BROADBAND NEGATIVE RESISTANCE OSCILLATOR CIRCUITS

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Negative resistance oscillators can perform various functions other than just fixed frequency oscillations. For example, the electronic tuning effect is commonly used to generate FM signals and the injection locking phenomenon can be utilized for FM amplification, limiting and demodulation. For fixed frequency oscillations, the oscillator resonant circuit is generally designed to have as high an external Q as possible for good frequency stability and noise performance. However, for the other applications mentioned above, relatively broadband circuits are desired. This paper discusses various factors to be considered in their design.

Let us first review the well-known behavior of a single-tuned oscillator. The equivalent circuit is shown in Fig. 1, where $-\overline{G} + j\overline{B}$ indicates the device admittance. Both $\overline{G}$ and $\overline{B}$ are functions of the amplitude A of the terminal voltage. The locus of the admittance which the device "sees" is a straight vertical line as shown in the figure on the right-hand side. The markers on the line indicate equally spaced frequencies and the arrow shows the direction of increasing frequency. In this figure, the device line $\overline{G} - j\overline{B}$ is also plotted with amplitude A as the parameter and the arrow indicates the direction of increasing A. The intersection P of the above two lines gives the operating point from which the oscillation frequency and amplitude are determined. The more crowded the frequency markers at the intersection, and the sharper the intersecting angle, the noisier the oscillator output. If either of the arrows points in the opposite direction, the intersection does not represent a stable operating point.

Now suppose that $\overline{B}$ is increased to $\overline{B} + \Delta\overline{B}$ utilizing the electronic tuning effect, then the device line moves down by $\Delta\overline{B}$ and hence the oscillator frequency deviates by

$$\Delta f = -\frac{f_o}{2Q_{ext}} \frac{\Delta\overline{B}}{G_o} . \qquad (1)$$

Next, suppose that a locking signal at frequency f_s is injected and draw a circle with center at f_s on the admittance plane and radius $2G_o\sqrt{P_s/P_o}$, where P_s and P_o represent the injected signal power and the free-running output power, respectively. If this circle intersects the device line, the oscillator is locked and the intersection on the left-hand side gives the operating point. Therefore the locking range is given by

$$\left|\frac{f_s - f_o}{f_o}\right| < \frac{1}{Q_{ext}} \sqrt{\frac{P_s}{P_o}} \sqrt{1 + \left(\frac{r}{s}\right)^2} \tag{2}$$

where s and r represent the saturation factors of the device conductance and susceptance defined by $-(A/G_o)(\partial\overline{G}/\partial A)$ and $(A/G_o)(\partial\overline{B}/\partial A)$, respectively, at the operating point.

We are now in a position to discuss a general oscillator with a multiple-tuned circuit. Suppose the admittance locus has three intersections with the device line, P_1, P_2 and P_3, as shown in Fig. 2. Of these three intersections, only P_1 and P_3 give stable operating points. If the oscillation is taking place at P_1 and the device line is gradually moved up by decreasing $\overline{B}$, then eventually the intersection P_1 disappears and the operating point jumps to P_3' in the figure. Just before the jump takes place, the oscillator becomes noisy since the angle of intersection between the admittance locus and the device line approaches zero. After the jump, if the device line is gradually moved down, another jump in the oscillation frequency will be observed. The frequency versus $\overline{B}$ clearly shows a hysteresis. During this operation, parastic oscillations may be observed at $f_o \pm \Delta f$ if three points, $\overline{G} - 1/2\, sG_o - j(\overline{B} + 1/2\, rB_o)$, $G_+ + jB_+$ and $G_- + jB_-$ happen to align on a straight line, where $G_\pm + jB_\pm$ corresponds to the circuit admittance at $f_o \pm \Delta f$. For injection locking, the distance from the point corresponding to f_s on the locus to the device line has to be less than $2G_o\sqrt{P_s/P_o}$. In addition to this, the f_s point has to be a stable operating point for the free-running oscillation (with a minor modification at the boundary between the stable and unstable regions). If f_s corresponds to such a point as P_2 in Fig. 2, phase locking does not take place. When f_s sweeps over such an unstable region, typical output spectra appear as shown in Fig. 3. Thus, we see that the admittance locus which intersects the device line more than once is not suitable for broadband applications.

To illustrate how a broadband circuit suitable for oscillator applications can be obtained, let us consider the double-tuned circuit shown in Fig. 4. For simplicity, assume that $\omega_o^{-1} = \sqrt{L_1C_1} = \sqrt{L_2C_2}$, then the admittance locus becomes Fig. 4(a), (b), (c) depending on the relative magnitudes of $Q_1 = \omega_o C_1/G_o$ and $Q_2 = \omega_o L_2 G_o$. Figure 4(a) is a suitable locus for broadband applications. Provided that Q_1 and Q_2 are not too close together, Eqs. (1) and (2) hold with Q_{ext} replaced by $Q_1 - Q_2$. This means that the external Q of an oscillator can be effectively reduced by means of a double-tuned circuit.

The above discussion can be easily extended to multiple-tuned circuits. Various design techniques developed for filters can then be utilized to obtain the desired oscillator characteristics.

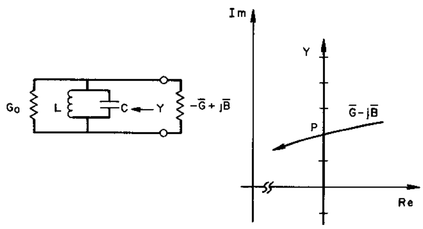


FIG 1 EQUIVALENT CIRCUIT OF A SINGLE—TUNED OSCILLATOR AND ADMITTANCE LOCUS

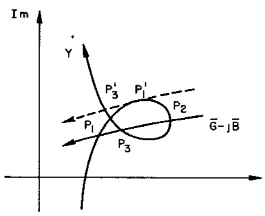


FIG 2 ADMITTANCE LOCUS OF A GENERAL MULTIPLE—TUNED OSCILLATOR

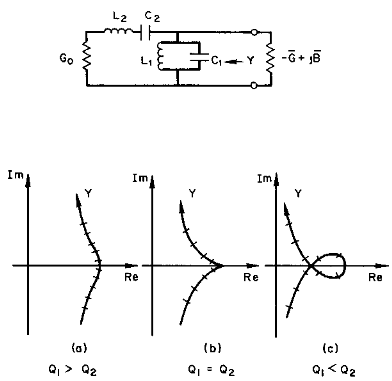
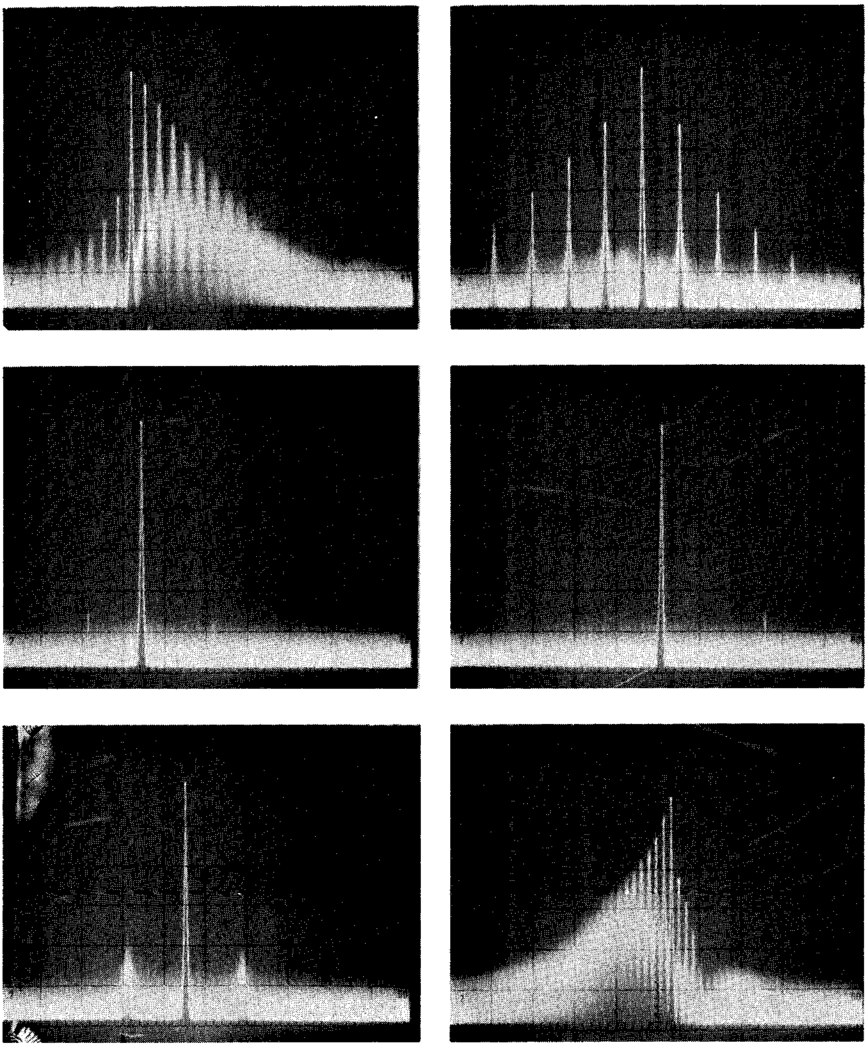


FIG 4 EQUIVALENT CIRCUIT OF A DOUBLE — TUNED OSCILLATOR AND ADMITTANCE LOCI



HORIZONTAL SCALE: 30 MHz/DIV
CENTER FREQUENCY: ≈ 9.4 GHz

FIG. 3 TYPICAL OUTPUT SPECTRA WITH INJECTION SIGNAL SWEEPING OVER UNSTABLE REGION