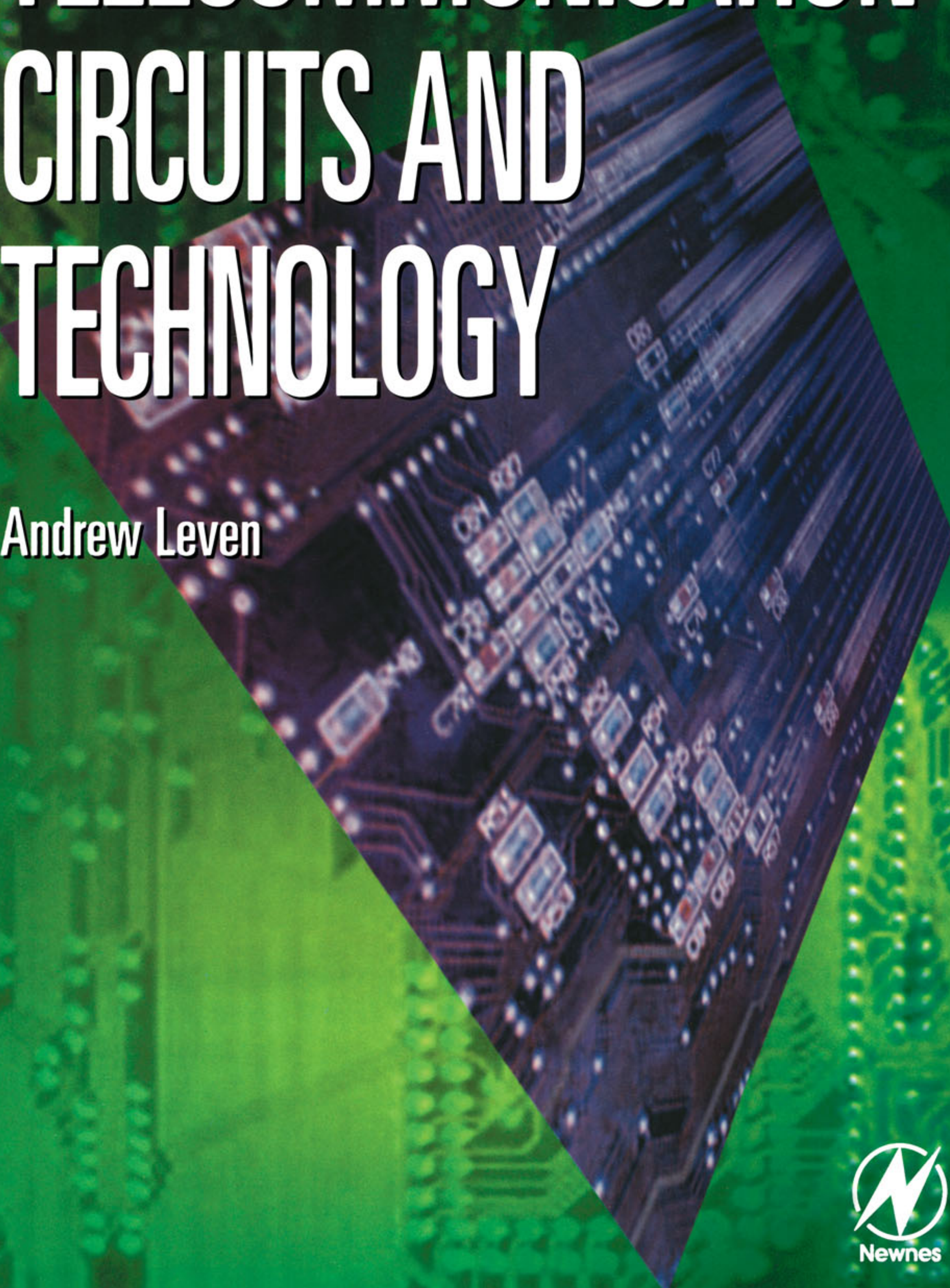
TELECOMMUNICATION CIRCUITS AND TECHNOLOGY

Andrew Leven



Newnes

Telecommunication Circuits and Technology

This Page Intentionally Left Blank

Telecommunication Circuits and Technology

Andrew Leven
BSc (Hons), MSc, CEng, MIEE, MIP

BUTTERWORTH
HEINEMANN
OXFORD AUCKLAND BOSTON JOHANNESBURG MELBOURNE NEW DELHI

Butterworth-Heinemann
Linacre House, Jordan Hill, Oxford OX2 8DP
225 Wildwood Avenue, Woburn, MA 01801-2041
A division of Reed Educational and Professional Publishing Ltd

A member of the Reed Elsevier plc group

First published 2000

While the author has attempted to mention all parties, if we have failed to acknowledge use of information or product in the text, our apologies and acknowledgement.

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN 0 7506 5045 1

Typeset in 10/12pt Times by Replika Press Pvt Ltd,
Delhi 110 040, India
Printed and bound by MPG Books, Bodmin Cornwall

To my wife Lorna and the siblings, Roddy, Bruce, Stella and Russell.
They have all inspired me

This Page Intentionally Left Blank

Contents

This Page Intentionally Left Blank

1

Oscillators

1.1 Introduction

Communication systems consist of an input device, transmitter, transmission medium, receiver and output device, as shown in Fig. 1.1. The input device may be a computer, sensor or oscillator, depending on the application of the system, while the output device could be a speaker or computer. Irrespective of whether a data communications or telecommunications system is used, these elements are necessary.

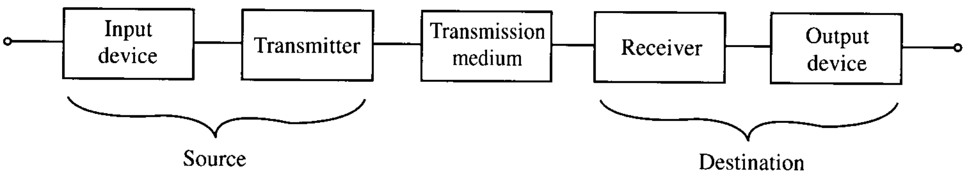


Fig. 1.1

The source section produces two types of signal, namely the information signal, which may be speech, video or data, and a signal of constant frequency and constant amplitude called the carrier. The information signal mixes with the carrier to produce a complex signal which is transmitted. This is discussed further in Chapter 2.

The destination section must be able to reproduce the original information, and the receiver block does this by separating the information from the carrier. The information is then fed to the output device.

The transmission medium may be a copper cable, such as a co-axial cable, a fibre-optic cable or a waveguide. These are all guided systems in which the signal from the transmitter is directed along a solid medium. However, it is often the case with telecommunication systems that the signal is unguided. This occurs if an antenna system is used at the output of the transmitter block and the input of the receiver block.

Both the transmitter block and the receiver block incorporate many amplifier and processing stages, and one of the most important is the oscillator stage. The oscillator in the transmitter is generally referred to as the master oscillator as it determines the channel at which the transmitter functions. The receiver oscillator is called the local oscillator as it produces a local carrier within the receiver which allows the incoming carrier from the transmitter to be modified for easier processing within the receiver.

Figure 1.2 shows a radio communication system and the role played by the oscillator. The master oscillator generates a constant-amplitude, constant-frequency signal which is used to carry the audio or intelligence signal. These two signals are combined in the modulator, and this stage produces an output carrier which varies in sympathy with the audio signal or signals. This signal is low-level and must be amplified before transmission.

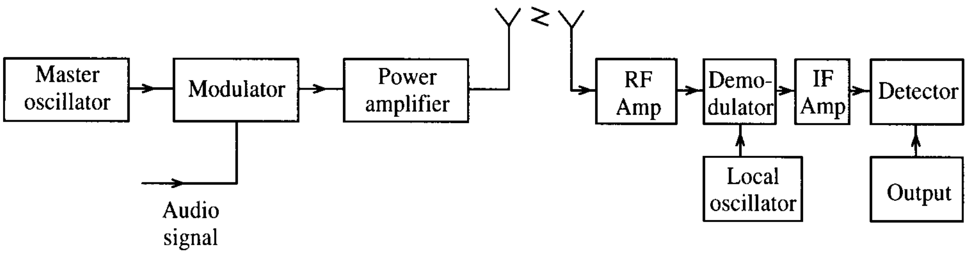


Fig. 1.2

The receiver amplifies the incoming signal, extracts the intelligence and passes it on to an output transducer such as a speaker. The local oscillator in this case causes the incoming radio frequency (RF) signals to be translated to a fixed lower frequency, called the intermediate frequency (IF), which is then passed on to the following stages. This common IF means that all the subsequent stages can be set up for optimum conditions and do not need to be readjusted for different incoming RF channels. Without the local oscillator this would not be possible.

It has been stated that an oscillator is a form of frequency generator which must produce a constant frequency and amplitude. How these oscillations are produced will now be explained.

1.2 The principles of oscillation

A small signal voltage amplifier is shown in Fig. 1.3.

In Fig. 1.3(a) the operational amplifier has no external components connected to it and

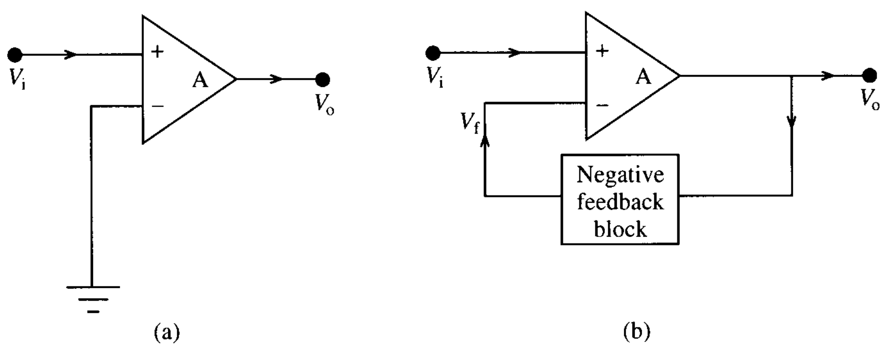


Fig. 1.3

the signal is fed in as shown. The operational amplifier has an extremely high gain under these circumstances and this leads to saturation within the amplifier. As saturation implies working in the non-linear section of the characteristics, harmonics are produced and a ringing pattern may appear inside the chip. As a result of this, a square wave output is produced for a sinusoidal input. The amplifier has ceased to amplify and we say it has become unstable. There are many reasons why an amplifier may become unstable, such as temperature changes or power supply variations, but in this case the problem is the very high gain of the operational amplifier.

Figure 1.3(b) shows how this may be overcome by introducing a feedback network between the output and the input. When feedback is applied to an amplifier the overall gain can be reduced and controlled so that the operational amplifier can function as a linear amplifier. Note also that the signal fedback has a phase angle, due to the inverting input, which is in opposition to the input signal (V_i).

Negative feedback can therefore be defined as the process whereby a part of the output voltage of an amplifier is fed to the input with a phase angle that opposes the input signal. Negative feedback is used in amplifier circuits in order to give stability and reduced gain. Bandwidth is generally increased, noise reduced and input and output resistances altered. These are all desirable parameters for an amplifier, but if the feedback is overdone then the amplifier becomes unstable and will produce a ringing effect.

In order to understand stability, instability and its causes must be considered. From the above discussion, as long as the feedback is negative the amplifier is stable, but when the signal feedback is **in phase** with the input signal then positive feedback exists. Hence positive feedback occurs when the total phase shift through the operational amplifier (op-amp) and the feedback network is 360° (0°). The feedback signal is now in phase with the input signal (V_i) and oscillations take place.

1.3 The basic structure and requirements of an oscillator

Any oscillator consists of three sections, as shown in Fig. 1.4.

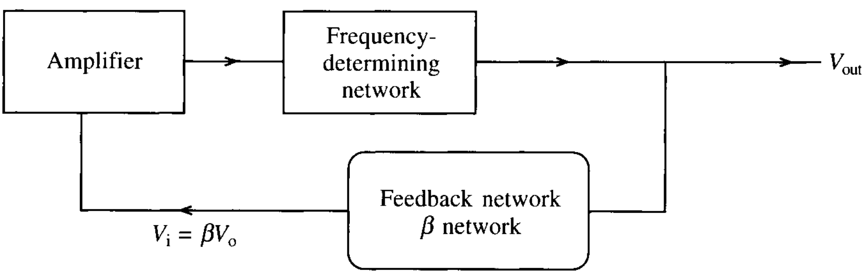


Fig. 1.4

The frequency-determining network is the core of the oscillator and deals with the generation of the specified frequency. The desired frequency may be generated by using an inductance–capacitance (*LC*) circuit, a resistance–capacitance (*RC*) circuit or a piezo-electric crystal. Each of these networks produces a particular frequency depending on the values of the components and the cut of the crystal. This frequency is known as the

resonant or **natural frequency** of the network and can be calculated if the values of components are known.

Each of these three different networks will produce resonance, but in quite different ways. In the case of the *LC* network, a parallel arrangement is generally used which is periodically fed a pulse of energy to keep the current circulating in the parallel circuit. The current circulates in one direction and then in the other as the magnetic and electric fields of the coil and capacitor interchange their energies. A constant frequency is therefore generated.

The *RC* network is a **time-constant** network and as such responds to the charge and discharge times of a capacitor. The frequency of this network is determined by the values of *R* and *C*. The capacitor and resistor cause phase shift and produce positive feedback at a particular frequency. Its advantage is the absence of inductances which can be difficult to tune.

For maximum stability a crystal is generally used. It resonates when a pressure is applied across its ends so that mechanical energy is changed to electrical energy. The crystal has a large *Q* factor and this means that it is highly selective and stable.

The amplifying device may be a bipolar transistor, a field-effect transistor (FET) or operational amplifier. This block is responsible for maintaining amplitude and frequency stability and the correct d.c. bias conditions must apply, as in any simple discrete amplifier, if the output frequency has to be undistorted. The amplifier stage is generally class C biased, which means that the collector current only flows for part of the feedback cycle (less than 180° of the input cycle).

The feedback network can consist of pure resistance, reactance or a combination of both. The feedback factor (β) is derived from the output voltage. It is as well to note at this point that the product of the feedback factor (β) and the open loop gain (A) is known as the loop gain. The term **loop gain** refers to the fact that the product of all the gains is taken as one travels around the loop from the amplifier input, through the amplifier and through the feedback path. It is useful in predicting the behaviour of a feedback system. Note that this is different from the **closed-loop gain** which is the ratio of the output voltage to the input voltage of an amplifier.

When considering oscillator design, the important characteristics which must be considered are the range of frequencies, frequency stability and the percentage distortion of the output waveform. In order to achieve these characteristics two necessary requirements for oscillation are that the loop gain (βA) must be unity and the loop phase shift must be zero.

Consider Fig. 1.5. We have

$$V_f = \beta V_o = -\beta A_V \cdot V_i$$

but

$$V_f = V_i$$

therefore

$$V_i = -\beta A_V \cdot V_i$$

or

$$V_i(1 + \beta A_V) = 0$$

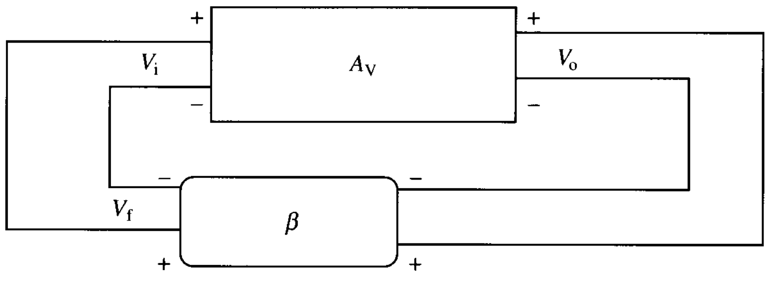


Fig. 1.5

since

$$V_i = 0$$

or

$$1 + \beta A_V = 0$$

then we have

$$\beta A_V = -1 + j0 \tag{1.1}$$

Thus the requirements for oscillation to occur are:

(i) $A_V = 1$.

(ii) The phase shift around the closed loop must be an integral multiple of 2π, i.e. 2π, 4π, 6π, etc.

These requirements constitute the Barkhausen criterion and an oscillating amplifier self-adjusts to meet them.

The gain must initially provide $\beta A_V > 1$ with a switching surge at the input to start operation. An output voltage resulting from this input pulse propagates back to the input and appears as an amplified output. The process repeats at greater amplitude and as the signal reaches saturation and cut-off the average gain is reduced to the level required by equation (1.1).

If $\beta A_V > 1$ the output increases until non-linearity limits the amplitude. If $\beta A_V < 1$ the oscillation will be unable to sustain itself and will stop. Thus $\beta A_V > 1$ is a necessary condition for oscillation to start. $\beta A_V = 1$ is a necessary condition for oscillation to be maintained.

There are many types of oscillator but they can be classified into four main groups: resistance–capacitance oscillators; inductance–capacitance oscillators; crystal oscillators; and integrated circuit oscillators. In the following sections we look at each of these types in turn.

1.4 *RC* oscillators

There are three functional types of *RC* oscillator used in telecommunications applications: the phase-shift oscillator; the Wien bridge oscillator; and the twin-T oscillator.

Phase-shift oscillators

Figure 1.6 shows the phase-shift oscillator using a bipolar junction transistor (BJT). Each of the *RC* networks in the feedback path can provide a maximum phase shift of almost 60°. Oscillation occurs at the output when the *RC* ladder network produces a 180° phase shift. Hence three *RC* networks are required, each providing 60° of phase shift. The transistor produces the other 180°. Generally $R_5 = R_6 = R_7$ and $C_1 = C_2 = C_3$.

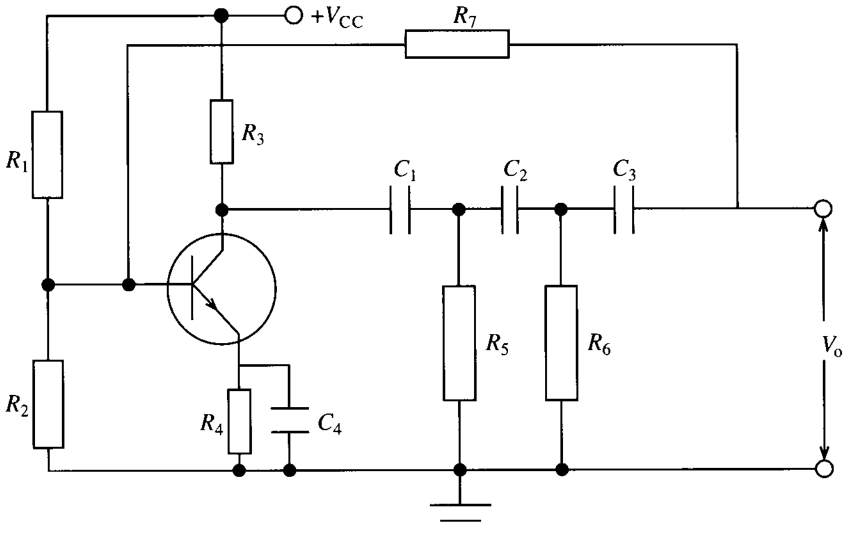


Fig. 1.6

The output of the feedback network is shunted by the low input resistance of the transistor to provide voltage–voltage feedback.

It can be shown that the closed-loop voltage gain should be $A_V = 29$. Hence

$$\beta = \frac{1}{29} \tag{1.2}$$

Also the oscillatory frequency is given as

$$f = \frac{1}{2\pi RC\sqrt{6 + \dfrac{4R_3}{R}}} \tag{1.3}$$

The derivation of this formula, as with other formulae in this section, is beyond the requirement of this book and may be found in any standard text. The application of the formula is important in simple design.

Exactly the same circuit as Fig. 1.6 may be used when the active device is an FET. As before the loop gain $A_V = 29$ but the frequency, because of the high input resistance of the FET, is now given by

$$f = \frac{1}{2\pi CR\sqrt{6}} \tag{1.4}$$

Figure 1.7 shows the use of an op-amp version of this type of oscillator. Formulae (1.2) and (1.4) apply in this design.

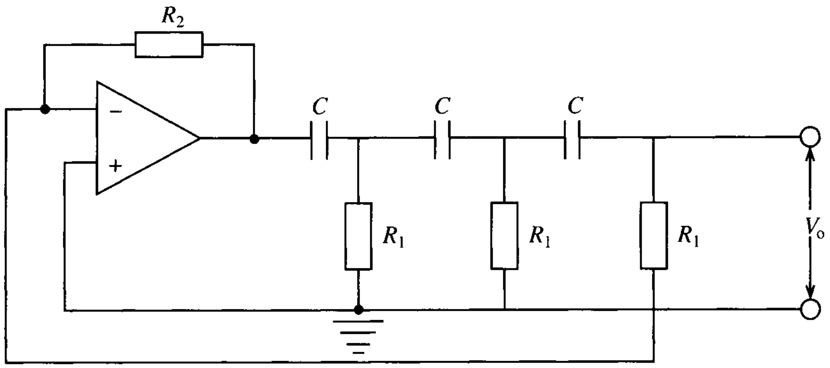


Fig. 1.7

One final point should be mentioned when designing a phase-shift oscillator using a transistor. It is essential that the h_{fe} of the transistor should have a certain value in order to ensure oscillation. This may be determined by using an equivalent circuit and performing a matrix analysis on it. However, for the purposes of this book the final expression is

$$h_{fe} > 4\left(\frac{R_3}{R}\right) + 23 + 29\left(\frac{R}{R_3}\right) \qquad (1.5)$$

Example 1.1
A phase-shift oscillator is required to produce a fixed frequency of 10 kHz. Design a suitable circuit using an op-amp.

Solution

$$f = \frac{1}{2\pi C R_1 \sqrt{6}}$$

Select $C = 22$ nF. Rearranging as expression for f, we obtain

$$R_1 = \frac{1}{2\pi C f \sqrt{6}} = \frac{1}{2\pi \times 22 \times 10^{-9} \times 10^4 \times \sqrt{6}} = 295.3\ \Omega$$

As this value is critical in this type of oscillator, a potentiometer should be used and set to the required value. Since

$$A = \frac{R_2}{R_1} = 29$$

$$R_2 = AR_1 = 29 \times 295.3 = 8.56\ \text{k}\Omega$$

A value slightly greater than this should be chosen to ensure oscillation.

Wien bridge oscillator

This circuit (Fig. 1.8) uses a balanced bridge network as the frequency-determining network. R_2 and R_3 provide the gain which is

$$A_V = 3 \tag{1.6}$$

The frequency is given by

$$f = \frac{1}{2\pi RC} \tag{1.7}$$

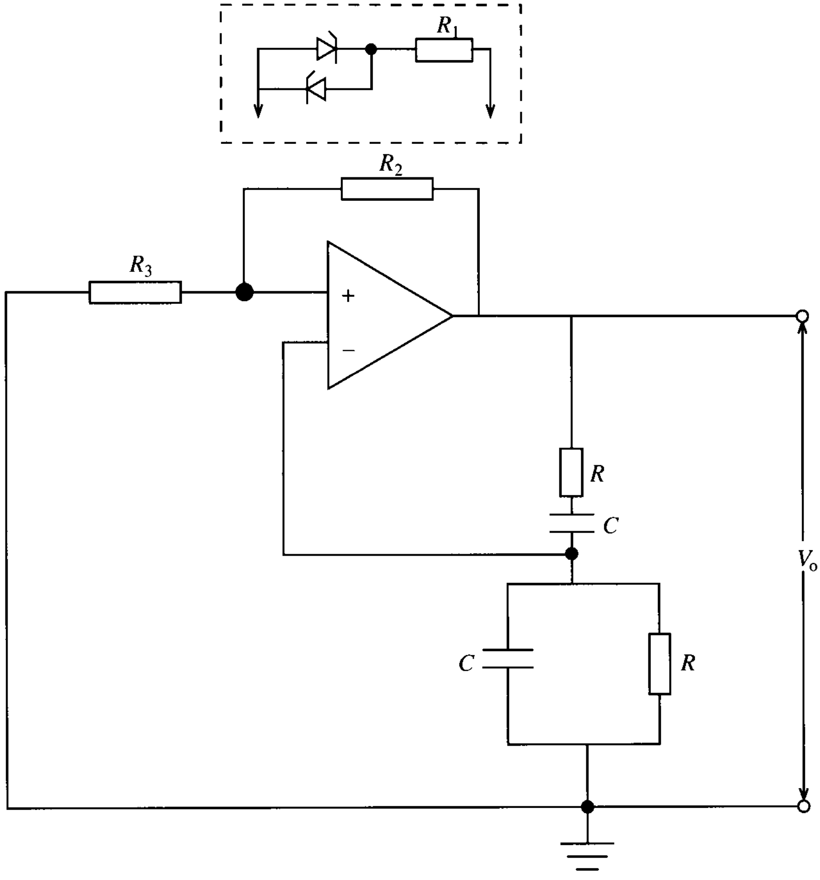


Fig. 1.8

The following points should be noted about this oscillator:

(i) R and C may have different values in the bridge circuit, but it is customary to make them equal.

(ii) This oscillator may be made variable by using variable resistors or capacitors.

(iii) If a BJT or FET is used then two stages must be used in cascade to provide the 360° phase shift between input and output.

(iv) The amplitude of the output waveform is dependent on how much the loop gain $A\beta$ is greater than unity. If the loop gain is excessive, saturation occurs. In order to prevent this, the zener diode network shown in Fig. 1.8 should be connected across R_2.

(v) The closed loop gain must be 3.

Example 1.2

A Wien bridge oscillator has to operate at 10 kHz. The diagram is shown in Fig. 1.9. A diode circuit is used to keep the gain between 2.5 and 3.5. Calculate all the components if a 311 op-amp is used.

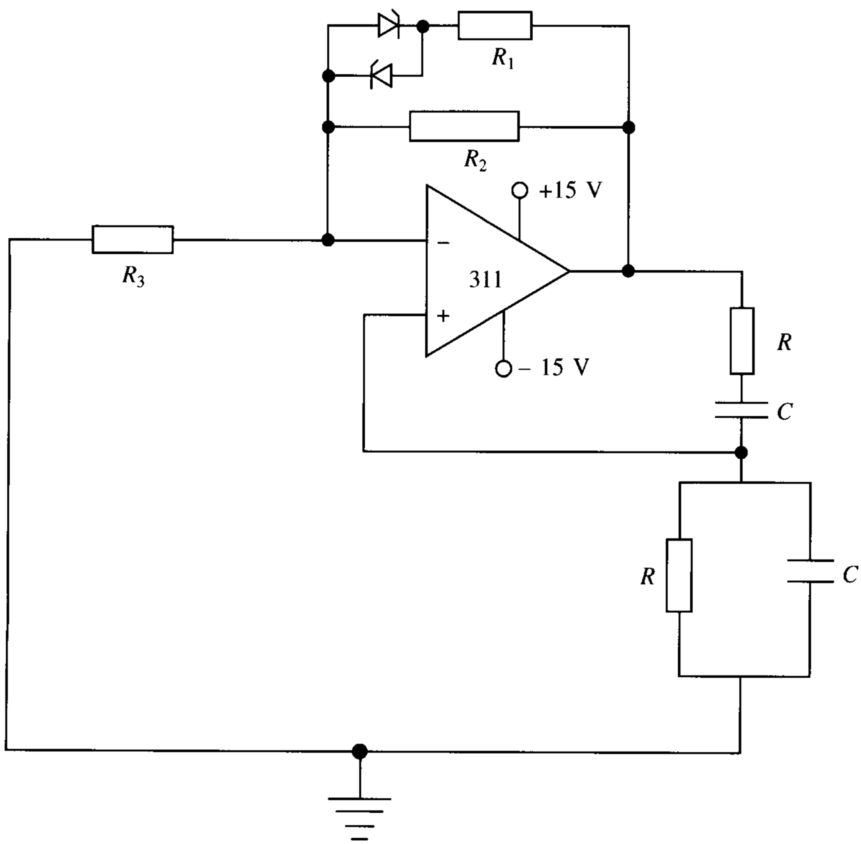


Fig. 1.9

Solution

When the op-amp is operating with a gain of 3, R_2 and R_3 may be calculated by using

$$A_V = 1 + \frac{R_2}{R_3}$$

However, for practical purposes this gain is dependent on the current flowing through R_2 and this should be very much larger than the maximum bias current, say 2000 times. The