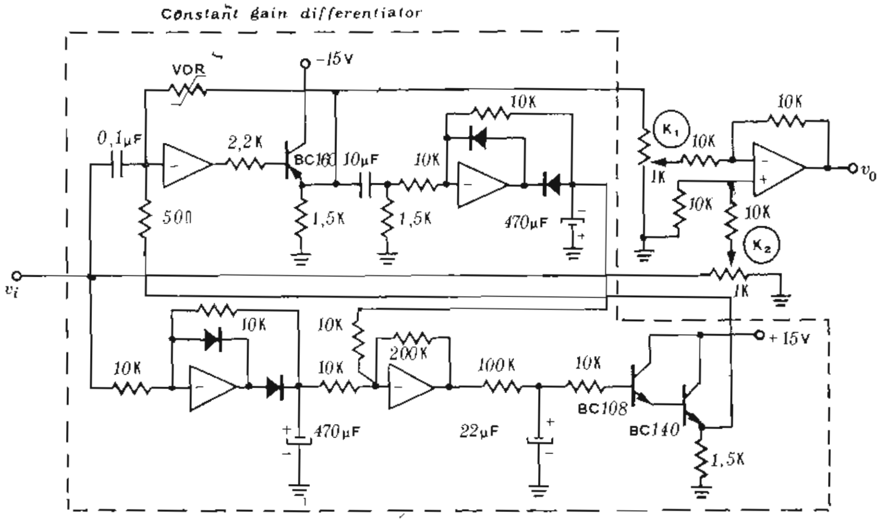


Fig. 3. The constant phase shifting circuit. Phase shift can be adjusted by potensiometers K_1, K_2.

$$\frac{A_{max}}{A_{min}} = \left(\frac{V_{i\,max}}{\beta R}\right)^{\frac{\alpha-1}{\alpha}} \tag{15}$$

The values of $V_{i\,max}$ and α correspond to a limiting point on the characteristic curve which may originate from the saturating voltage of the operational amplifier which is used in the circuit.

The frequency band of the constant phase circuit is determined by the lower and upper gain limits of the static curve of fig. 2 (b). Thus, if ω_{min} and ω_{max} are the two limiting frequencies which cause the differentiator to work respectively in the high and low gain portions of its static characteristic, and since for the closed loop circuit the gain remains constant, from eqns (13) and (14) it must be

$$\omega_{min} C r_0 = \omega_{max} C r_0 \left(\frac{V_{i\,max}}{\beta R}\right)^{\frac{1-\alpha}{\alpha}} \tag{16}$$

Hence

$$\frac{\omega_{max}}{\omega_{min}} = \frac{A_{max}}{A_{min}} = \left(\frac{V_{i\,max}}{\beta R}\right)^{\frac{\alpha-1}{\alpha}} \qquad (17)$$

for $V_{i\,max} > 0$.

4. THE CIRCUIT IN DETAIL.

The constant phase shifting circuit in detail is presented in fig. 3. It consists of, the differentiator described above, the output of which is passed through a capacitor for DC voltage rejection, two precision amplitude voltage rectifiers with filters, and a double input amplifier which provides the DC bias voltage V_i through a Darlington voltage follower. Also, it has two potentiometers for adjusting constants K_1 and K_2 from which the amount of the phase shift is determined and a linear substructor giving the output signal υ_0. The frequency responce of the constant gain differentiator is shown in fig. 4.

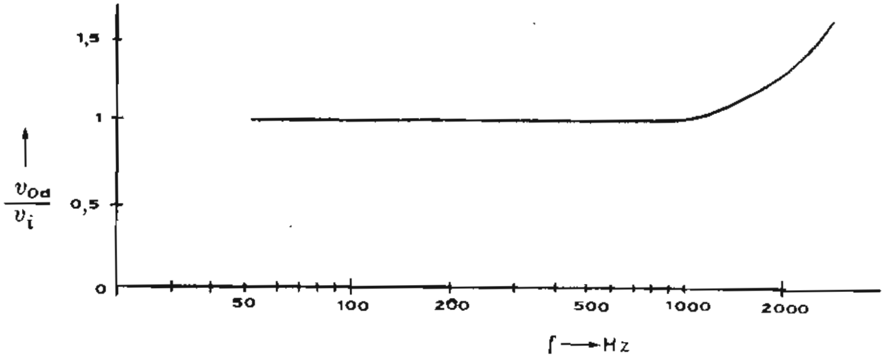


Fig. 4. Frequency response of constant gain differentiator.

It is seen that the useful frequency range of the differentiator is extended from $f_1 = 50Hz$ up to $f_2 = 1KHz$, i.e. the frequency ratio is $f_2/f_1 \simeq 20$. Because the voltage rectifier circuits contains large time constants, the above constant phase shifting network has a slow time response to a step frequency change.

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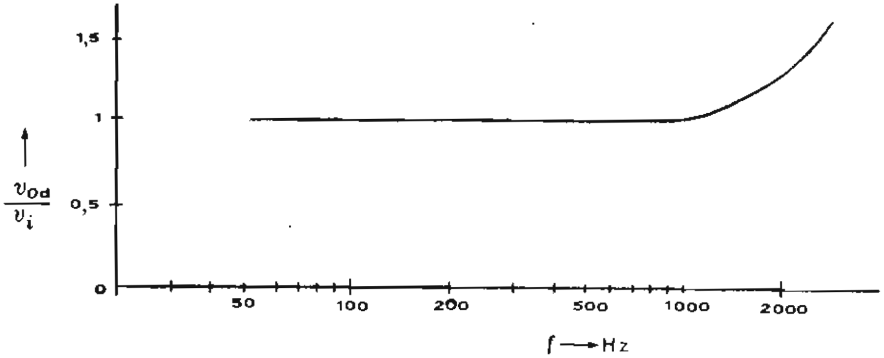

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ΠΕΡΙΛΗΨΗ

ΕΝΑ ΔΙΚΤΥΩΜΑ ΠΟΥ ΠΡΟΚΑΛΕΙ ΣΤΑΘΕΡΗ ΑΛΛΑ ΡΥΘΜΙΖΟΜΕΝΗ ΚΑΙ ΑΝΕΞΑΡΤΗΤΗ ΤΗΣ ΣΥΧΝΟΤΗΤΑΣ ΑΛΛΑΓΗ ΦΑΣΕΩΣ

Ὑπὸ
Κ. Α. ΚΑΡΥΜΠΑΚΑ
Ἐργαστήριο Ἠλεκτρονικῆς Φυσικῆς Πανεπιστημίου Θεσσαλονίκης

Στὴν ἐργασία αὐτὴ προτείνεται ἕνα δικτύωμα ποὺ προκαλεῖ μία σταθερὴ ἀλλὰ ρυθμιζόμενη καὶ ἀνεξάρτητη τῆς συχνότητας ἀλλαγὴ φάσεως στὸ σῆμα εἰσόδου. Ἡ λειτουργία τοῦ κυκλώματος κυρίως βασίζεται σ' ἕνα μὴ γραμμικὸ κύκλωμα διαφοριστὴ ποὺ προκαλεῖ διαφορὰ φάσεως 90°. Ἡ σταθερὴ καὶ ἀνεξάρτητη τῆς συχνότητας διαφορὰ φάσεως ποὺ προκαλεῖ ὁ διαφοριστὴς ἐπιτυγχάνεται μὲ μία ἀντίσταση VDR ποὺ τοποθετεῖται στὸν δρόμο ἀνατροφοδοτήσεως. Ἡ δυναμικὴ ἀντίσταση αὐτοῦ τοῦ μὴ γραμμικοῦ στοιχείου ἐλέγχεται μὲ ἀνασύζευξη ἔτσι ὥστε τὸ κέρδος νὰ διατηρεῖται σταθερὸ παρὰ τὴ μεταβολὴ τῆς συχνότητας. Τὸ κύκλωμα μπορεῖ νὰ δώσει καλὴ συχνοτικὴ ἀπόκριση σὲ ζώνη μιάμισης δεκάδας ἀλλὰ δίνει βραδεία χρονικὴ ἀπόκριση σὲ βηματικὴ ἀλλαγὴ τῆς συχνότητας καθότι περιέχει δικτυώματα γιὰ φιλτράρισμα μὲ μεγάλες σταθερὲς χρόνου.