universal OTA PLL

Elektor has taken a lead in drawing attention to the possibilities of the PLL (Phase Locked Loop), and has devoted a number of articles to designs incorporating this versatile circuit, as well as to explaining the principles of different applications. The Universal OTA (Operational Transconductance Amplifier) PLL described here is a printed-circuit module which can form the nucleus of many different types of receiver.

Performance Data

Narrow-band FM reception
(VCO free-running frequency approximately 10.7 MHz)

Capture and hold ranges

	Capture	Hold
Input 160 μV	190 kHz	540 kHz
Input 1.6 mV	250 kHz	4 MHz
Input 10 mV	400 kHz	10 MHz

AM Suppression

Input 160 μV	⩾60 dB
Input 100 μV	>40 dB

Sensitivity
Deviation = ±3 kHz

Minimum input	= 3.2 μV
With input = 4 μV:	
output	= 700 mV,
signal/noise ratio	= 40 dB

Wide-band Stereo FM reception
(VCO free-running frequency approximately 455 kHz)

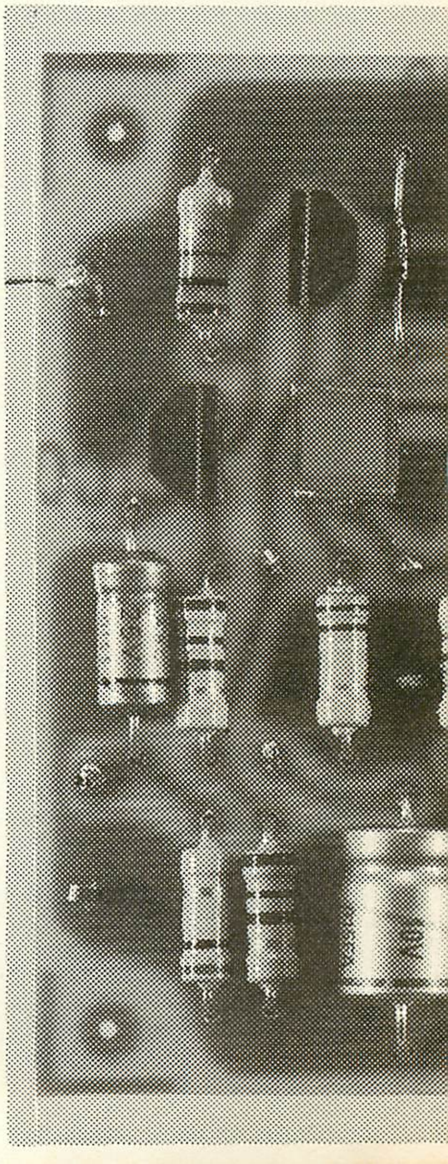
Capture and hold ranges
With minimum input (12.6 μV):
Capture range ≈ hold range ≈ 400 kHz

Sensitivity
(Deviation = ±30 kHz)

Minimum input	= 12.6 μV
With input = 500 μV:	
output	= 360 mV,
signal/noise ratio	⩾40 dB

Most of the integrated PLLs now available for FM receivers are expensive and require a 24-volt power supply, which makes them inconvenient for either portable or car-borne use. This universal PLL works quite happily on a 5-volt supply, but the working voltage may be determined in practice by the needs of a MOSFET RF amplifier, which can require 9 volts. This, however, is easy to provide in battery-powered portable equipment, and it also leaves a margin for stabilisation when running from a 12 V car supply.

Sensitivity on a 10.7 MHz FM input with 3 kHz deviation is 3.2 μV for a 700 mV audio output.
For a receiver for the 144 to 146 MHz band, the aerial signal is pre-amplified and converted to a band from 10 MHz to 12 MHz by a stable 134 MHz mixer-oscillator. Any signal in the 2 MHz-wide band can then be tuned in by adjusting (with a potmeter) the frequency of the voltage-controlled oscillator incorporated in the PLL.
Figure 1 shows a block diagram of the arrangement. The 134 MHz local oscillator will normally be a crystal oscillator of lower frequency in conjunction with a multiplier. Assuming the combined gain of the pre-amplifier and the mixing stage to have the easily-achievable value



of 20 dB, the overall receiver sensitivity for the quoted audio output of 700 mV will be some 0.3 μV, which is better than that of most commercial receivers for this band.
For reception of wide-band broadcast FM signals, the unusual arrangement of a double superheterodyne, with a second IF as low as 455 kHz, is used (see figure 2). The low modulation index of a stereo FM signal makes demodulation with a good signal-to-noise ratio difficult to achieve, and even in the best (and most expensive) receivers this is seldom above 50 dB on strong signals. With this very low second IF, 60 dB is achieved.

Yet again; what is a PLL?

For those who have not yet had an opportunity to familiarise themselves with the basic concept of the phase-locked loop, the essential features of this circuit can be repeated. The key element is a voltage-controlled oscillator. When the loop is used in a receiver, this oscillator is automatically synchronised with the carrier of the incoming signal. The other elements in the loop are subservient to the main purpose of keeping the oscillator synchronised. In practice, this is done by maintaining a constant phase difference between the incoming

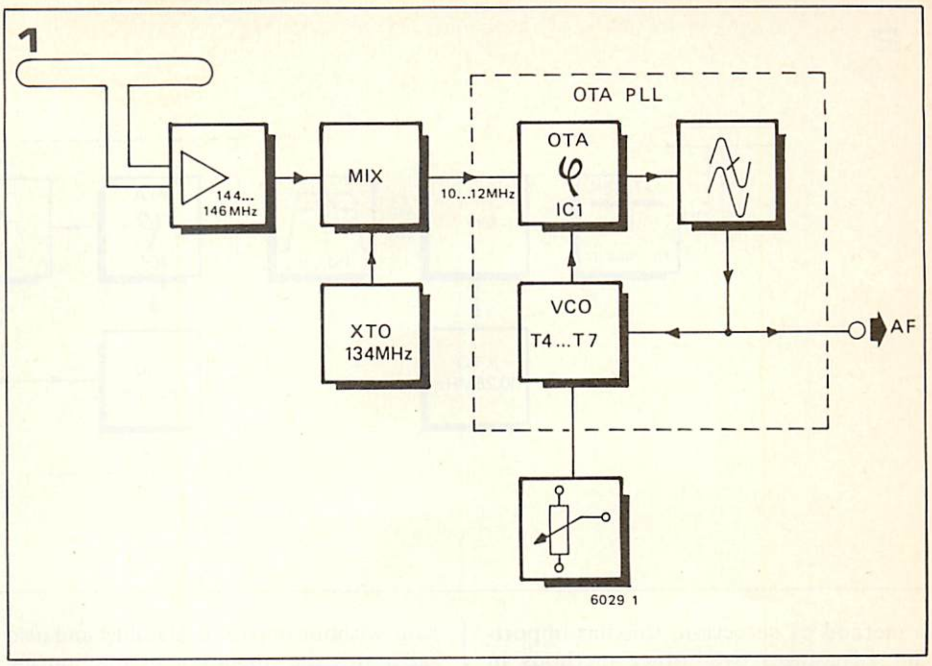
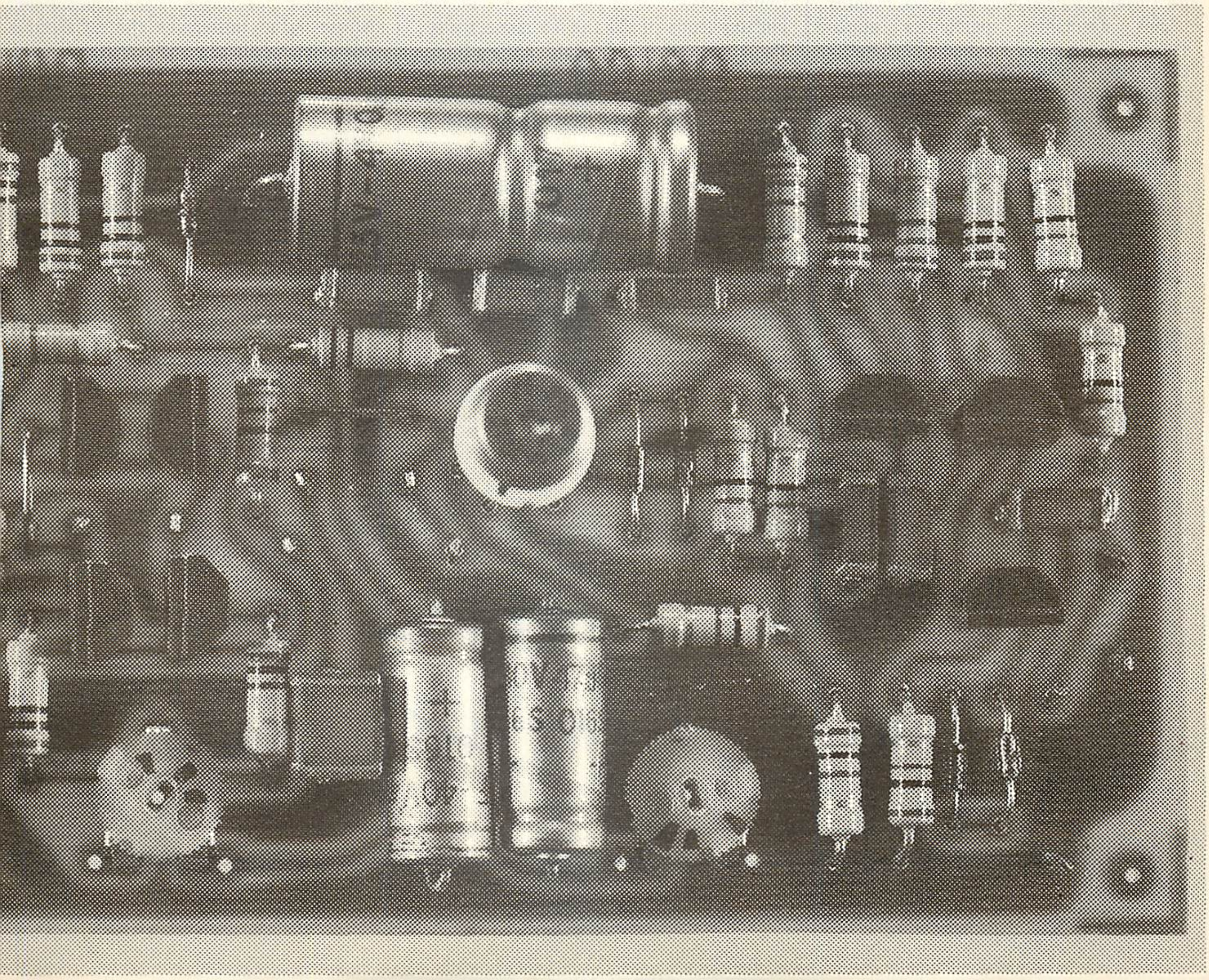


Figure 1. Block diagram of a receiver for narrow-band FM transmissions in the 144 MHz-146 MHz amateur band, with a fixed-frequency mixing oscillator and band-spread tuning by varying the intermediate frequency.

signal and the oscillator output: hence the term 'phase-locked loop'.
By definition, the oscillator is voltage-controlled. So if the incoming signal is frequency-modulated, the control voltage applied to the oscillator to keep it synchronised becomes, of itself, the demodulation of the incoming signal. As



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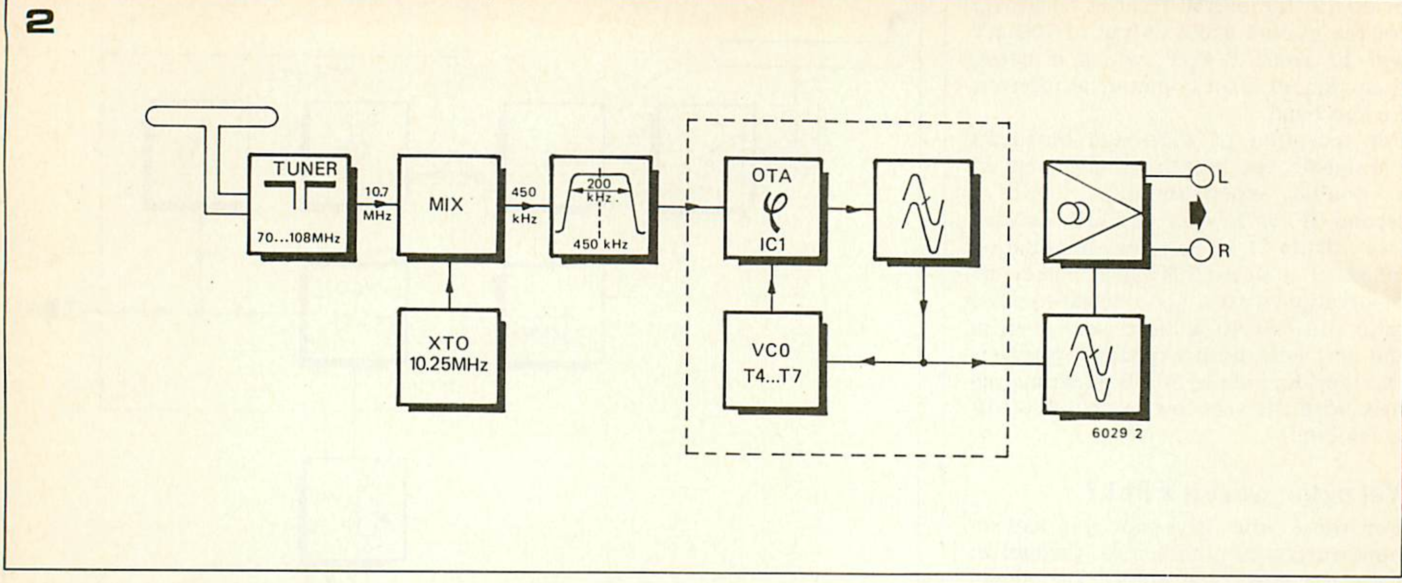

a method of detection, this has important advantages over other methods in terms of better rejection of interfering signals, lower distortion, and better signal-to-noise ratio.

Circuit description

The input is fed in across resistor R1 (figure 3). The value of this resistor must be selected to give correct matching to the preceding mixer stage, and suitable values will be given in later articles describing particular applications. Transistors T1 and T2 form a differential amplifier with an asymmetrical input, while T3 and diodes D1 and D2 stabilise the current flowing through T1 and T2. The two collectors of the differential amplifier are connected through capacitors C4 and C5 to the two differential inputs (2 and 3) of the CA3080 operational transconductance amplifier IC1. The use of both inputs in this fashion gives an extra 6 dB gain without impairing stability and also facilitates the operation of the limiting diodes D3 and D4.

In addition to receiving the RF (or IF) signal at the differential inputs (pins 2 and 3), IC1 is fed via pin 5 with the output of the voltage-controlled oscillator formed by T4 and T5. Although this oscillator is described as voltage-controlled, it should more properly be called current-controlled, the current being regulated by T6 and T7 in the emitter leads of T4 and T5 respectively. It can, however, be said without too much straining of the truth that the commoned bases of T6 and T7 are voltage-controlled from the output (pin 6) of IC1.

In the foregoing description the path of the loop has, in effect, been followed in the reverse direction. Recapping and going the correct way round: the DC component of the signal at pin 6 of the phase-comparator IC1 is amplified by T6 and T7 and controls the frequency of oscillator T4 + T5.

As in all FM detectors, AM rejection is important. The CA 3080 has good AM rejection at low input-signal levels, but is less good at higher levels. These higher levels, however, are taken care of by the clipping diodes D3 and D4, which begin contributing to AM rejection when the peak-to-peak signal between pins 2 and 3 of IC1 exceeds 1 volt.

Capacitor C11 is one of the components whose value influences the VCO free-running frequency (455 kHz in the broadcast FM receiver, or about 10 MHz in the narrow-band FM receiver) so its value is quoted for particular applications (see Table). When the receiver is tuned by varying the VCO frequency, as in the narrow-band FM receiver, potmeters P1 and P2 come into play. When the working IF frequency is fixed, these potmeters can be used for preset adjustment.

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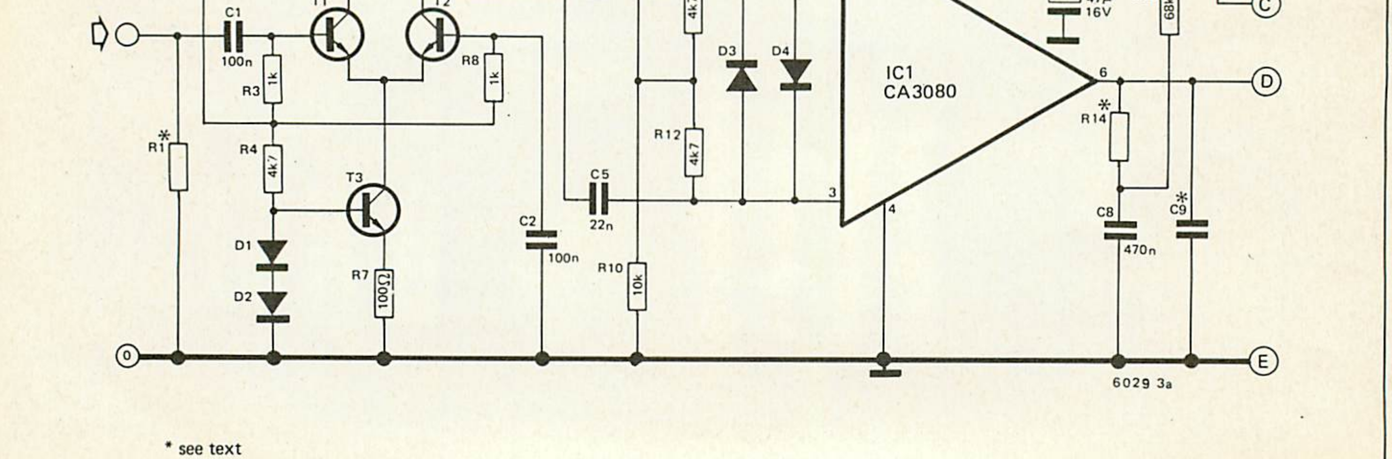


* see text

Figure 2. Block diagram of a double superheterodyne for stereo FM reception, with intermediate frequencies of 10.7 MHz and 455 kHz.

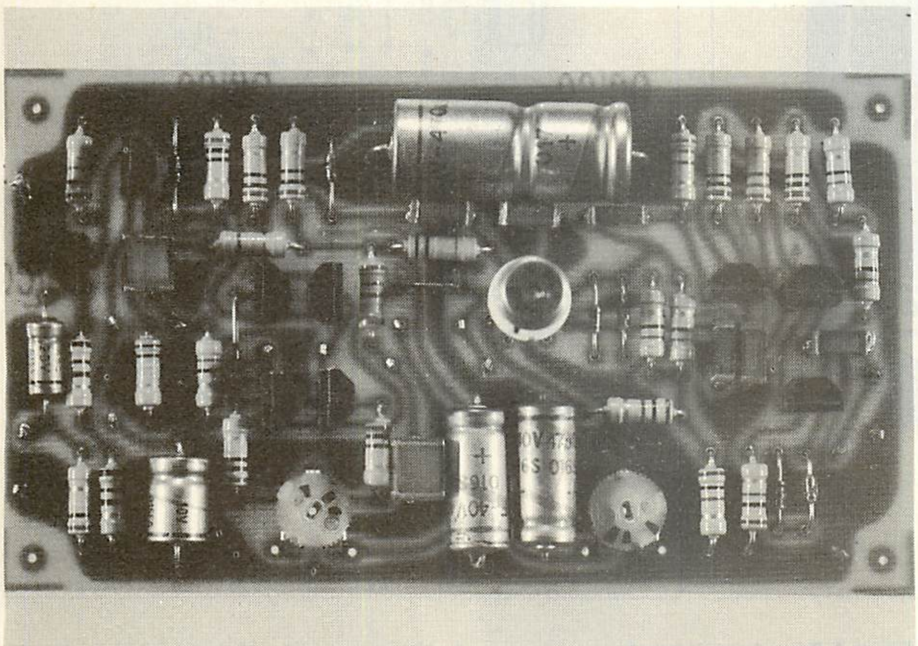
Figure 3. Circuit of the Universal OTA PLL.

Table: Values of R1, R14, R24, C9, C11 and C14 for specific applications.

Values of R1, R14, R24, C9, C11 and C14 for specific applications

Mode of operation (all FM)			Supply voltage	R1	R14	R24	C9	C11	C14
Type of transmission	Intermediate frequency	Minimum input*							
Wide band mono	10.7 MHz	160 µV	9	330 Ω	1 k	150 Ω	–	100 p	10 n
Narrow band	10.7 MHz	3.2 µV	9	330 Ω-2k2	47 k	0 Ω	–	220 p	10 n
Wide band mono	455 kHz	400 µV	9	–	47 k	2k2	560 p	2n2	10 n
Narrow band	455 kHz	20 µV	9	3k3	47 k	82 Ω	560 p	2n2	10 n
Wide band stereo	455 kHz	500 µV	9	–	47 k	2k2	220 p	2n2	–
Wide band stereo	455 kHz	200 µV	12	–	47 k	2k2	220 p	2n2	–

* At the PLL! (– = omitted)



The low-pass filter which removes the unwanted 'sum' frequency (oscillator plus input signal) is formed by C8, C9, R14 and R16. As the values of these resistors also effect the VCO free-running frequency, they have to be selected carefully for each application. In practice, R16 is given a fixed value of 68 kΩ while R14 is specified for each application. This also applies to the feedback resistor R24 which controls the gain of the output audio amplifier T8 and T9. Resistor R28 and capacitor C14 provide de-emphasis. It will be seen that the whole of the DC component at the output (pin 6) of the phase comparator is passed to the VCO: this helps to ensure a large 'hold range' for the loop.

Detailed descriptions of applications of the Universal PLL will be given in later articles, but the two which have already been mentioned can be briefly discussed here.

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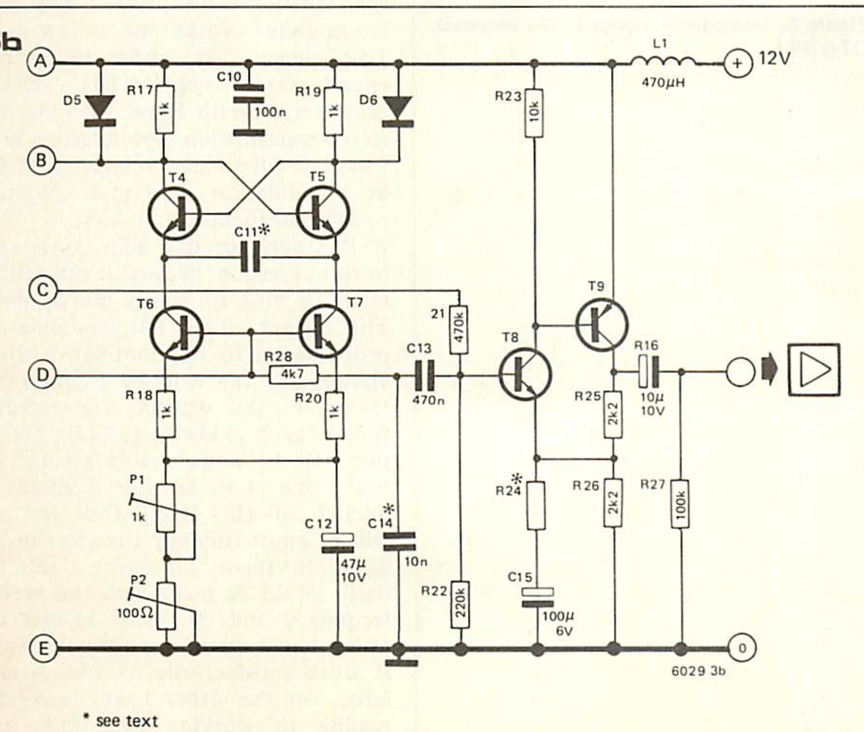

* see text

Parts list

Resistors:
R1,R14,R24 = see table
R2,R4,R11,R12,R28 = 4k7
R3,R8,R15,R17,R18,R19,R20 = 1 k
R9,R10,R23 = 10 k
R5,R6 = 560 Ω
R7 = 100 Ω
R27 = 100 k
R13,R22 = 220 k
R16 = 68 k
R21 = 470 k
R25,R26 = 2k2
P1 = 1 k
P2 = 100 Ω

Capacitors:
C1,C2,C6,C10 = 100 n
C3 = 470 µ/16 V
C4,C5 = 22 n
C7 = 47 µ/16 V
C8,C13 = 470 n
C9,C11,C14 = see table
C12 = 47 µ/10 V
C15 = 100 µ/6 V
C16 = 10 µ/10 V

Inductor:
L1 = 470 µH

Semiconductors:
T1 ... T7 = BF 494
T8 = BC 547
T9 = BC 557
IC1 = CA 3080
D1 ... D6 = 1 N 4148

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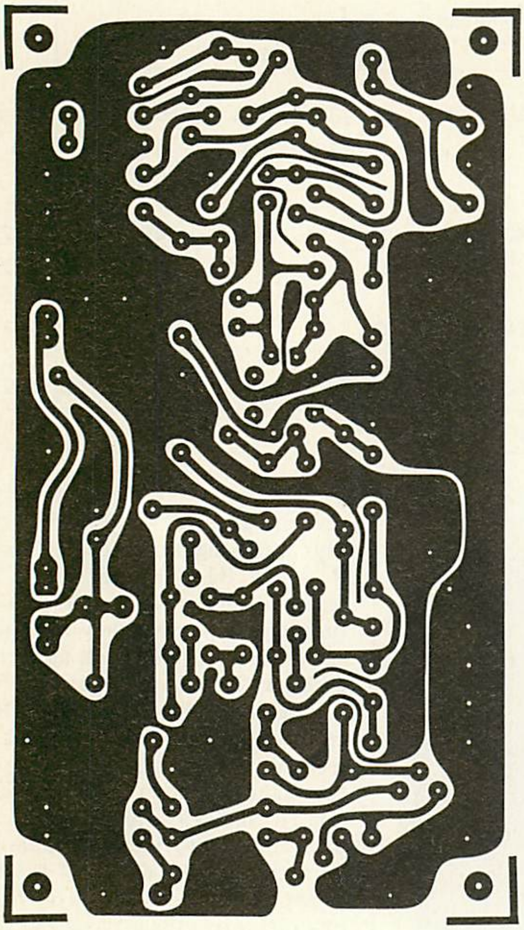

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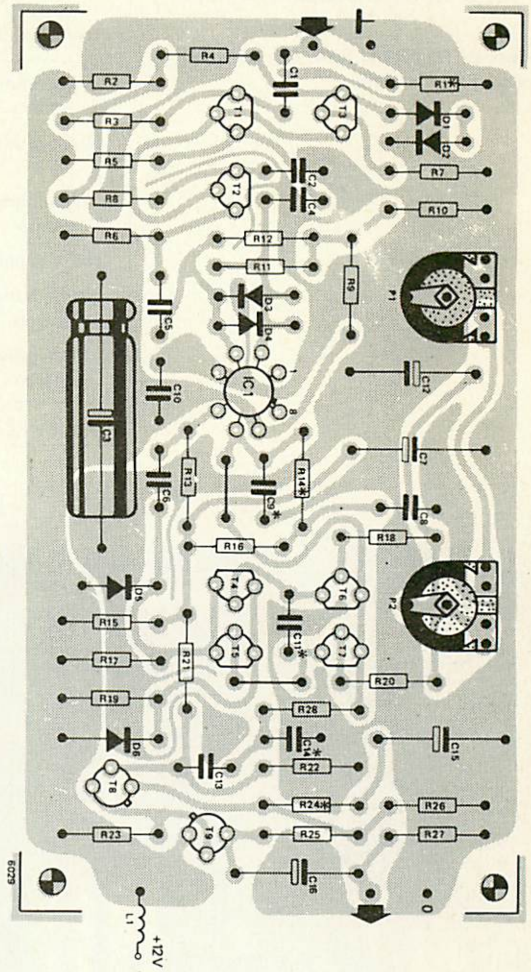

Figure 4. Printed circuit board.

Figure 5. Component layout of the universal OTA PLL.

Narrow-band FM receiver

In narrow-band FM systems, noise always tends to be a problem because the modulation index (the ratio of the maximum deviation to the highest modulation frequency) is by definition low, but the good noise performance of a PLL demodulator goes a long way towards overcoming this handicap. The limiting sensitivity of the Universal PLL, when used in a narrow-band FM receiver, has already been stated to be 3.2 μV, not counting the gain of the RF and mixer stages preceding it. With an input of 4 μV – slightly above the limiting value – the signal-to-noise ratio is 40 dB.

The principle of using a crystal-controlled fixed-frequency local oscillator, and tuning the IF with the VCO, offers a very simple and effective form of band-spreading.

Stereo FM receiver

FM sound broadcasting has a maximum deviation of 75 kHz, which gives a modulation index of 5 on mono transmissions having a 15-kHz audio bandwidth. With a stereo transmission, the maximum modulation frequency is 53 kHz, but the effective bandwidth of the composite stereo signal is greater than this, and in practice the modulation index works out as low as 0.6. This means that, 'other things being equal', stereo reception has a signal-to-noise ratio 20 dB lower than the same stereo transmission reproduced in mono. These problems are discussed more fully in 'Modulation Systems' (Elektor 2, p. 246 and Elektor 3, p. 454).

A PLL detector can help considerably in this situation, because it can easily be made to work on a very low second IF. The output of an FM demodulator is proportional to the quotient of the deviation and the working frequency. If, therefore, the working (intermediate) frequency is as low as 455 kHz, the output will be considerably greater than with the normal intermediate frequency of 10.7 MHz, while the noise will be approximately the same in both cases. In theory, a 'normal' discriminator could be made with this working frequency and the usual 75-kHz deviation, but it would be difficult to make it work satisfactorily. A PLL demodulator, on the other hand, lends itself readily to working with these parameters and enables a 60-dB signal-to-noise ratio to be obtained.