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電晶體內在電容對斜置調諧放大器之影響
Effect of Internal Feedback Capacitor on Maximally Flat Stagger Tuned Amplifier

劉濬堯 Jiunn-Yau Liou

Department of Electrophysics, N. C. T. U.

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Abstract——One-stage maximally flat stagger tuned amplifier with internal feedback capacitor has been analyzed in terms of hybrid-π model. In this approach, physical insight for circuit design has been pointed out and equations for response characteristics are also derived. This analysics can be served as a guide for multi-stage amplifier deisgn.

I. Introduction

Maximally flat stagger tuned amplifiers has been widely used in communication amplifiers, such as in AM, FM, TV and radar circuits. These circuits can be analyzed in terms of h or y-parameters, although this approach may be mathematically convenient but the physical insight, which is important in circuit design, is lost. In the following analysis, this problem is discussed in hybrid-π model and hence physical feeling for circuit design can be grasped.

II. Theory

The schematic diagram for one-stage stagger tuned amplifier and its small signal equivalent circuit are shown in Fig. 1 and Fig. 2.

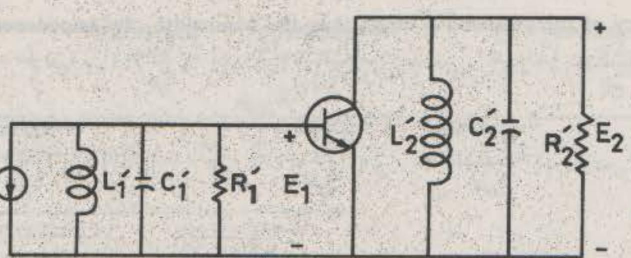

Fig. 1. Schematic diagram of one-stage stagger tuned amplifier with biasing circuit omitted

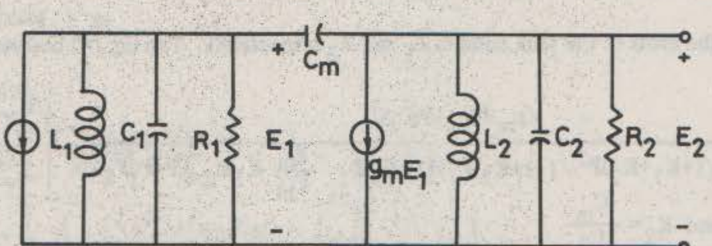

Fig. 2. Small signal equivalent circuit of Fig.1. γ_π, C_π and other parasific elements are incorporated in the lamped elements.

In the small signal equivalent circuit, the feedback element is represented by a capacitor C_m, this is in general true for frequency below 100 MHz and below 200 MHz for high frequency transistors such as 2N2415[2].

This small signal equivalent circuit can be redrawn as Fig. 3 and its analysis is shown below

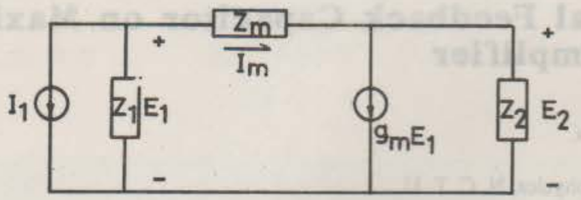

Fig. 3. Representation of the small signal equivalent circuit in Z-parameters

$$E_1 - E_2 = I_m Z_m \tag{1}$$

$$E_1 = -(I_1 + I_m) Z_1 \tag{2}$$

$$E_2 = (I_m - g_m E_1) Z_2 \tag{3}$$

$$\therefore \frac{E_2}{I_1} = \frac{Z_1 Z_2 (g_m Z_m - 1)}{g_m Z_1 Z_2 + Z_1 + Z_2 + Z_m} \tag{4}$$

$$Z_{in} \equiv -\frac{E_1}{I_1} = \frac{Z_1 (Z_m + Z_2)}{g_m Z_1 Z_2 + Z_1 + Z_2 + Z_m} \tag{5}$$

1. Frequency Response Characteristics

From Eq. 4 , it is found that Z_1 and Z_2 are interchageable and hence the transresistance is unaffected by whether Z_1(or Z_2) is tuned below or above the center frequency of the passband.

When the center frequency of the passband is larger than the bandwidth, the impedance of the tank circuits can be approximated by

$$Z_1 = \frac{1/2C_1}{P - P_1}$$

$$Z_2 = \frac{1/2C_2}{P - P_2}$$

and

$$Z_m = \frac{1}{PC_m}$$

where P_1 and P_2 are the roots of the tank circuits Z_1 and Z_2 respectively. The Eq. (4) becomes

$$\frac{E_2}{I_1} = \frac{(g_m - PC_m)/4C_1C_2}{(1+K_1+K_2)P^2 - [(1+K_2)P_1 + (1+K_1)P_2 - \frac{g_m}{C_m} K_1 K_2] P + P_1 P_2} \tag{6}$$

where $K_1 = \frac{C_m}{2C_1}$ and $K_2 = \frac{C_m}{2C_2}$

In general, $g_m \gg PC_m$ and $C_1, C_2 \geq 150$pf and $C_m \sim 3$pf, thus we have $K_1 \ll 1$ and $K_2 \ll 1$

$$\therefore \frac{E_2}{I_1} \simeq \frac{g_m/4C_1C_2}{P^2-(P_1+P_2-\frac{g_m}{C_m}K_1K_2)P+P_1P_2}$$

Consider the case of maximally flat stagger tunning, then $C_1 \cong C_2 \equiv C$, $R_1 \cong R_2 \equiv R$ and

$$P_1 = -\alpha + j(\omega_o - \alpha)$$

$$P_2 = -\alpha + j(\omega_o + \alpha)$$

where $\alpha = \frac{1}{2RC} = 0.35(BW)$, also, under the assumption of narrow-band, we can approximate $\frac{g_m}{C_m}K^2P \simeq j\frac{g_m}{C_m}K^2\omega_o$ where $K \equiv K_1 = K_2$. Since

$$P_1+P_2 = 2(-\alpha + j\omega_o)$$

$$P_1 \cdot P_2 = (-\alpha + j\omega_o)^2 + \alpha^2$$

$$\therefore P^2-(P_1+P_2-\frac{g_m}{C_m}K^2)P+P_1P_2 = [P-(-\alpha+j\omega_o)]^2 + j\frac{g_m}{C_m}K^2\omega_o + \alpha^2$$

$$= \{P-(-\alpha+j\omega_o) - \frac{u_o}{2}[(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} - \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1}) - j(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} + \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1})]\}.$$

$$\{P-(-\alpha+j\omega_o) + \frac{u_o}{2}[(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} - \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1}) - j(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} + \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1})]\} \quad (7)$$

where $u_o^2 = \frac{g_m}{C_m}K^2\omega_o$ and hence

$$\frac{E_2}{I_1} = \frac{g_m/4C^2}{\{P-[-\alpha+\frac{1}{2}u_o(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} - \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1})]-j[\omega_o - \frac{u_o}{2}(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} + \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1})]\}\{P-[-\alpha-\frac{u_o}{2}(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} - \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1})]-j[\omega_o + \frac{u_o}{2}(\sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}+1} + \sqrt{\sqrt{1+(\frac{\alpha^2}{u_o^2})^2}-1})]\}} \quad (8)$$

2. Alignability

Define the alignability factor δ as

$$\delta \equiv \frac{\left|\frac{dZ_{in}}{Z_{in}}\right|}{\left|\frac{dZ_2}{Z_2}\right|} = \left|\frac{dZ_{in}}{dZ_2}\right| \left|\frac{Z_2}{Z_{in}}\right| \quad (9)$$

$$\therefore \delta = \left|\frac{1}{Z_2+Z_m}\right| \left|\frac{Z_1Z_2(1-g_mZ_m)}{g_mZ_1Z_2+Z_1+Z_2+Z_m}\right| = \left|\frac{1}{Z_2+Z_m}\right| \left|\frac{E_2}{I_1}\right|$$

$$Z_2+Z_m \simeq \frac{1/2C}{P-P_2} + \frac{1}{PC_m} = \frac{1}{2C_2}\left[\frac{(1+K)P-P_2}{KP(P-P_2)}\right]$$

if $K_2 \ll 1$, then $Z+Z_m \simeq \frac{1}{PC_m}$

$$\therefore\ \delta = \left|PC_m\right| \left|\frac{E_2}{I_1}\right| \cong \omega_o C_m \left|\frac{E_2}{I_1}\right| \tag{10}$$

For frequencies within the passband

III. Conclusions

1. From Eq. (4), it is found that whether Z_1 (or Z_2) is tuned below or above the center frequency is unimportant about the frequency response characteristics.

2. From Eq. (6), we have found the effect of internal feedback capacitor depends on the ratio of this capacitance to the capacitance of the tank circuit. In order to minimize this effect, we have to maximize the capacitance of the tank circuit. However, this process tends to reduce the transresistance.

3. From Eq. (8), we found oscillation occurs when

$$u_o\left(\sqrt{\sqrt{1+\left(\frac{\alpha^2}{u_o^2}\right)^2}+1} - \sqrt{\sqrt{1+\left(\frac{\alpha^2}{u_o^2}\right)^2}-1}\ \right) > 2\,\alpha$$

or

$$u_o^4 > 8\,\alpha^4$$

or

$$u_o^2 > 2\sqrt{2}\,\alpha^2$$

or

$$g_m R > \sqrt{2}\,\frac{1}{QK} \tag{11}$$

where $Q= \omega_o RC$ is the quality factor of the tank circuit.

4. With the approximation $\sqrt{1+x} = 1+\frac{1}{2}x$ for small x if

$$\frac{\alpha}{u_o} > 10 \quad \text{or}$$

$$g_m R < \frac{1}{200}\,\frac{1}{QK} \tag{12}$$

then Eq. (7) becomes

$$P^2-(P_1+P_2-\frac{g_m}{C_m}K^2)P+P_1P_2$$

$$=\{P+\alpha\,[1-\frac{1}{2}(\frac{u_o}{\alpha})^2]-j(\omega_o-\alpha)\}\ \{P+\alpha\cdot[1+\frac{1}{2}(\frac{u_o}{\alpha})^2]-j(\omega_o+\alpha)\}$$

$$\simeq [P+\alpha-j(\omega_o-\alpha)]\,[P+\alpha-j(\omega_o+\alpha)]$$

Thus when Eq. (12) is satisfied, the pole positions of $\left|\frac{E_2}{I_1}\right|$ is unchanged and hence we can neglect the effect of the feedback capacitor C_m for an accuracy better than 1%.

5. When $\frac{1}{200}\,\frac{1}{QK} < g_m R < \sqrt{2}\,\frac{1}{QK}$, the response for frequencies lies within the passband is quite complex and Eq. (8) should be employed for calculating the transresistance, harmonic distortion, etc.. However, its filtering characteristic is always better compare with that of synchrously tuned amplifier(3).

6. The alignabilitv factor is found in Eq. (10) and it is in directly proportional to the operating frequency and

transresistance. Hence the higher the midband frequency and gain (transresistance), the more difficult to align the amplifier.

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