FAST AMPLITUDE STABILIZATION OF AN RC OSCILLATOR

This technique for stabilizing the output amplitude of an RC sine-wave oscillator uses a multiphase rectifier to convert the oscillator output to d.c. This voltage does not require further filtering, which results in a short amplitude settling time. An experimental circuit demonstrates the technique.

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A stable sine-wave oscillator with amplitude control usually incorporates a voltage-controlled attenuator. The d.c. input to this attenuator must have a very small ripple to avoid excessive distortion of the output waveform. If this direct voltage is derived from the usual half-wave rectifier, an extremely large filter time constant is required: the oscillator output level consequently settles very slowly. This behaviour is undesirable in low-frequency applications. Several solutions have been proposed to solve these problems, one of which has been to combine analogue and digital circuitry to use amplitude sampling[1,2] or correction to the capacitor initial conditions,[3,4]. This involves relatively complicated circuits. A more direct and simpler circuit approach is to use oscillator networks with available four-phase voltage[5] or multiphase oscillators[6] with the rectified, multiphased voltage obtained from the oscillator. The circuit proposed here also uses multiphase rectified voltages, but these voltages are obtained in a special circuit from two sinusoidal voltages shifted by 90°. The circuit consists of summing operational amplifiers.

The full circuit of the RC oscillator with the eight-phase rectifier is shown in Fig. 1. It includes an RC resonator (operational amplifiers A_1, A_2 and A_3) with the voltage-controlled attenuator (the transconductance amplifier g_m and resistors R_7 to R_8); the control circuit with the error amplifier A_4 and the two-stage multiphase rectifier (the operational amplifier A_5 to A_{10} and diodes D_1-D_8) mentioned above.

Two sinusoidal voltages V_1 and V_7 of equal amplitudes are applied to the inputs of two inverting operational amplifiers A_5 and A_6 in the first stage. At the output of this first stage we obtain four sinusoidal voltages shifted with respect to each other by 90° (Fig. 2(a)). The second stage produces eight sinusoidal voltages shifted with respect to each other by 45° (Fig. 2(b)). Here we use the fact that operational amplifier produces vector summation of the voltages applied to its inverting input. For example

$$\dot{V}_6=-\frac{1}{\sqrt{2}}\dot{V}_1-\frac{1}{\sqrt{2}}\dot{V}_3 \qquad (1)$$

where $\dot{V}_1$, $\dot{V}_3$ and $\dot{V}_6$ are phasors corresponding to v_1, v_3 and v_6.

The multiplying factor $1/\sqrt{2}$ in (1) is achieved by the special choice of the resistors connected to the operational amplifier A_{10}. Changing their values we could obtain a phase shift of $\dot{V}_6$ with respect to $\dot{V}_1$ and $\dot{V}_3$ which is different from ± 135°. Thus, in principle, we can obtain any m-phase voltage system if we have two sinusoidal voltages with phase shift different from 0° and 180°. The output voltages appear simultaneously with the input voltages and the multiphase rectifier produces the output d.c. voltage.

$$V_R=\frac{\sin \pi/m}{\pi/m}V_m$$

where V_m is the amplitude of the m-phase voltage. The multiplier $\sin\pi/m\div\pi/m$ approaches unity when m increases (for $m=8$ it is equal to 0.975). Hence, such an m-phase rectifier can be used as a unit which produces a direct voltage proportional to the oscillation amplitude and without any delay (theoretically, at least), with low harmonic content. The requirement of any additional filtering when m increases is eliminated.

The output voltage of the operational amplifier A_1 coincides in phase with V_5. We could use it and save one operational amplifier in the first stage. But the voltages V_1 and V_7 have the lowest amount of harmonics and using only these two voltages we obtain less total harmonic distortion (t.h.d.) at the oscillator output.

In the steady-state condition, the output voltage amplitude of the oscillator is determined by the equality

$$V_R=E_R$$

where E_R is the reference voltage. The amplitude control system is a Type 1 system due to the fact that an RC oscillator acts as an integrator with respect to an amplitude change[1,7] in the amplitude control system.

During the static oscillations the condition

$$g_m\frac{R_7}{R_6+R_7}=\frac{1}{R_5}$$

is satisfied.

The tranconductance g_m is determined by the d.c. control current I_c in the resistor R_8 and, for the CA 3080 transconductance amplifier which we used in our experiments,

$$g_m\approx\frac{I_c}{2V_T}$$

where V_T is threshold voltage[8] ($V_T \approx 26mV$ at 300°K). The resistors R_6 and R_7 are chosen from the condition that

$$V_7\cdot\frac{R_7}{R_6+R_7}\leqslant V_T$$

where V_7 is the amplitude of v_7. This ensures the linear operation of the transconductance amplifier. The value of R_8 was chosen in such a way that the control current I_c (in the steady state condition) is approximately equal to one half of the maximum control current allowable for linear operation. The control input (pin 5) d.c. potential is close to the negative of the power supply for CA 3080. In this case, the linear operation will be preserved for the whole output voltage range of the error amplifier A_4 and at the same time the value of R_5 will be low. As a result the displacement of poles from the $j\omega$-axis into the left

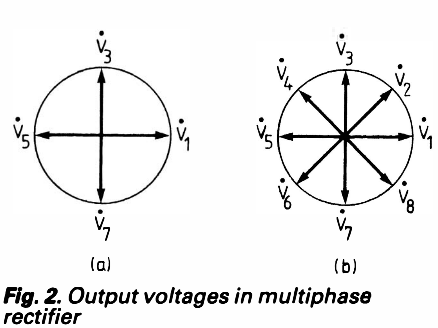

***Fig. 2.** Output voltages in multiphase rectifier*
(a) first stage
(b) second stage

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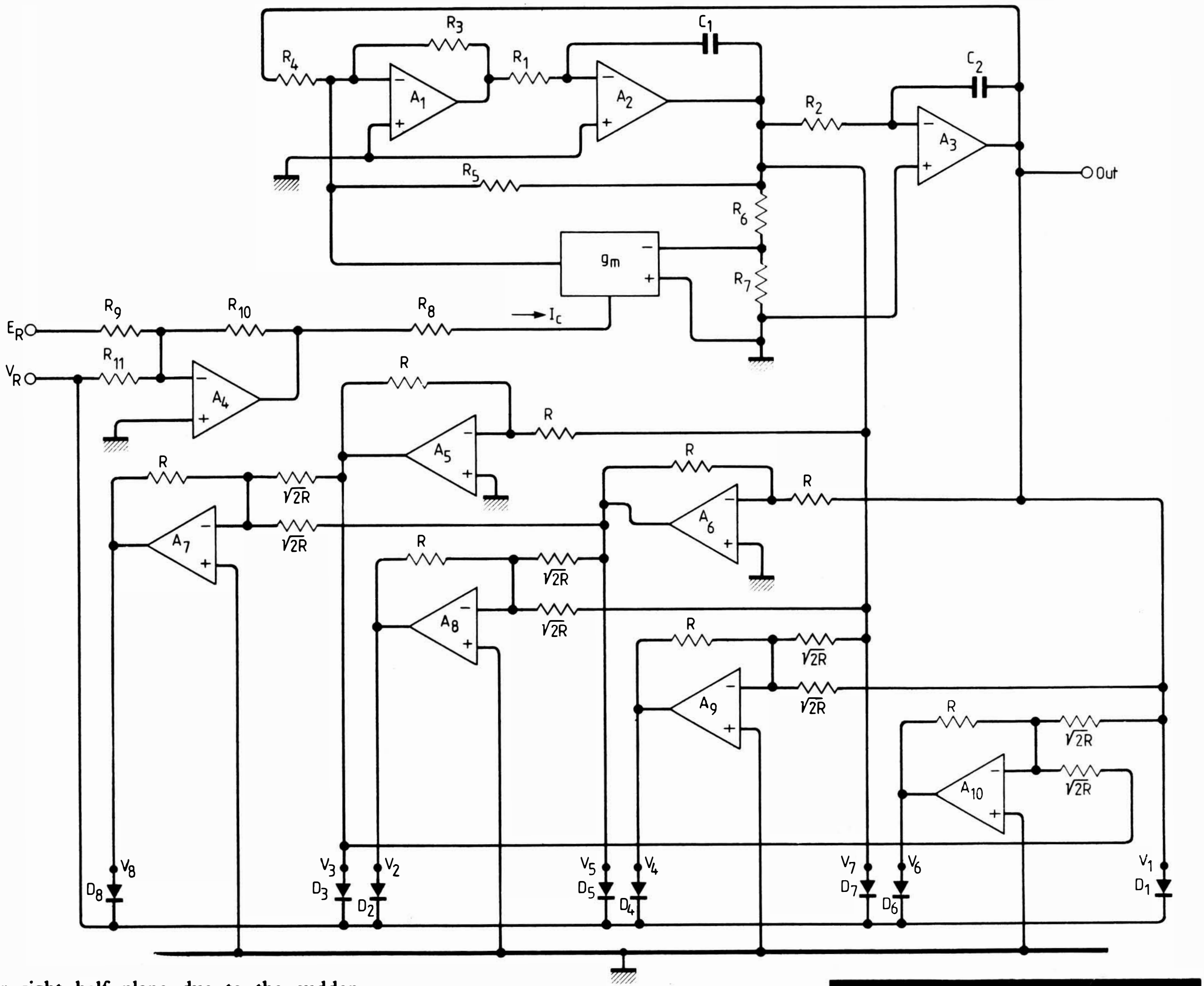

Fig. 1. RC oscillator with multiphase rectifier

or right half plane due to the sudden change in the E_R level will be maximum and the transient response duration will be shortened.

The output voltage of the multiphase rectifier includes the small ripple voltage also. The amplitude of the k-th harmonic equals

$$a_k=2V_m \cdot \frac{\sin \pi/m}{\pi/m} \cdot \frac{(-1)^{k+l}}{k^2m^2-1}$$

This ripple voltage will be amplified in A_4 and applied to the control input modulating the transconductance g_m. The approach used by Vannerson and Smith[5] allows us to calculate the output distortion voltage which consists of only two significant harmonics given by

$$v_d=\frac{1}{2}\frac{R_3}{R_8}\cdot\frac{R_{10}}{R_{11}}\cdot\frac{V_m^2}{V_T}\frac{R_7}{(R_7+R_6)}\cdot\frac{\sin \pi/m}{\pi/m}\cdot$$

$$\left[\frac{1}{(m^2-1)}\left(\frac{\cos(m-1)\omega_0}{(m-1)^2-1}+\frac{\cos(m+1)\omega_0}{(m+1)^2-1}\right)\right.$$

where ω_0 is the oscillator frequency.

In the test oscillator,

R_1, R_2, R_3, R_4 15kΩ
R_5 47kΩ, R_6 39kΩ
R_7 100Ω, R_8 33kΩ
R_9, R_{11} 75kΩ
R_{10} 220kΩ, R 15kΩ
C_1, C_2, 10nF.

For the output amplitude of $V_1=10$V, the total harmonic distortion is 0.2% approximately. Further reduction of the t.h.d. can be obtained by reducing the ratio R_{10}/R_{11}.

Figure 3 shows the transient response of this oscillator when the reference voltage E_R is modulated by a 60Hz square wave that changes from 10 to 6.6V. The transient response duration is not more than two periods of the output voltage.

If the ratio R_{10}/R_{11} is decreased to 1 (decreasing the t.h.d. to less than 0.01%) the transient response duration will increase from 2 to 5 periods which is also acceptable in many cases.

The control zone is from 0.7V (or 0.3V if we use germanium diodes) to saturation voltage of operational amplifiers.

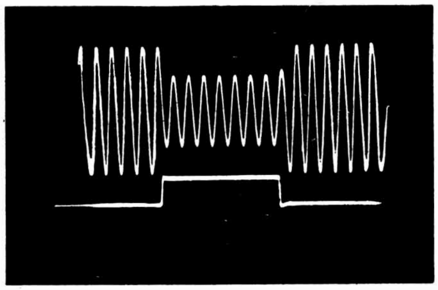

Fig. 3. Modulation of the reference voltage and the oscillator output voltage.

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