Experiments of RC Phase-Shift Oscillator

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1. Introduction

Positive feedback results when the feedback factor $\dot{\mu}\dot{\beta}$ is positive and less than 1, where the term $\dot{\mu}$ is called the open-loop voltage gain, and the symbol $\dot{\beta}$ is used here to denote the fractional gain of the feedback network. If $\dot{\mu}\dot{\beta}$ is increased to unity, the gain with feedback becomes theoretically infinite and the amplifier functions as an oscillator. The condition $\dot{\mu}\dot{\beta}=1$ is true at a single and precise frequency, and at this frequency the feedback signal appering at the input is exactly in phase with the input signal. If $\dot{\mu}\dot{\beta}=1$, oscillations still occur and the amplitude of oscillation increases theoretically without limit.

In actual practice, nonlinearity limits the the theoretically infinitive gain to some finite value for both $\dot{\mu}\dot{\beta}\geqq 1$.

The important characteristics of an oscillator are its frequency stability, amplitude stability, outout power, and harmonic content. And oscillators can also be classified as either negative-impedance, or feedack oscillator. But all oscillators can be regarded as negative-impedance oscillators, if we aim at only build-up of the oscillation.

The purpose of this paper is to propose new experimental results about conditions for build up oscillation using RC phase-shift oscillator.

2. Condition for Oscillation and Its Build-UP

It was pointed out, as is well known, that the oscillators must be satisfied as a condition for sustained osclillations, or $\dot{\mu}\dot{\beta}=1$. However, oscillators are theoretically designed so that $\dot{\mu}\dot{\beta}>1$ in order to ensure build-up of oscillation. Under this condition, an oscillator must build up oscillations, which maintain constant stable waveform when reaching the steady state.

Although it is possible that under consideration of minor changes in circuit or device parameters in actual practice, $\dot{\mu}\dot{\beta}$ might become larger than 1, on the assumption that the parameters have no changes, papers have never been found about what percentage $\dot{\mu}\dot{\beta}$ might become more than 1 to hold build up possility. As the result that we made, then, experiments on a RC phase-shaift oscillatory circuit of Fig. 1 in order to solve the above question, practical oscillators would

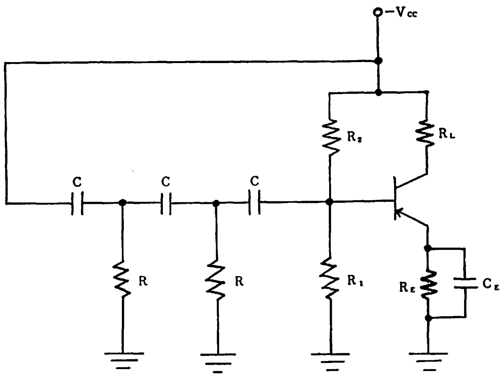

Fig. 1. Transistor phase shift or RC oscillator

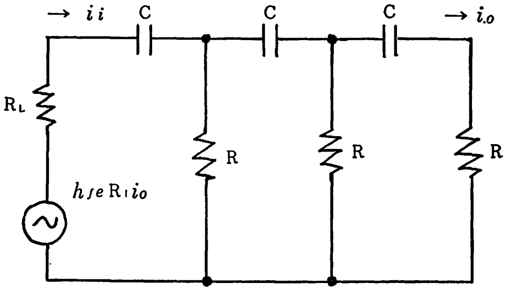

Fig. 2. Equivallent circuit of transistor RC oscillator

be designed so that $\dot{\mu}\dot{\beta}>1$ by about 5 percent.

The experiments is as follows.

First, this circuit would be driven by rectangular pulse waveform whose repetitive frequency and voltage are about 40 Hz, and 6 V, respectively. In this case, transistor being kept extremely over saturation state on account of little transistor base current flows by variable resistor connected from the base to the earth, loop gain of this circuit would almost become zero. Under these condition, sinusoidal signal whose frequency 950 Hz equals that of RC phase-shift oscillator is applied to the transistor base by external oscillator in order to seek the critical oscillatory condition. Actually the Toshiba 2SB 54 being selected as the transistor of oscillatory circuit, oscillatory frequency is 950 Hz as abovementioned.

Consequently the feedback voltage at transistor base, when this RC oscillatory circuit is self-sustaining, is 38 mV, collector output voltage is 2.23 V, and voltage amplification factor $|\dot{\mu}|\cong 60$. However, in accordance with the experimental results, base input voltage by external oscillator at critical oscillatory conditions have the value of 0.4 to 1.7 mV.

Taking the percentage as the ratio of the base input voltage at the critical oscillatory conditions to the feedback voltage to the base when the RC oscillator maintains a constant oscillatory amplitude, it is found that about from 1 to 5 %. And so if an oscillator is designed so that $\dot{\mu}\dot{\beta}=1$ at a particular frequency, $\dot{\mu}\dot{\beta}$ might become less than 1 for some reason, for example, with minor changes in device parameters, and oscillations would cease. To overcome this possibility, practical oscillators should be designed so that $\dot{\mu}\dot{\beta}>1$ by about 5 percent, on the assumption that oscillatory frequency and the fractional gain of the feedback network are constantly kept.

3. Quality Factor Q and Logarithmic Decrement δ in the Circuit

The equivalent circuit of a transistor RC phase-shift oscillator which is called a lead network is given in Fig. 2, if $R \cong R_1 \| h_{ie}$, , and $R_2 \gg R_1$,

where h_{ie} = input resistance with output short-circuited for common emitter

and so the Q in the feedback circuit can be calculated as follows;

$$Q = \frac{\omega_0}{2} \left| \frac{d\theta}{d\omega} \right|_{\omega \to \omega_0}$$

where ω_0 = the resonant frequency

θ = the phase shift between input and output

When considering output current i_0 and input current i_i, we can calculate $\dot{\beta} = i_0 / i_i$ and phase difference θ between output current and input current, they become

$$\theta = \tan^{-1} \frac{x\,(6 - x^2)}{(1 - 5x^2)}$$

$$Q = \frac{\omega_0}{2} \left| \frac{d\theta}{d\omega} \right|_{\omega \to \omega_0} = \frac{6\sqrt{6}}{29} \cong \frac{1}{2}$$

where $x = \frac{1}{\omega CR}$

As the logarithmic decrement δ when critical build-up of oscillation is found nearly 6 using oscilloscope experimentally. The quality factor Q of this circuit may be found by using next equation

$$Q = \frac{\pi}{\delta} = 0.52$$

Since it is seen that the Q of the RC phase-lead network is theoretically about 0.5, experimental value 0.52 is considerably better in checking respect. To find what percentage of increase of $\dot{\mu}\dot{\beta}$ is necessary for ensure oscillation, it may be useful to measure the frequency of the RC oscillator which must build up oscillation before reaching the steady state. The frequency at the beginning of build-up of oscillation, which is now found on the oscilloscope, is within from 870 to 900 Hz.

Consequently, taking the ratio of the frequency for the build-up to that for steady state of oscillation, it is seen to be the range from 5 to 9%. However, since above calculated result is only my suspicion, practical oscillator should be designed so that $\dot{\mu}\dot{\beta} > 1$ by about 5 percent in order to they build up oscillations.

4. Negative-Impedance Characteristics on RC Phase-Shift Oscillator

The generation of oscillation at RC phase-shift oscillllator takes place when above condition is satisfactory. It may be shown that at the instant of RC oscillator build up oscillations before reaching the steady state, which serves to supply of the negative impedance by about 5 percent of input impedsnce of oscillatory circuit. When the oscillations reach the steady state, at which each cycle of the generated waveform is identical to the preceding one by some circuit nonlinearity to define an amplitude; i. e., here the negative impedance changes into zero.

As mentioned in the previous section, oscillators can be considered both as positive feedback circuits and negative impedance circuits. Although the conception of feedback oscillatory condition can be illustrated by the phase shift around the feedback loop is 0 or 360°, it is also considered by negative impedance concepts as an aid to the understanding of the circuit application of the Esaki diode and unijunction transistor. However, there are basically two types of negative impedance characteristics a device might have. These are either short-circuit stable or open-circuit stable. The characteristics are also referred to as voltage stable and current stable, respectively. The voltage-current characterics of these types have, in at least one portion, a negative slope, which accompanied with two regions of a positive slope.

It is seen that feedback oscillatory circuits are somewhat self-regulating, since the amplitude of oscillation is controlled by the nonlinear characteristics or limiting effect.

On the other hand, we can see how the amplitude of the oscillators is governed in the type of the negative impedance oscillator. As the amplitude of swing increases, the positive impedance region will eventually be reached. When the operation swing into the region where the negative impedance no longer balances out the circuit impedance the amplitude rise will be stopped. It is the nonlinearities that limit the amplitude of this type of oscillator.

5. Difference Between RC Phase-Shift and LC Tuned Oscillator

In case of the qualitative analysis of RC feedback circuit, if the circuit can be regarded as a feedback amplifier in which the value of $\dot{\mu}\dot{\beta}$ equals unity, the system takes place self-oscillation and has a limit cycle. If the feedback theory described here is limited to small-signal analysis where equivalent circuit representation is valid, the oscillatory amplitude will being decided by the method of perturbation, the relation between the performance quantities of the system and the shape of the limit cycle will be clearly made.

If the variation of the signal which is applied to the base of the transistor satisfy only little deviations from the critical voltage amplification factor 29 to sustain oscillations at the RC phase-shift oscillator using the phase-lead feedback network, as long as the amplification factor hardly any changes over so wide range, the RC oscillator will be almost said a linear conservative system. Thus the solution of the differential equation with respect to RC phase-shift oscillator will nearly become sinusoidal waveform, if the distortion limits of the oscillatory amplitude at the base of the transistor are not too stringent. In order to understand the above condition, it is useful to consider the output voltage of RC feedback oscillator will appear at the pure resistance load for output side, therefore the output waveform precisely regenerate the collector voltage of the oscillatory transistor.

However, an LC circuit produces nearly sinusoidal waveform, even if the waveforms of collector voltage differ from sinusoidal waveform, since the LC circuit is basically an electric oscillator if the condition that $Q > 10$ is satisfied. From above considerations, we have found the thetheoretical difference between RC oscillator and LC tuned oscillator.

6. Conclusions and Remarks

As the results we have discussed, practical oscillators should be designed so that $\dot{\mu}\dot{\beta}$ is more than unity by about 5 percent in order to ensure oscillation. We made experiments on a RC phase-shift oscillatory circuit this time. According to another experimental result, taking the ratio of the build-up frequency to that for steady state of the oscillation, the percentage of the increase of $\dot{\mu}\dot{\beta}$ is seemed to be the range from 5 to 9%. However, as this result based only on my suspicion, it will be necessary to examine the proper way or not. Since this paper only says the experimental result on RC phase-shift oscillator, we should more widely experiment and examine for many other oscillators, for instance, LC tuned, crystal, and negative-resistance oscillators etc.

Acknowledgement

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