Synchrodyne/homodyne receiver

Michael Slifkin and Noam Dori describe the benefits of synchrodyne and homodyne reception for medium wave, rounding off with a complete design incorporating both receiver techniques.

Since the beginning of World War II, all commercial radio receivers have been superheterodyne receivers. In the future we will see digital receivers, but it is unlikely that they will be completely oust the much cheaper superheterodyne.

The superheterodyne works by beating a local oscillator with the incoming signal so that the signal is converted to a fixed intermediate frequency – normally 455kHz for the medium wave. This system replaced the original tuned radio frequency receiver which suffered from many drawbacks.

Selectivity and sensitivity were both a function of the frequency. As you tuned through a waveband, the properties of the receiver varied considerably. The superheterodyne overcame this problem as the gain and selectivity was carried out at the one intermediate frequency.

But the superheterodyne also has its drawbacks. It is more complex and expensive than the earlier tuned radio frequency receiver. The most obvious drawback of the superheterodyne is image rejection. Strong stations can be heard at twice and even four times the intermediate frequency away from the true frequency.

Furthermore, the presence of a local oscillator means that you can hear harmonics of this oscillator which gives rise to *spurii* – i.e. squeals and birdies – as you tune the radio. There are more esoteric drawbacks too such as reciprocal mixing and phase noise.

Why synchrodyne?

In the mid-forties, Tucker in Australia introduced the synchrodyne direct-conversion radio receiver.[1] This worked by beating or mixing the incoming signal with a local oscillator of the same frequency so that the carrier wave was converted down to zero frequency leaving only the audio frequencies. Thus the incoming wave was converted directly to audio frequency by a simple mechanism.

Another advantage of this system is that synchronous detection of this type is linear right down to zero. In theory, the signal from a synchrodyne receiver is of better quality than that from a superheterodyne using a diode detector. Diode detectors are not linear and the weaker the signal the more the distortion.

Distortion can also occur on very strong signals. Even with moderate strength signals there will be some distortion because of the non-linear characteristics of the diode. Indeed top of the range modern superheterodyne receivers use synchronous detectors working at the intermediate frequencies.[2]

The major drawback of Tucker's synchrodyne receiver was that while tuning between stations there was a piercing whistle due to the local oscillator beating with off frequency

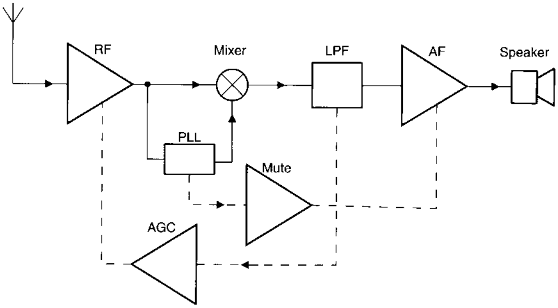


Fig. 1. Synchrodyne receivers work by mixing the incoming signal with a local oscillator of the same frequency, making conversion to audio frequencies simple.

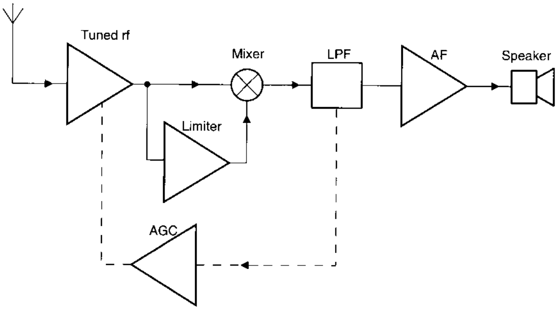


Fig. 2. Unlike the synchrodyne, the homodyne receiver does not suffer from heterodyne whistles while tuning between stations, eliminating the need for muting.

stations. Another problem is that the local oscillator needs to be in phase with the signal.

Nowadays these problems can be solved by using a phase-locked loop, or pll, with a lock detector operating a mute circuit. A description of the pll is given in a separate panel.

The pll not only gives a local oscillator locked to the signal frequency but it also allows the radio to be muted when the pll is out of lock. This gets rid of the heterodyne whistle while tuning between stations.

In spite of Tucker's valiant efforts to popularise his system, it never was accepted commercially. But it did catch on to a limited extent in radio amateur circles. Several manufacturers have sold relatively cheap amateur single side band transceivers incorporating a synchrodyne.

One LO for Tx and Rx

The big advantage for this equipment is that one local oscillator can operate both the receiver and the transmitter, as they operate at the same frequency. In contrast, with the superheterodyne, the local oscillator is offset from the transmission frequency by the intermediate frequency.

I must point out here that a direct-conversion receiver for ssb and Morse code reception has to be considerably more complicated than one intended for simple amplitude-modulation. This is because you can only allow one of the sidebands to be detected which means some form of phasing circuit to remove the unwanted sideband. When the incoming carrier is down-converted to zero frequency, the lower side band, which is now at a negative frequency, folds over and lies on top of the upper sideband. In amplitude-modulated signals both sidebands are identical.

In frequency-modulated signals however, the upper and lower sidebands are not identical so that this technique cannot be used without modification. This means that signals appearing in both sidebands are copied simultaneously. For wavebands intended for ssb and continuous-wave traffic, this is a disadvantage as the channels above and below the carrier frequency might be carrying different signals.

Figure 1 is a schematic diagram of the synchrodyne. The two additions in dotted lines are the mute and the automatic gain control needed to make the synchrodyne a more useful device.

The very earliest version of the synchrodyne contained no radio-frequency amplification. This could cause problems with microphonics due to all the amplification being at audio frequencies. It was not possible to provide automatic gain control either. But by distributing the gain to both radio and audio frequency stages though, you can avoid microphonics and provide automatic gain control.

The homodyne

Another variation of the direct conversion receiver is the homodyne. A description of this was given by J.W. Herbert in the September 1973 issue of *Wireless World*.

With the homodyne, incoming signal is filtered at rf and split into two halves. One half beats against the other to down convert to zero frequency. In theory this sounds simple, but in practice there are problems.

The signal that takes the place of the local oscillator does not have a sufficiently well-defined carrier because of the sidebands from the audio. However by putting this half through a limiting amplifier, i.e. an amplifier working at very high gain so that the signal saturates the amplifier produces a square wave at the signal frequency. The limiting effect removes the amplitude information that is the cause of the sidebands.

Furthermore, it is normally necessary to inject the local oscillator – in this case the signal itself – at a fairly high level into the mixer. Again, this is taken care of by the limiting amplifier. Moreover the detection is synchronous which should give this system an advantage over diode detector receivers.

Figure 2 is the homodyne's schematic. The addition of the automatic gain control shown in dotted lines makes this a more useful device. Unlike the synchrodyne this does not suffer from heterodyne whistles while tuning between stations, and the mute is not required.

John Linsley Hood described an AM synchrodyne receiver in the January 1986 issue of *Wireless World* but it was complex and expensive. The parts alone came to over £75.

About 11 years ago, one of us with a collaborator (Slifkin and Abbott, *Radio and Wireless World* Dec. 1987) presented some circuits for both homodyne and synchrodyne techniques. These were based on Plessey 600 series ICs which were meant for the professional market and carried a commensurate price tag.

Either radio could have been be built for less than £30 sterling. The replacement of the 600 series ICs by the now available cheaper 1600 series would have further lowered the price.

At that time, the pll ICs available had no built-in 90° phase shift. As a result, we had to construct a 90° phase shifter to bring the two signals back into phase and at all frequencies covered by the radio. This added to the complexity and cost of the receiver. Nowadays, pll ICs are available including a 90° phase shifter which greatly simplifies the design.

There are clearly several ICs which can be shared between the two

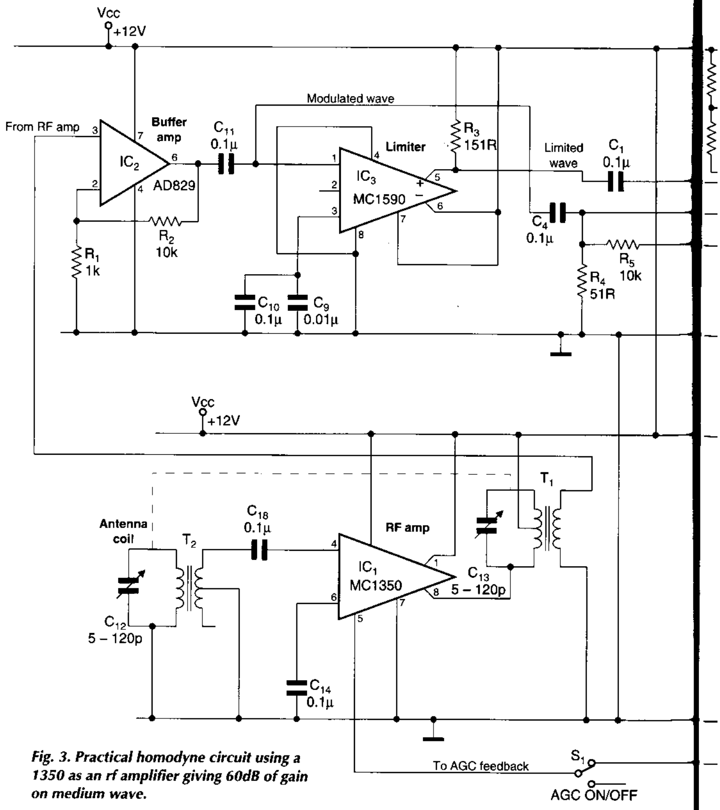


Fig. 3. Practical homodyne circuit using a 1350 as an rf amplifier giving 60dB of gain on medium wave.

designs. Our ambition at the time we published our first circuits was to build a joint homodyne/synchrodyne radio on one baseboard which could be switched from one to the other and using mainly the same components.

We were defeated though by being unable to tune the local oscillator for the synchrodyne by the same elements that were used to tune the homodyne. This problem is solved in the design presented here.

Locking on

The heart of the phase-locked loop device is a free running voltage controlled oscillator, or vco.

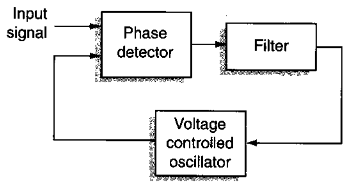
Output from the vco is mixed with the incoming signal. The output from this mixer is amplified by the error amplifier and sent through a low-pass filter to produce a dc signal voltage. This direct voltage feeds back to the vco in such a sense as to move the vco closer in frequency to the incoming signal. There is no output from the mixer when the two signals are exactly at the same frequency and 90° out of phase.

Two important parameters need to be considered, namely the lock range and the capture range. The capture range is that frequency range over which the incoming signal can be captured and locked onto by the vco. The lock range is that frequency range which once locked the signal stays locked to the vco.

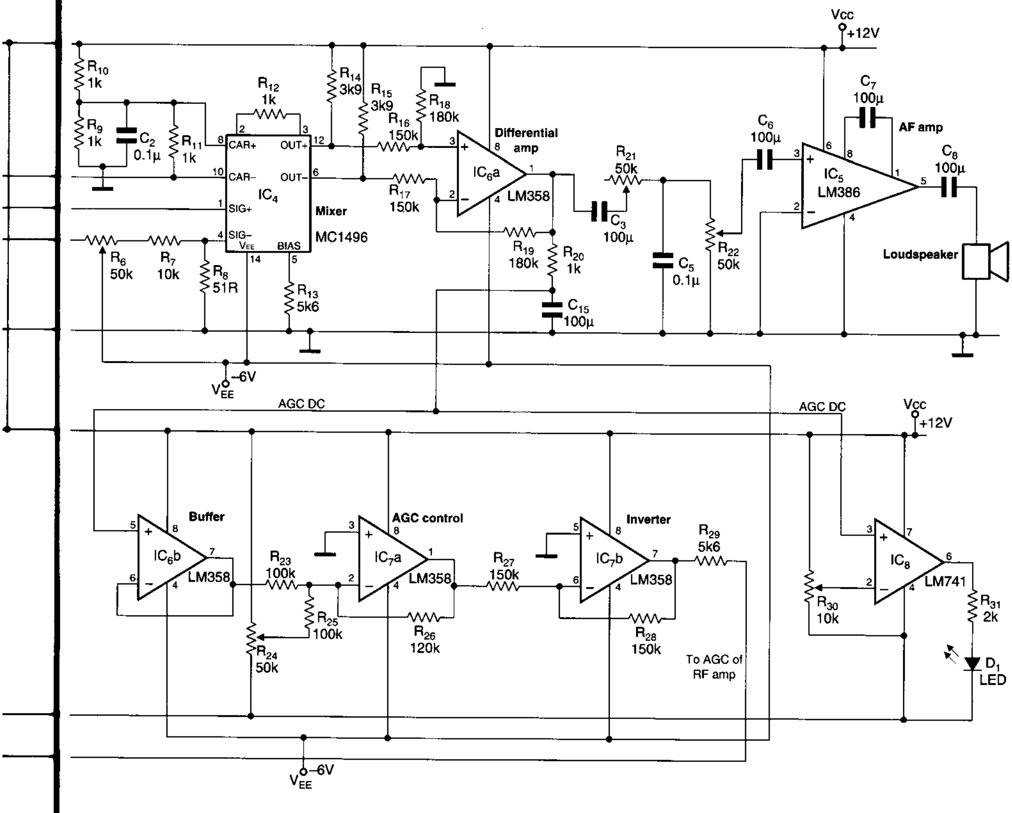
A narrow capture range can cause the system to miss the lock completely if tuning is too rapid. In addition the signal is more easily thrown out of lock by a noise pulse. Too wide a capture range means that one very strong signal in a frequency range locks on to the exclusion of all the other weaker signals.

Another parameter is the time – usually expressed as the number of cycles – that the pll requires to go to lock. This is determined by the low-pass filter in the feedback loop between the error amplifier and the vco.

All of these factors are important when designing a synchrodyne radio receiver.



Elements of the phase-locked loop.



In one small box we have combined the homodyne and synchrodyne using shared components. Both are tuned by the same tuning element. You can switch from one to the other with a simple toggle switch and find yourself on the same frequency.

In designing the circuits described here, we have used cheap readily available components. The layouts of the receivers are not crucial since the frequency range is only 540 to 1600kHz.

A practical homodyne design

A practical homodyne circuit is shown in **Figure 3**. A ferrite-rod antenna forms the input.

The rf amplifier is an easily obtainable *MC1350* device. This is in fact a tuned-frequency amplifier meant for video purpose but it is highly suitable as an AM radio-frequency amplifier as it has a built-in automatic gain controller. At medium wave, its gain is 60dB.

In this circuit, the radio-frequency stage of the homodyne is tuned with a conventional air spaced variable capacitor. Note the use of two tuned circuits with ganged capacitors; one tuned circuit would not provide us with the selectivity we needed.

The tuned circuits and ferrite rod were stripped from an old Pilot radio. We would imagine than any ferrite rod antenna and tuning circuit designed for the medium wave band could be used.

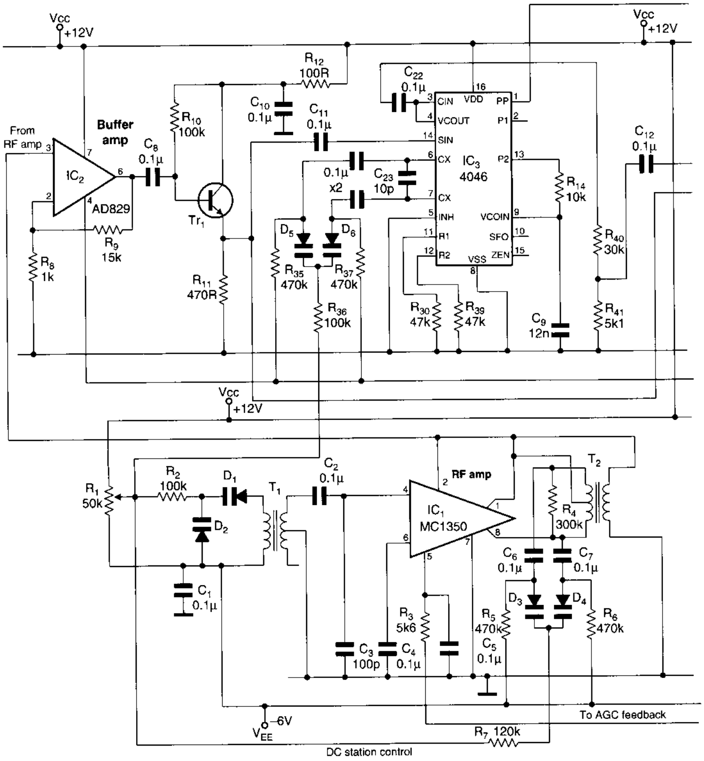
The limiter consists of an *AD829* low noise video operational amplifier used as a buffer, followed by an *MC1590* amplifier which performs the actual limiting. Mixing is performed by an *MC1496* balanced modulator. This has a differential output so an *LM358* configured as a differential amplifier is used to process the signal. Maximum input for this device is 200mV.

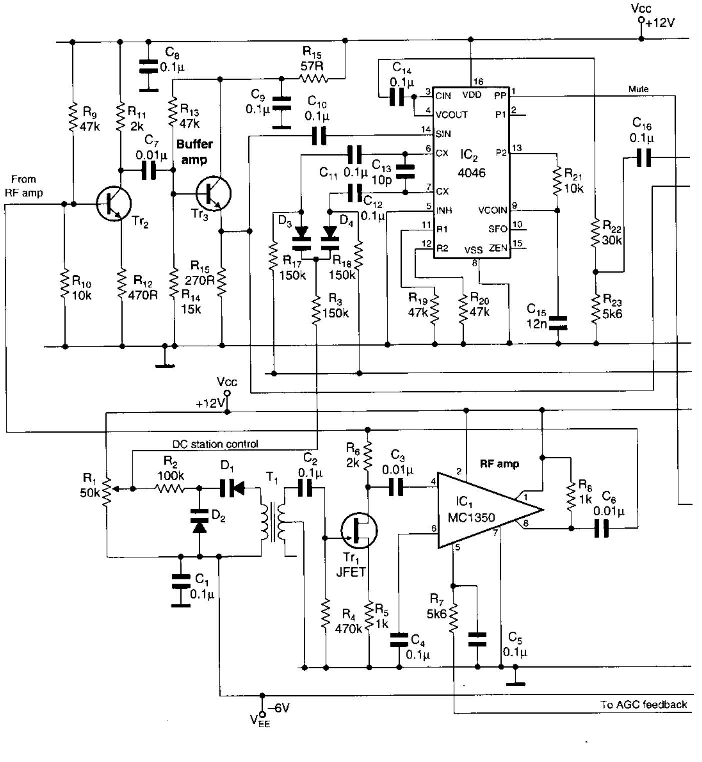
The low-pass filter at the output of the limiter determines its bandwidth, that is, selectivity. This is set for 9kHz. At the output of the mixer, there is also filter with a time constant of 200ms. This produces the rf amplifier's automatic gain-control signal.

Automatic gain control

Conditioning of the automatic gain-control line to obtain the correct amplitude with correct polarity is done by three operational amplifiers. These act respectively as a buffer, an amplifier and an inverter.

Overall gain of the gain control is around 70dB. This gives a rather restricted dynamic range, but it is sufficient if you are only interested in local signals, which is usually the





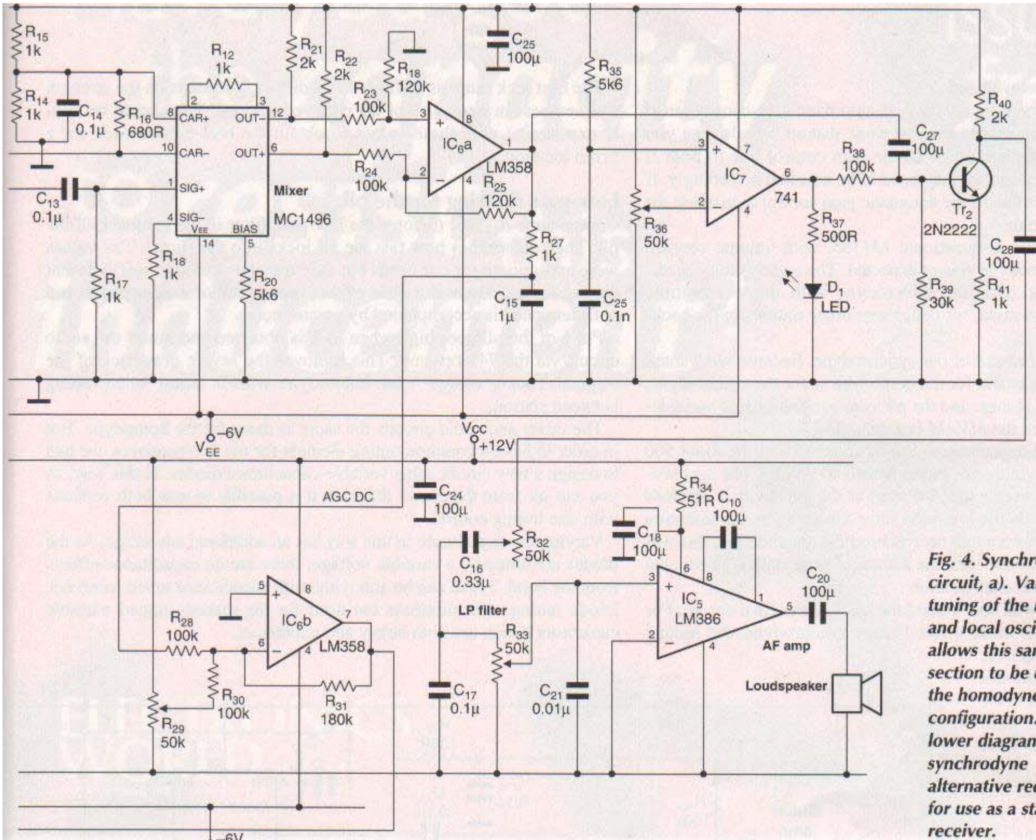
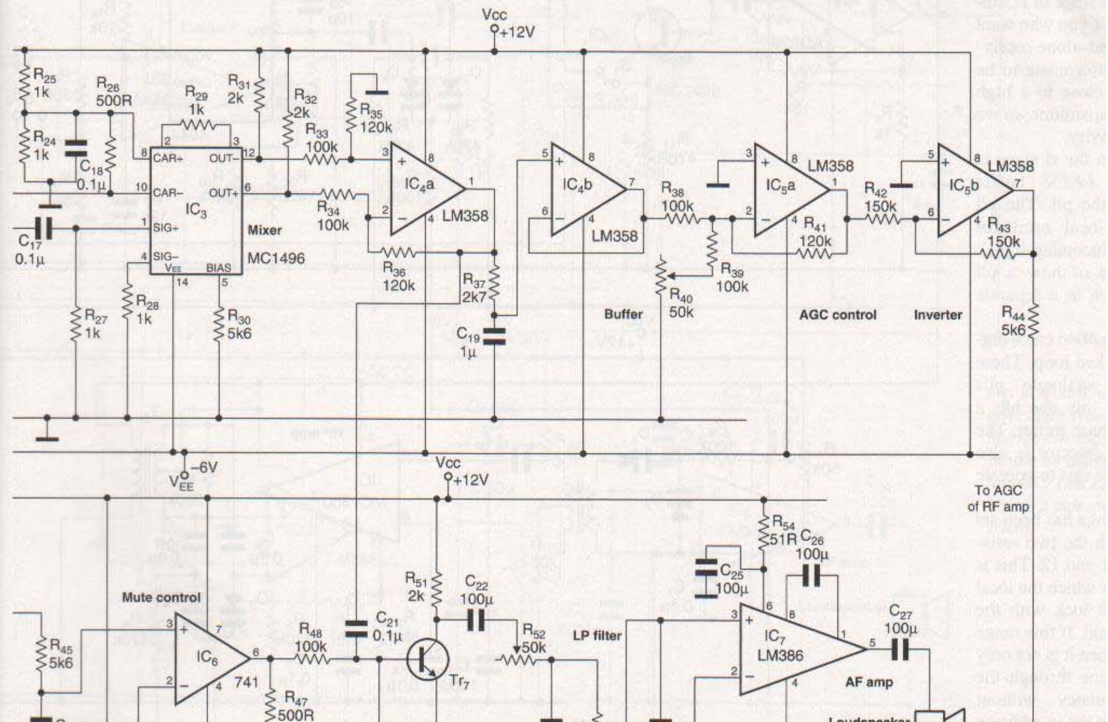


Fig. 4. Synchrodyne circuit, a). Varicap tuning of the rf stage and local oscillator allows this same tuning section to be used with the homodyne configuration. In the lower diagram, b), is a synchrodyne alternative redesigned for use as a stand-alone receiver.



case with the medium-wave band.

Good quality receivers normally have an automatic gain-control range of about 100dB. If you want to receive weak distant signals then you should add a second rf stage and take the gain control line to both rf amplifiers. Gain of the amplifier may need to be adjusted accordingly. If you want to, you can switch off the automatic gain control to increase the gain for very weak signals.

The audio stage uses a conventional *LM386*, with volume control. Performance of the homodyne was as expected. The audio quality is certainly superior to that of a superheterodyne with diode detection. However, particularly at night, we could hear other stations in the background.

Figure 4a) shows the circuit of our synchrodyne. Because we wanted to use the same tuning element for the homodyne as for the synchrodyne, we have tuned both the rf stage and the pll local oscillator using variable-capacitance diodes from the *MVAM* family.

The *MVAM109* has a capacitance ratio of about 15 to 1, or about 500 to 30pF as the reverse voltage is varied from 1 to 9 volts. The synchrodyne does not normally need a tuned rf stage as the selectivity is obtained after the mixer stage from the low-pass filter. However as our intention was to make a switchable homodyne/synchrodyne combination, this was our test rig to see if we could combine a tuned rf stage with a tuned local oscillator using the same control knob .

This section worked well and formed the basis of our final design. For those of you wanting to make a stand alone synchrodyne, the second tuned stage is not required. The first stage also does not need to be tuned, except in the presence of very strong local stations to prevent the front end being overloaded.

Simpler front end

In Fig. **4b)** we show the circuit diagram of a synchrodyne with only one stage of rf tuning for those of you who want to build a stand-alone receiver. We are unfortunate to be located very close to a high power AM transmitter, so we need rf selectivity.

Output from the rf stage is fed via an *LF358* buffer amplifier to the pll. The pll obtains the local oscillator locked to the incoming signal. A description of how a pll works is given in a separate panel.

We used the 4046 cmos digital phase-locked loop. There are several analogue plls available but this one has a built-in 90° phase shifter. The built-in lock detector is also useful. We use this to operate the mute.

The lock range has been set at 20kHz with the two resistors at pins 11 and 12. This is the range over which the local oscillator will lock with the incoming signal. If this range is too small, then it is not only possible to tune through the correct frequency without acquiring lock but in addition noise pulses can more easily throw the pll out of lock.

The best lock range is difficult to predict as it depends on the strength and nearness in frequency of the received stations. You should certainly experiment with these values to obtain the best combination for a given location.

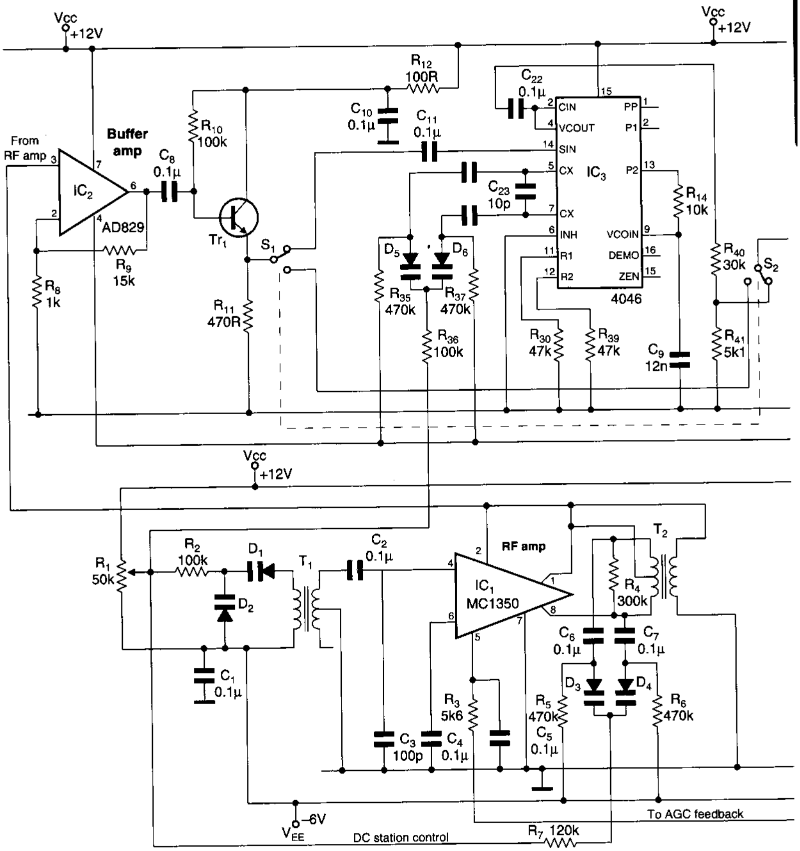
Low-pass filtering for the pll

Components R_{14} and C_9 form the low-pass filter in the feedback of the pll. They determines how fast the pll locks into the signal. The values were appropriate for our needs but they may be altered to suit different circumstances. There is a trade off between speed of lock-in and noise. A faster speed is accompanied by greater noise.

Pin 1 of the pll goes high when lock is obtained and mutes the audio circuit via the 741 op-amp. This removes the severe drawback of the original Tucker design – the heterodyne whistle heard when tuning between stations.

The mixer and audio circuits the same as those for the homodyne. But in order to have a common tuning element for the two receivers, we had to design a new circuit using variable-capacitance diodes. In this way, as you can see from the circuit diagram, it is possible to tune both versions with one tuning control.

Varying the capacitance in this way has an additional advantage. As the diodes are tuned by a variable voltage, there are no capacitance effects from the hand. These can be annoying with capacitance tuned receivers. Diode tuning also eliminate the need for air-spaced ganged variable capacitors which are both heavy and expensive.



Performance of the synchrodyne is impressive. The audio quality is similar to that of frequency modulation. In addition, because of the lock-in ability of the pll, you only hear one station – even at night when the range of distant stations is greatly increased.

The tuning properties of the radio are quite different from those of a standard AM receiver. Too fast a tuning rate results in stations being skipped over. In addition, you do not have the 'out-of-tune' sound of a station that you get from a superheterodyne that is slightly off frequency.

Homodyne and synchrodyne in one

Finally we present in **Fig. 5** the circuit of the combined homodyne/synchrodyne. This was built on a base board measuring 10 by 10cm.

We included an LED to indicate when the synchrodyne is in lock . The tuning dial was calibrated against our local stations.

A simple toggle switch takes you from homodyne to synchrodyne mode. It is possible to hear more stations with the homodyne than with the synchrodyne. This is because with the synchrodyne, weak stations near in frequency to strong ones are never heard as the strong station always locks in preference to the adjacent weak station.

It is possible that lowering the lock/capture range might improve the situation. This obviously lends itself to some experimentation. The homodyne, on the other hand, while having the same audio quality as the synchrodyne, cannot exclude stations on the same or nearby wavelengths. This means that you can hear more than one station simultaneously – especially at night.

For anyone interested in these types of receivers, these combined circuits can be used as an experimental rig to test out the different parameters, and to compare the homodyne directly with the synchrodyne.

Using readily available integrated circuits has enabled homodyne and synchrodyne receivers for the medium wave to be built cheaply *and* easily. If you had to build these devices using only discrete components, it would be a major undertaking.

However the use of these ICs is not without disadvantages. They often have a restricted range of input voltages and require, as in our case, a rather unusual negative voltage supply.

We would advise anyone building such devices to study the manufacturers' data sheets rather than just relying on the circuit values given here.

Although we have limited our design to the medium wave, there is no reason why an AM synchrodyne couldn't be built for the short wave. Analogue plls and mixers are available that operate up to at least 150MHz. Remember that you would need to use a long wire or rod antenna though, as ferrite rods are not efficient above about 2MHz. ■

References

1. Tucker, DG, 'The History of the Homodyne and the Synchrodyne' *J. Brit. IRE* April 1954.
2. Hawker, Ps., *Wireless World*, September 1972. (An account of synchronous detection).
3. Herbert, JW, *Wireless World*, September 1973. (Description of the homodyne).

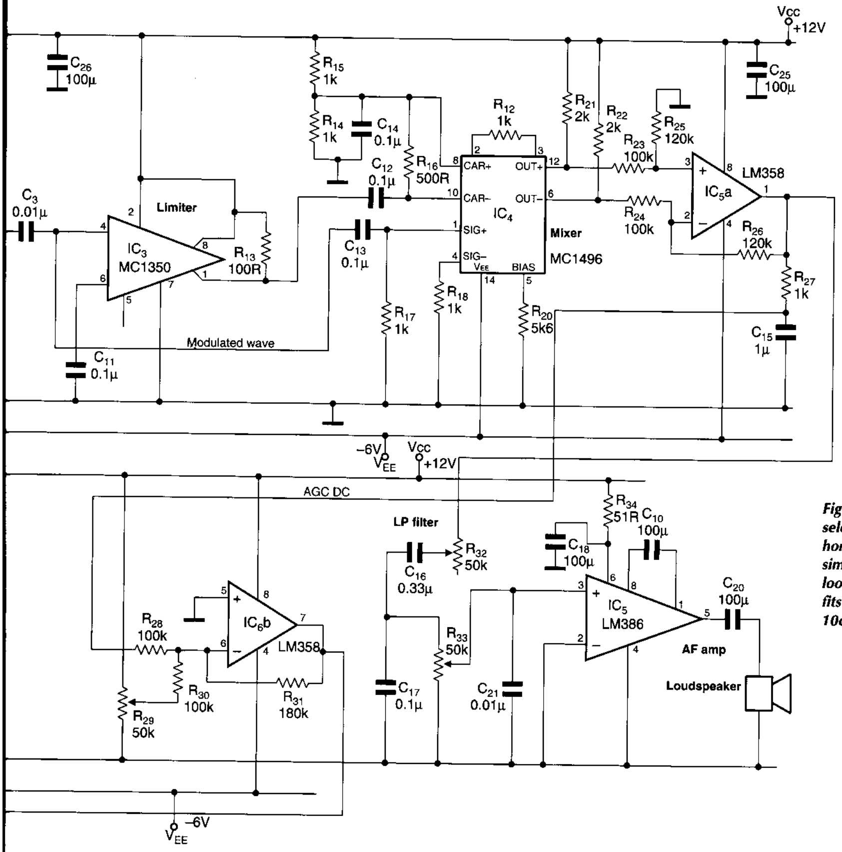


Fig. 5. Combined switch-selectable synchrodyne and homodyne receiver is kept simple by using a phase-locked loop IC. This complete design fits on a pcb measuring 10 by 10cm.