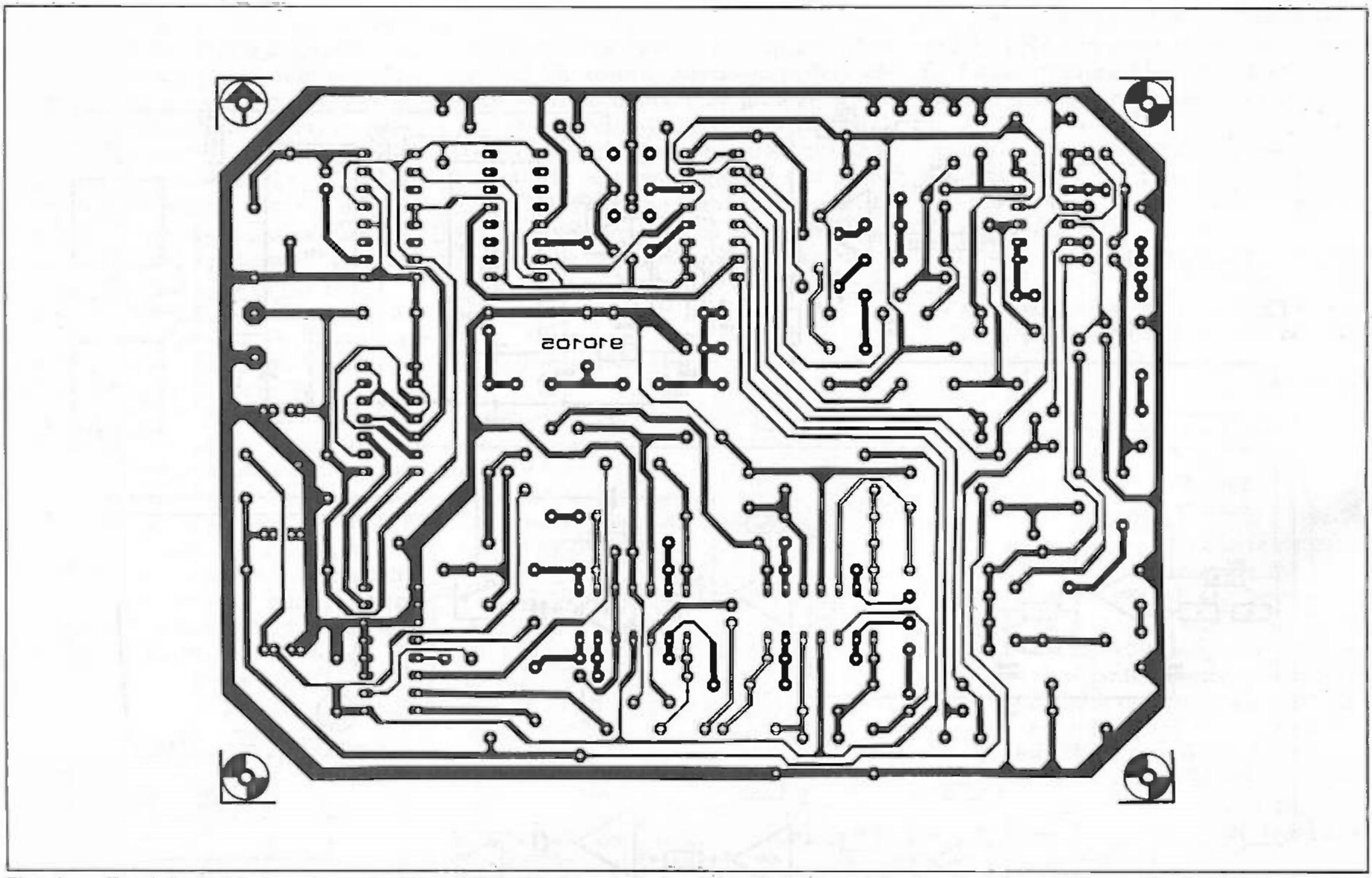

Fig. 6a. Track layout (mirror image) of the single-sided printed circuit board designed for the spectrum shift encoder/decoder.

calculated as follows. Assuming a spectrum shift of 1,500 Hz, then:

$f_{osc} / 15 - f_{osc} / 16 = 1{,}500$
$\therefore 16 f_{osc} / 240 - 15 f_{osc} / 240 = 1{,}500$
$\therefore f_{osc} / 240 = 1{,}500$
$\therefore f_{osc} = 360$ kHz.

Since the 24-kHz frequency must be available as four signals with a phase shift of 90°, i.e., 0°, 90°, 180° and 270°, the actual oscillator frequency is four times higher than calculated, i.e., 1.44 MHz, while the divisors of 15 and 16 change to 60 and 64 respectively. This is illustrated in Fig. 3. The 24-kHz signal is fed in quadrature to two identical mixers (4053). After adding the results of the multiplication, the upper sideband is compensated. Via a 30-kHz low-pass filter, the signal is fed to the third multiplier where it is transformed to the original frequency band.

The encoder

So far, we have not discussed the encoder, and this has a very good reason: it is virtually identical to the decoder! In fact, the same circuit is used, which allows the encoder and the decoder to be built on identical printed-circuit boards. The only difference between the two units is the value of 29 passive components, of which a number determine the frequency response of the phase filter built around two opamps, IC3 and IC4 (see the circuit diagram in Fig. 5). These components define a pass-band of 1 kHz to 10 kHz in the decoder, and a pass-band of 120 Hz to 7 kHz in the encoder. The accuracy of the phase filter is determined by the accuracy of the passive components used. The performance of the filter depends on the number of sections it consists of, and the ratio between the highest and the lowest input frequency. This ratio is about 10 in the decoder, which, based on a phase filter with three sections, achieves an *S/N* ratio of about 60 dB. Also based on three filter sections, but designed to handle a max/min frequency ratio of about 58 (7,000 Hz/120 Hz), the encoder has a worse *S/N* performance of about 40 dB, which is not bad given the simplicity of the design. In any case, the results are perfectly acceptable for speech.

The shift of +1.5 kHz in the encoder (instead of −1.5 kHz in the decoder) is achieved by suppressing the lower sideband instead of the upper sideband (see also Fig. 2b). Since the spectrum in Fig. 2b then extends from 24 kHz to about 31 kHz, the roll-off frequency of the 30-kHz low-pass filter must be shifted up to about 36 kHz. In addition, the input and output filters must be adapted to the spectrum to be passed. All the changes necessary to effect this, i.e., to turn the decoder into an encoder (or vice versa), are summarized in the components table you find inset in Fig. 5.

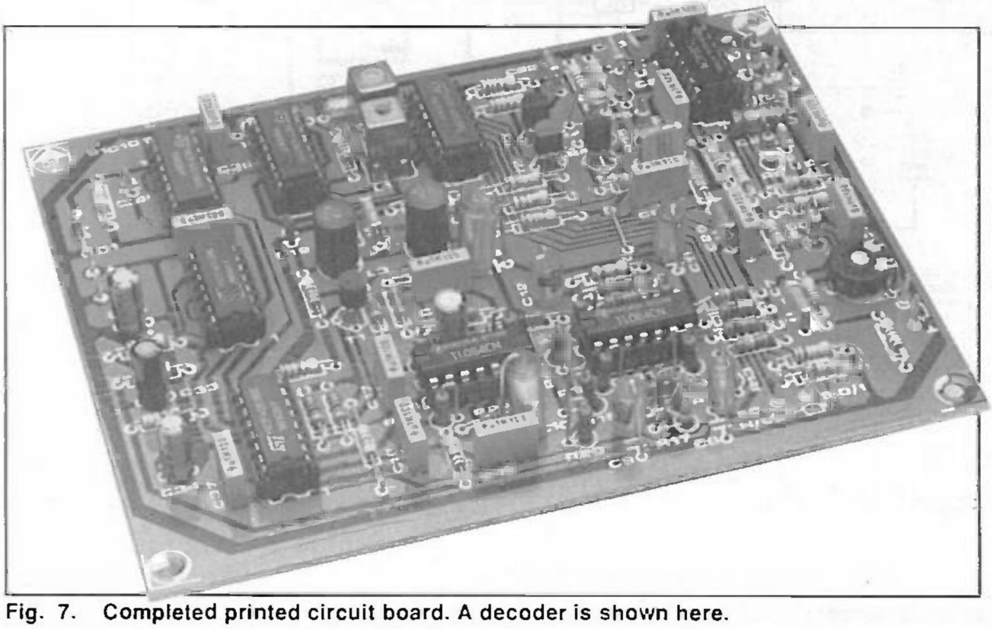

Fig. 7. Completed printed circuit board. A decoder is shown here.