Antiphase or 180° phase shift?

A clarification

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The 180° phase difference between the signals at the base and the collector of a common-emitter amplifier is well known. Indeed many of us have been aware of it for as long as we can remember; originally, of course, we knew it as the 180° phase difference between the signal voltages at the grid and anode of a valve, but the principle is the same. It is not surprising therefore that an engineer once designed a piece of electronic equipment in which the fundamental mode of operation depended on this phase difference. The equipment did not work and at the ensuing post mortem it was discovered that a common-emitter amplifier does not introduce 180° phase shift: instead it inverts the input signal and this is a fundamentally-different process.

Fig. 1 illustrates the difference. The waveform chosen for this illustration is a sine wave together with some second harmonic. The effect of adding the harmonic is to exaggerate the peak of one half cycle of the sine wave and to flatten the peak of the other so that it is possible to distinguish one half cycle from the other. Fig. 1 shows the effect of phase shifting this signal by 180° and of inverting it. The two results are quite dissimilar waveforms showing that the two processes are fundamentally different. To facilitate comparison of the waveforms any increase in amplitude due to amplification has been ignored in this diagram and all the waveforms are shown with equal amplitudes. What has caused the confusion between 180° phase shifting and inversion is that, for a waveform which is symmetrical about the time axis, the effects give identical results; this is illustrated in Fig. 2 for a sine wave.

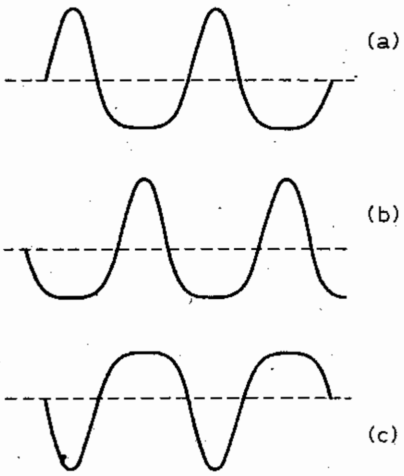

Fig. 1. The effect on an assymmetrical waveform (a), of phase-shifting it by 180° (b), and inverting it (c). Note that (b) and (c) are different.

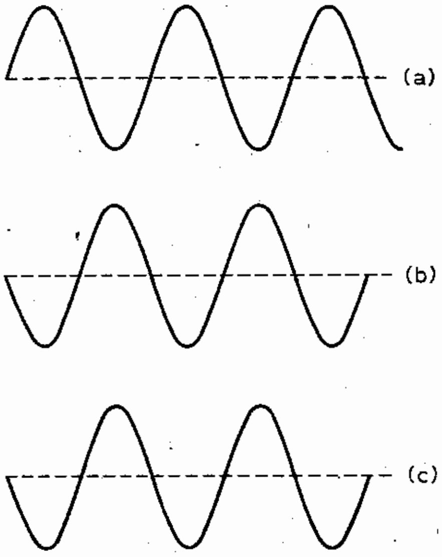

Fig. 2. The effect on a symmetrical waveform (a), of phase-shifting it by 180° (b), and inverting it (c). Note that (b) and (c) are the same.

It is surprising that the myth of the 180° phase shift introduced by a transistor or valve should ever have gained credence. The only way of introducing phase shift is by the use of combinations of reactance and resistance e.g. capacitance and resistance or inductance and resistance. An ideal transistor or valve certainly contains resistance but it has no capacitance or inductance and cannot possibly therefore introduce any phase shift. All it can do is to invert the input signal and this has nothing to do with phase shift. In fact the term "antiphase" is a little unfortunate because it suggests that the process of inverting a signal has some connection with phase. "Signal inversion" might be a better phrase than "antiphase".

To summarise then, for a wave symmetrical about the time axis the effects of 180° phase shift and of signal inversion are indistinguishable; for an asymmetric wave the two processes give quite different results.

These considerations are of importance in the design of an oscillator which can be regarded in general as a combination of a maintaining amplifier and a frequency-determining network as shown in Fig. 3. The requirements to be satisfied for oscillation to occur are: (a) that at the frequency of oscillation the frequency-determining network must introduce signal inversion which, with the inversion in the maintaining amplifier, gives the overall positive feedback which is essential for oscillation and (b) that the gain of the maintaining amplifier must exceed any attenuation in the frequency-determining network at the frequency of oscillation.

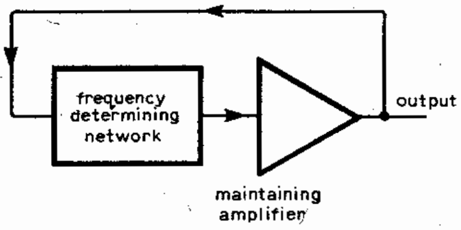

Fig. 3. A fundamental block diagram for an oscillator.

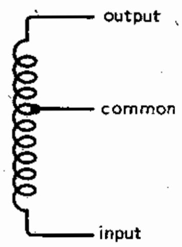

Fig. 4. A simple method of obtaining signal inversion using a tapped inductor.

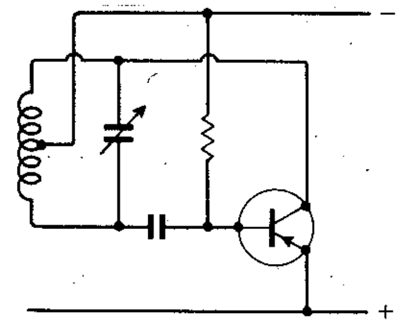

Fig. 5. A Hartley oscillator.

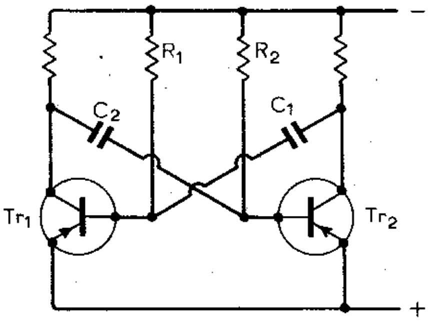

Fig. 6. An astable multivibrator circuit drawn in the conventional manner.

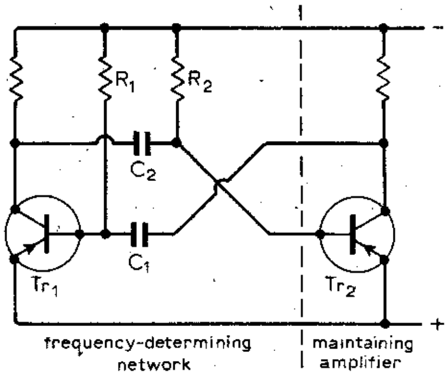

Fig. 7. The circuit of Fig. 6 re-arranged to show that it agrees with the basic form of the oscillator (Fig. 3).

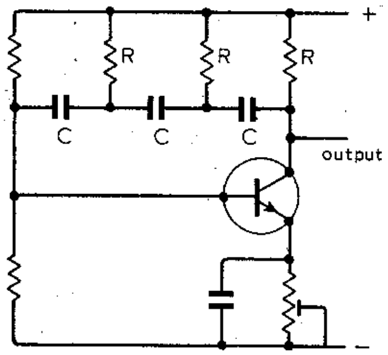

Fig. 8. An oscillator which relies on phase shift in the R-C filter for its operation.

The frequency-determining network must then give signal inversion at the oscillation frequency. One simple way of achieving signal inversion is by the use of a tapped inductor as shown in Fig. 4 and this can be tuned by a parallel-connected capacitor to give operation at a particular wanted frequency. By adding a common-emitter circuit as maintaining amplifier we obtain the familiar circuit of the Hartley oscillator shown in Fig. 5. In a similar way, by tapping the capacitive branch of a resonant circuit to obtain signal inversion, the Colpitts' oscillator circuit can be derived.

Any type of frequency-determining network can be used, and oscillation will result, provided the two conditions set out above are fulfilled. Thus a common-emitter amplifier can be used as a frequency-determining network. It introduces the necessary signal inversion but there is no attenuation. Instead there is usually considerable voltage and current gain at the frequency of operation and this, together with the gain of the maintaining amplifier, means that there is an excess of positive feedback — far more than is necessary just to sustain oscillation. As a result the oscillation amplitude grows rapidly until it is limited on one extreme by collector-current cut off and on the other extreme by the collector voltage falling to base potential and so applying a low-resistance shunt across the circuit. In other words this particular oscillator generates rectangular waves; it is, of course, a multivibrator and because of the symmetry of the circuit either transistor can be regarded as the maintaining amplifier or frequency determining network. The circuit diagram is shown in its familiar form in Fig. 6 but if it is recast as in Fig. 7 it is easier to visualise the circuit as a combination of maintaining amplifier and frequency-determining network. The components R_1C_1 and R_2C_2 are chiefly responsible for determining the free-running frequency which is given approximately by

$$f=\frac{1}{0.7(R_1C_1+R_2C_2)}$$

So far in this discussion on oscillators it has not been necessary to mention the word "phase" but there is a type of oscillator in which the frequency-determining network operates by introducing phase shift. This is a workable solution if a symmetrical signal is being generated because, as shown in Fig. 2, for such signals the effect of 180° phase shift and signal inversion are indistinguishable. Thus in one form of phase-shift oscillator the frequency-determining network consists of a three-stage RC filter each section of which introduces 60° phase shift at the required frequency of oscillation. The circuit diagram is given in Fig. 8. If all three frequency-determining resistors have the same value R and all three frequency-determining capacitors have the same value C, the oscillation frequency is given by

$$f=\frac{1}{2\pi\sqrt{6RC}}$$

and the current attenuation at this frequency is 29. The current gain of the transistor must hence exceed 29 for oscillation to occur but it should not greatly exceed this value, otherwise the oscillation amplitude will grow as in the multivibrator circuit and, if it is limited by circuit features such as collector-current cut off, the output will no longer be sinusoidal. As shown in Fig. 8 a preset resistor in the emitter circuit can be used to adjust the current gain to the critical value which gives a sine-wave output, but a system of a.g.c. which keeps the maintaining transistor operating in class A is perhaps the best method of securing a pure output waveform.

Sixty Years Ago

The tremendous transmission distances nonchalantly achieved by Marconi operators and the commonplace use of wireless in military form might tend to obscure the fact that communication was still, in 1916, chiefly telegraphic, using spark-gap oscillation generators. A review article in June 1916 covered the field of such generators and was one of the earliest articles to fully explain the valve oscillator, to be used for the transmission of speech.

"In 1884 Edison showed that an incandescent filament of carbon (such as a lamp filament) possesses the property of ionising the surrounding air, so that it becomes a unilateral conductor.

"This property has been turned to practical utility by Dr Fleming and others, and forms the basis of the well-known Fleming oscillation valves which are now often used as wireless detectors. Some of these values have characteristics (ie volt-ampere curves) which at some point are negative, like an arc characteristic, and hence it is possible to use such valves as generators of oscillations just as the arcs can be so used.

"The mode of operation of this type of apparatus may be briefly summarised as follows: The hot filament has the property of emitting negative electrons, and hence the combination of hot filament and cold plate in an exhausted vessel forms an electrical conductor, which will allow current to flow in one direction only — that is to say, it is a unilateral conductor, and therefore will exert a rectifying action on an alternating P.D. applied to it. Since the current passing through this vacuous space is carried by a stream of moving electrons, and since an electron is merely a negative electric charge, it is evident that the motion of the electrons can be influenced either by an electro-static or by a magnetic field, . . ."