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H03F 3/38

(52) UK CL (Edition J)
H3T TAC T3X

(56) Documents cited
None

(58) Field of search
UK CL (Edition J) **H3T TAC, H3W**
INT CL⁴ **H03F**

(54) Low level D.C. amplifier

(57) A D.C. amplifier comprising a number of modulators, in this case 2 (ABCD) and (EFGH), followed by A.C. amplifiers, A1 and A2, demodulators, (JKLM) and (NPQR), and D.C. amplifiers A3 and A4.

The modulators are so driven that, while one channel is changing phase, the other channel(s) are not changing phase.

A signal at the input is sequentially inverted by the modulators, which are time displaced from one another. In the case of a two channel system, the modulators and demodulators would normally be displaced from each other by a phase angle of 90 degrees.

Following synchronous demodulation, the signals are added together and further amplified by D.C. amplifiers.

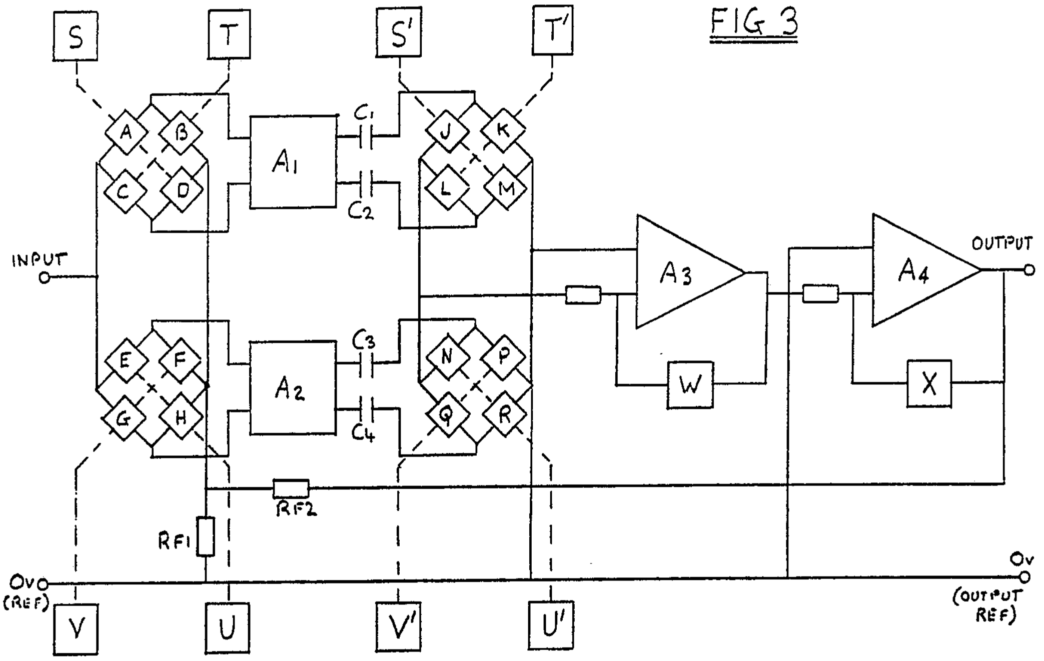

FIG 3

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FIG 1

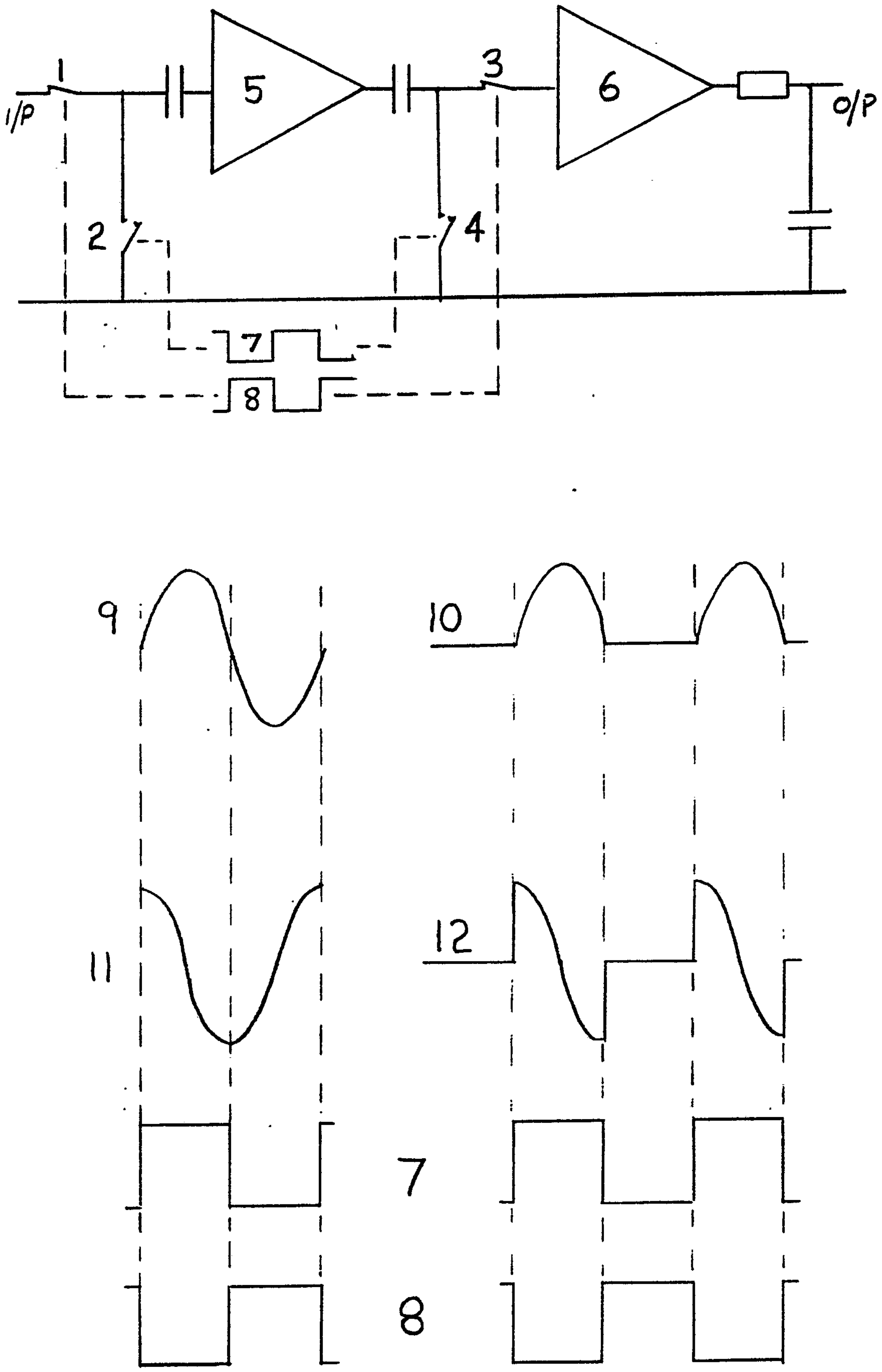
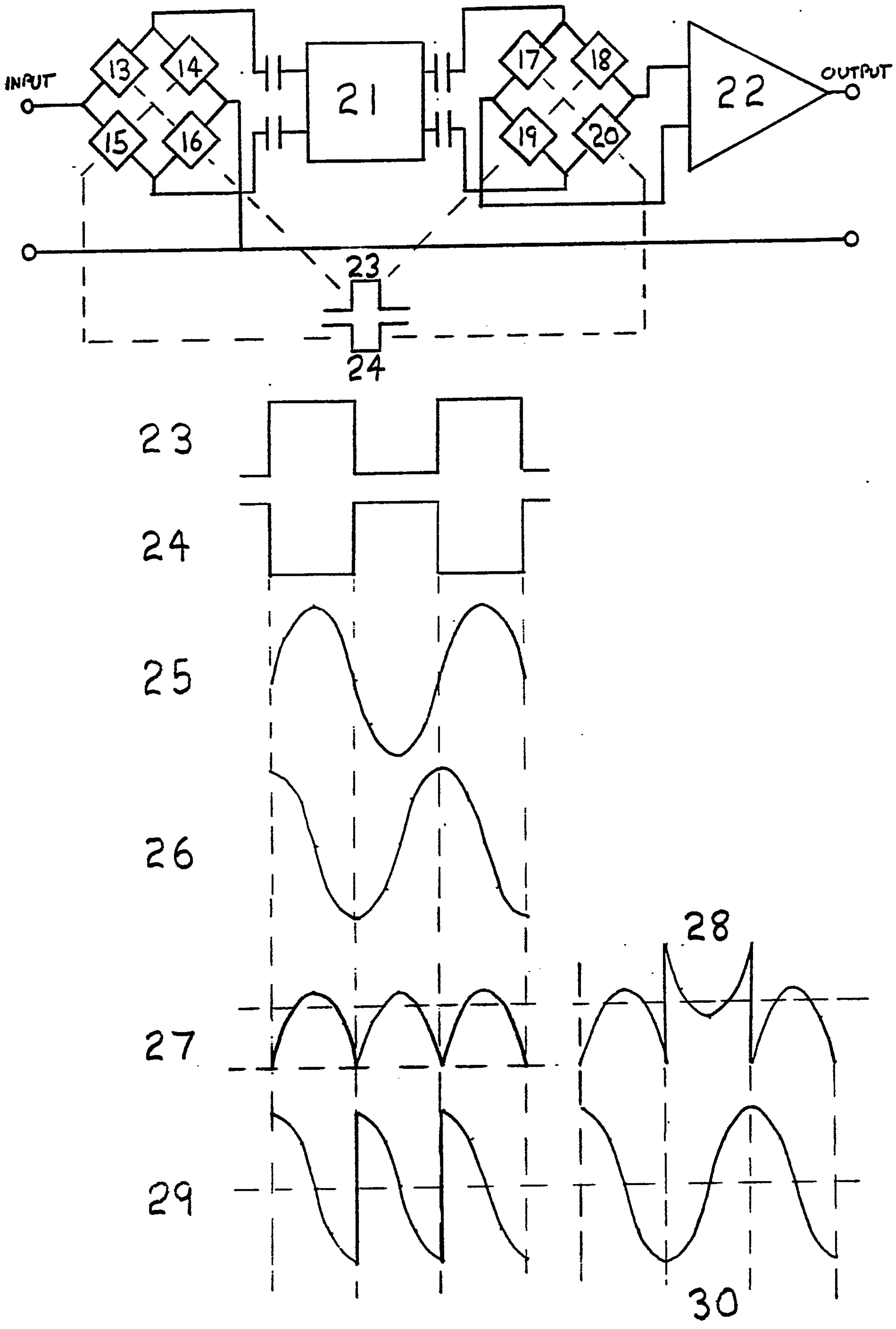


FIG 2


INPUT
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OUTPUT
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FIG 3

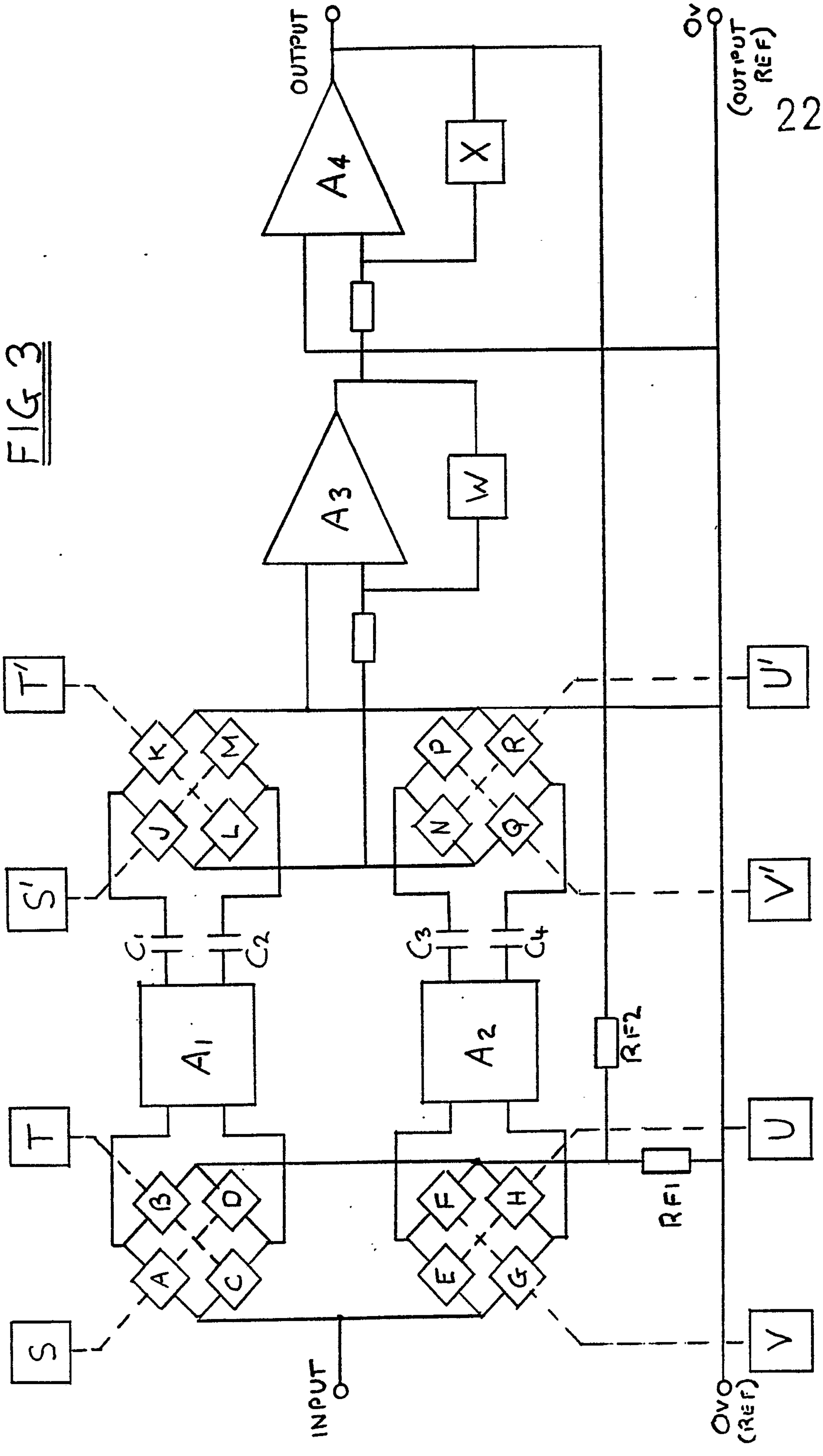


FIG 4

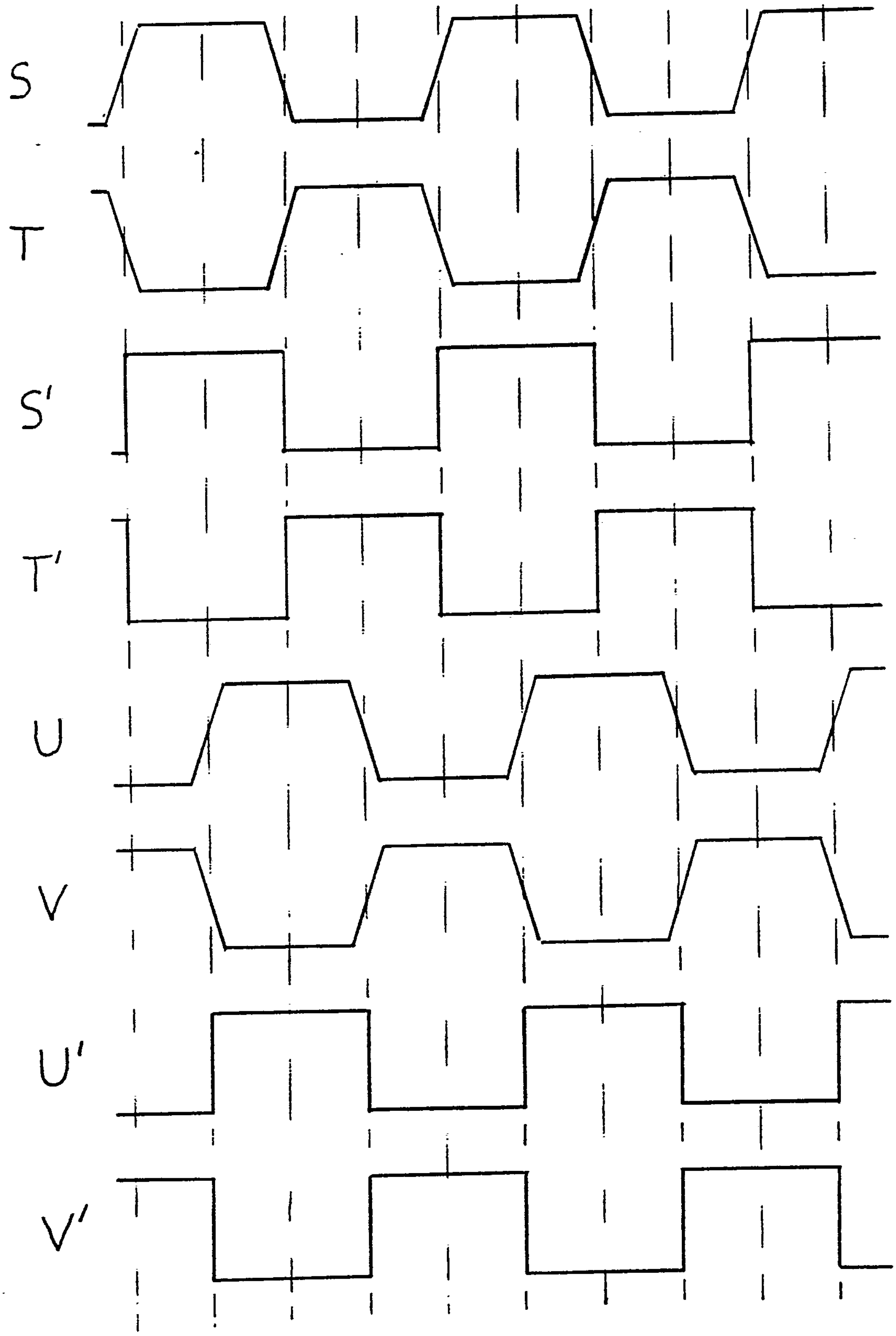
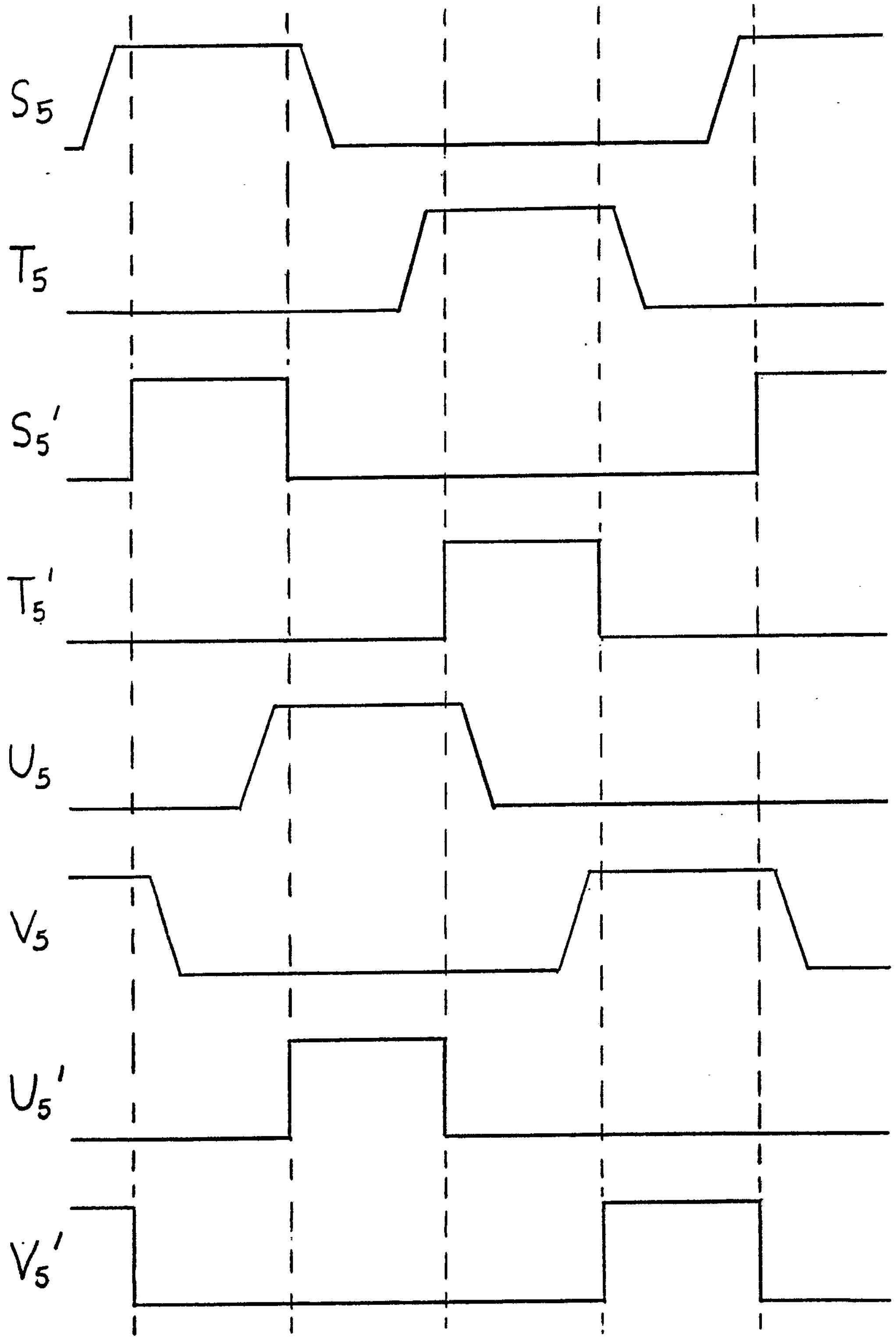


FIG 5



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A LOW LEVEL D.C. AMPLIFIER

The requirement for D.C. amplifiers used in measurement and data aquisition is that they are able to amplify signals to as low a level as possible. At the same time it is encumbent on them that they disturb the circuit being measured as little as possible. It is also necessary that the amplifier will be able to respond to changes in the signal as rapidly as possible. The requirements are often contradictory.

Advances have been made in the performance of low level, bi-polar integrated circuits which provide quite good detection levels down to fairly low frequencies. However, by virtue of the input devices, which require current to operate them, they are only suitable for very low impedance sources, and even then, their noise levels at very low frequencies (i.e. D.C. to 0.1Hz) limit their sensitivity. This type of device is unsuitable for measuring equipment such as digital voltmeters.

One method of overcoming this problem of noise at very low frequency is the use of modulation techniques, which have been used for many years with varying degrees of success, and there are problems associated with modulation.

Considerable advances have been made in the use of complex modulating techniques to achieve improvements in noise at low frequency. See for example British Patents No 1168873 and 2118391B. It is the purpose of the present method to advance the techniques of D.C. amplification still further.

f.37

One difficulty, which has been mentioned in the cited examples, is the complex nature of the transfer function of a modulated amplifier at and around the modulation frequency and also to a smaller extent at the harmonics of modulation frequency.

The very serious nature of the problem can be appreciated by considering an A.C.coupled, modulated D.C. amplifier operating with an input signal approaching the modulating frequency. See fig 1.

In this example,

1 2 3 and 4 are switches or choppers driven in anti-phase such that 1 and 3 conduct while 2 and 4 are non conducting and vice versa.

5 is an A.C. coupled amplifier.

6 is a D.C. amplifier including or followed by a low pass filter.

Consider the case where the input signal is at the same frequency as the modulator and with a phase displacement of 0 degrees or 180 degrees as at 9. After passing through the modulator (switches 1 & 2), the signal will be in the form shown at 10. After amplification and demodulation, the signal will be substantially an amplified version of 10. There will be some distortion of this waveform because the A.C. amplifier will be unable to pass the D.C. component of waveform 10 and the demodulating switches, 3 and 4 are unable to reproduce the exact enlarged signal. This will be enlarged on later. The output in this case however, will contain a D.C. component at the output and, following further D.C. amplification and low pass filtering, will give a D.C. output. It should be remembered that, in this example, there was no D.C. bias to the input signal.

If the phase of the input signal with respect to the modulator drive is moved by + or - 90 degrees, as in 11, then it can be seen that, following modulation, amplification, and demodulation, the resultant signal at the demodulation output will be as 12.

Following D.C. amplification and filtering, the output will be substantially zero. Thus a change of phase of input signal, or a very slight difference in frequency from the modulating frequency causes the output signal to change from a maximum, through zero, to a minimum. For this reason, modulated feedback amplifiers have a loop gain of less than unity at modulating frequency.

In the quest for greater reduction of noise from modulated amplifiers, differential modulated systems are employed. See fig 2.

In this example,

13 14 15 and 16 form a bridge of switching devices such that a D.C. level at the input is sequentially inverted and applied to a differential A.C. amplifier 21.

17 18 19 and 20 form a second bridge which converts the amplified A.C. signal at the output of 21 into D.C. once again, and this D.C. signal may then be further amplified by a D.C. amplifier 22.

The switches 13 16 19 and 18 are driven from a signal such as 23 and 14 15 17 and 20 are driven by the anti-phase signal 24.

Consider now an A.C. input, such that the frequency and phase are the same as the modulator, as at 25. After modulation the wave form will be as 27 and before demodulation, the signal will be amplified and the D.C. component removed. After demodulation, the wave form will appear as at 28. This occurs because the amplifier 21 is A.C. coupled.

If the phase of the input signal is shifted to the position shown at 26 then after modulation, the signal will be as shown at 29 and, after demodulation, as at 30.

If the amplifier 21, were D.C. coupled to avoid these problems, it would have to have a very low drift characteristic to avoid a high degree of generation of modulator frequency component, in the action of the demodulator. This would largely defeat the object of the modulated amplifier even if it could be achieved.

It can be seen from this example that as the phase of the input signal at about modulator frequency changes, the output varies from 28 which contains little signal frequency (and most of the remainder is third harmonic) to 30, containing a maximum of signal frequency. Over a very narrow frequency band, therefore, the gain changes by a large amount, which means that there is a large phase shift, over this frequency range. For this reason it is desirable to reduce the loop gain to less than unity at modulator frequency, in this example also.

Even though modulated D.C. amplifiers have been used for many years, there are still problems associated with them that have not been overcome, thus limiting their closed loop gain at high frequency and hence their response times.

It is the object of the amplifier circuit described here to contribute to the quest for the ideal D.C. amplifier, i.e. one which has negligable noise, drift, offset current, input conductance, and response time.

According to the present invention there is provided a D.C. amplifier comprising at least two modulated amplifying channels, each of which sequentially inverts the input signal and each of which has its modulating action displaced in time from the other channels, such that while the modulator of one channel is changing phase, at least one other channels' input modulator is operating without changing phase.

A specific embodiment of the invention will now be described by way of example with reference to figs 3, 4 and 5, and the following notation is used.

A to R are switching devices arranged in four active bridges which:

A D J and M are driven in phase with waveform S

B C K and L are driven in phase with waveform T

E H N and R are driven in phase with waveform U

F G P and Q are driven in phase with waveform V

A1 and A2 are amplifiers which may be differential and may be A.C. coupled.

A3 and A4 are D.C. amplifiers with respective feedback networks W and X.

The modulator and demodulator drive sequences are shown in fig 4.

The input signal is modulated by two full wave modulators which sequentially invert the input signal and apply it at the inputs of two differential amplifiers A1 and A2. If the input signal is D.C. then the signal applied to the two amplifiers would be a square wave.

The first modulator A B C D is driven from the waveforms S and T such that when A and D are conducting, B and C are non conducting and vice versa.

This ensures that the input signal is sequentially applied to the inputs of amplifier A1 in an alternately inverting sequence.

Furthermore, the second modulator E F G H is driven from the waveforms U and V such that when E and H are conducting, G and F are non conducting and vice versa.

This ensures that the input signal is sequentially applied to the inputs of amplifier A2 in an alternately inverting sequence.

The drive signals S and T are 180 degrees out of phase with each other and the signals U and V are 180 degrees out of phase with each other. The set of drive waveforms S and T are also phase shifted from the set of waveforms U and V by some other angle, in this case 90 degrees. This sequence ensures that when one amplifier is being inverted, the other amplifier is operating normally.

After being amplified by A1 and A2 the signals are then demodulated to restore an amplified D.C. signal.

In fig 4 if S T U and V are the drive signals for the modulators, then the corresponding demodulators are operated by S' T' U' and V'.

Referring back to the problems of the single channel amplifiers, see fig 2, if one channel of the new system were operating with the waveforms 25 27 and 28, then the other channel will be operating as at 26 29 and 30 (fig 2) Even if the level of signal at 28 resulted in zero output, the other channel would be operating at a maximum, thus the greatest possible amplitude deviation would be 6dB, and this amount is fairly easy to allow for.

It can readily be seen that the worst case has been considered. There is a small amount of deviation at harmonics of modulator frequency, particulaly odd harmonics.

The restored D.C. signal is now amplified by further D.C. amplifiers (in this case A3 and A4) if required and overall feedback may be applied, whereupon the normal criteria for stability in feedback amplifiers applies. The criteria are well known and well documented. Various phase shifting networks, such as at X and Y may be used to this purpose.

One further point worth mentioning is that of noise reduction. The modulation frequency is chosen as a compromise between the best frequency to suit the noise characteristic of the input active devices in A1 and A2 and the need to keep the frequency as low as possible, to minimise the effect of the modulator drives injecting current spikes into the input circuit. The use of two amplifiers, effectively in parallel, gives a noise reduction of 3dB over a single amplifier, which is an added bonus of the two channel system.

The amplifier is not limited to two channels. Any number of channels could be employed, and any phase shifted arrangement could be used. The system is not limited, either, to differential amplifiers or to A.C. coupled amplifiers. For example, non differential amplifiers could be used with transformers at the inputs. The amplifiers could be D.C. coupled amplifiers, but this does raise a further difficulty as explained previously.

A further variation is to use a sequence shown by the waveforms of fig 5, which are labelled S5, S5' etc, but which operate the same functions S, S' etc of fig 4, shown in fig 3. In this case the demodulator selects one of four conditions in sequence.

1. Amplifier A1 phase 0 degrees
2. Amplifier A2 phase 90 degrees
3. Amplifier A1 phase 180 degrees
4. Amplifier A2 phase 270 degrees

The sequence is then repeated.

The modulator drives are arranged such that they switch on before the corresponding demodulator and switch off after the corresponding demodulator. This ensures that the input switching function does not affect the corresponding amplifier beyond its associated demodulator, which is one advantage of this technique.

One disadvantage is that the noise reduction associated with having more than one input device effectively in parallel does not apply, as there is only one amplifier operating at any given time.

In an actual embodiment of the circuit of fig 3, the value of RF1 would be low enough so that it does not contribute significantly to the noise. In such an embodiment the input active devices of A1 and A2 are low noise differential field effect transistors. The noise associated with each device is typically equivalent to a perfect resistor of about 1000 ohms. Each differential amplifier would then have a noise resistance of about 2000 ohms. In the case where two amplifiers are effectively in parallel, the 'equivalent noise resistance' is then reduced to 1000 ohms. This is borne out in practice.

In this practical amplifier, once the normal gain and phase shift, at the considered range of frequency, requirements have been met, it is possible to build a low noise D.C. amplifier with very high gain at D.C. and a bandwidth very much higher than the modulator frequency, which is stable with feedback.

A practical example has a D.C. gain of 10^{13} which is reduced to unity at a frequency of more than 10^{6}Hz, and which is stable with 100% feedback.

CLAIMS

1. A D.C. amplifier comprising at least two modulated amplifying channels, each of which sequentially inverts the input signal and each of which has its modulating action displaced in time from the other channels, such that while the modulator of one channel is changing phase, at least one other channels' input modulator is operating without changing phase.
2. A D.C. amplifier as claimed in claim 1 wherein each of the amplifying channels is phase inverted by its modulator and demodulator to provide substantially continuous amplification in each channel.
3. A D.C. amplifier as claimed in claim 1 wherein the demodulators of all channels are switched in sequence so as to provide overall continuous amplification.
4. A D.C. amplifier as claimed in claim 1 in which the input modulator switching overlaps in time its associated demodulator switching.
5. A D.C. amplifier as claimed in claims 1 to 4 in which the individual amplifiers are differential amplifiers.
6. A D.C. amplifier as claimed in claims 1 to 4 in which the individual A.C. amplifiers are transformer coupled.
7. A D.C. amplifier substantially as described herein with reference to figures 1 to 5 of the accompanying drawings.

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