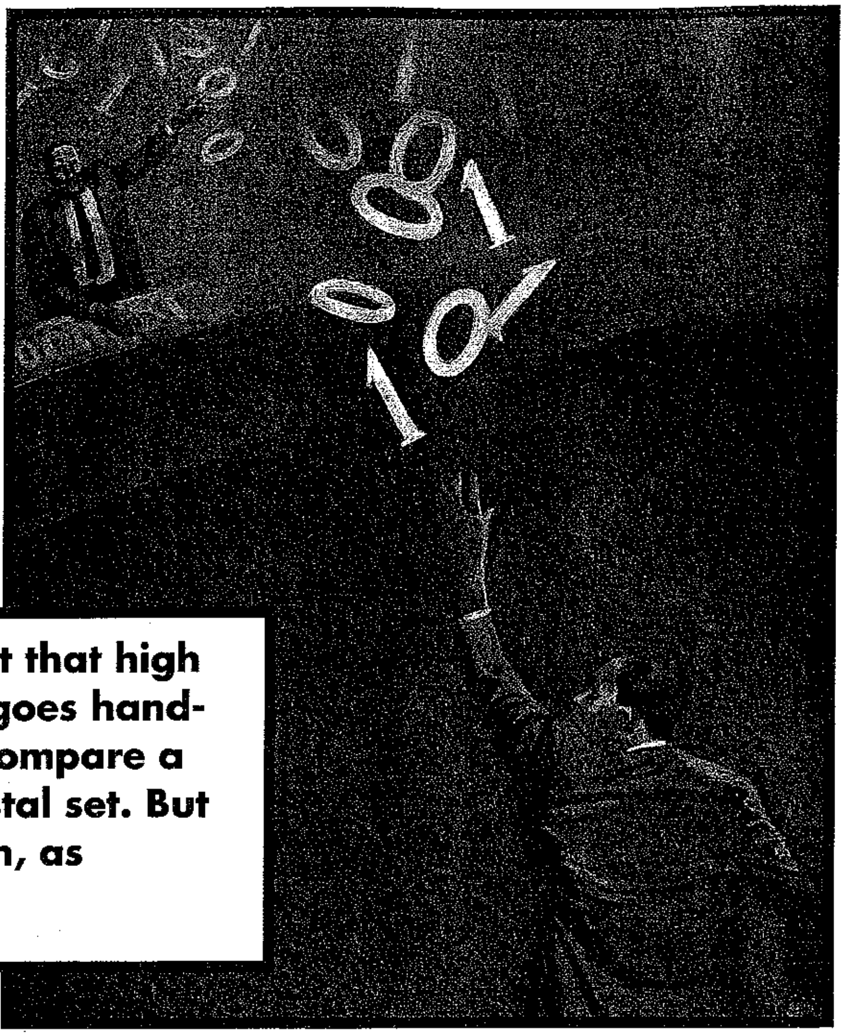

Conventional wisdom has it that high performance in a receiver goes hand-in-hand with complexity. Compare a comms receiver with a crystal set. But there is a notable exception, as Ian Hickman explains.

Super-regen or super-replacement?

As a lad, my introduction to wireless technology was a crystal set, given me by my grandmother.

Wanting something better, I was soon building battery sets of my own, and experiencing the thrill of DXing – receiving distant stations – thanks to the greatly increased sensitivity afforded by an expertly wielded reaction control.

Reaction – or in simple terms, positive feedback at rf – is the key to obtaining a receiver with high sensitivity while keeping the component count low. With reaction as it is normally implemented though, you need to be skillful in using both the tuning and reaction controls, in order to achieve the best performance.

But all this is effectively automated in the 'super-regenerative' receiver, which dates from well before the Second World War. It was described – but not explained – in reference 1. This description left me unclear about how the super-regenerative receiver worked. The author gives a reference to another description, reference 2, which I hope is more illuminating, although I have not seen it.

While I could find no mention of the 'super-regen' in the Admiralty Handbook of Wireless Telegraphy of 1925, by the 1939 edition it had duly made its appearance. Army veterans of the Second World War may remember a super-regen set used for communication between tanks, and operating in the uhf range.

The receiver with reaction

In a simple receiver with reaction, sensitivity and selectivity both increase as the degree of positive feedback is increased. This increase continues until the set is on the verge of oscillation, or actually oscillating very weakly. Any further increase in the positive feedback actually reduces the sensitivity, as the following explanation shows.

In any oscillator circuit, the gain of the active device – at the fundamental, i.e. the resonant frequency of the tuned circuit around which reaction is applied – falls with increasing amplitude. This is the mechanism which stabilises the amplitude of oscillation.

In a circuit suitably designed for use as a receiver with reaction, the way the loop gain changes with amplitude is all

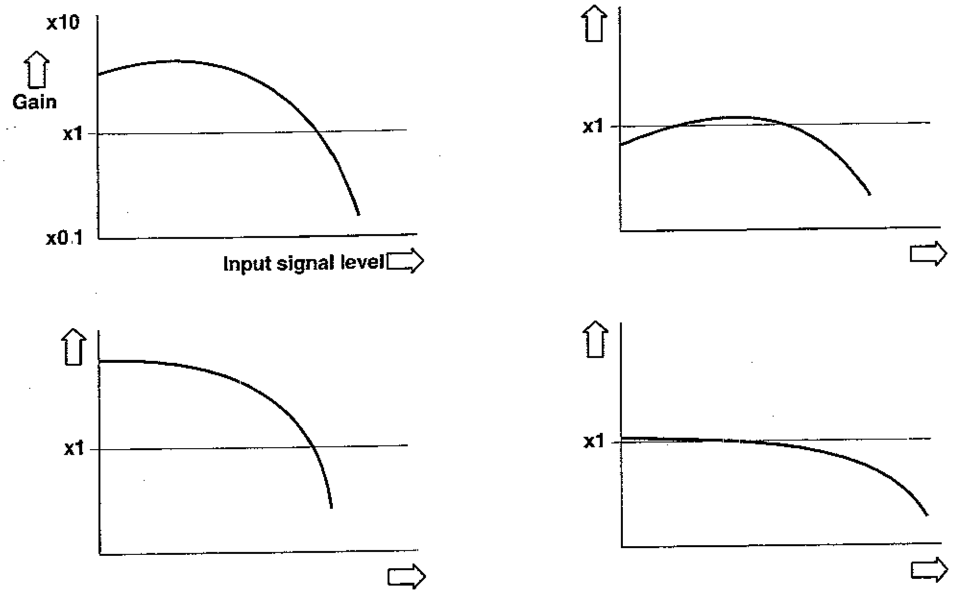

Fig. 1. Showing various ways the open-loop gain of an oscillator can vary with signal level.

ortant. Several characteristics are shown in **Fig. 1**.

Characteristic **a)** – and even more so **c)** – is ideal for a high-stability low-noise oscillator. The rapid change of loop gain with amplitude, in the region of unity loop gain, results in low amplitude modulation noise sidebands. The fm noise sideband performance is governed mainly by other factors.

But for a receiver with reaction, characteristic **d)** is just what is wanted. The shallow angle at which the characteristic cuts the unity gain level makes the oscillator extremely susceptible to influence by any outside factor, such as an incoming signal.

Characteristic **b)**, on the other hand is no good to man nor beast. As an oscillator, it will usually start, being kicked into life by the switch-on transient, but may occasionally fail too. As a reaction-aided receiver, as the degree of reaction is increased, it will suddenly burst into oscillation. It will not stop until the reaction control is wound back down some way, where the gain is low again – an annoying sort of hysteresis effect.

Many ingenious attempts have been made to harness reaction, automating it so as always to be at the optimum level. Older readers may remember the 'Sobellette' small valve table radio from the fifties. This was a superhet, with but one IF transformer and no IF stage! Instead, the usual double-diode triode detector stage was replaced by a pentode leaky grid detector with reaction.

The theory was that, at the fixed IF, a fixed degree of reaction could be applied, achieving gain and selectivity equivalent to a conventional superhet four-valve-plus-rectifier line-up, but one less valve.

So much for the theory: the output impedance of the frequency changer varied across the band. This changed the damping on the IF transformer, severely limiting the degree of factory-preset reaction that could safely be applied.

The super-regenerative receiver

The super-regen receiver is another attempt at harnessing the gain increase achievable with reaction. Reverse bias on an initially cut-off valve or transistor rf amplifier with feedback is gradually reduced, until the stage begins to oscillate. When the oscillation has built up to the intended design amplitude, the beyond-cut-off bias is again applied, and the oscillation dies away again.

There are two ways of implementing the periodic cut-off of the device.

the externally quenched super-regen, a separate quench oscillator is used, resulting in a fixed quench frequency, **Fig. 2**. This is usually in the supersonic or low-rf range, typically 50 to 100kHz.

Alternatively, the oscillator can be provided with self biasing, with an over-long time-constant, so that it 'squegs'. This results in bursts of class-C operation, each burst cutting off the device until the reverse bias dies away again sufficiently for oscillation to recommence. The self-quenching frequency is again typically in the range 50 to 100kHz in the absence of an incoming signal, but will increase somewhat in the presence of a signal.

The arrangement is usually similar to Fig. 2, but with the time-constant *CR* increased, and the separate quench oscillator replaced by a short circuit.

External versus internal quenching

Figure 3 shows the build-up of amplitude of rf oscillation, lower trace, in sympathy with the quench waveform, middle trace, in the absence or presence of an incoming signal, top trace. The external quench waveform is shown as sinusoidal, but in the case of a self-quenching circuit, it would be the typical sawtooth waveform of a squegging oscillator.

In the absence of an incoming signal, the oscillation has to build up from the level of the noise floor in the circuit. With an on-tune incoming signal, the build-up starts from a higher level. Consequently, the amplitude reaches any given level sooner than would otherwise be the case.

Thus in the externally quenched case, the burst of oscillation is longer, as in Fig. 3, while in the self quenched case, the amplitude reaches the level needed to cut off the circuit sooner, **Fig. 4**. Either way, the current drawn from the supply increases, and as in Fig. 2 this may be taken as the detected signal level.

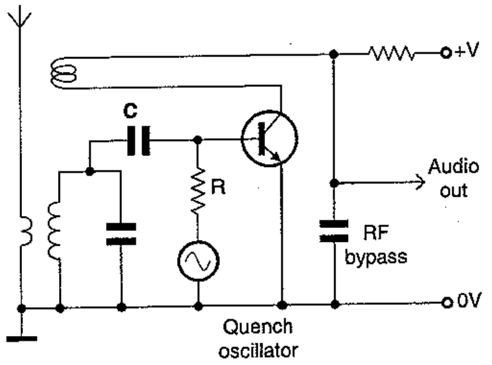

Fig. 2. Simplified circuit diagram of a basic super-regenerative receiver.

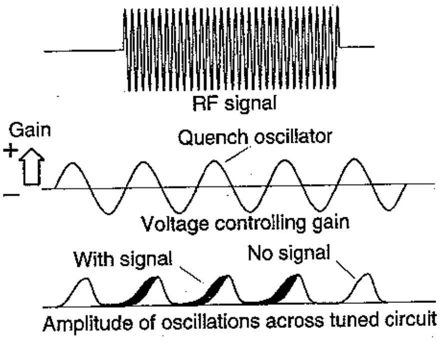

Fig. 3. Illustrating the circuit action of a basic super-regen receiver.

Whether self or externally quenched, a super-regenenerative receiver can be designed to run in either of two modes. In the linear mode, each newly started burst of oscillation is quenched before ever reaching its maximum possible value. The result is a detected signal which varies linearly with the incoming signal level, over a wide range.

Alternatively, the amplitude of oscillation may be designed to reach almost the maximum possible for the given supply rail, before being quenched. This 'logarithmic mode' provides the greatest sensitivity to the smallest signals, giving a kind of limiting or automatic-gain control action with larger signals. Thus the dynamic range of the output is compressed to a manageable value, over a wide range of input levels.

Under the floor

It is important to note that, whether using linear or log mode, external or self-quenching, the off period must be long enough to allow the amplitude of oscillation in the tuned circuit to die down to below the level of the noise floor in the circuit.

Thus each burst of oscillation starts in a random noise-initiated phase, rather than a phase coherent with the previous burst of rf. Otherwise, the receiver will 'hear' itself, as well as any external signal, with resultant reduced sensitivity.

The super-regen circuit, in common with the reactive receiver, provides great sensitivity with a low component count. But it does not enjoy the other virtue of the receiver with reaction.

The reactive receiver shows enhanced selectivity as well as enhanced sensitivity, due to the Q multiplying effect of reaction. But clearly, the faster build-up of oscillation in the super-regen will be caused by any signal within the bandwidth of the tuned circuit.

At this early stage in the process, there is as yet no Q enhancement. As a result, the relevant bandwidth is simply the natural, unenhanced bandwidth of the tuned circuit.

The other main drawback of the super-regen receiver, besides its poor selectivity, is its antisocial behaviour towards other users of the band in which it operates. In addition to being a receiver, the super-regen also acts as a very effective broadband jammer.

The narrow pulses of rf, seen in the time domain in Fig. 4, correspond to a forest of spectral lines, spaced at the receiver's pulse repetition frequency. These appear in the frequency domain

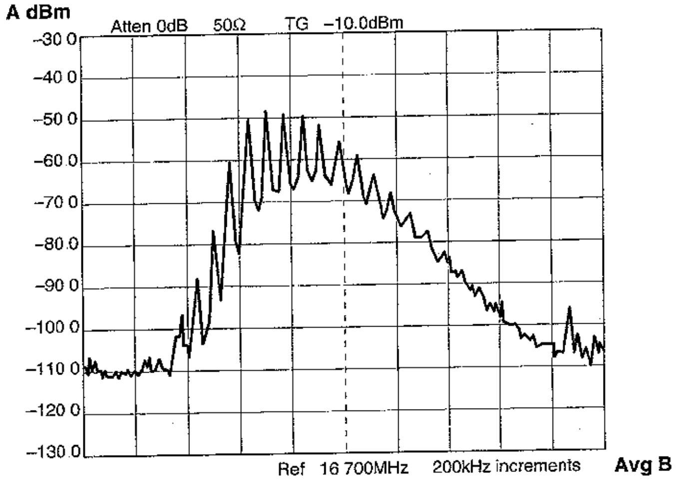

Fig. 5. Typical spectrum of the stray radiation from a super-regen receiver, actually from that shown in Fig. 4. The broad band of interference makes the super-regen a social outcast among receiver architectures.

Fig. 4. Bursts of rf in a self quenching super-regen receiver. The no-signal quench frequency – upper trace – is about 80kHz. The increased pulse rate – with a consequent increase in supply current drawn – is seen in the lower trace. The ragged appearance of the rf pulses is due to sub-sampling of the waveform by the digital storage oscilloscope used.

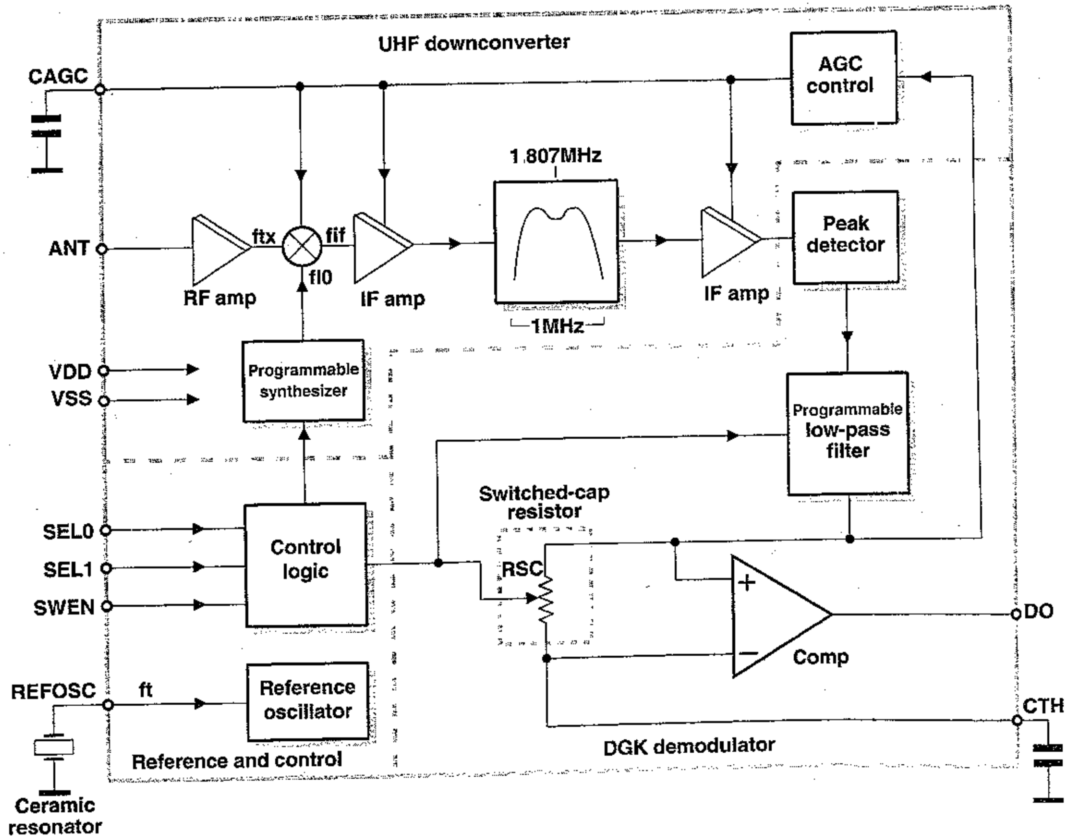

Fig. 6. Block diagram showing the internals of the MICRF001 uhf superhet receiver.

as he spectrum analyser display of Fig. 5 The typical appearance shown has earned the super-regen the fanciful, if not entirely inappropriate nickname of the 'hedgehog'.

One ingenious scheme to render the super-regen receiver somewhat less obnoxious appeared in the literature a year or two ago. In this, an additional grounded-gate junction-fet stage preceded the receiver proper, in an attempt to prevent the quench-frequency-modulated rf getting back up the aerial How effective this was I am unable to report, but the idea does not seem to have caught on.

Simple, but not a super-regen

Imagine your boss comes in one lunchtime, saying that he wants a receiver design for the UK low power radio 418MHz licence-exempt band to MPT1340, and he wants it on his desk by following morning.

For a quick solution, a super-regen might appear to be the answer But they are tricky things to get right, and there's not enough time for a superhet design. The answer – ready by teabreak that same afternoon – might be a functional replacement for the super regen, which has recently appeared This offers the same low component count combined with high sensitivity as the super-regen circuit, but without any of the troublesome stray radiation of the latter.

The *MICRF001 QwikRadio*[3] is in fact a fully functional superhet receiver, but the level of integration is so great that an absolutely minimal component count is achieved

Figure 6 shows the internal workings of the device, which comes in either a 14-pin plastic DIL package or a 14 pin SC Both options operate over –40 to +85°C and draw just 6 3mA from a +5V supply. The claimed sensitivity is –95dBm, making it directly comparable with a super-regen receiver.

The design range of receive frequencies is 300 to 440MHz, over which the device handles on-off keying, data rates of 100 up to 4800bit/s. Talking to the Micrel rep. on the company's stand at the recent Low Power Radio Association Exhibition and Conference, he boasted that the *MICRF001* was the only uhf radio chip you could build into a working radio on experimenter's plug-board.

A uhf radio on bread board?

I obtained a sample for evaluation and, decided to put his boast to the test My circuit was just about the crudest, simplest that one could devise, **Fig. 7**. Built on the well known *Experimentor* wi plug-board, testing commenced as soon as a suitable reference frequency crystal had been procured. This was at 3.1969MHz, which is effectively multiplied by a factor of 130 in the device's synthesiser to produce a local oscillator frequency of 415.602MHz

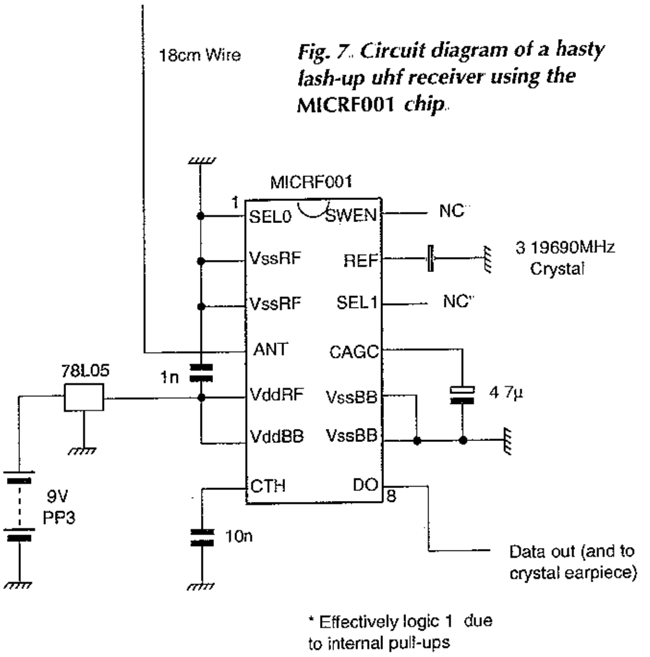

Fig. 7. Circuit diagram of a hasty lash-up uhf receiver using the **MICRF001** *chip.*

* Effectively logic 1 due to internal pull-ups

Technical support

MICRF001 – Micrel Semiconductor (UK) Ltd., 21 Old Newtown Road, Newbury, RG14 7DP. Tel: 01635 524455, fax: 10635 524466, e-mail: info@micrel.co.uk, Website www.micrel.com

3.1969MHz crystal, Golledge Electronics Limited, Ashwell Park, Ilminster, Somerset, TA19 9DX. Tel: 01460 256100, fax: 01460 256101, e-mail: sales@golledge.co uk, Website www.golledge.co.uk.

Given the device's intermediate frequency, which is itself a weak function of the reference frequency, this sets the receive frequency as 418MHz There's more on this in the panel entitled 'The single-chip superhet'.

Being temporarily without a uhf signal generator, I connected 18cm of wire to the output terminal of a Leader *LSG-16* 100kHz to 100MHz signal generator, to act as a quarterwave whip. The receiver, a metre or so away, was similarly equipped With internal 1kHz AM selected, the signal generator's output frequency was set to 83.6MHz.

The *MICRF001* receiver picked up the generator's fifth harmonic, slicing the envelope cleanly to recover what looks like a 010101 data stream running at 2kbit/second, **Fig. 8**, top trace. This is quite a feat, given the low level of the fifth harmonic. In addition, the low modulation depth – barely 20% – hardly resembles on/off keying by a long margin, Fig 8, lower trace. However, it gave no real indication of the range that I could expect in practice

Fortunately, an open-site test range on the extensive flat rooftop of a factory, plus a wide range of test equipment, was available to me at the time. This permitted a more quantitive measurement approach.

A Marconi *2022D* 10kHz to 1GHz signal generator, with its front panel horizontal and standing on a 1m high parapet, was set to 418MHz and 18cm of wire left poking up from its output socket The output level was set to –33dBm (500nW), with 99% amplitude modulation depth at 1kHz.

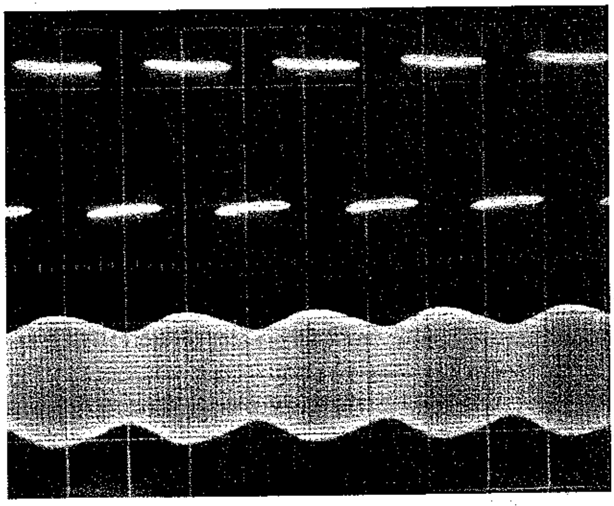

***Fig. 8.* Upper trace – a 010101 data stream at 2kbit/s, recovered from the fifth harmonic of the 83.6MHz output of a signal generator. 2V/div. vertical, 500µs/div horizontal. In the lower trace is the signal generator output, showing just 20% amplitude modulation depth. 50mV/div vertical, 500µs/div horizontal.**

Range testing

I monitored the receiver's data output at pin 8 with a crystal earpiece Walking away with the receiver handheld at about the same 1.5m height, the clear 1kHz tone held out to a range of about 20m. Beyond this distance, it disappeared in the noise. Clearly, this brief test involved no danger of interference with other, off-site users.

The permitted transmitter power in the 418MHz band, per MPT1340, is 250µW, or some 500 times as much as the signal generator was delivering. So taking the optimistic free space loss figure of –6dB per doubling of range would predict a working range of 450m This assumes a transmitter working within the legal limit of power

The flat earth loss figure of –12dB PDOR is more realistic than the free space loss, and predicts a range of just under 100m in a clear site.

Clearly, under more cluttered conditions, the useful range would be less, but then the circuit of Fig. 7 really does not take full advantage of the IC's potential. The pin 4 antenna input impedance at uhf is about 6kΩ in parallel with 2pF, whereas the impedance of a quarter wave whip working against a ground plane is 37Ω – a horrendous mismatch.

The antenna

In the typical application circuit of **Fig. 9**, some simple antenna tuning is incorporated. This provides some selectivity to reduce the possibility of blocking or desensitisation by large out-of-band signals. Matching the antenna into a tap on the inductor would further increase sensitivity.

The arrangement in Fig 9 provides protection against response to other

The single chip superhet

An rf amplifier feeds the mixer, the local oscillator for which is supplied by the synthesiser. The mixer output is fed to an IF amplifier stage, followed by the IF filter.

The filter has a 1MHz bandwidth, centred on 2.25MHz nominal. But as equation 1 shows, the exact value is a function of F_{ref}. The IF filter output passes to a final IF amplifier stage, and thence to a peak detector.

A post-detection low-pass filter with programmable cut-off frequency permits selection of the optimum bandwidth for the data rate used. The filter output supplies automatic gain control to the mixer and IF stages, as well as driving the demodulator via a programmable single-pole low-pass filter.

The time constant of this filter is usually in the range 5 to 50ms, its output forming the comparator reference level. The comparator slices the recovered analogue data relative to the reference level, converting it to a 5V logic output. The slicing action, for typical data, is shown in **Fig. 10**.

The device is designed primarily as a more sanitary replacement for the super-regen receiver. One 'advantage' of the super-regenerator is that its selectivity is so poor that it can be used in conjunction with a very cheap transmitter whose frequency, being determined simply by an *LC* circuit, is poorly defined.

To achieve the same broad bandwidth, the *MICRF001* uses a low IF, so that signals can be received with the local oscillator either high or low. Furthermore, two modes of working are available, in one of which, namely the sweep mode, the effective bandwidth is further increased as described later.

The equation relating the the intermediate frequency F_{if} and the synthesiser reference frequency F_{ref} is,

$$F_{if} = \left(\frac{F_{ref} \times (M + \alpha)}{390} \right) \times 2.25 \tag{1}$$

where all frequencies are in megahertz, M=128 and α=1 for Sweep mode or α=2 for Fixed mode.

Fixed mode. This mode is used with transmitters having a good frequency stability. These would have, for example, a SAW or crystal frequency reference. In this mode the transmitter, receiver IF and local oscillator frequencies are related by,

$$F_{if} = F_{tx} - F_{lo} \tag{2}$$

and the synthesiser reference frequency becomes,

$$F_{ref} = \frac{F_{lo}}{(M+2)} \tag{3}$$

This assumes low-side mixing. From these three equations,

$$F_{lo} = F_{tx} \times \left(1 + \frac{2.25}{390} \right)^{-1} \tag{4}$$

So, for a given transmitter frequency, F_{lo} is determined from equation 4, where F_{ref} is given by equation 3.

As an example, for operation in the UK's 417.9 to 418.1MHz band, as specified by MPT1340, operation at 418.000MHz would require an F_{ref} of 3.1969MHz. Manufacturers may use other frequencies in the band, which is intended for a variety of applications including those requiring a wide bandwidth.

In various European countries, the band 433.050-434.709MHz is available for non-specific SRDs, as per CEPT Recommendation CEPT/ERC/REC 70-03, which may be viewed at www.ero.dk

Sweep mode. In sweep mode, the local oscillator sweeps a band centred on the nominal transmit frequency, so that the effective bandwidth is much greater than the IF pass bandwidth F_{bp}, as shown in **Fig. 11**.

In this mode,

$$F_{lo(\min)} = F_{ref} \times M$$
$$F_{lo(\max)} = F_{ref} \times (M + 2) \tag{5}$$

thus the sweep range ΔF_{sw}=2×F_{ref}. The resultant coverage is ΔF_{sw}+(2×F_{if})+F_{bp}. In Sweep mode, F_{ref} is simply given by,

$$F_{ref} = \frac{F_{tx}}{(M+1)} \tag{6}$$

So, for example, given F_{tx}=387MHz ±0.5%, including initial tolerance, temperature and ageing, then from equation 6, F_{ref}=387/129=3.00MHz – a standard ceramic resonator frequency.

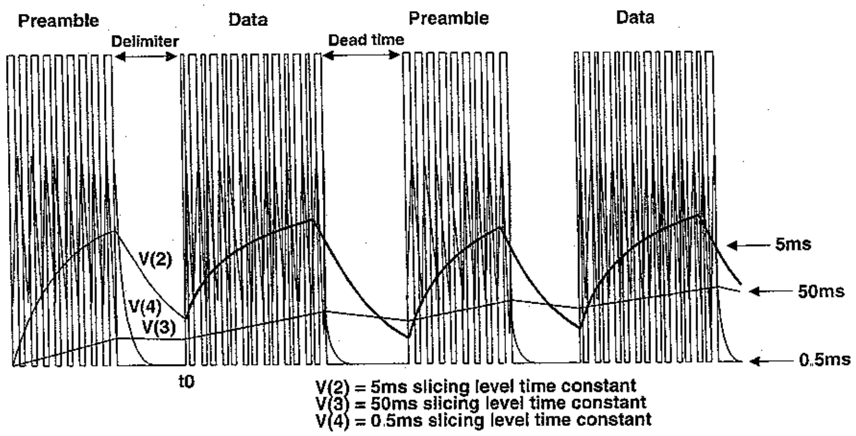

Fig. 10. Comparator action with various reference level filter time constants.

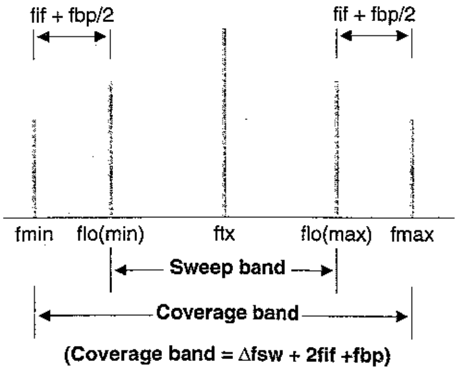

Fig. 11. Showing how in Sweep mode, the effective bandwidth is increased by sweeping the local oscillator.

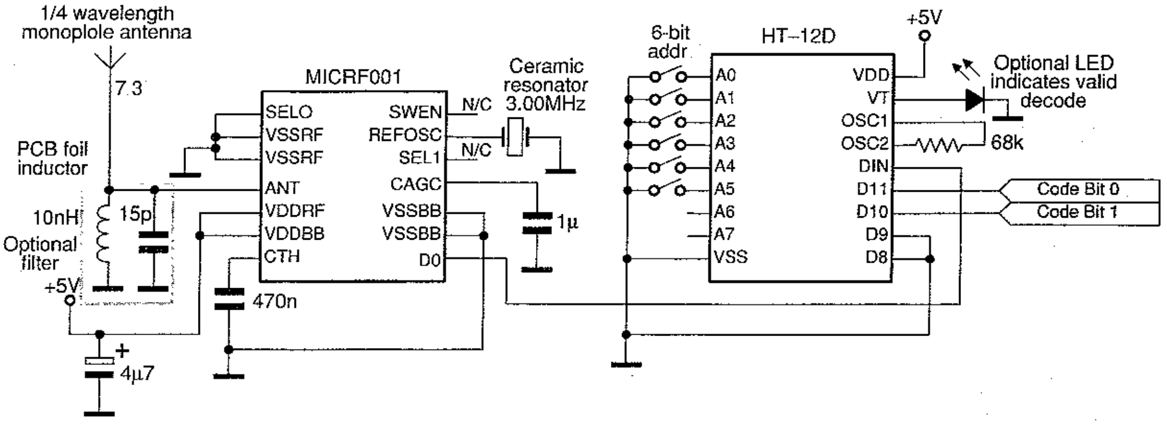

Fig. 9. A typical application circuit for the **MICRF001** *for North American use.*

transmissions, which may appear on the same channel. It does this by virtue of the coding supplied by the Holtek *HT12D* address/data decoder shown, and its companion coder in the transmitter.

Data receipt

The receiver only responds to the appropriate one of 64 different codes, providing on receipt up to four different commands which can be decoded from data bits D_{11} and D_{12}. Note that in Fig. 8, a 3MHz ceramic resonator is used as the reference frequency. This arrangement is possible due to the more generous spectrum allocation and relaxed frequency accuracy requirements for srds (short range devices) in North America and some other countries.

Even allowing for the additional cost of a crystal or surface-acoustic-wave device to provide the greater frequency accuracy demanded by the European market, clearly the device provides a quick and economical answer for anyone needing to design a receiver for the 418MHz or 433MHz licence exempt bands.

Note that while srd transmitters and receivers for these bands are licence exempt as far as the *user* is concerned, the manufacture *must* obtain type approval to the relevant specifications for any countries in which he intends to sell his products. ■

References

1. The Manual of Modern Radio, J. Scott-Taggart, The Amalgamated Press Ltd., London 1933
2. See an article on the super-regenerative receiver by J. Dent, *Wireless World*, June 16, 1933
3. Produced by Micrel Inc. 1849 Fortune Drive, San Jose, CA 95131, USA.