

The optoelectronic rangefinder described here was originally developed for film cameras. A connected control circuit then had to set the appropriate focal distance automatically for the measured distance of the subject. For the circuits described below, after appropriate modifications, there are numerous other possible applications. To mention one further application, for example, a highly-sensitive proximity switch in alarm systems. This equipment can equally well be used as a highly-accurate level detector in silos or tanks, while it should be emphasised, that the measurement takes place without contact with the contents.

### 23.1

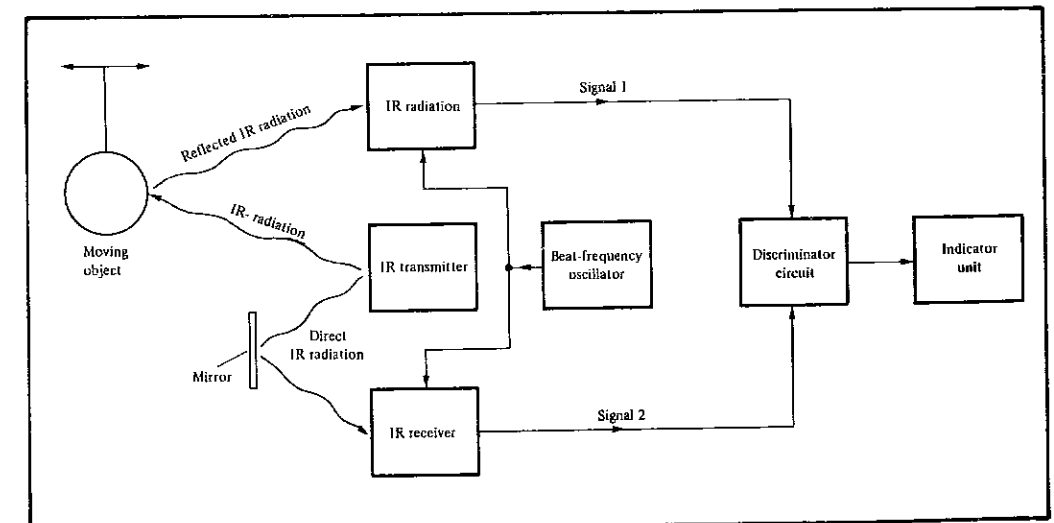
#### Phase measurement as a measuring principle

This short-range rangefinder, the principle of which is illustrated in *Figure 23.1*, is suitable for measuring the distance from fixed and moving objects in the range from 1 m to 15 m. The phase-measurement principle is applied. The emitter delivers

modulated infra-red radiation, which is optically focussed onto the object. The radiation is modulated with a crystal-controlled oscillator with an accurate frequency of 4433 kHz (this frequency was chosen, because low-priced crystals are available). As the IR source, a GaAs luminescence diode is used.

In the IR receiver, which forms part of a fixed assembly with the source, the IR radiation is first demodulated, to recover the modulation frequency. A fast-acting Si photodiode serves as the photodetector. According to the propagation time of the IR beam, the distance travelled by which is equal to twice the distance  $r$  to the object, the received signal shows a lagging phase displacement  $\varphi$ . Since, through the relationship with the velocity of light,  $c$ ,  $\varphi$  is proportional to  $r$ , the measurement of the distance  $r$  can be obtained directly from the measurement of  $\varphi$ .

$$\text{For the propagation time: } t = 2 \frac{r}{c} \quad (23.1)$$



*Figure 23.1*  
Construction principle of an optoelectronic rangefinder

and for the phase displacement:

$$\varphi = 2\pi f \cdot t \quad (23.2)$$

$$\text{Therefore: } \varphi = \frac{4\pi r \cdot f}{c} \quad (23.3)$$

At a frequency of 4.433 MHz and a distance of 10 m, the phase displacement obtained is:

$$\begin{aligned} \varphi &= \frac{4\pi \cdot 10 \text{ m} \cdot 4.433 \cdot 10^6 \text{ s}^{-1}}{3 \cdot 10^8 \text{ ms}^{-1}} \\ &= 0.5911 \cdot \pi = \varphi = 106^\circ \end{aligned} \quad (23.4)$$

Because of the circuit selected, phase measurement is possible up to an angle  $\varphi = \pi$  ( $\cong 180^\circ$ ). At a frequency of 4.433 MHz, the maximum measurable distance  $r_{\text{max}}$  is then

$$\begin{aligned} r_{\text{max}} &= \frac{\varphi \cdot c}{4\pi \cdot f} = \frac{\pi \cdot 3 \cdot 10^8 \text{ ms}^{-1}}{4\pi \cdot 4.433 \cdot 10^6 \text{ s}^{-1}} \\ &= 16.9 \text{ m} \end{aligned} \quad (23.5)$$

The measured result is completely independent of the signal amplitude. The signal received by the photodetector and then demodulated is amplified, so that phase comparison with the modulation signal is possible. At the same time, exact measurement of the phase displacement is only possible, if the stability of the circuit fulfils strict requirements.

By using the method, which is often used in phase meters, of superimposing an auxiliary frequency from a second oscillator, the received electrical signal is transposed to a lower frequency while retaining the same phase displacement  $\varphi$ . For reasons of stability, this beat-frequency oscillator is also a quartz crystal oscillator. Its frequency is 80 Hz higher than that of the transmitter. A difference frequency of 80 Hz is then formed in the mixer stage. Following the mixer stage, this low frequency is amplified further with relatively simple low-frequency amplifiers and is freed of interfering noise

components with non-critical and economical RC filters. To improve the interference rejection further, the signal is limited in its amplitude in subsequent limiter stages. This is permissible, because the distance information is present in the time-displacement of the zero crossing point voltage of the signal and not in its amplitude. Simple and cheap transistor circuits are adequate for limiting, while, because of the low frequency used, the transistor storage time does not yet have an interfering effect.

Furthermore, through the frequency conversion from 4.433 MHz to 80 Hz, the system accuracy is significantly increased. A phase difference which is still detectable, of  $\Delta\varphi = \pm 1/4^\circ$  at 80 Hz corresponds, from equation (23.2), to a time displacement of

$$\begin{aligned} \Delta t &= \frac{\Delta\varphi}{360^\circ \cdot f} \\ \Delta t &= \pm \frac{1}{4 \cdot 360 \cdot 80 \text{ s}^{-1}} \approx \pm 8.6 \mu\text{s} \end{aligned} \quad (23.6)$$

Since the phase displacement is carried over in the frequency transposition, it corresponds to a change in the propagation time of the high-frequency signal of

$$\Delta t = \pm \frac{1}{4 \cdot 360 \cdot 5 \cdot 10^6 \text{ s}^{-1}} \approx \pm 138.8 \text{ ps} \quad (23.7)$$

According to equation (23.1), this change in propagation time is equal to a range tolerance of

$$\begin{aligned} r &= \pm \frac{138.8 \cdot 10^{-12} \text{ s} \cdot 3 \cdot 10^8 \text{ ms}^{-1}}{2} \\ &\approx \pm 2 \cdot 10^{-2} \text{ m} \end{aligned} \quad (23.8)$$

In order that the phase comparison can be carried out with at least the same accuracy, a reference signal with good time stability must be available.

Figure 23.2 shows the block diagram of the rangefinder. Through the circuit selected, a reference signal of high stability is produced. Two IR receivers of identical construction are used. Each receiver has a photodetector at its input. The IR radiation from the transmitter is directed through an optical lens system on to the object to be measured and is fed, as the reflected component, delayed by the propagation time, to the IR receiver 1. In front of the photodetector, this also has a lens system with a narrowly focussed radiation characteristic, directed at the target. A small part of the transmitter radiation is taken off before or after the transmitter lens system and fed by a short, direct path to the IR receiver 2. This can be done by deflection of the beam at the inner wall of the equipment housing or by a small reflecting mirror.

This method with two IR receivers eliminates the effect of interfering phase shifts in the stages of the transmitter, since the paths of the signals for receivers 1 and 2 pass through identically-constructed stages and have the same phase shift.

The signal photocurrent from the photodiode and the original current from the beat-frequency oscillator meet at the HF band-pass and pass together through the HF amplifier to the mixer stage, in which the product of mixing – the difference frequency – is produced. Since the two frequencies have little difference between them, the effect of phase shift on both signals is practically equal, so that the low-frequency signal is formed without a recognisable phase error. Since the following LF amplifiers are of similar construction, residual phase displacements, which may occur in the RC band-passes and in the LF amplifier, cancel each other out between signals 1 and 2.

The last assembly in the rangefinder is the discriminator circuit. This has the function of an exclusive-OR gate. As shown in the truth table

Signal 1	Signal 2	Output
L	L	L
L	H	H
H	H	L
H	L	H

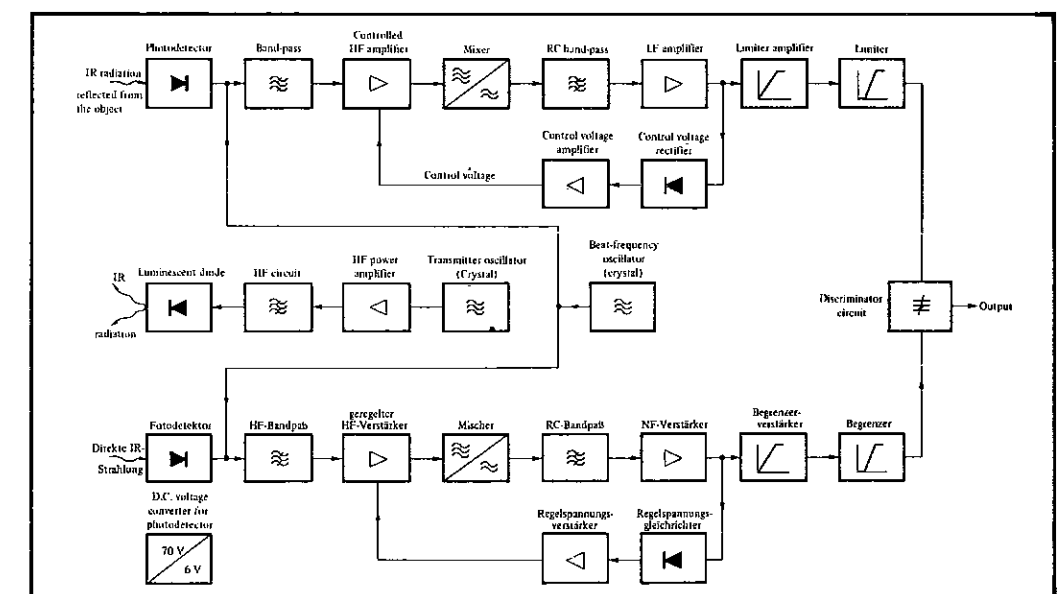


Figure 23.2  
Block diagram of the rangefinder

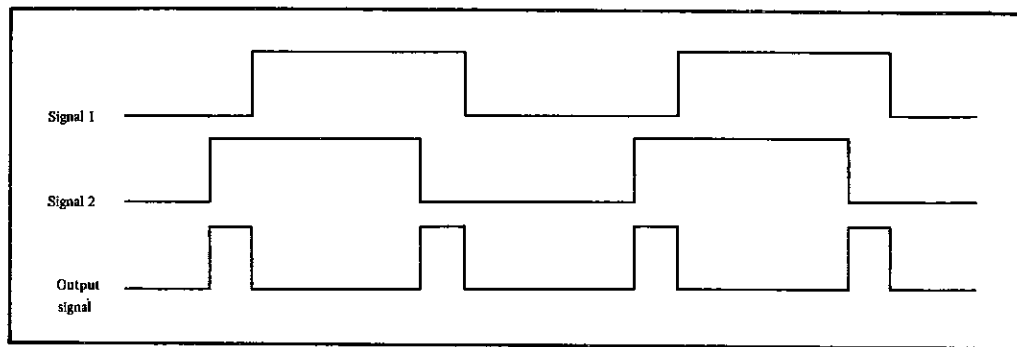


Figure 23.3  
Phase comparison of the two received signals

a high level signal appears at the output, whenever the signals 1 and 2 are different from one another. Figure 23.3 shows two signals 1 and 2, limited to square-wave form, while signal 1 has a phase delay in relation to signal 2. The output signal shown below has a pulse width which is equal to the time displacement between signals 1 and 2. Both rising and falling edges are used to form the output signal. For this reason, the maximum phase displacement which can be evaluated is  $180^\circ$ . The relationship between the output pulse width and the distance is linear.

An appropriately calibrated moving coil instrument can indicate the distance directly in metres. By integration with an RC

network, an analogue voltage, the value of which is a measure of the distance, is obtained. For control purposes, the output signal can be fed directly to a comparator stage, in order to control a servo-motor.

### 23.2 Practical circuit of the rangefinder

In Figure 23.4, the IR transmitter circuit is shown, with its design values. A frequency-stabilised quartz crystal oscillator drives the modulator stage T16 through the emitter follower T15. The parallel-tuned circuit in the collector lead of T16 is tuned to the oscillator frequency of 4.433 MHz. The

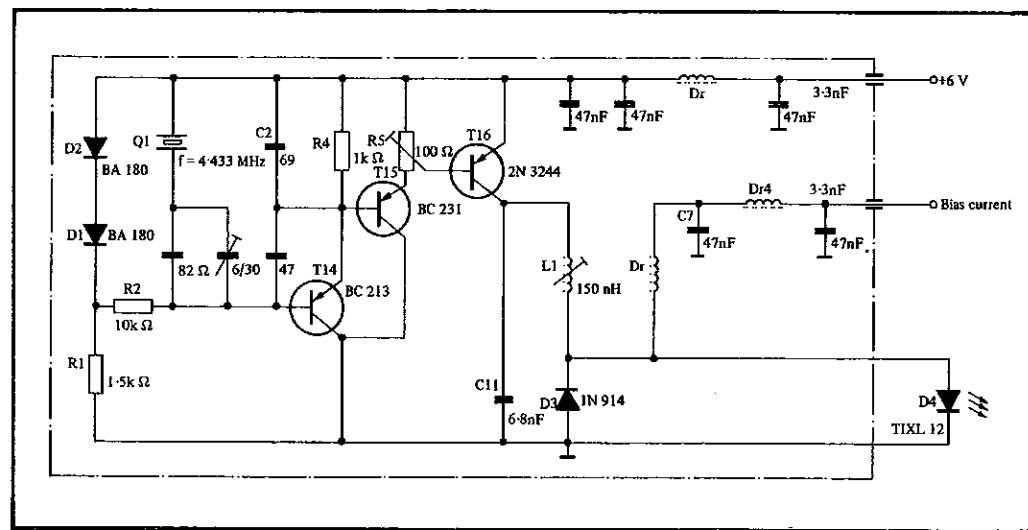


Figure 23.4  
IR transmitter circuit of the optoelectronic rangefinder

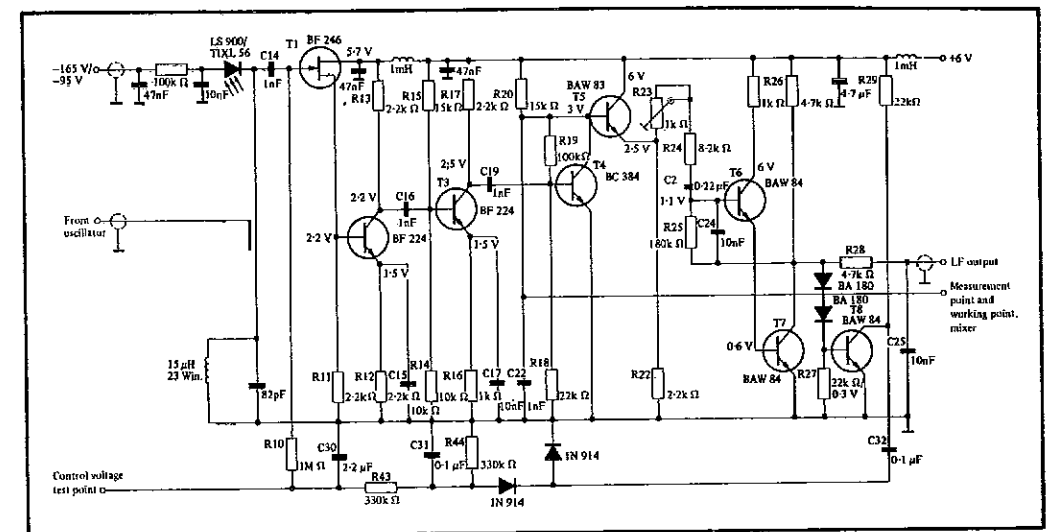


Figure 23.5  
IR receiver of the optoelectronic rangefinder

working point of the modulator stage is set with the potentiometer R5. The GaAs diode is connected in series with the coil L1 of the tuned circuit. Thus the modulation current (coil current) is higher than the total current in the leads by the Q factor of the tuned circuit. GaAs diodes have a low breakdown voltage. Therefore the TIXL 12 is protected against excess negative potentials by a 1N 914 silicon diode, connected in opposing

parallel. The GaAs diode can be operated with or without bias current, as desired.

Direct and indirect cross-talk from the transmitter to the receiver is prevented by various measures. The transmitter is well screened to prevent electromagnetic pick-up. In the same way, the main receiver, the references receiver and the auxiliary oscillator are each well screened as individual

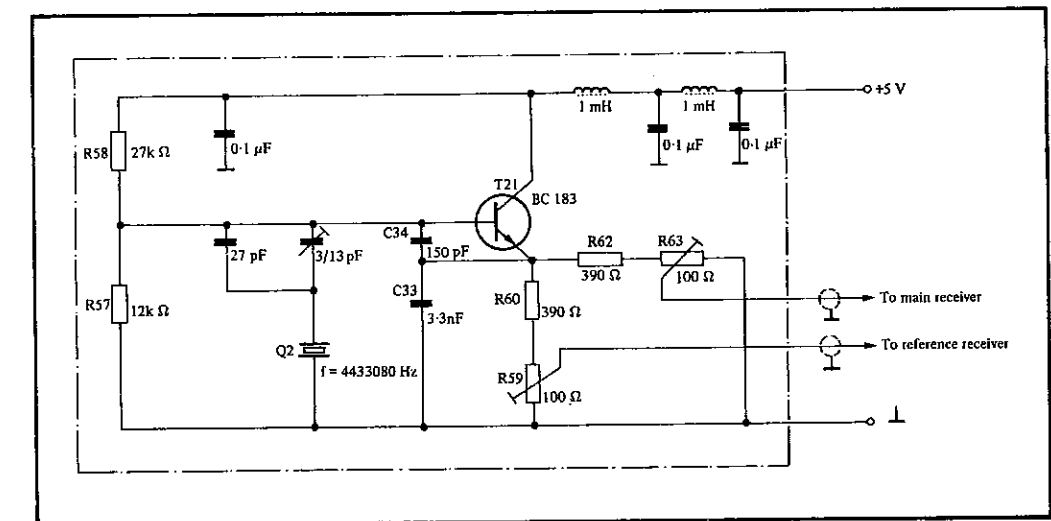


Figure 23.6  
Circuit of the auxiliary oscillator

modules. The supply leads inside and outside the modules contain effective HF filters. In general, all leads are kept short and some are screened. Each module has only one ground connection. Thus undesirable earth loops can be simply avoided throughout the system.

Figure 23.5 shows the receiver circuit for the main and reference receivers. The difference between the two receivers lies in the fact that the main receiver contains a highly sensitive Si photo-avalanche diode and the reference receiver contains a Si photodiode with low dark current and a high limiting frequency. The reverse voltage of approximately 165 - 170 V, applied to the photo-avalanche diode, must be adjusted to the most favourable signal/noise ratio. In addition, the reverse voltage is stabilised, at least with an accuracy of 0.1%.

The load impedance of the photodiodes in each case is a parallel-tuned circuit, tuned to the modulation frequency. The input stage

of the subsequent HF amplifier is an FET source-follower. With this, the damping of the tuned circuit is still relatively slight. The working point of the FET is determined by the control voltage, according to the received signal. For this, the positive half-waves of the LF output signal are amplified by T8. From the T8 output signal, the control voltage is obtained through a peak-path rectifier. The time constant of the subsequent control voltage filter chain is so designed, that large changes in the reception level, occurring in relatively rapid succession, are well compensated for by the control voltage. Otherwise, the mixer stage T4 will be overloaded. The transistor T4 in the mixer stage is the low-flicker-noise type BC 384. The LF amplifier contains a band-pass tuned to the mixer output of 80 Hz.

Figure 23.6 shows the auxiliary oscillator circuit. The phase angle can be controlled with the 100  $\Omega$  potentiometers.

Finally, in Figure 23.7, the evaluation section is shown. The LF output signals

from the main receiver and the reference receiver are formed into symmetrical square-wave pulses in the relevant limiter amplifiers. The operating voltage is stabilised with a value of 5 V. The limiter amplifiers are

TTL-compatible, because a TTL circuit, connected as an exclusive-OR gate can carry out the phase comparison. The measured distance is indicated by a moving-coil instrument.

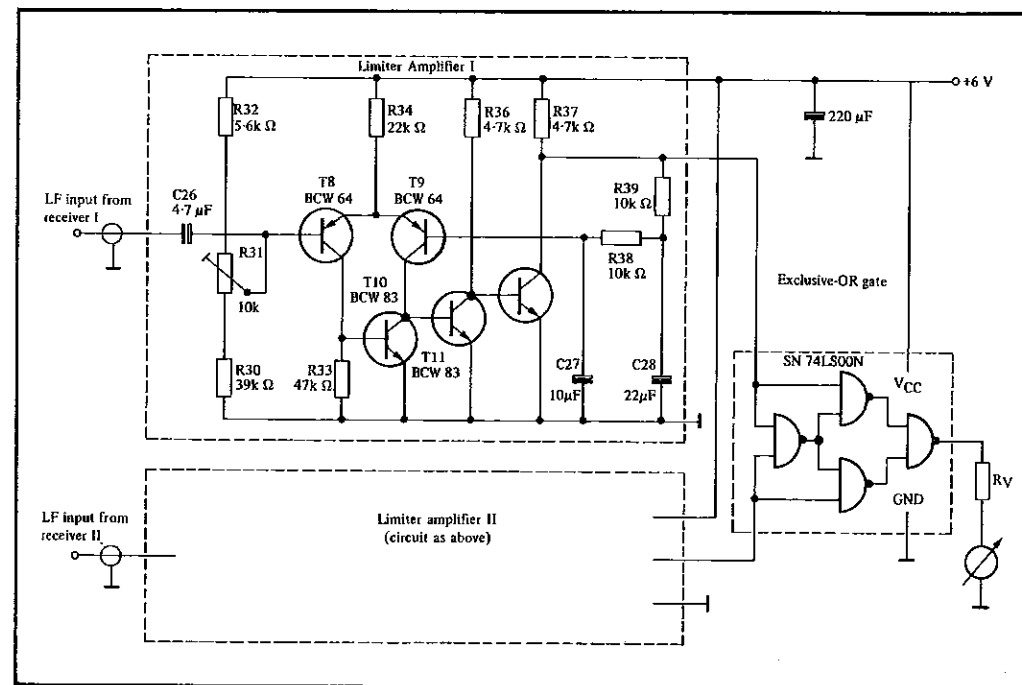


Figure 23.7  
Evaluation section of the optoelectronic rangefinder