Redifon And The 'Third Method' Of SSB

by Brian Austin, G0GSF

In June 1962, Redifon Limited, the London-based subsidiary of the Rediffusion Organization, produced its GR.410 HF SSB transmitter/receiver. In itself that might not appear to be especially significant because by then single sideband (SSB) was already regarded, at least in the USA, as the preferred mode for long-distance HF communication. But the GR.410 generated (and demodulated) SSB in a most unusual way and that fact alone made it rather different. Viewed now, nearly fifty years later, it may well have been unique and this makes the technique deserving of some special attention.

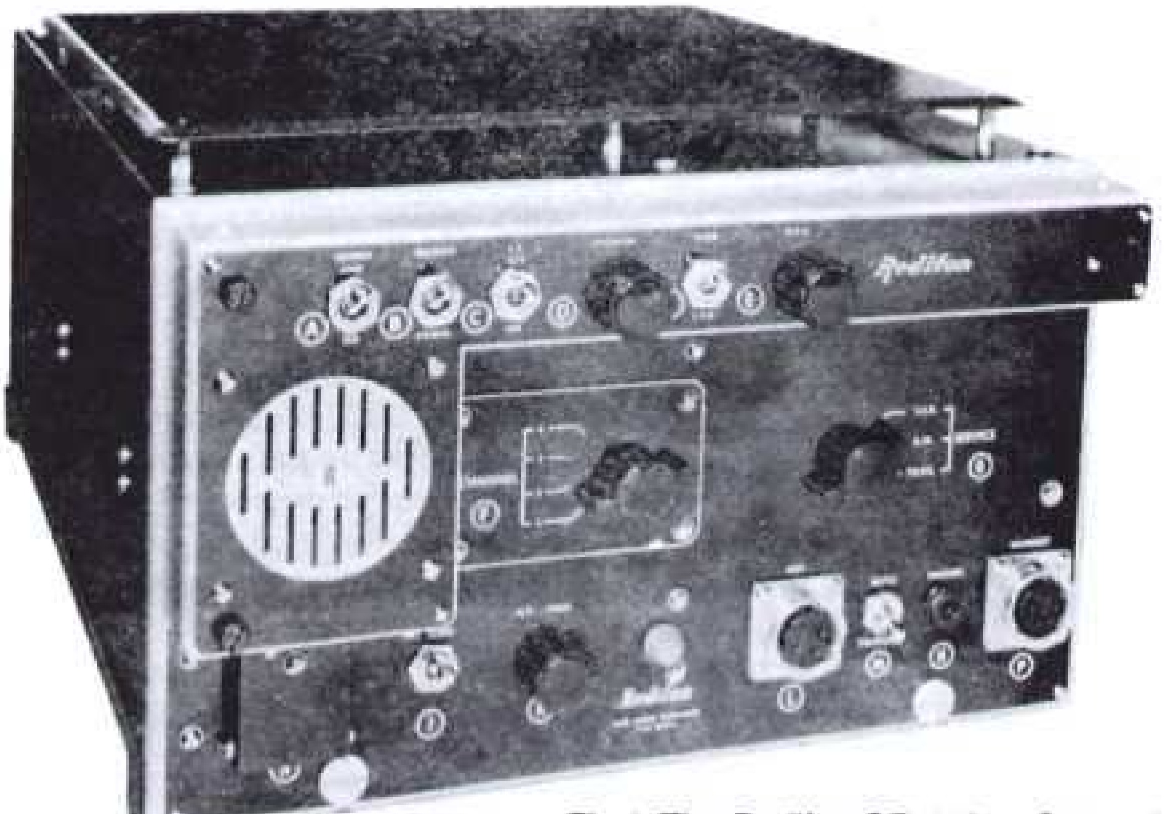


Fig.1. The Redifon GR.410 or C14 as it was known in the British Army

Origins Of Single Sideband

In 1962 SSB wasn't new. Though it really began to establish itself in the United States during the mid-1950s, its real beginnings were actually much earlier. The technique of suppressing one sideband plus the carrier, and of transmitting just a single sideband, followed directly from the discovery in 1914 of two sidebands, one on either side of the carrier, which contained exactly the same information.

Shortly afterwards J.R. Carson, an engineer at the American Telephone and Telegraph Company (AT&T), proved conclusively that no loss in intelligibility (and considerable savings in energy) would result if just a single sideband and no carrier were transmitted. Carson eventually patented a method for doing this in 1923 and is therefore justifiably recognised as the father of SSB.

Trans-Atlantic radio telephone traffic was the first beneficiary of Carson's work with the transmission, in 1927, of multi-channel voice signals between New York and London. These signals occupied discrete slots of bandwidth on either side of a suppressed carrier, thereby increasing the capacity of the system considerably. By 1931, the Deutsche Reichspost in Germany were also using SSB on their HF circuits to New York, while what is possibly the first military application of the mode also occurred in Germany when, in 1944, the Siemens company developed an SSB adapter for the famous E52 'Köln' receiver.

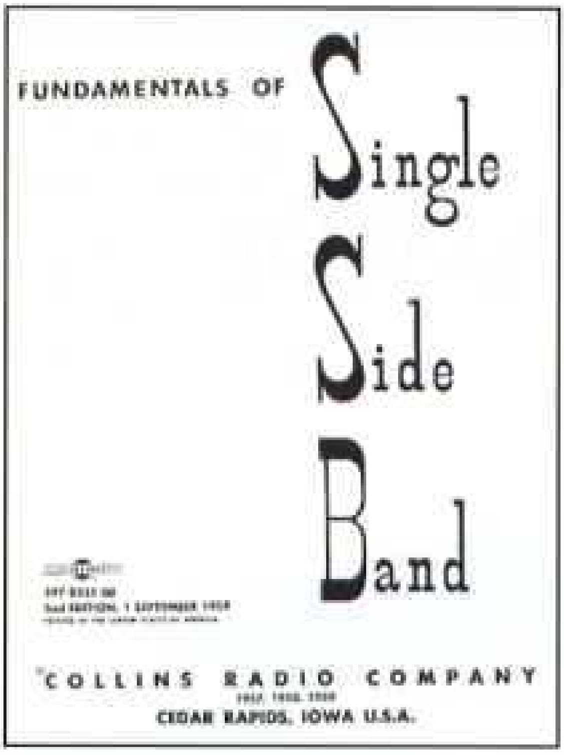
The earliest recorded British research on SSB, published in 1933, was especially cosmopolitan in that it was carried out in France and described a shortwave radio link between Spain and South America. The work actually took place in the ITT (International Telephone and Telegraph) laboratories in Paris, but the man responsible for it was indeed an English engineer by the name of A. H. Reeves.

Alec Reeves was soon to become even more famous as the inventor of pulse-code modulation (PCM) in 1938 and then, during the war, for his development of the radio navigation system, code-named Oboe, that played such a significant role within the RAF's Bomber Command. For the sheer breadth of his electronic achievements alone, Reeves must surely stand alongside Alan Blumlein in the pantheon of Britain's greatest electronics engineers.

Amateur Transmissions

Immediately after the war, research at Stanford University by Oswald G. Villard, Jr, W6QYT, led to the first successful SSB transmissions on the amateur bands from the university's club station W6YX in 1947. The SSB era had indeed begun and conventional amplitude modulation (AM), which required the transmission of both sidebands as well as the carrier, was eventually to be superseded by its technically more advanced cousin.

The stage had clearly been set for a revolution in HF radio communications and the American electronics industry was not slow to take advantage of it. By the mid-1950s, companies such as Collins Radio, RCA and Hallicrafters were gearing up to produce SSB equipment for both the military and amateur radio markets, while Central



FUNDAMENTALS OF

Single
Side
Band

COLLINS RADIO COMPANY

CEDAR RAPIDS, IOWA U.S.A.

Fig.2. The famous Collins Radio Company SSB monograph of the late 1950s

Electronics, General Electric and even lesser-known manufacturers such as Eldico had already made tentative ventures into SSB.

In 1957, the Strategic Air Command (SAC) of the US Air Force, under General Curtis Lemay W6EZV, adopted SSB as the primary HF mode for its long-range B-52 aircraft following very successful trials the previous year. Soon the Collins Radio Company, which had taken the decision in 1955 to switch all its HF systems from AM to SSB, and whose equipment played a part in that USAF trial, began to dominate the field. The Company's monograph on the subject, 'Fundamentals of Single Side Band' appeared in 1957 and became the definitive text on all matters related to this exciting new radio communications technology.

SSB In England

During the immediate post-war decade, British military (especially tactical) communications underwent something of a revolution, albeit slowly, with the shift from AM to FM and especially from HF to VHF. But there was still a need for HF, particularly within the Royal Navy and the Royal Air Force, where a long-range communications capability was vital.

The equipment in use, however, was mostly the old tried and tested AM hardware that had seen service during the war and the change to SSB, though in the minds of many engineers, was still very much on the horizon. And this was despite the fact that SSB was known to provide as much as a 9dB signal-to-noise ratio advantage over AM when both are operated under comparable conditions.

But such major changes in technology always take time to assimilate and sometimes even longer to implement. And they certainly did in England, as the Government's Signals Research and Development Establishment (SRDE), the organization responsible for the next-generation of the Army's communications equipment, struggled somewhat to adapt itself to the post-war world.

Things, though, were different in the commercial world and one of the companies that soon exploited the opportunities offered by SSB was Redifon. By the late 1950s they had designed the GR.400 SSB transmitter/receiver and it was soon followed by the GR.410 that appeared in 1962. Both sets were close to the cutting edge of technology at the time in that they used transistors in all the low-power circuits, but even more interesting was their use of a somewhat obscure technique for generating and detecting SSB. It was known as the 'Third Method' simply because its two rivals, the so-called filter and phasing methods, were already well-established.

Donald K. Weaver Jr at the Stanford Research Institute in California fully developed the 'Third Method' and described it in the famous SSB Issue of the *Proceedings of the Institute of Radio Engineers* (always known as the IRE) in December 1956. However, there was apparently no rush to use it, until Redifon, in England, designed the GR.400 and then the GR.410 in the early 1960s.

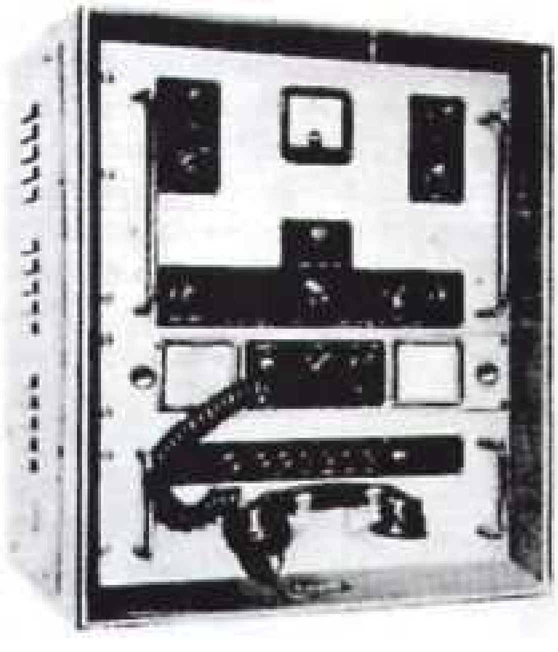


Fig.3. The Redifon GR.400, the earliest Third Method transceiver

What is the Third Method, how does it work and why did Redifon decide to use it? Before answering those questions it's probably worth reminding ourselves what the first and second methods were all about.

Other SSB Methods

The easiest way of producing an SSB signal is to use a sharp cut-off bandpass filter (usually of the crystal lattice type, or one involving mechanical resonators) centred on the wanted sideband at some convenient IF. The unwanted sideband, and what remains of the carrier, after being significantly reduced by a balanced modulator, is then effectively suppressed by falling some tens of decibels down the filter skirt. Though initially given a run for its money by the second method, this filter technique soon established itself as the dominant technology, especially when crystal filter costs fell and the need for minimal adjustment reduced overall production costs compared with any of its rivals.

The second method was introduced by Donald E. Norgaard W2KUJ of GE in 1948 following earlier work by R. V. L. Hartley, the man responsible for a well-known oscillator that bears his name. It is mathematically more elegant than the somewhat brute force approach of the filter method in that both the modulated AF and RF signals, in two channels, are suitably phased with respect to each other, and their relative amplitudes carefully controlled, so that on addition one sideband will reinforce itself while the other (the unwanted sideband) will experience total cancellation – if the phase and amplitude balance is perfect.

Whereas it's an easy matter to achieve the necessary 90 degree, or 'quadrature', phasing at a single RF frequency, it is considerably more difficult to do so over the wide band of frequencies typical of speech. Special networks requiring close tolerance components, and even some post-assembly tweaking, are necessary to do this effectively. It was for this reason that this 'phasing method' generally fell by the wayside.

Both the first and second methods have their disadvantages: filter complexity (and hence cost) in one, and the need for a rather complicated broadband phase-shift network in the other. The Third Method purported to solve both problems and, certainly, if SSB techniques are to be judged on their mathematical elegance alone

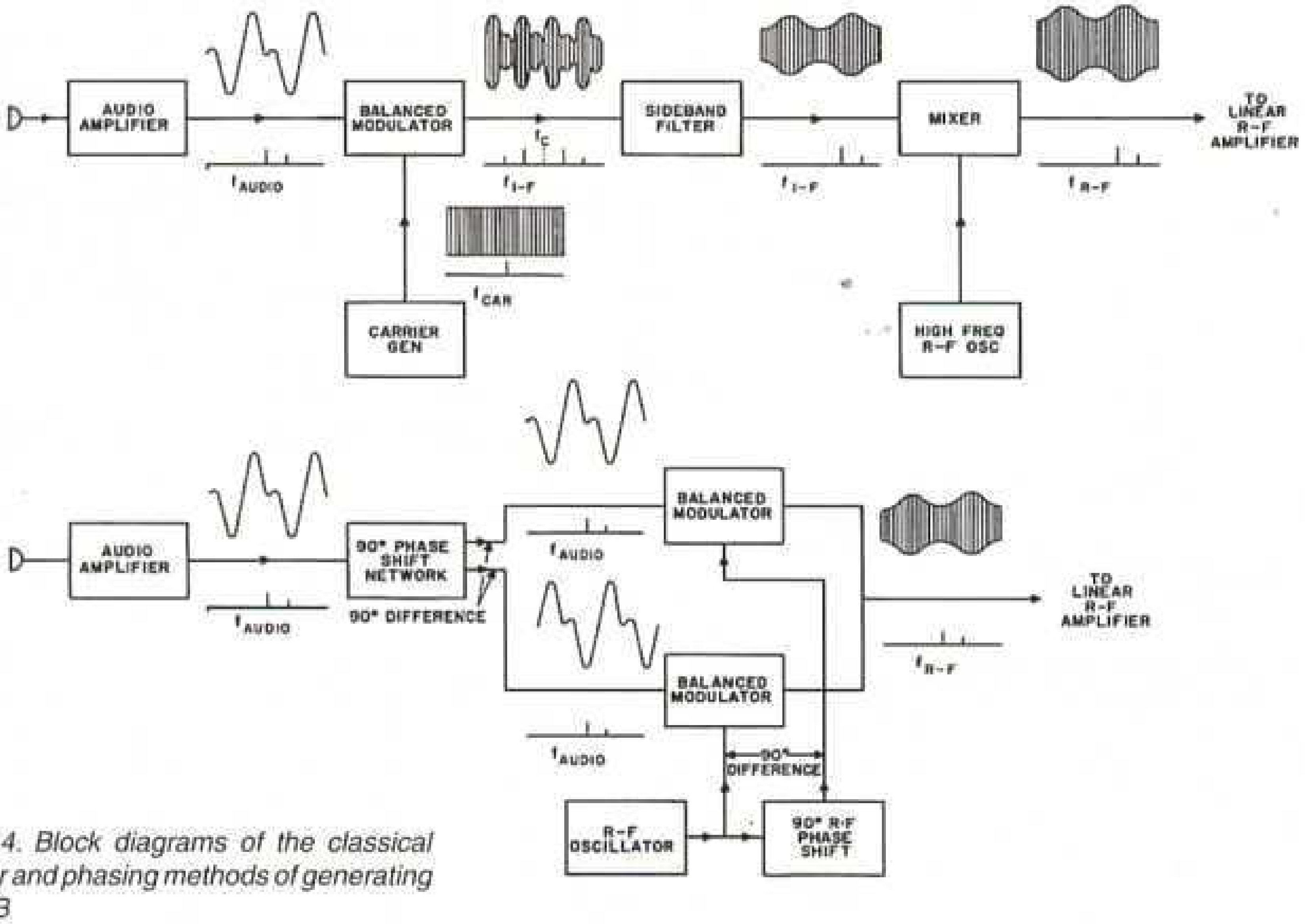


Fig.4. Block diagrams of the classical filter and phasing methods of generating SSB

then Weaver's has much to offer. It (and especially the part played by the British company Redifon Ltd in using it commercially) will now be discussed.

Redifon's Radios

Little is known of the GR.400 SSB transmitter/receiver other than its Third Method circuit configuration and its use of some of the earliest germanium transistors (types OC44, OC45, OC71 and OC170) in all the solid-state circuits, including the balanced modulators. From its general appearance, and especially the large telephone handset, the GR.400 looks as though it may have been intended for maritime use aboard vessels then converting from AM to SSB in terms of the international Safety of Life at Sea or SOLAS convention of 1960.

The GR.410 by contrast had a somewhat more military appearance despite not being 'ruggedized'. This is the usual term for such protuberances and pieces of bent metal that stiffen the mechanical structure and protect knobs and other vulnerable bits projecting from the front panel of typical modern military hardware. But the GR.410 actually did have a military pedigree and was known as the C14 in the inventory of the British

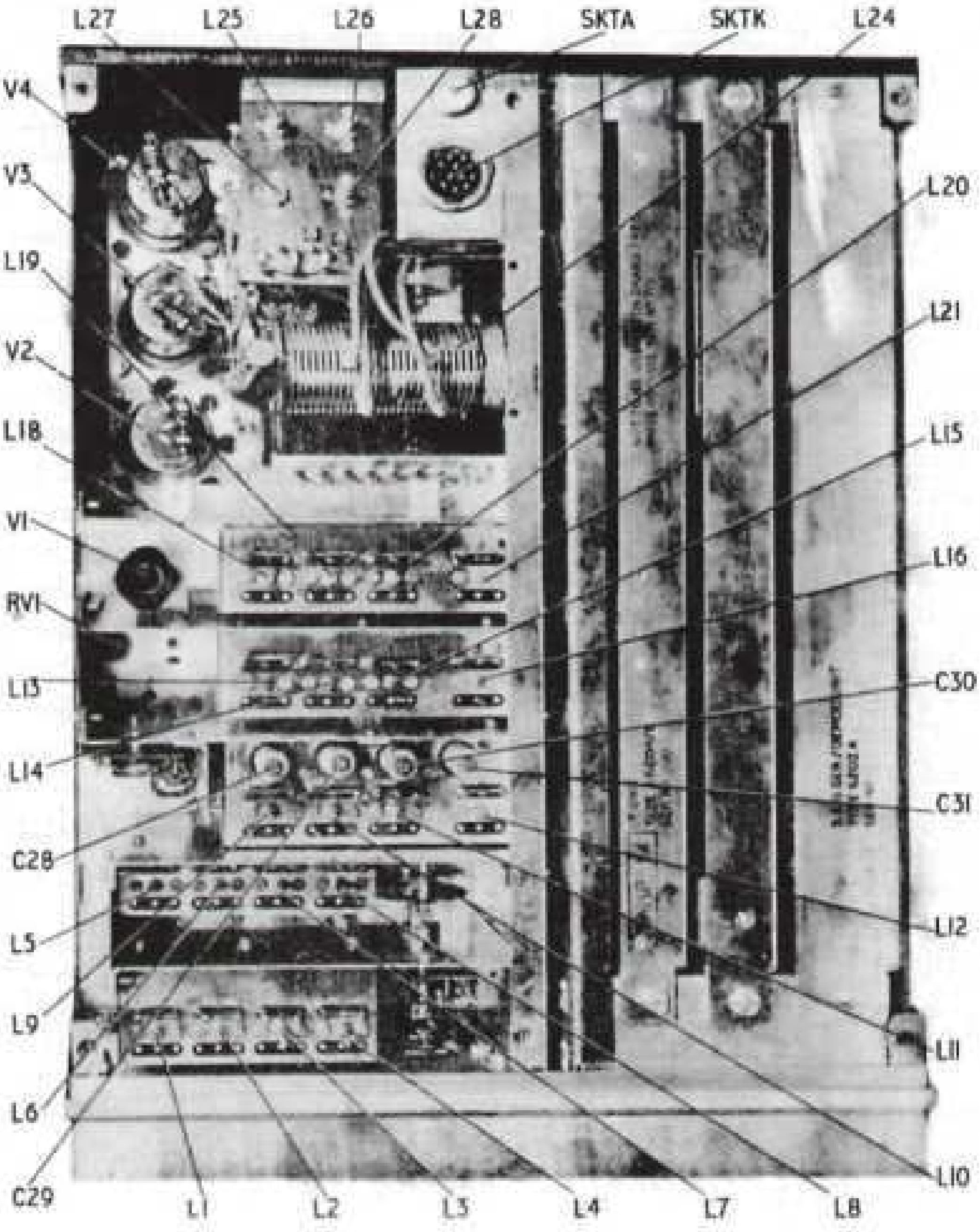


Fig.5. Above chassis view of the GR.410 showing the SSB generato demodulator unit and the three parallel 6146s in the PA stage

army's radio equipment. According to Louis Meulstee's admirable repository of such information, it was intended for formation and rear-link use during the early stages of air-transportable operations.

The equipment was fully tropicalised and could be powered either from the 240V mains or from either 12V or 24V DC supplies. It produced 100W PEP and was capable of both AM and SSB, as well as MCW and CW on four crystal-controlled channels between 2 and 16MHz. But by far its most interesting feature was the way that the GR.410 generated and demodulated SSB using Weaver's rather curious and now somewhat obscure, so-called, 'Third Method'.

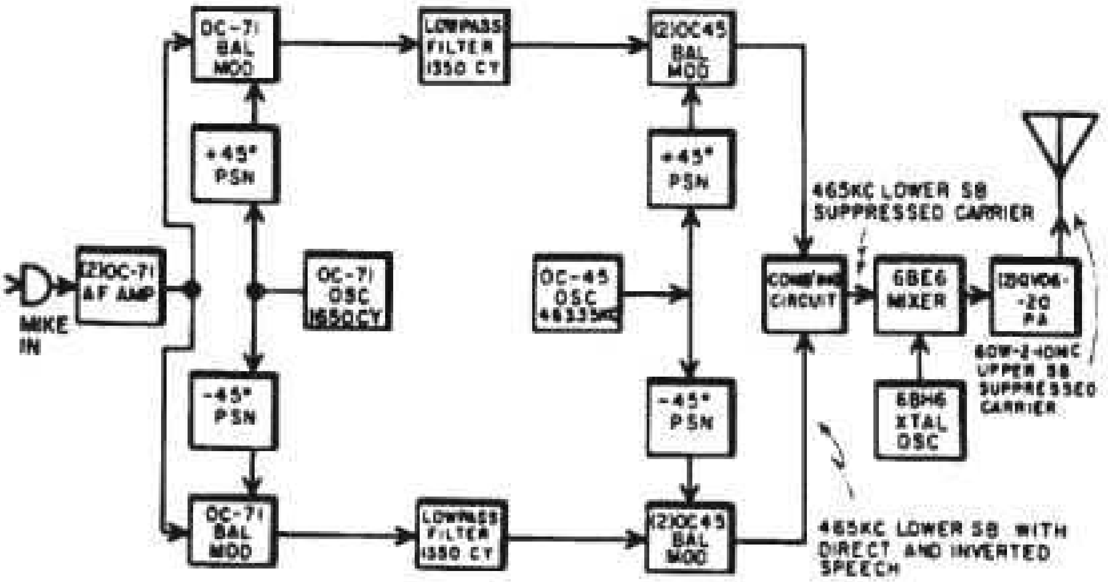


Fig.6. Block diagram of GR.400 Third Method SSB generator/demodulator, which is identical to that in the GR.410 except for its use of transistors instead of diodes in the balanced modulators. The subsequent mixer and amplifier stages differ too in the number and types of valves used

Third Method Of SSB

To some extent Weaver combined the best and worst of both worlds when he developed his unique way of generating single sideband (SSB). The Third Method contains not one but two filters and requires four phase-shift networks. But the filters are relatively simple (and alike), while those phase-shifting networks operate at single frequencies, with one pair actually functioning at audio (AF), which makes their design easy and their stability a non-issue.

The block diagram opposite, which is actually that of the GR400, illustrates the technique. Its actual implementation in hardware is a detail; the configuration is always the same. However, one interesting circuit change in the GR.410 was the use of diodes instead of the OC71 and OC45 germanium transistors in both pairs of balanced modulators. This made the SSB section of the equipment bilateral in that signals were able to pass as easily from left to right as from right to left. Hence it was now capable of generating and demodulating SSB, when in the receive mode, without the need for any complicated switching. It was, therefore, ideal for use in a true transceiver.

The first point to notice is that the Third Method (just as in Norgaard's phasing method) splits the incoming audio frequency signal into two channels. They are identical except that the oscillator signals that drive them differ in phase by 90 degrees. Today, they would be called the *I* and *Q* channels to represent their in-phase and quadrature states. In practice, it is usually easier to use lead and lag networks together to yield a total phase difference of 90 degrees by causing one channel to be driven by a +45 degree, or leading, network and the other by one that lags by – 45 degrees.

These phase-shift networks are clearly seen in the block diagram. It will be noted too that the oscillator producing this AF signal runs at 1650Hz (or CY as it's marked in the diagram) in the GR.400 just as it did in the later model, the GR.410. The reason for this most unusual choice of frequency is the key to the Third Method and will now be discussed.

Mixing or modulating in a double-balanced modulator a band-limited AF signal, with a tone positioned at the arithmetic centre of that AF band, causes all those audio components to be folded around that central or pilot tone. This sounds awfully complicated and it is – in words! But by using some numerical values and a suitable diagram it should be much easier to follow. Examine just the upper channel since the behaviour of both the upper and lower channels is exactly the same except for the quadrature phase shift between them.

Some Numerical Values

Consider a voice signal with its bandwidth limited to 2.7kHz, as is typical for most speech communication systems. Its lower cut-off frequency would usually be 300Hz with the upper cut-off at 3kHz. The actual mid frequency – its arithmetic centre – lies at half the 2.7kHz bandwidth value plus 300Hz above the 0Hz or DC limit. Thus the pilot carrier, which we call f_p, will be set to 1350 + 300 = 1650Hz. Now this 1650Hz signal is mixed with the band of speech frequencies, in the first balanced modulator (BM). Since it is of the double-balanced variety neither the pilot carrier at 1650Hz, nor the speech frequency signals alone appear at the BM output, only their sum and difference frequencies do.

Those sum components extend from 1950Hz to 4650Hz, as the usual upper sideband (USB), but the difference components undergo an interesting folding process which involves some of the AF signals actually folding back on themselves about the DC or zero Hz value. And – just to add some spice to the mix – that DC component should ideally be preserved because it actually represents a part of the unfolded signal. This requires DC coupling throughout the Third Method signal chain if a notch is not to occur in the AF pass band.

To understand the sideband-folding consider the numbers and refer to **Figure 7** for clarification. Subtracting 300Hz, and then all the higher frequency components of the speech signal up to a value of 1650Hz, from the 1650Hz pilot produces a band of frequencies that run from 1350Hz down to 0Hz, the DC value referred to earlier. They are the usual inverted lower sideband (LSB) outputs from the BM. However, all speech frequencies above the pilot at 1650Hz will produce negative values on being subtracted: e.g. a 2kHz tone will yield 1650 – 2000 = minus 350Hz, while subtracting the top speech frequency of 3kHz produces minus 1350Hz.

Since negative frequencies cannot exist in practice that part of the spectrum is folded around into the positive part of the graph and overlays

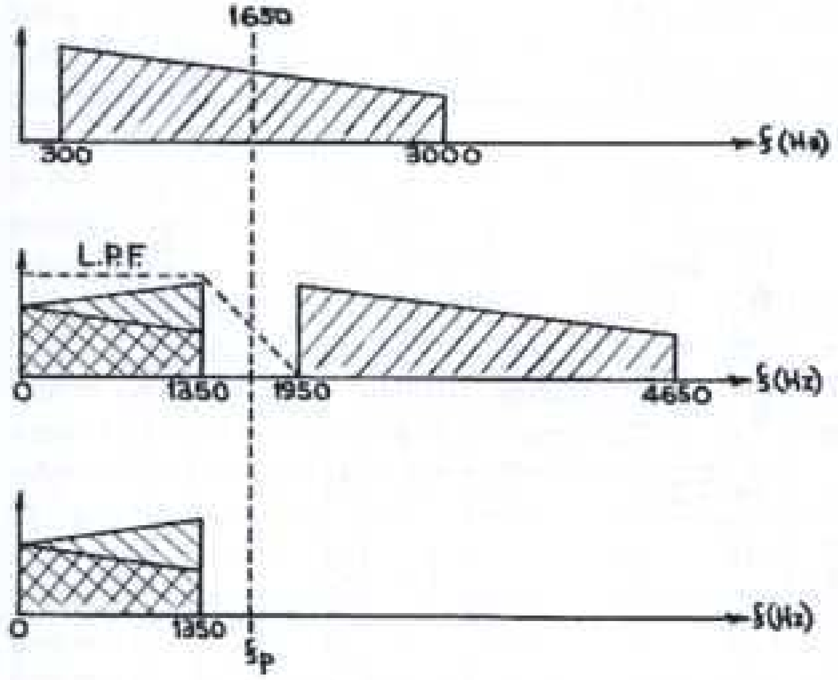


Fig.7. Graphs showing the baseband signal, the position of the pilot tone and the spectra after sideband-folding and then following the low pass filter

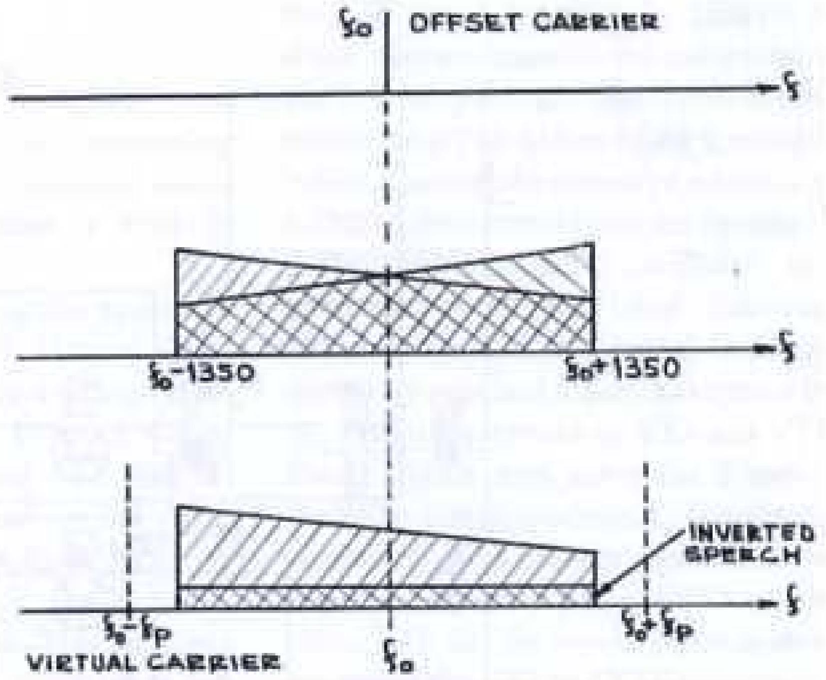


Fig.8. Spectra of the 'offset carrier', the output from the second balanced modulator and the SSB signal following combination of the two channels. The in-band inverted sideband is shown. Also indicated are the two 'virtual carriers' above and below the sideband

the other positive components, but as a mixture of normal and inverted speech. This folded spectrum also includes the component at DC that actually represents any 1650Hz energy within the voice bandwidth. Note, too, that the complete 2.7kHz speech bandwidth has now been accommodated in half that spectrum, or just 1350Hz. To the unsuspecting this is all most intriguing!

Low Pass Filter

The output from the first balanced modulator is then filtered by the low pass filter (LPF) with a cut-off frequency f_c of 1350Hz. Only the folded LSB signals pass through, while the USB ones do not. The slope of the filter's skirt is important in the overall performance of the Third Method SSB generator and demodulator. The stop band attenuation at 600Hz above the cut-off (ie at 1950Hz) must be sufficient to reduce significantly those USB components lying above that frequency.

Since this filter operates at audio frequencies, it only has to produce the necessary attenuation (typ. 40dB) at a frequency almost 50 per cent above its cut-off frequency. By contrast, the typical high frequency crystal filter used in a conventional filter-type SSB generator would have to yield the same sort of attenuation a mere fraction of a percent above its cut-off frequency in order to reject the unwanted sideband sufficiently.

This makes the design and construction of the LPF in the Third Method exciter a very simple matter indeed compared with that of a typical crystal lattice filter. In the days when such crystal filters were not nearly the common-or-garden components that they became later on, this feature must have been one of the Third Method's key attributes that influenced Redifon's design engineers when weighing up their options.

Modulating, Some Magic And Then SSB

The process of mixing the two low pass-filtered, folded signals in the second pair of balanced modulators, and then adding their outputs together, not only produces the required SSB – as an unfolded signal 2.7kHz wide – but it also manages to achieve two other rather remarkable results. One is the absence of any unwanted sideband in the adjacent channel; the other is a rather strange suppressed carrier frequency, which actually doesn't exist at all! All this follows directly from the underlying mathematics, but this is hardly the place for multi-factorial equations. Words and pictures will have to suffice again to explain the magic.

The output from each of the second balanced modulators consists of two sidebands, each 1350Hz wide. However, the full 2.7kHz input signal is contained within that spectrum because it was folded in half, with each sideband consisting of two components, one being the low frequency part of the audio signal, the other the high-frequency part, but one pair is inverted in that high frequencies appear as low frequencies and vice versa.

What happens next is precisely the same process that occurs in the phasing method where the two channel outputs, in phase quadrature, are now combined. As long as the signals from those channels are balanced in amplitude and are exactly 90 degrees apart in phase, one of those pairs of signals will be cancelled out and a reconstituted, unfolded, SSB signal with the full 2.7kHz bandwidth results.

If the amplitude or phase balance is not perfect then cancellation is incomplete and some of the unwanted inverted signals do exist, but they fall within the same band as the wanted signal. This is completely unlike the situation when either the filter or phasing methods misbehaves. There, the unwanted sideband falls above or below the wanted signal, possibly to cause problems to other legitimate users of those adjacent channels. A malfunctioning Third Method transmitter, by contrast, only irritates the intended recipient of its signal with incomprehensible background noise. All these intriguing features are shown in **Figure 8**.

Those who have followed this tortuous process so far may well be wondering how such an SSB signal is to be tuned in at the receiving end. Where among all these folded and shifted frequencies is the suppressed carrier, the usual marker of the transmitting frequency?

In both the filter and phasing methods, the suppressed carrier lies either above or below the sideband

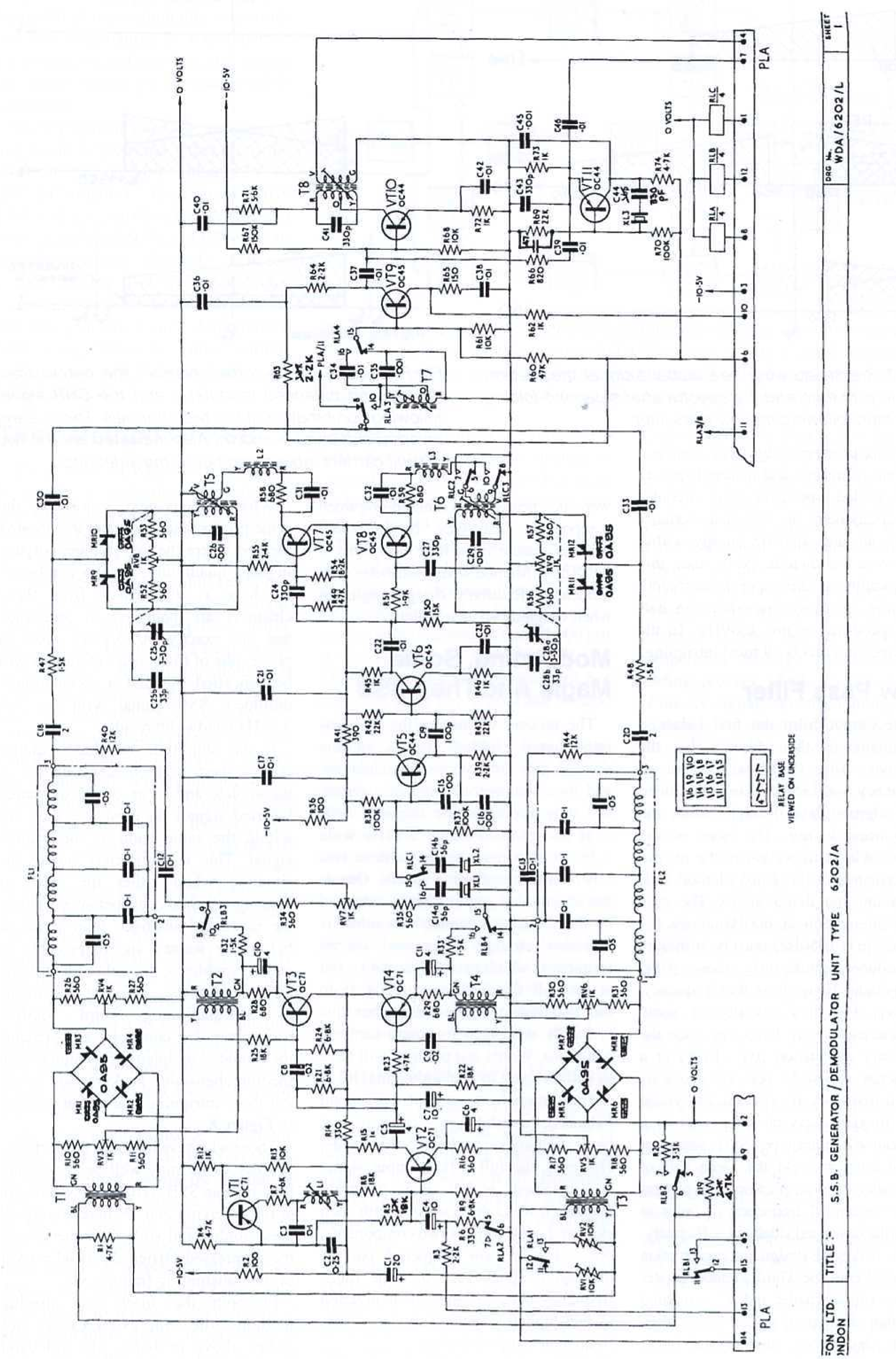


Fig.9. The circuit diagram of the GR.410 SSB generator/demodulator section

being transmitted and its position defines the frequency of transmission, even though it is not itself transmitted. But in the Third Method no signal is even generated at either of those positions so there is nothing to suppress.

The component that comes closest to being the 'carrier' (called f_o in the system described here) actually falls right at the centre of the transmitted sideband and it is indeed suppressed by the action of those second balanced modulators. But it's not the suppressed carrier we usually use to define the frequency of an SSB signal. That frequency – the one to which a receiver must be tuned – is actually related to the frequencies of both oscillators within the Third Method generator and it lies above or below the transmitted sideband at $f_o + f_p$ or $f_o - f_p$, depending on whether it's the lower or upper sideband that's transmitted.

But these combined signals involving the sum or difference of f_o and f_p do not exist in practice, being simply a manifestation of the mathematics, and so they cannot occur at the output. For this reason the elusive suppressed carrier of the Third Method is sometimes known as a synthetic or virtual carrier frequency.

Third Method Idiosyncracies

Weaver's approach to generating an SSB signal clearly contains many surprises. How well does it work in practice?

A look at the block diagram again will confirm that the Third Method lends itself very well to transceiver operation because it is bilateral. In other words, an audio signal entering from the left leaves as an SSB signal on the right, while feeding in SSB at the appropriate frequency on the right produces an audio signal at the left. This assumes that all four balanced modulators are bilateral, which is true for the various diode configurations in the GR.410, but may not necessarily be the case if active mixers are used.

The circuit diagram (**Figure 9**) shows the SSB generator/demodulator of the GR.410. Its inherent symmetry indicates the bilateral nature of the circuit. On transmit, audio signals enter from the left through transformers T1 and T3. They are then modulated in two ring balanced modulators, MR1 to MR8, in the two channels, before being fed to the 1350Hz low pass filters FL1 and FL2. Further mixing takes places in the shunt modulators MR9 to MR12 to produce the SSB signal at nominally 250kHz IF when the two channels are combined at pin 9 of relay RLA3. This signal is then buffered by VT9 before being applied to VT10, a mixer, the output of which is at 1.2MHz, the second IF of the system.

The 1650Hz pilot oscillator that generates f_p is VT1 and following buffering in VT2, that signal is phase-shifted by plus and minus 45 degrees by the lead-lag networks in VT3 and VT4. These signals then drive the *I* and *Q* chains in phase quadrature. The crystal controlled IF oscillator, switched for upper and lower sideband, is VT5 with its buffer VT6 and the two IF phase shifters are within the VT7 and VT8 circuits.

On receive, the IF signal at nominally 250kHz enters the circuit at pin 9 of relay RLA3 from where it splits into the two parallel chains. The processing that then takes place is simply the reverse of that in the transmit mode with the recovered audio signal from transformers T1 and T3 after cancellation of the inverted speech components.

Inverted Speech

The possible existence of inverted speech within the same pass band as the wanted SSB signal is not as peculiar as it may (and indeed does) sound. It occurs when the upper and lower channels

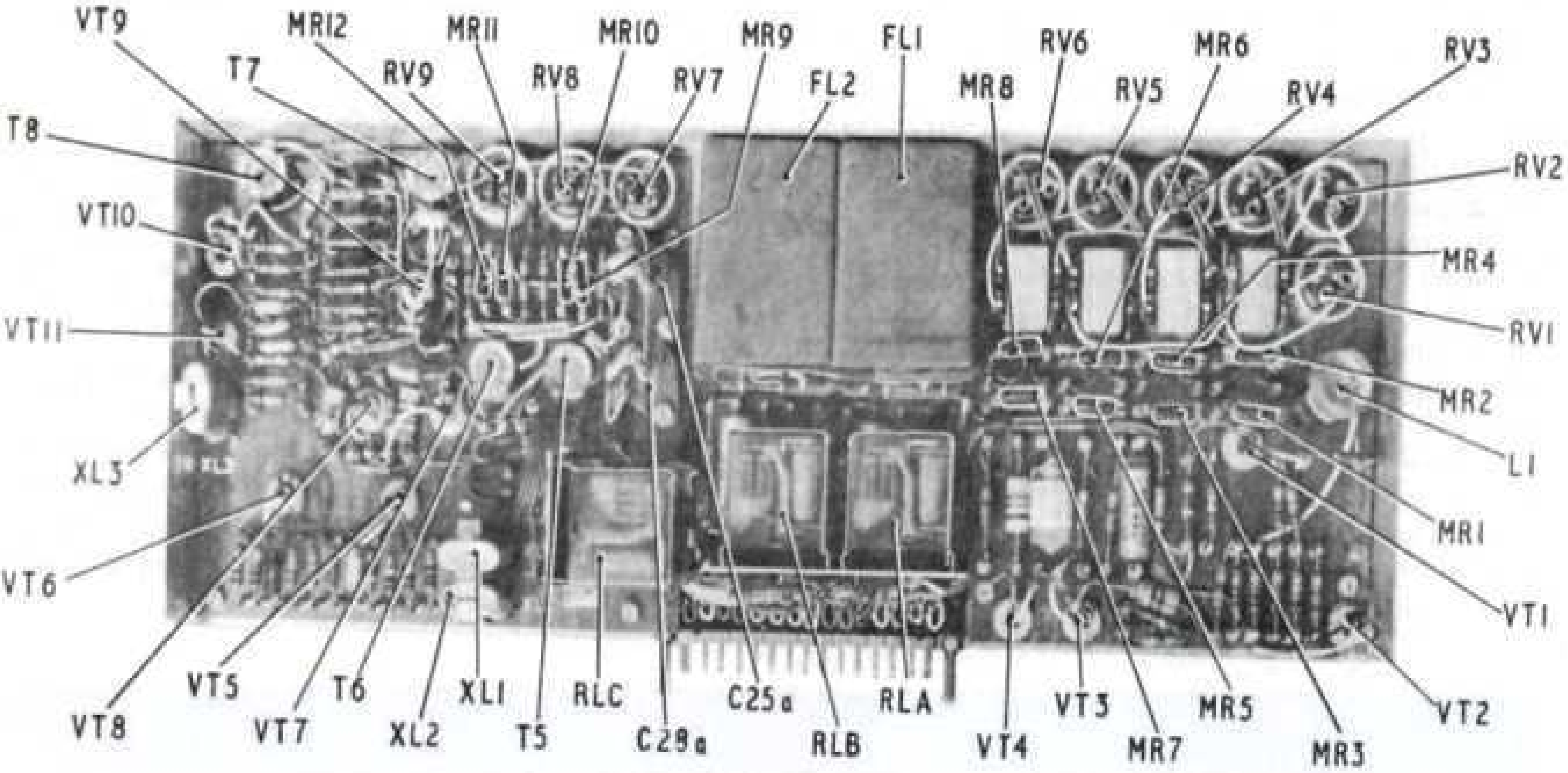


Fig.10. The GR.410 SSB generator/demodulator component layout showing the two low pass filters FL1 and FL2, ring modulator diodes MR1 to MR8 and the crystals XL1 and XL2 for selecting the upper and lower sidebands in the output mixer VT10

are not correctly phased or balanced with respect to one another. However, as mentioned, instead of producing an unwanted sideband in the adjacent channel, the unwanted signal is folded back into the same band of frequencies occupied by the wanted signal. In addition, the folding action inverts the signal and so the listener encounters perfectly intelligible speech on top of a pronounced sing-song effect due to the inverted component.

Fortunately, the human ear and brain are remarkably adept at ignoring this confusion, even when it is no more than 20dB down, and since it's an easy matter to achieve at least 30dB of suppression, this strange phenomenon is never a problem in practice.

Unbalance within the various modulators causes an audible whistle at the frequency of the pilot oscillator f_p. Though annoying to the operator, its effect is confined within the transmission bandwidth and so other users of the spectrum suffer no interference. If the low pass filter does not have a steep roll-off into its stop band then unwanted sidebands, both above and below the wanted signal, may also exist. However, the degree of filter selectivity required to suppress those components at the low frequency of a Third Method low pass filter is considerably less demanding than it is at the higher frequencies typical of the classical filter method.

Finally, there is the matter of DC coupling. As mentioned, the sideband folding that occurs within the low-frequency balanced modulator in each chain produces a DC component which actually represents an AF input signal equal to the pilot tone frequency f_p. Hence, to reproduce that AF spectrum faithfully requires DC coupling between the output of the first balanced modulator and the input of the second one. But this DC signal could upset the critical balance of those modulators, so capacitive coupling is used in the GR.410 between the LPF output and the second balanced modulators. The notch caused by those capacitors (C18 and C20) is just 10Hz wide at low speech frequencies and is quite imperceptible to the listener.

Conclusion

In more than fifty years since Weaver published his most unusual method of generating and detecting SSB, only Redifon amongst the world's designers and manufacturers of radio communications equipment seems to have turned it into a commercial product at HF. But, in more recent times with the advent of digital circuit techniques, digital signal processing (DSP) and now, the software defined radio (SDR), both Weaver's technique and the more conventional phasing method have enjoyed a resurgence of interest. They offer some useful possibilities to the designers of modern communications systems, especially the ubiquitous cellular telephone that operates at UHF, and so it seems these 'old' methods are now very much back in favour.

Acknowledgements

I am particularly indebted to Pat Hawker MBE, G3VA for his most interesting recollections of the issues relating to the first SSB manpack in the UK and of Redifon's involvement with it. Likewise, his 'T.T.' columns in *RadCom* which, over so many years, covered all aspects of SSB were always fascinating and are now legendary in themselves.

I also thank both Adam Farson VA7OJ and Michael O'Beirne G8MOB for the many useful discussions we've had on the historical and technical aspects of SSB and other related issues. Adam's website at **www.ab4oj.com/** is especially germane as are Michael's many articles in *RB* over recent years.

Notes, References And Bibliography

1. *Proceedings of the IRE* (the 'SSB issue'), December 1956. This is the journal of the US Institute of Radio Engineers in which the three original methods of producing SSB, the 'filter', 'phasing' and 'third' methods were all described collectively for the first time.

2. The Collins Radio Company produced and published a superb book, *Fundamentals of Single Side Band*, in 1959. Early Collins equipment is described in detail while the chapters on HF antennas, transmission lines and ionospheric propagation make the book quite unique.

3. A. H. Reeves, *The Single-side-band system applied to Short-wave Telephony Links*, J.IEE (London), pp.245-279, September 1933.

4. Don Stoner, W6TNS, *New Sideband Handbook*, CQ Technical Series, Cowan Publishing Corp., New York, 1962. Probably the first comprehensive review of SSB techniques and equipment for the radio amateur.

5. Redifon Limited, London, 1962, *Handbook for Transmitter/Receiver GR.410*.

6. Donald K. Weaver Jr, *A Third method of Generation and Detection of Single-Sideband Signals*, Proc.IRE, pp.1703 – 1705, December 1956.

7. It's interesting to note that Weaver's method followed quite closely ideas published by N.F. Barber in 1947 and J.R. Hall in 1955. Barber used a similar process of modulation to produce a bandpass filter, while Hall's method of SSB generation by phase rotation precedes both Weaver's and Norgaard's.

8. E. W. Pappenfus, W. B. Bruene and E. O. Schoenike, 1964, *Single Sideband Principles and Circuits*, McGraw-Hill, New York. This is the Collins Radio Company's second publication on SSB. It remained the pre-eminent book on the subject for many years.

9. ARRL, 1965, *Single Sideband for the Radio Amateur*, ARRL, Conn.

10. B. A. Austin, 1969, *The Third Method or Phase-Shift Method of SSB Generation* B.Sc (Eng) dissertation, University of the Witwatersrand, Johannesburg (unpublished).

RB