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Frequency Stabilization of Transistor Oscillator

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Abstract

This report contains an analysis of the condition under which the frequency of an oscillator may be independent of variations in the operating conditions. The method of analysis is based upon the theory of four-pole networks and applied in detail to the basic transistor oscillators. Experimental data are not discussed in the present paper.

I. Introduction

The ability to maintain the frequency constancy is the most important requirement and considerable works have been done by various individuals to make an oscillator as free from the effects of variable quantities. F. B. Llewellyn [(1)] [(2)] attacked the problem from a circuit theoretical standpoint and showed that in certain cases of vacuum tube oscillators the mathematical procedure indicates means of making the oscillation frequency independent not only of a variable load resistance, but also of the battery voltages. Experimental data were cited which show that the best adjustment was in substatial agreement with that predicted by the theory. The purpose of this paper is to develope the method of Llewellyn in terms of the familier theory of four-pole networks interchanging the vacuum tubes with the transistors.

II. Basic Formulae

First of all, the basic formulae are derived. The definition of stable oscillator used in this study is given to such oscillator that produces oscillation of natural frequency of the passive network, and which is independent of the characteristics of the active elements.

The feedback oscillator consists of or may be resolved into, a passive four-pole network to which is attached a transistor. Fig. 1 shows the schematic representation of such oscillator. In accordance with the theory of the operation of oscillators, the following relation must be satisfied in the system when the assumed current conditions are as shown by the arrows:

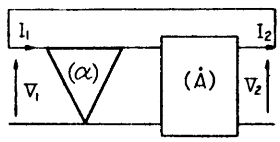

Fig. 1

$$(\dot{\mathbf{A}}-1)(\dot{\mathbf{D}}-1)=\dot{\mathbf{B}}\,\dot{\mathbf{C}}, \tag{1}$$

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(1) F. B. Llewellyn, "Constant Frequency Oscillators," Proc. I. R. E., Vol. 19, Dec., 1931, pp. 2063—2094

(2) F. B. Llewellyn, "Constant Frequency Oscillators," B. S. T. J., 1932. pp. 67—100.

where

$$\begin{vmatrix} \dot{\mathrm{A}} & \dot{\mathrm{B}} \\ \dot{\mathrm{C}} & \dot{\mathrm{D}} \end{vmatrix} = \begin{vmatrix} \alpha & \beta \\ \gamma & \delta \end{vmatrix} \begin{vmatrix} \dot{\mathrm{A}} & \dot{\mathrm{B}} \\ \dot{\mathrm{C}} & \dot{\mathrm{D}} \end{vmatrix}.$$

The transmission constants of the transistor are shown with real quantities (α, β, γ, δ) since the operation of transistor is supposed to be independent of freqneucy. ($\dot{\mathrm{A}}$, $\dot{\mathrm{B}}$, $\dot{\mathrm{C}}$, $\dot{\mathrm{D}}$) show the complex transmission constants of the passive four-pole network.

In order for (1) to be true, both the real and the imaginary portions must separately be equal to zero. From (1), then, following two equations are derived:

$$\xi+1-(\alpha\mathrm{A}+\beta\mathrm{C}+\gamma\mathrm{B}+\delta\mathrm{D})=0, \qquad \text{(A)}$$

$$\alpha\overline{\mathrm{A}}+\beta\overline{\mathrm{C}}+\gamma\overline{\mathrm{B}}+\delta\overline{\mathrm{D}}=0, \qquad \text{(B)}$$

where $\xi=\alpha\delta-\beta\gamma$, and (A, B, C, D), ($\overline{\mathrm{A}}$, $\overline{\mathrm{B}}$, $\overline{\mathrm{C}}$, $\overline{\mathrm{D}}$) are the groups of the real and the imaginary terms of ($\dot{\mathrm{A}}$, $\dot{\mathrm{B}}$, $\dot{\mathrm{C}}$, $\dot{\mathrm{D}}$). A great simplification results when it is recalled that the circuits external to the transistor are assumed to have no other elements than reactance. With this understanding, $\overline{\mathrm{A}}$, $\overline{\mathrm{D}}$, B and C vanish from (A), (B) Accordingly for the oscillator with reactance four-pole network, (A), (B) become:

$$\xi+1-(\alpha\mathrm{A}+\delta\mathrm{D})=0, \qquad \text{(A)}'$$

$$\beta\overline{\mathrm{C}}+\gamma\overline{\mathrm{B}}=0. \qquad \text{(B)}'$$

It may be clear that the representation of oscillation frequency derived from (B)′ contains the transistor parameters, and which does not coincide with the natural frequency since $\beta \neq 0$, $\gamma \neq 0$. In other words, the definition of stable oscillator given at the beginning is satisfied only when both terms $\overline{\mathrm{B}}$ and $\overline{\mathrm{C}}$ become zero at the natural frequency.

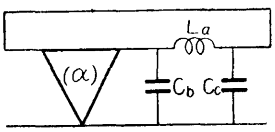


Fig. 2

For instance, from (B)′ of the familier Colpitts type transistor oscillator shown in Fig. 2, the actual angular frequency is given by the expression:

$$\omega^2=\frac{C_b+C_c}{L_a C_b C_c}+\frac{\gamma}{\beta}\frac{1}{C_b C_c}. \qquad (2)$$

The natural angular frequency ω_0 is given by the first term. The second one indicates the quantity of frequency deviation from ω_0. Furthermore, it is very clear that the real frequency of oscillation is affected by the transistor characteristics β, γ, which are sensitive to temperature and other conditions. Then it will be evident that it is necessary to introduce some means to cancel out the second portion in order to make the oscillator become stable.

Needless to say, however, there are some networks which are satisfactory to the necessary condition of stable oscillator. For instance, if the passive four-pole network is a series impedance type of single tuning circuit of L, C and R, then the term $\overline{C}$ becomes zero and the frequency is decided only by $\overline{B}=0$. In this case the real frequency coincides with the natural frequency. When the passive network is parallel admitance type four-pole network with L, C, R tuning circuit, the term $\overline{B}$ becomes null. Then $\overline{C}=0$ gives the natural frequency of this stable oscillator. Although the above are special examples of feedback oscillator, in the following part, the principles of frequency stabilization by cascade arrangements applicable to general configurations are considered with Π type and T type reactance four-pole networks.

In the oscillator with Π type reactance four-pole network shown in Fig. 3 (a), (B)′ becomes:

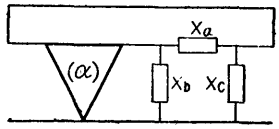


Fig. 3 (a)

$$\frac{\beta}{X_b X_c}(X_a+X_b+X_c)+\gamma X_a=0. \qquad (3)$$

For instance, for the oscillator of the Colpitts type, the above equation has the form:

$$\beta\omega C_b C_c\left(\omega L_a-\frac{1}{\omega C_b}-\frac{1}{\omega C_c}\right)-\gamma L_a=0. \qquad (4)$$

Generally speaking, as was also pointed out previously and is clear with practical examples such as (4), both terms of (3) cannot become null at the same frequency. However, connection of series impedance type reactance four-pole netwowk on the left hand of the Π type as shown in Fig. 3 (b) gives the transmission matrix:

$$\begin{vmatrix} 1 & jX_d \\ 0 & 1 \end{vmatrix}\begin{vmatrix} A & j\overline{B} \\ j\overline{C} & D \end{vmatrix}=\begin{vmatrix} A-X_d\overline{C} & j(\overline{B}+X_d D) \\ j\overline{C} & D \end{vmatrix}.$$

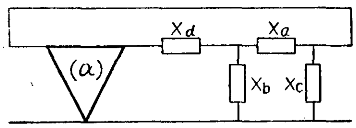


Fig. 3 (b)

Then (B)′ of this newly examined oscillator becomes:

$$\beta\overline{C}+\gamma(\overline{B}+X_d D)=0, \qquad (5)$$

or

$$\frac{\beta}{X_b X_c}(X_a+X_b+X_c)+\gamma\left(X_a+X_d\cdot\frac{X_a+X_b}{X_b}\right)=0. \qquad (6)$$

As is evident, the natural frequency of the original passive network is decided by the first term. Thus it may be reasoned that the frequency must be stabilized if the value of this additional element X_d is selected so as to make the second term become null at the frequency given by the first term.

The natural angular frequency ω_0 of the Colpitts type oscillator is decided by (4), namely:

$$\omega_0^2=\frac{C_b+C_c}{L_a C_b C_c}. \qquad (7)$$

Equating the second term of (6) to zero at this angular frequency ω_0, the value of

L_d is given by the expression:

$$L_d = \frac{C_c}{C_b} \cdot L_a .$$

For capacitance stabilization, negative value is needed.

The above discussion is on the method of left hand insertion of stabilizer only. Analogous considerations are possible for the method of right hand and both hands stabilizations. Generally speaking, the values of stabilizers connected on the left and right hands are different. Furthermore the two elements connected on the both hands are so correlated that one cannot be decided independently of the other one. There are four combinations of reactance stabilizers at both sides, but one of them must be neglected where negative value is required in the real element.

The results of the above consideration are summarized in Table (1). From now on, let the left and the right of the passive network be named the input and the output of it for brevity's sake.

Similar treatments are possible in the oscillators of T type four-pole networks schematically shown in Fig. 4 (a). The stabilizer elements should be inserted into the parallel arms of the original networks. When the stabilizer is inserted in the input of the T type four-pole network as is indicated in Fig. 4 (b), the transmission matrix becomes:

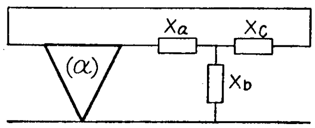


Fig. 4 (a)

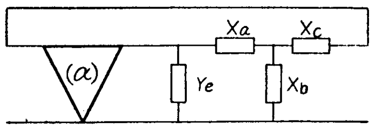


Fig. 4 (b)

$$\begin{vmatrix} 1 & 0 \\ jY_e & 1 \end{vmatrix} \begin{vmatrix} A & j\overline{B} \\ j\overline{C} & D \end{vmatrix} = \begin{vmatrix} A & j\overline{B} \\ j(\overline{C}+Y_eA) & D-Y_eB \end{vmatrix} .$$

Then (B)′ is written as follows:

$$\beta(\overline{C}+Y_eA)+\gamma\overline{B}=0 . \qquad (8)$$

The oscillator may be stable if the two terms of (8) are nullified at the natural frequency. The results of similar consideration with that previousely mentioned are also summarized in Table 1.

III. Results of Calculation

Table 2 and Table 3 respectively show the results of calculations of the stabilizers for oscillators of Π type and T type reactance networks.

The discussion stated above is limited to the condition (B)′. But for sustained oscillation, (A)′ must also be satisfied. So some remarks about this are given in brief.

Comparison of (A)′ of the stabilized oscillator and the unstabilized one is possible by insertion of the natural frequency and the real frequency into (A)′ respectively. Let the Colpitts type oscillator be used as an example to show the relation. (A)′ is

Table 1.

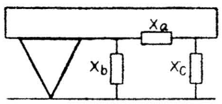
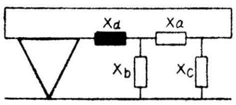
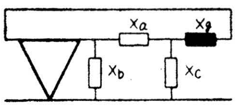
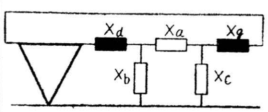
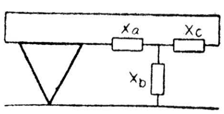
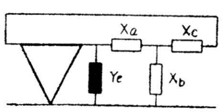
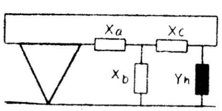
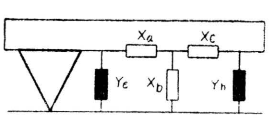
Oscillators	(B)′	Design Formulae of Stabilizers
	$\beta\overline{C}+\gamma\overline{B}=0.$ $\frac{\beta}{X_bX_c}(X_a+X_b+X_c)+\gamma X_a=0.$	
	$\beta\overline{C}+\gamma(\overline{B}+X_dD)=0.$ $\frac{\beta}{X_bX_c}(X_a+X_b+X_c)+\gamma\left(X_a+X_d\cdot\frac{X_a+X_b}{X_b}\right)=0.$	$\overline{B}+X_dD=0.$ $X_d=-\frac{X_aX_b}{X_a+X_b}$
	$\beta\overline{C}+\gamma(\overline{B}+X_gA)=0.$ $\frac{\beta}{X_bX_c}(X_a+X_b+X_c)+\gamma\left(X_a+X_g\cdot\frac{X_a+X_c}{X_c}\right)=0.$	$\overline{B}+X_gA=0.$ $X_g=-\frac{X_aX_c}{X_a+X_c}$
	$(\beta-\gamma X_dX_g)\overline{C}+\gamma(\overline{B}+X_dD+X_gA)=0.$ $\frac{\beta-\gamma X_dX_g}{X_bX_c}\cdot(X_a+X_b+X_c)+\gamma\left(X_a+X_d\cdot\frac{X_a+X_b}{X_b}+X_g\cdot\frac{X_a+X_c}{X_c}\right)=0.$	$\overline{B}+X_dD+X_gA=0.$ $X_d=-\frac{X_b}{X_a+X_b}\left(X_a+X_g\cdot\frac{X_a+X_c}{X_c}\right)$
	$\beta\overline{C}+\gamma\overline{B}=0.$ $\beta+\gamma(X_aX_b+X_bX_c+X_aX_c)=0.$	
	$\beta(\overline{C}+Y_eA)+\gamma\overline{B}=0.$ $\beta\{1+Y_e(X_a+X_b)\}+\gamma(X_aX_b+X_bX_c+X_cX_a)=0.$	$\overline{C}+Y_eA=0.$ $Y_e=-\frac{1}{X_a+X_b}$
	$\overline{\beta}(\overline{C}+Y_hD)+\gamma\overline{B}=0.$ $\beta\{1+Y_h(X_b+X_c)\}+\gamma(X_aX_b+X_bX_c+X_cX_a)=0.$	$\overline{C}+Y_hD=0.$ $Y_h=-\frac{1}{X_b+X_c}$
	$\beta(\overline{C}+Y_eA+Y_hD)+(\gamma-\beta Y_eY_h)\overline{B}=0.$ $\beta\{1+Y_e(X_a+X_b)+Y_h(X_b+X_c)\}+(\gamma-\beta Y_eY_h)(X_aX_b+X_bX_c+X_cX_a)=0.$	$\overline{C}+Y_eA+Y_hD=0.$ $Y_e=-\frac{1}{X_a+X_b}\{1+Y_h(X_b+X_c)\}$

Table 2.

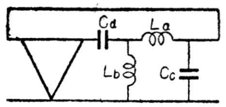
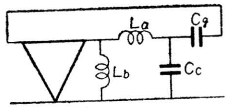
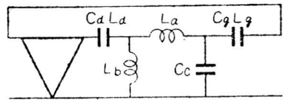
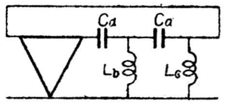
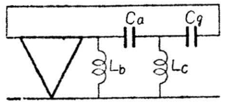
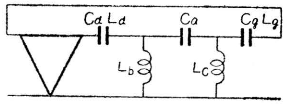
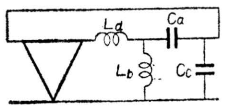
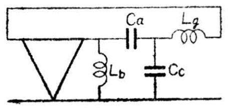
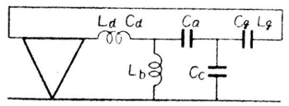
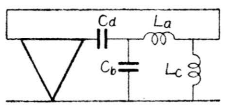
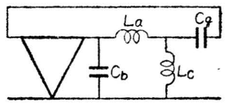
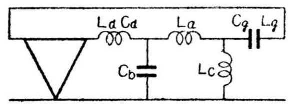
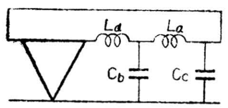
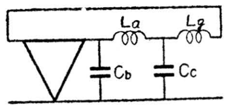
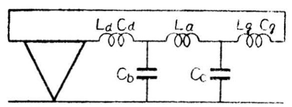
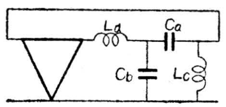
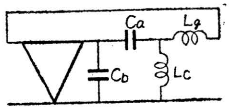
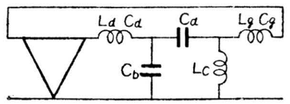
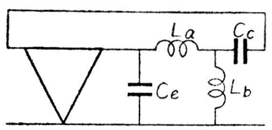
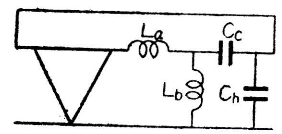
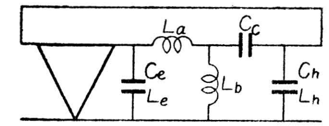
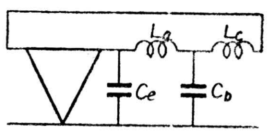
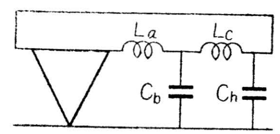
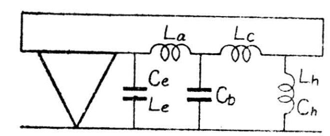
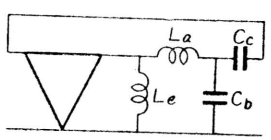
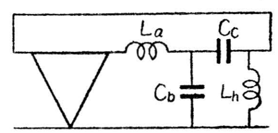
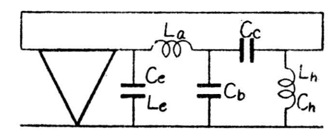
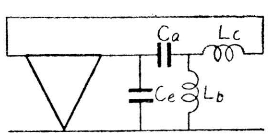
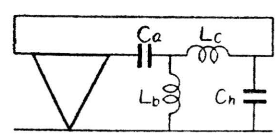
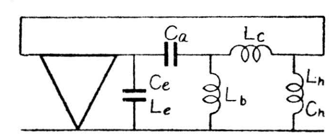
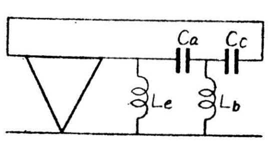
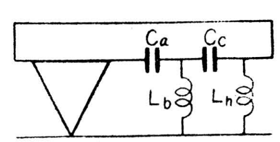
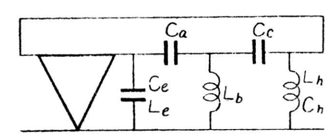
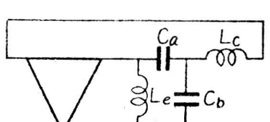
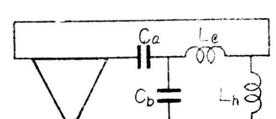
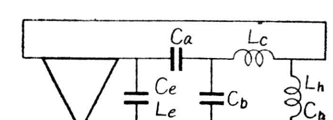
Input Stabilization	Output Stabilization	Input-Output Stabilization	(A)′ of Stabilized Oscillators $\xi+1+\alpha k+\frac{\delta}{k}=0$	(A)′ of Unstabilized Oscillators
 $C_d=\frac{(L_a+L_b)^2}{L_a L_b}C_c$	 $C_g=\frac{L_b}{L_a}C_c$	 $L_a+L_d\left(\frac{L_a+L_b}{L_b}\right)-\frac{C_c}{C_g}L_b=0$ $L_a-\frac{C_c(L_a+L_b)^2}{L_b C_d}+\frac{L_b L_g}{(L_a+L_b)}=0$ $L_a-\frac{C_c(L_a+L_b)^2}{L_b C_d}-\frac{L_b C_c}{C_g}=0$	$k=\frac{-L_b}{L_a+L_b}$	$\xi+1+\alpha\frac{k(1+\sigma)}{1-k\sigma}+\frac{\delta}{k}=0$ $k=-\frac{L_b}{L_a+L_b}$, $\sigma=\frac{\gamma}{\beta}\cdot\frac{L_a}{C_c}$
 $C_d=\frac{L_c}{L_b}C_a$	 $C_g=\frac{L_b}{L_c}C_a$	 $\frac{1}{C_a}+\frac{L_c L_d}{L_b(L_b+L_c)C_a}-\frac{L_b}{L_c C_g}=0$ $\frac{1}{C_a}-\frac{L_c}{L_b C_d}+\frac{L_b L_g}{L_c(L_b+L_c)C_a}=0$ $\frac{1}{C_a}-\frac{L_c}{L_b C_d}-\frac{L_b}{L_c C_g}=0$	$k=\frac{L_b}{L_c}$	$\xi+1+\alpha k(1+\sigma)+\frac{\delta}{k}(1+k\sigma)=0$ $k=\frac{L_b}{L_c}$, $\sigma=\frac{\gamma}{\beta}\frac{L_c}{C_a}$
 $L_d=\frac{C_c}{C_a}L_b$	 $L_g=\frac{C_a C_c}{(C_a+C_c)^2}L_b$	 $\frac{1}{C_a}-\frac{L_d}{L_b C_c}-\frac{(C_a+C_c)^2}{L_b C_a^2 C_c}L_g=0$ $\frac{1}{C_a}-\frac{L_d}{L_b C_c}+\frac{C_a+C_c}{C_a C_g}=0$ $\frac{1}{C_a}+\frac{C_a}{C_a+C_c}\cdot\frac{1}{C_d}-\frac{(C_a+C_c)^2}{L_a C_a^2 C_c}L_g=0$	$k=\frac{-(C_a+C_c)}{C_a}$	$\xi+1+\alpha k+\delta\cdot\frac{1+\sigma}{k-\sigma}=0$ $k=\frac{-(C_a+C_c)}{C_a}$, $\sigma=\frac{\gamma}{\beta}\cdot\frac{L_b}{C_a}$
 $C_d=\frac{L_c}{L_a}C_b$	 $C_g=\frac{(L_a+L_c)^2}{L_a L_c}C_b$	 $L_a+\frac{L_c L_d}{L_a+L_c}-\frac{(L_a+L_c)^2}{L_c C_g}C_b=0$ $L_a-\frac{L_c C_b}{C_d}+\frac{(L_a+L_c)}{L_c}L_g=0$ $L_a-\frac{L_c C_b}{C_d}-\frac{(L_a+L_c)^2}{L_c C_g}C_b=0$	$k=-\frac{L_a+L_c}{L_c}$	$\xi+1+\alpha k+\delta\frac{1+\sigma}{k-\sigma}=0$ $k=\frac{-(L_a+L_c)}{L_c}$, $\sigma=\frac{\gamma}{\beta}\frac{L_a}{C_b}$
 $L_d=\frac{C_c}{C_b}L_a$	 $L_g=\frac{C_b}{C_c}L_a$	 $L_a-\frac{C_b}{C_c}L_d-\frac{C_c}{C_b}L_g=0$ $L_a-\frac{C_b}{C_c}L_d+\frac{L_a C_c^2}{(C_b+C_c)C_g}=0$ $L_a+\frac{L_a C_b^2}{(C_b+C_c)C_d}-\frac{C_c}{C_b}L_g=0$	$k=\frac{C_c}{C_b}$	$\xi+1+\alpha(k+\sigma)+\frac{\delta}{k}(1+\sigma)=0$ $k=\frac{C_c}{C_b}$, $\sigma=\frac{\gamma}{\beta}\frac{L_a}{C_b}$
 $L_d=\frac{C_a C_b}{(C_a+C_b)^2}L_c$	 $L_g=\frac{C_b}{C_a}L_c$	 $\frac{1}{C_a}-\frac{(C_a+C_b)^2}{L_c C_a^2 C_b}L_d-\frac{L_g}{L_c C_b}=0$ $\frac{1}{C_a}-\frac{(C_a+C_b)^2}{L_c C_a^2 C_b}L_d+\frac{C_a}{(C_a+C_b)C_g}=0$ $\frac{1}{C_a}+\frac{C_a+C_b}{C_a C_d}-\frac{L_g}{L_c C_b}=0$	$k=\frac{-C_a}{C_a+C_b}$	$\xi+1+\alpha\frac{k(1+\sigma)}{1-k\sigma}+\frac{\delta}{k}=0$ $k=-\frac{C_a}{C_a+C_b}$, $\sigma=\frac{\gamma}{\beta}\cdot\frac{L_c}{C_a}$

Table 3.

Input Stabilization	Output Stabilization	Input - Output Stabilization	(A)′ of Stabilized Oscillators $\xi+1+\alpha k+\frac{\delta}{k}=0$	(A)′ of Unstabilized Oscillators
 $C_e=\frac{L_a L_b C_c}{(L_a+L_b)^2}$	 $C_h=\frac{L_a}{L_b}C_e$	 $1+\frac{L_a+L_b}{L_e}-\frac{L_b C_h}{L_a C_c}=0$ $1-\frac{(L_a+L_b)^2}{L_a L_b C_c}C_e+\frac{L_b^2}{(L_a+L_b)L_h}=0$ $1-\frac{(L_a+L_b)^2}{L_a L_b C_c}C_e-\frac{L_b C_h}{L_a C_c}=0$	$k=-\frac{L_a+L_b}{L_b}$	$\xi+1+\alpha k+\alpha\cdot\frac{1+\sigma}{k-\sigma}=0$ $k=-\frac{L_a+L_b}{L_b},\ \sigma=\frac{C_c}{L_b}\cdot\frac{\beta}{\gamma}$
 $C_e=\frac{L_c}{L_a}C_b$	 $C_h=\frac{L_a}{L_c}C_b$	 $1+\frac{L_a^2}{(L_a+L_c)L_e}-\frac{L_c C_h}{L_a C_b}=0$ $1-\frac{L_a C_e}{L_c C_b}+\frac{L_c^2}{(L_a+L_c)L_h}=0$ $1-\frac{L_a C_e}{L_c C_b}-\frac{L_c C_h}{L_a C_b}=0$	$k=\frac{L_a}{L_c}$	$\xi+1+\alpha(k+\sigma)+\delta\cdot\frac{1+\sigma}{k}=0$ $k=\frac{L_a}{L_c},\ \sigma=\frac{C_b}{L_c}\cdot\frac{\beta}{\gamma}$
 $L_e=\frac{C_c}{C_b}L_a$	 $L_h=\frac{(C_b+C_c)^2}{C_b C_c}L_a$	 $1-\frac{L_a C_c}{C_b L_e}-\frac{L_a(C_b+C_c)^2}{C_b C_c L_h}=0$ $1-\frac{L_a C_c}{C_b L_e}+\frac{C_b+C_c}{C_b C_c}\cdot C_h=0$ $1+\frac{C_c C_e}{C_b(C_b+C_c)}-\frac{L_a(C_b+C_c)^2}{C_b C_c L_h}=0$	$k=-\frac{C_c}{C_b+C_c}$	$\xi+1+\alpha\frac{k(1+\sigma)}{1-k\sigma}+\frac{\delta}{k}=0$ $k=-\frac{C_c}{C_b+C_c},\ \sigma=\frac{C_b}{L_a}\cdot\frac{\beta}{\gamma}$
 $C_e=\frac{L_c}{L_b}C_a$	 $C_h=\frac{L_b L_c C_a}{(L_b+L_c)^2}$	 $1+\frac{L_b^2}{(L_b+L_c)L_e}-\frac{(L_b+L_c)^2}{L_b L_c C_a}=0$ $1-\frac{L_b C_c}{L_c C_a}+\frac{L_b+L_c}{L_h}=0$ $1-\frac{L_b C_e}{L_c C_a}-\frac{(L_a+L_c)^2}{L_a L_c C_a}C_h=0$	$k=\frac{-L_b}{L_b+L_c}$	$\xi+1+\alpha\frac{k(1+\sigma)}{1-k\sigma}+\frac{\delta}{k}=0$ $k=\frac{-L_b}{L_b+L_c},\ \sigma=\frac{C_a}{L_b}\cdot\frac{\beta}{\gamma}$
 $L_e=\frac{C_c}{C_a}L_b$	 $L_h=\frac{C_a}{C_c}L_b$	 $1-\frac{L_b C_c}{C_a L_e}-\frac{L_b C_a}{C_c L_h}=0$ $1-\frac{L_b C_c}{C_a L_e}+\frac{C_a C_h}{C_c(C_a+C_c)}=0$ $1+\frac{C_c C_e}{C_a(C_a+C_c)}-\frac{L_b C_a}{C_c L_h}=0$	$k=\frac{C_c}{C_a}$	$\xi+1+\alpha(k+\sigma)+\delta\frac{1+\sigma}{k}=0$ $k=\frac{C_c}{C_a},\ \sigma=\frac{C_c}{L_b}\cdot\frac{\beta}{\gamma}$
 $L_e=\frac{(C_a+C_b)^2}{C_a C_b}L_c$	 $L_h=\frac{C_a}{C_b}L_c$	 $1-\frac{L_c(C_a+C_b)^2}{C_a C_b L_e}-\frac{L_c C_a}{C_b L_h}=0$ $1-\frac{L_c(C_a+C_b)^2}{C_a C_b L_e}+\frac{C_a C_h}{C_b(C_a+C_b)}=0$ $1+\frac{C_a+C_b}{C_a C_b}\cdot C_e-\frac{L_c C_a}{C_b L_h}=0$	$k=\frac{-(C_a+C_b)}{C_a}$	$\xi+1+\alpha k+\delta\frac{1+\sigma}{k-\sigma}=0$ $k=\frac{-(C_a+C_b)}{C_a},\ \sigma=\frac{C_b}{L_c}\cdot\frac{\beta}{\gamma}$

given by the following equation:

$$\xi+1-\alpha(1-\omega^2 L_a C_c)-\delta(1-\omega^2 L_a C_b)=0. \tag{9}$$

When the stabilization is completed, insertion of ω_0 shown by (7) into (9) produces the following:

$$\xi+1+\alpha\frac{C_c}{C_b}+\delta\frac{C_b}{C_c}=0. \tag{10}$$

Introducing a new coefficient $k=\frac{C_c}{C_b}$, it becomes:

$$\xi+1+\alpha k+\frac{\delta}{k}=0. \tag{11}$$

As is shown in Table 2 and Table 3, (A)′ has the form of (11) which is common to all types of oscillator included in the tables. The common form (11) is extracted and the coefficient is shown in each case.

(A)′ for the original Colpitts oscillator is obtained by insertion of (2) into (9). That is:

$$\xi+1+\alpha\left(\frac{C_c}{C_b}+\frac{\gamma}{\beta}\frac{L_a}{C_b}\right)+\delta\left(1+\frac{\gamma}{\beta}\frac{L_a}{C_b}\right)\frac{C_b}{C_c}=0. \tag{12}$$

Introducing another representation $\sigma=\frac{\gamma}{\beta}\frac{L_a}{C_b}$, (12) becomes:

$$\xi+1+\alpha(k+\sigma)+\delta(1+\sigma)\frac{1}{k}=0.$$

The similar kind of σ appears in each case as is shown in the tables.

IV. Remarks and Conclusions

At the end of this report, several remarks may be made about the theory mentioned above.

First of all, about the method of frequency decision which has an important role in the theory: (A)′, (B)′ are derived as the necessary conditions for sustained oscillation and they have quite the same significance to the frequency decision. In spite of this, in the theory the frequency is regarded as given only by (B)′. Of course, when the frequency is not contained in (A)′, there remain no matters to be discussed about the subject. Although, if (A)′ contains ω either in explicit or in implicit, it may not be reasonable to consider that the way of frequency decision and stabilizer design are completely sufficient method. After all, an oscillator may become constant frequency when one of the conditions (A)′ or (B)′ decides the frequency and the other is completely independent of the frequency.

In the second place, about the premise of the theory: It may be pointed out that it is not an easy matter in general to realize in practice the premise used in the theory. For instance, it is required that the passive networks must not contain other than the reactance elements. But there are many cases where this condition cannot be satisfied even in approximation. For such cases, (A) and (B) must be considerd in stead of (A)′ and (B)′.

On the other hand, the active elements should be independent of frequency and their characteristics must be represented by real quantities. In transistors, however, the effects of capacitances appear even at comparatively low frequencies. Furthermore, it may be considered that variation of temperature affects primarilly the inductance and the capacity of the passive circuit, but does not change the performance of vacuum tubes. In general, however, semiconductors have undesirable sensitively to temperature. Consequently, there may be severer restriction for transistor oscillators than for vacuum tube oscillators from the standpoint of frequency stabilization.

The theory is based upon the assumption that the sustained oscillation has only pure sine wave of single frequency. But practical transistor oscillators may contain a good deal of higher harmonic frequencies. The stabilizer designed by the theory is not effective to the harmonic components.

Acknowledgement

The writer is indebted to Professor Teruo Suezaki for his invaluable guidance and encouragement.