

wireless world

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A.m. receivers without interference

A method of interference cancellation for double sideband signals

by Lewis Illingworth, B. Eng.

Two systems which work with d.s.b. amplitude modulated carriers are described. As the signals are those propagated in long, medium and short wave bands throughout the world, there is a universal application. The systems make use of the fact that a.m. signals have symmetrical sidebands spreading out each side of the carrier frequency so that a modulated carrier has a constant phase, that of the carrier. Interference is not symmetrical even when it spreads through the same frequencies and this asymmetry can be used against it.

Double sideband a.m. transmission has especially desirable characteristics. In the *IRE Proceedings* for December 1956, John P. Costas wrote an article "Synchronous communications — the optimum a.m. system" which explains that double sideband, suppressed carrier a.m. signals, similar to broadcast signals but with the carrier removed, are easier to generate than single sideband and permit straightforward synchronous reception with superior performance in the presence of jamming and other interference. What was not mentioned was the additional possibility of cancelling out some of the received interference when synchronous reception is employed. One article which did cover this was an excellent paper in *Wireless World* by P. L. Taylor (July 1977) showing how one overlapping signal can be completely separated from another. Another fascinating paper on co-channel interference was given by J. S. Lothian at the *International Broadcasting Convention*, September 1974.

Our approach to the interference problem does not look for particular types of interfering signal and home in on them, as in P. L. Taylor's system, but to apply a general correction to a received band and accept whatever improvement one piece of circuitry will give. The systems described here completely eliminate interfering signals that are restricted to either side of the carrier. For the more difficult case of a fully modulated signal with carrier, at a slightly different carrier frequency from the wanted signal, the improvement in signal-to-noise ratio drops to about 10dB. As interference becomes progressively complex and finally degenerates to noise, the improvement drops to zero. This

performance could be improved but at the expense of some intermodulation between signal and interference.

While such performance is less than ideal, it must be remembered that the figures show improvement over the generally accepted theoretical limit for reception and represent considerable improvement over the performance of an equivalent s.s.b. receiver. This is achieved by conventional circuits and although the quantity of circuitry is not trivial, it is straightforward and works automatically.

Synchronous reception

An unexpected and welcome benefit from the addition of these systems is apparent when used with a synchronous receiver. Such sets, for example the General Electric AN/FRR-48 (XW-1) while operating well on fixed frequencies within the range of carrier phase lock are not at all nice to use when searching for signals. Off frequency unsuppressed carriers are demodulated as ear splitting whistles. For experiments on signals from a receiver, rather than instruments, a synchronous adapter was tied into the 455kHz i.f. of a conventional receiver, leading to adequate and painful listening experience. The new circuits however see such off-tune carriers as interference and eliminate them accordingly. A synchronous receiver now becomes quite nice to use with off-tune stations sounding like single sideband "wasp in the matchbox" accompanied by low background whistle with the mess disappearing as the carrier is tuned within frequency limits.

Development

My work on interference began some four years ago with a system that measured interference amplitude at carrier zero crossings. An initial guess at interference phase was taken to be that of the incoming signal, containing both signal and interference components, and the interference amplitude was estimated using that assumption. Signal amplitude was then deduced and subtracted from the incoming signal-interference composite to provide a better guess at incoming interference phase. Such a recursive system has to operate within tight, almost impossible envelope delay restrictions. Practical tests suggested however that such a system could be developed for general use and so a patent application (Canadian)

was made. Further development showed fair operation with simpler forms of interference and the system would even reduce noise levels at very low signal-to-noise ratios. However it was abominably unstable and the nonlinear recursive operation nigh on impossible to analyze. Response to it in official circles was negative — (See my letter to *Wireless World*, 15 September, 1977).

The simple system described here is an outcome of a search for a nonrecursive solution. While it is intended as a basis for forays into the realm of reducing levels of complex interference and even noise it stands in its own right as an extremely useful tool in cleaning up radio reception.

Theory

A double sideband modulated carrier with carrier frequency f_c and modulation frequency f_m can be written down as:

$$m \cos 2\pi(f_c - f_m) + c \cos 2\pi f_c + m \cos 2\pi(f_c + f_m)$$

where m and c are amplitudes. This is for a simple sinusoidal modulation and ignores modulation phase, but suffices for this basic analysis.

Demodulating the signal by multiplying by the carrier frequency $\cos 2\pi f_c$ gives us:

$$m \cos 2\pi f_c \cos 2\pi(f_c - f_m) + c \cos^2 2\pi f_c + m \cos 2\pi f_c \cos 2\pi(f_c + f_m)$$

$$= \frac{m}{2} [\cos 2\pi f_m + \cos 2\pi(2f_c - f_m)] +$$

$$\frac{c}{2} (1 + \cos 4\pi f_c) +$$

$$\frac{m}{2} [\cos 2\pi f_m + \cos 2\pi(f_c + f_m)]$$

$$= m \cos 2\pi f_m + \frac{m}{2} [\cos 2\pi(2f_c - f_m) +$$

$$\cos 2\pi(2f_c + f_m)]$$

and when filtered leaves a lower sideband at modulation frequencies: $(c/2 + m \cos 2\pi f_m)$. The carrier product $c/2$ is constant and removed by a.c. coupling to leave the modulation $m \cos 2\pi f_m$.

Demodulating the signal by multiplying with the carrier frequency shifted through 90° , $\sin 2\pi f_c$, gives us:

$$m \sin 2\pi f_c \cos 2\pi(f_c - f_m) + c \sin 2\pi f_c \cos 2\pi f_c + m \sin 2\pi f_c \cos 2\pi(f_c + f_m)$$

$$= \frac{m}{2} [\sin 2\pi f_m + \sin 2\pi(2f_c - f_m)] +$$

$$\frac{c}{2} \sin 4\pi f_c + \frac{m}{2} [-\sin 2\pi f_m + \sin 2\pi(2f_c + f_m)]$$

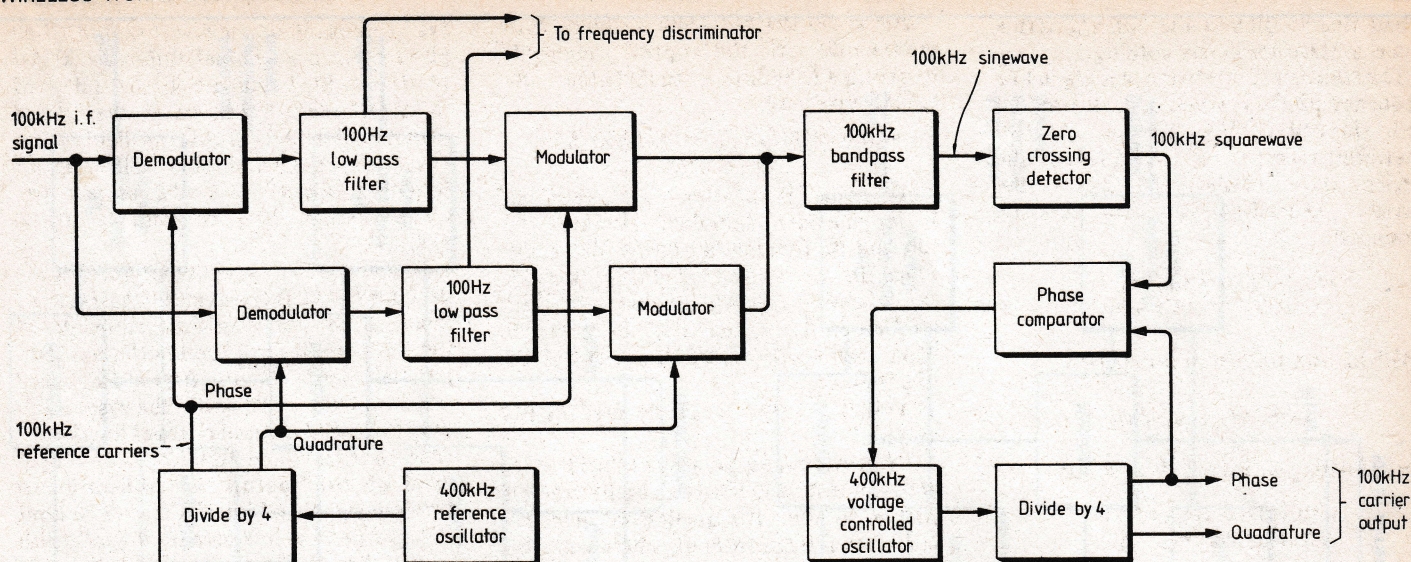


Fig.2. Carrier filter for synchronous receiver

At first sight this system must appear cumbersome in an age of phase locked loops. The reason for it is quite simple: phase locked loops do not operate well under high interference conditions; the loop frequency response must be high enough to permit a lock to be regained after a disturbance, a necessary response that allows interference to get into the loop and so leads to phase jumps in the oscillator output. Narrowing down the response to prevent this happening also prevents phase locking. In the early synchronous receivers phase jitter would not cause much of a problem because a 10° phase error would only reduce the detected amplitude to $\cos 10^\circ$, 0.985, a drop of only 1.5%. With these interference cancelling systems, however, the quadrature value of the signal under the same conditions, $\sin 10^\circ$, 0.174 is considerable, 17.4%, and is seen by the circuitry as interference. A stable narrow band filter minimizes these phase perturbations in the detected carrier.

Two carrier phases are required, one in phase with the incoming signal and the other in quadrature. Each is used to demodulate the 100kHz i.f. signal to produce audio. The 'in phase' demodulation contains the sum of modulation and interfering signals, the 'quadrature' demodulation has the difference between interfering frequencies lying above and below the carrier. A final step adjusts the relative phases of these two outputs by 90° so that signal and interfering components are either in phase or 180° out of phase. It is convenient to refer to the phase corrected phase and quadrature demodulated outputs as 'sum'

and 'difference' signals because they are similar to equivalent signals derived from other radio and non-radio sources.

Figure 6 shows a typical circuit of a 90° phase shift network. Two RC networks both attenuate and phase shift the 'sum' and 'difference' audio signals in such a way that attenuation is uniform over the frequency range but there is a constant 90° phase difference produced in signals traversing them.

Figure 2 shows the carrier filter in detail. This has phase and quadrature demodulators and modulators together with low pass active filters to produce extremely stable amplitude and phase characteristics. It is the same type of filter that is used with remarkable success in navigation equipment and is not difficult to make.

The 100kHz i.f. signal is demodulated using 100kHz phase and quadrature reference carriers to produce audio low frequency outputs. Figure 7 shows a typical divider to generate these carriers from a 400kHz stable source. A matched pair of 100Hz cut off low pass active filters eliminate modulation, interference and other higher frequencies. These signals are re-modulated, again in phase and quadrature, back to 100kHz and added together. A simple 100kHz conventional filter removes higher modulation products to leave a clean reconstructed carrier. The result is an overall 200Hz bandwidth with stability equal to that of the reference oscillator. One point to watch is the complete cancellation of carrier leaks in the modulators,

these will tend to produce jitter in the carrier output.

A 400kHz voltage controlled oscillator drives a divide by 4 circuit to generate 100kHz phase and quadrature carrier outputs. A conventional phase locked loop ties these carriers to the squared up 100kHz filter output. Such a phase lock loop in this position causes no problem because interference has been eliminated from the system.

Figure 3 shows the frequency discriminator used to derive the frequency control voltage for the 555kHz heterodyne oscillator. This is driven by low frequency signals from within the carrier filter. The 'quadrature' demodulated low pass filter output is differentiated to generate a signal that increases with amplitude as the frequency difference increases between the 100kHz received carrier and 100kHz reference. It is in phase with the 'phase' signal when the carrier frequency is higher than the reference and is 180° out of phase when the carrier frequency is lower. The differentiated quadrature signal is added to the phase signal and results in a low frequency a.c. voltage whose amplitude increases when the carrier is above the reference and decreases when it is below. A complimentary a.c. signal is produced by inverting the differentiated 'quadrature' low pass output before adding to the phase signal. Here the amplitude decreases when the carrier is above the reference and increases when below. Both signals are rectified and applied to a differential amplifier to generate a d.c. oscillator control voltage.

The frequency lock is to within a couple of hertz under most operating conditions,

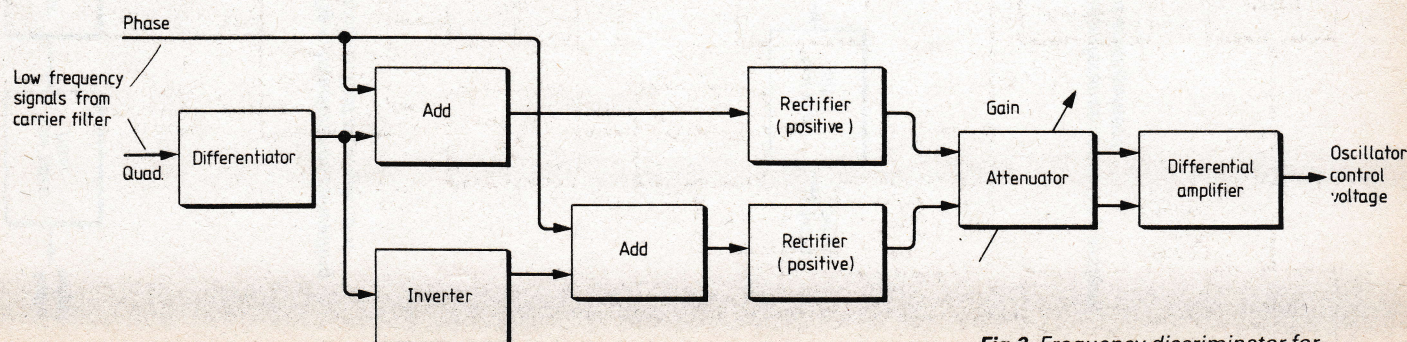


Fig.3. Frequency discriminator for synchronous receiver

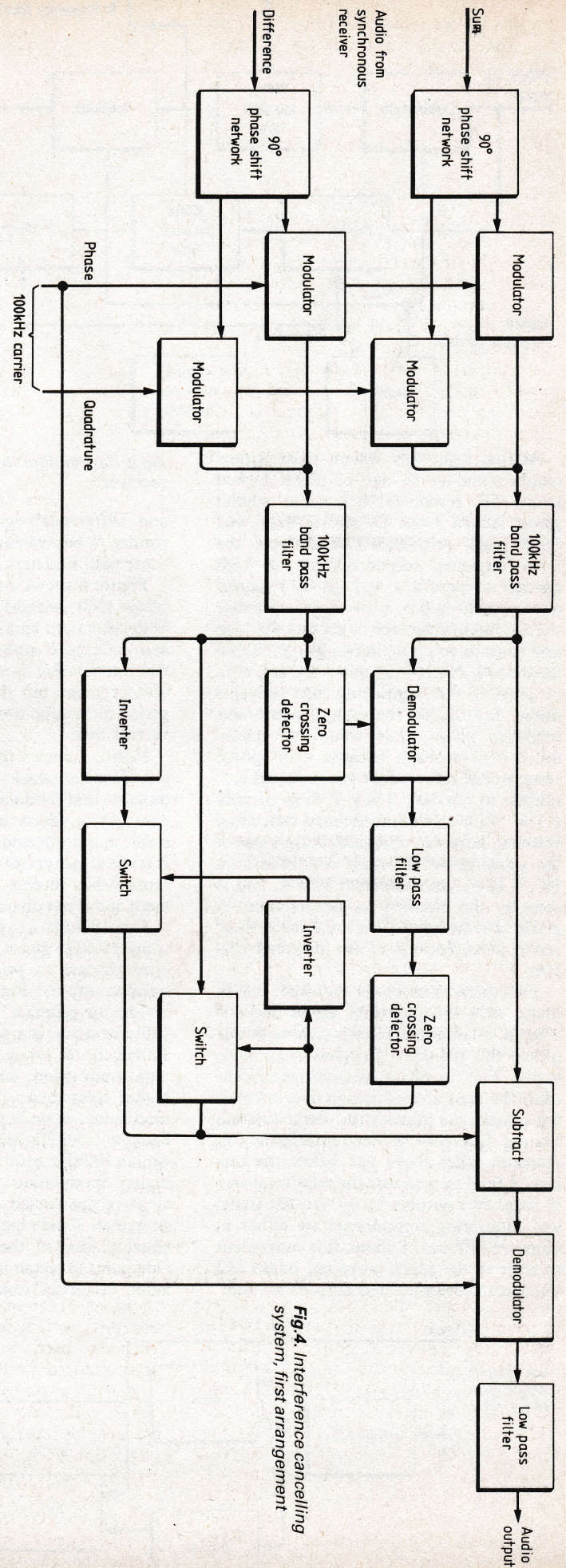


Fig.4. Interference cancelling system, first arrangement

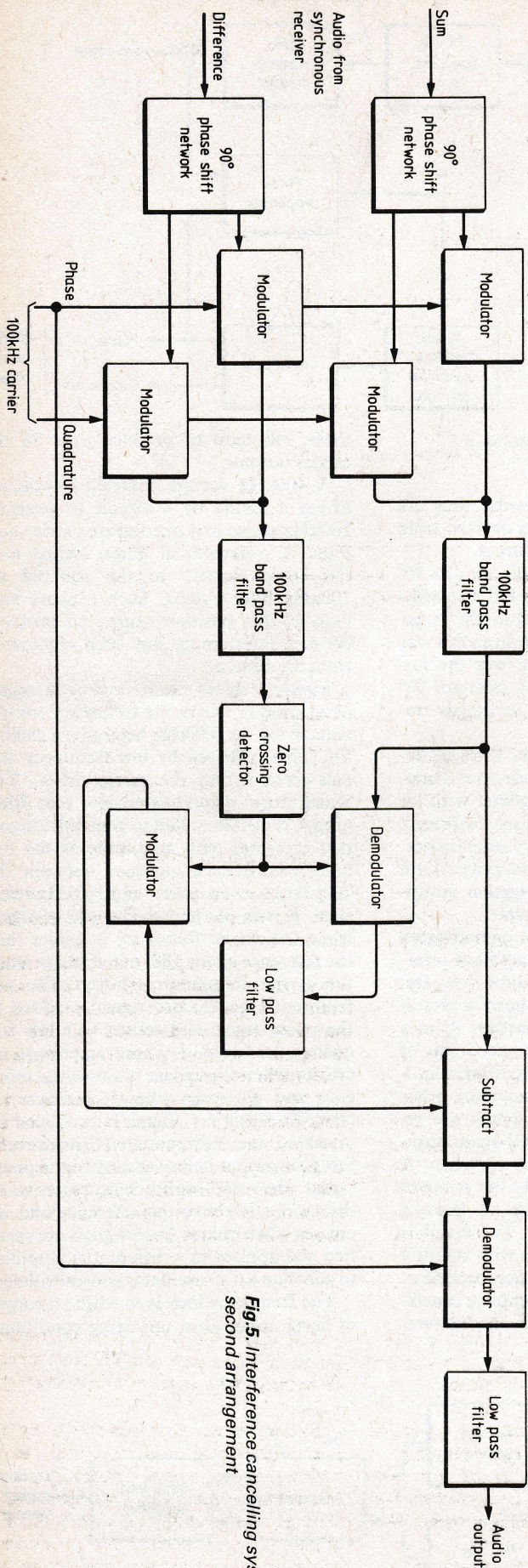


Fig.5. Interference cancelling system, second arrangement

and by virtue of control by the reference oscillator is not subject to drift. It is important that the carrier frequency be maintained close to the reference in order to minimize off tune phase errors introduced by the carrier filters.

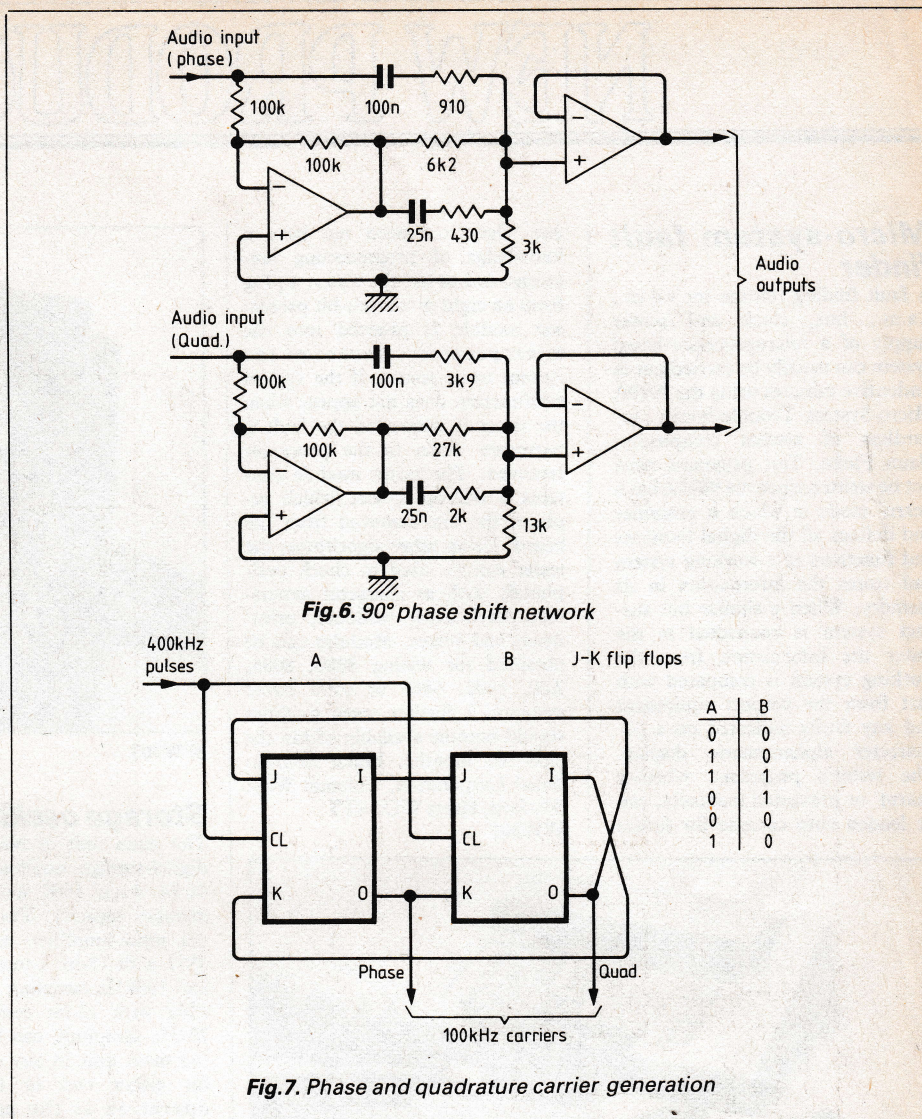
Interference cancelling system

The first step in interference cancellation is to raise the frequency up out of the audio range so that everything appears sinusoidal. In the first arrangement, Figure 4, the 'sum' and 'difference' audio outputs from the synchronous receiver are applied to 90° phase shift networks, and modulated by phase and quadrature 100kHz carriers to form upper sidebands of 100kHz. This is a conventional phase-shift method single sideband generation. Each signal is then filtered to remove higher order components. The 'difference' signal is squared up by a zero crossing detector and the output used as a carrier to demodulate the 'sum'. A low pass filter passes only the d.c. component of the demodulation. From this the interference polarity is extracted by a zero crossing detector, converted into a logic level and used to control switches to select either the direct or the inverted 'difference' signal. This puts the interference into the correct polarity where it is subtracted from the 'sum' to produce an improved signal-to-noise ratio. The signal is still at 100kHz, so a final step is demodulation using the 'phase' 100kHz carrier to generate an audio output.

The second system, shown in Figure 5, starts off in a similar manner. Signals are shifted to 100kHz, the 'difference' signal is squared up and used to demodulate the 'sum', and the output low pass filtered. In this system the low pass filter output is taken to represent both the amplitude and polarity of the interference. It is remodulated by the same squared up 'difference' signal to generate reconstituted interference for subtraction from the 'sum' signal-with-interference composite to be followed by demodulation down to audio.

Comments

Many system improvements suggest themselves and the most straightforward are currently being developed and assessed. There is unfortunately a practical limit beyond which processing errors in these



analogue systems outweigh advantages gained by increased complexity. We can look forward though to steadily improved signal-to-noise ratios as time and innovation permit.

This article does not pretend to describe an optimum or ultimate method for interference cancellation. The intent is to show that the performance we now accept from our radios is not as good as it could be and that significant improvements can be made by straightforward circuitry. The approach has value both in the improvement of radio reception and also as a basis for further experimentation, particularly

into the nature of interference and band limited noise.

The circuits are particularly adaptable to attenuation of interference when something is known about the nature of the interference, for example, military jamming or c.w. interference on frequency shift radio telegraphy.

There is an equivalent system under development for f.m. receivers. This takes the constant f.m. signal amplitude as reference, as opposed to the a.m. signal's constant phase. While showing promise, the technique is not yet sufficiently developed to warrant publication.

New UK group supports semiconductor manufacture

One of the first commercial ventures of the new British Technology Group formed by the merger of NRDC and NEB (News, September issue) is in an advanced field of semiconductor manufacture. This is a joint venture with the UK company Plasma-Therm Ltd, a subsidiary of Plasma-Therm Inc of Kresson, New Jersey, USA, who supply plasma process equipment (see below). The two partners will share the total cost of £170,000 of a two-year programme to develop new process control equipment for sale to European manufacturers of semiconductor devices. The equipment will be based on radio-frequency plasma

chemistry techniques, which offer advantages over traditional wet chemical methods used in the fabrication of semiconductor products.

A microprocessor-based monitoring system will be developed to give manufacturers more precise control in dry etching procedures based on radio-frequency plasmas by using optical emission spectroscopy. Also, a new power unit will be developed to complement Plasma-Therm's present range of radio frequency generators and so offer the ability to improve the adhesive qualities of plasma deposited passivation layers which protect the i.cs.

The agreement includes an arrangement for the NRDC part of BTG to recover its investment by a sales levy on relevant products.

Radio-frequency plasma chemistry techniques are being used more and more in making semiconductor devices, in place of wet chemical methods. One technical advantage is the ability to create the finer circuit patterns needed for producing a larger number of circuit elements per unit area. Certain gases, when ionized, form a reactive plasma which interacts with solid surfaces to selectively remove unwanted material without residual contamination.