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ADVANCED RECEIVER ARCHITECTURES IN RADIO-FREQUENCY APPLICATIONS

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ABSTRACT

Abstract: The general principles of several types of receivers fall under the two main headings of TRF (tuned radio frequency) receivers, where the received signal is processed at the incoming frequency right up to the detector stage, and the superhet (supersonic heterodyne) receiver, where the incoming signal is translated (sometimes after some amplification at the incoming frequency) to an intermediate frequency for further processing. There are however, a number of variants of each of these two main types. Regeneration (‘reaction’ or ‘tickling’) may be applied in a TRF receiver, to increase both its sensitivity and selectivity. This may be carried to the stage where the RF amplifier actually oscillates – either continuously, so that the receiver operates as a synchrodyne or homodyne, or intermittently, so that the receiver operates as a super-regenerative receiver, both of which have been described previously. The synchrodyne or homodyne may be considered alternatively as a superhet, where the IF (intermediate frequency) is 0 Hz. In this paper we present the new type of receiver architectures which work in radiofrequencies.

Keywords: Supersonic Heterodyne, Tuned Radio Frequency.

1. INTRODUCTION

The dominant receiver architecture, since the 1930s, has been the superhet in various forms, replacing the earlier TRF sets. Prior to and for a while after the Second World War ‘table radio’ sets were popular, typically with long, medium and short wavebands and a 5 valve line-up of frequency changer, IF amplifier, detector/AGC/AF amplifier, output valve and double diode full wave rectifier. The TRF architecture made a reappearance with the recommencement of television broadcasting after the war, only to be replaced by superhet ‘televisors’ with the advent of a second channel. Since then, TRF receivers have virtually vanished into history, and the superhet architecture has reigned supreme, except for some very specialized applications. For example, equipment containing a TRF receiver can be tele commanded from a distance, without any danger of the item being discovered by monitoring for radiation from a local oscillator.
The superhet is susceptible to certain spurious responses, of which the image response is one of the most troublesome. With the ‘local oscillator running high’, i.e. at (Fs + n), where Fs is the frequency of the wanted signal and n is the intermediate frequency or IF, an unwanted signal at (Fs + 2n), i.e. n above the local oscillator frequency, will also be translated to the IF. If n is a small fraction of Fs, it will be difficult if not impossible to provide selective enough front end tuning, adequately to suppress the level of the image frequency signal reaching the mixer.

In the case of an HF communications receiver covering 1.6 to 30 MHz, a commonly employed arrangement is to use a double superhet configuration, with the first IF much higher than 30 MHz . The image frequency is now in the VHF band, and easily prevented from reaching the first mixer.

2 .NEW TELEVISION RECEIVERS

Television receivers commonly use an IF in the region of 36 MHz or 44 MHz in the early days when TV signals were in Bands I or III, i.e. at VHF, the image presented no great problem. With the move to the UHF Bands IV and V (470–860 MHz), great care is necessary at the design stage to ensure satisfactory operation. An example of the economy which can result from the introduction of new components, concerns the burgeoning multimedia market. Figure .1 shows a block diagram of the front end of a conventional three band single conversion tuner. Three tracking filters as shown are needed to suppress the image, which is only some 80 MHz away from the wanted signal. Figure .2 shows a dual conversion tuner where, due to the high first IF of 1.22 GHz, the image is no longer a problem. This arrangement is possible due to the introduction of highly selective SAW (surface acoustic wave) filters operating at 1.22 GHz. The response of such a filter is shown in Figure .3. Whilst not a fundamentally different receiver architecture it represents a distinct advance in TV receiver design. SAW filters operating at UHF and higher frequencies are available from a number of manufacturers, including mu Rata and Fujitsu in addition to EPCOS.

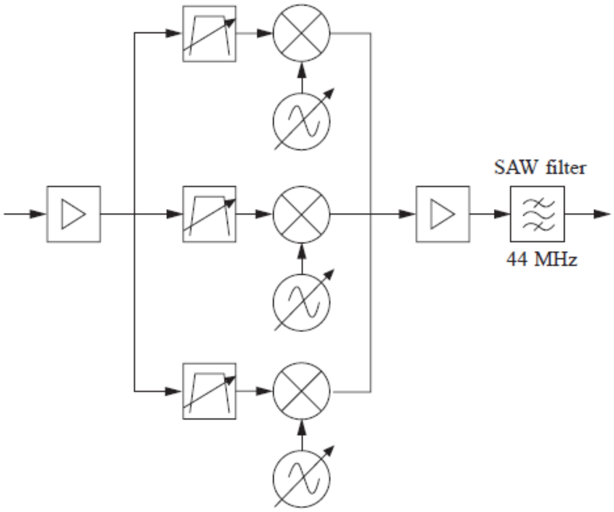

Figure 1: Basic front end block diagram of a conventional three band TV tuner. (Reproduced by courtesy of EPCOS AG)

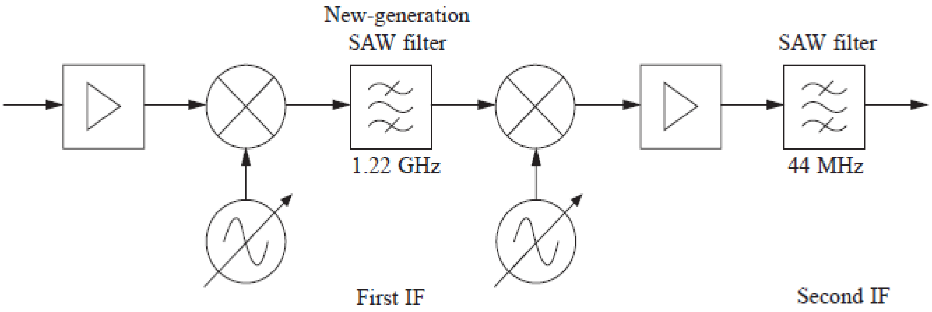

Figure 2: Basic front end block diagram of a dual conversion tuner.

The homodyne receiver gave an example of its use to receive FSK signals. With the local oscillator tuned midway between the tones, each will be translated to precisely the same baseband frequency. It is possible, by using two mixers fed with local oscillator drives in Quadrature, to distinguish between signals in the two channels.

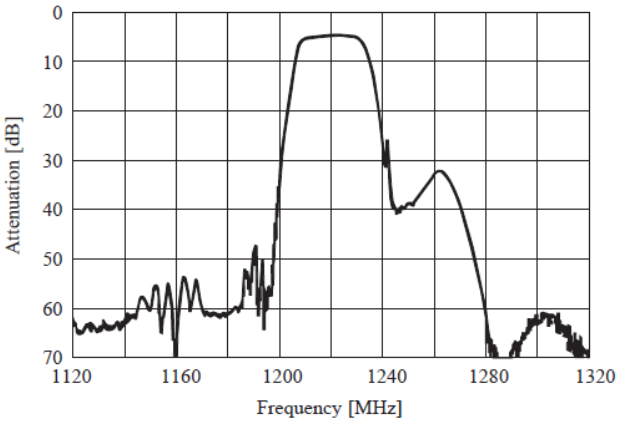

Figure 3: Attenuation versus frequency of the 1.22 GHz SAW filter used in Figure .2. (Reproduced by courtesy of EPCOS AG)

However, consider a modulation system where there are signal components in both sidebands, each side of the local oscillator frequency *n*, simultaneously. The upper sideband translates to *F*s-upper – *n*, a positive frequency. In the case of the lower sideband, since *n* is greater than *F*s-lower, the sideband translates to a 'negative frequency'. Thus both the I and the Q channels would contain both lots of information; special processing is then necessary to separate them. A signal which contains both positive and negative frequencies is called a 'complex' signal, as distinct from a 'real' signal. The latter, like the output from a microphone, contains only real frequencies and can consequently be entirely defined by the signal on a single circuit.

On the other hand, two distinct circuits or channels are necessary to fully define a complex signal. Figure .4 shows two local oscillator drives to two mixers, where the drive to the lower Q mixer lags that to the upper I mixer by 90^o, translating a signal input centered on the LO frequency (or offset from it) to 0 Hz or 'baseband' (or an intermediate frequency). A signal 100 Hz above the LO frequency will translate to baseband as 100 Hz, a positive frequency, whereas a signal 100 Hz below this frequency will translate to baseband as –100 Hz, a negative frequency. Vector diagram Figure .5a shows a positive frequency coming into phase with the Q local oscillator drive 90^o before coming into phase with the I LO drive, so for a positive frequency the Q channel output leads the I channel by 90^o, and vice versa for a negative frequency. (Note that coincident vectors have been offset slightly, for clarity.)

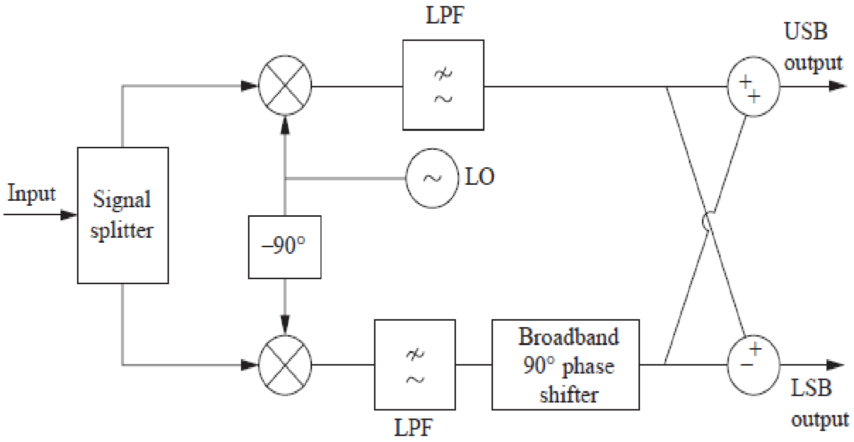

Figure.4: The arrangement of an image reject mixer, translating the input signal (centered on the same frequency as the local oscillator) to centered on 0 Hz. Where the signal and local oscillator frequencies differ, giving a finite intermediate frequency, the low-pass filters would be replaced by band-pass filters

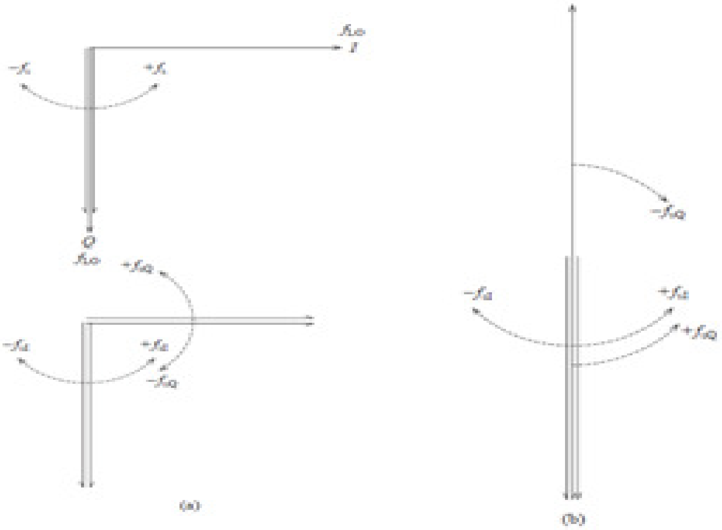

Figure 5: (a) Showing how, for a positive frequency *f*s, the Q channel baseband output leads the I channel by 90^o (b) After a 90^o phase shift, the components due to +*f*s in both channels are in phase, those due to –*f*s in anti phase. So summing recovers the upper sideband; differencing, the lower.

Figure .5a also shows the phases and phase rotation of the upper and lower sidebands out of the mixers, after translation to baseband. The baseband signal out of the Q mixer is subsequently passed through a broadband 90^{0}phase shifter, and Figure .5b shows the positions of the Q components coming out of the 90□□delay. Each is shown as where the Q components out of the mixer were, one quarter of a cycle *earlier*. The baseband signal due to the upper sideband is now in phase in both channels, whilst that due to the lower sideband is in anti phase. So if the two channels are added, the lower sideband contribution will cancel out leaving only the signal due to the upper sideband, whilst conversely, differencing the I and Q channel will provide just the lower sideband signal. This arrangement is known as an image reject mixer (Figure.4). The baseband 90^o phase-shifter (or 'Hilbert transformer') should cover the baseband of interest – outside this band the out-phasing no longer holds so sideband separation would not be complete. Such a receiver would be capable of receiving ISB (independent sideband) signals, where one suppressed carrier is modulated with two separate 300– 2700 Hz voice channels, one on each sideband.

3. POLY PHASE FILTER

In practice, due to limitations in mixer and channel balance and accuracy of the quadrature phase shifts, the rejection of the unwanted sideband is often limited to about 35–40 dB. Since, generally, each sideband will be received at much the same level; this would be adequate for ISB wireless telephony use. The image reject mixer can also be used for the reception of analog FM signals such as NBFM (narrow band FM) voice traffic [1]. An alternative to the arrangement of Figure .4 is shown in Figure .6. Here, a poly phase filter is used in place of low pass filters and Hilbert transformer. The poly phase filter is a network which has a pass band to positive frequencies and a stop band to negative frequencies, so combining the roles of the two filters and the broadband 90^o phase shifter of Figure .4. Poly phase filters provide a band-pass response, and can be used in low IF architecture receivers, where the data bandwidth is significant compared with the centre frequency. They have the advantage that the frequency response is symmetrical, avoiding ISI (inter-symbol interference). They may be realized as entirely passive networks [2], or active networks [3, 4]. The operation of poly phase filters is described in [5].

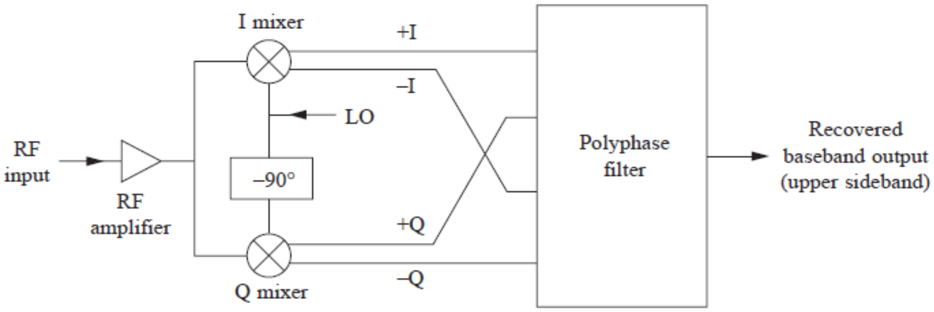

Figure .6: A poly phase filter combines the functions of the two low-pass filters and the Hilbert transformer of Figure .4

4. IMAGE REJECTION MIXER:

An image reject mixer may be used either at the incoming signal frequency direct, or as the final IF stage in a superhet. However, an image reject mixer is often of limited use as the first mixer in a superhet, due to the limited degree of available image rejection mentioned above. But it can be useful to provide extra image rejection where there is some front end tuning, but which is not quite selective enough on its own. The I and Q signals can be digitized in ADCs (analogue to digital converters) and subsequently processed in digital form, bringing us to the realm of modern architecture. A typical arrangement is shown in Figure .7. Many variations are possible upon this basic scheme.

Thus Figure .7 shows a single superhet, but the RF amplifier (if fitted) might be followed by a first mixer, first IF band-pass filter and first IF amplifier, ahead of the I and Q mixers, implementing a double superhet. The local oscillator might be chosen to translate the signal to a zero IF, i.e. direct to baseband, or might be offset slightly, so as to use a low 'near zero' IF. This avoids some of the problems, described below, that can occur with image reject mixers. The ADC sampling rate may be greater than twice the highest frequency component applied to it, meeting the Nyquist sampling criterion. Alternatively, with a high IF, having a small percentage bandwidth, the ADC may be run at a much lower frequency, one of its harmonics being centered in the IF band. It thus subsamples the IF signal, but aliasing does not occur provided the signal bandwidth on either side of the harmonic does not reach out as far as half way to the adjacent harmonics of the sampling frequency. Any of the architectures described may be used with the signal direction reversed, as a transmitter.

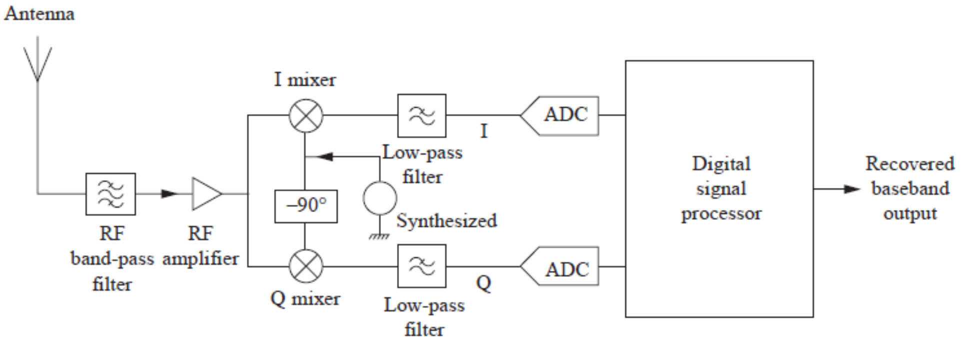

Figure .7 Block diagram of a digital receiver, using an image reject mixer followed by digital signal processing

The image reject mixer suffers from limitations such as dc offsets and gain differences in the two channels, and imperfect quadrature between them. One of the advantages of digitizing the two mixer outputs is that it may be possible to correct for quadrature, gain and offset errors, resulting in greatly enhanced rejection, at the expense of a greater workload for the DSP (digital signal processor). For many non-deterministic signals such as digitized speech, there is no dc component, and the long term average levels expected in the I and Q channels are equal. Two digital integrators with a long time constant can thus be used in a negative feedback loop to apply a correcting offset to each channel, to drive the long term average to zero. Similarly, a gain adjustment can be applied to one channel, to drive the long term average level to equal that in the other channel. Finally, if there is no quadrature error (i.e. the two channels are truly orthogonal), the long term average of the product of the two channels should be zero. So another servo loop, including multiplier and a long term integrator, can be arranged to add or subtract a small fraction of one channel to/from the other, driving the quadrature error to zero. Thus the signals applied to the sum and difference stages are fully corrected.

The explosive growth of the mobile phone market has been built upon a carefully organized frequency- and power-control plan. Various architectures are used by different manufacturers, but all depend upon the way communications between base station and mobile are organized. In particular, in the GSM system, used in Europe and many other countries (but not in the USA or Japan), the frequency band is split, into base station to-mobile links at one end, and mobile-to-base station at the other. On initiating a call, the mobile receiver scans the base station band looking for the nearest (strongest signal) base station. It then calls the base station on a channel marked as free, starting at low power and notching up until communication is achieved. Thereafter, the mobile transmits at the level dictated to it by the base station. In this way, at the base station, more distant mobiles are not blotted out by nearer mobiles, and due to the split band arrangement, image signals do not interfere with reception at the mobile. This scheme only works if the mobile's power output is accurately controlled, for which purpose ICs providing accurate true rms level sensing are available, from Analog Devices and other manufacturers. DECT (variously described as Digitally Enhanced Cordless Telephony, Digital European Cordless Telephone or Cordless III) operates rather differently, with ten 1.78 MHz wide channels in the 1.88 to 1.9 GHz band.

It uses alternate 5 ms time slots for two way communication between the base unit and one or more handsets, and thus uses both FDMA and TDMA (frequency division multiple access and time division multiple access). Each 5 ms period is further divided into 12 time slots, and each connection needs a time slot in each 5 ms period. Thus the system has 120 available channels, and when powered up, each unit scans the range of frequencies and time slices, preparing a table of 120 RSSI (received signal strength indication) figures. A free channel is chosen for communication, and furthermore, scanning continues during operation, to provide a seamless handover to another frequency or time slot if interference is encountered. Whilst most receivers at the present time are of the superhet variety, much activity is aimed at producing chip sets for GSM (now known as Global System Mobile, but originally the 'Groupe Speciale Mobile'), the alternative DCS/PCS systems, and DECT receivers, using the direct conversion architecture, i.e. operating as homodynes. However, for some specialized applications the TRF architecture may be making a come-back, despite the difficulty of achieving sufficient gain at the signal frequency, without instability due to unintentional feedback from output to input. Ref. [6] describes a system known as ASH – amplifier-sequenced hybrid. Here, front end selectivity is provided by a SAW filter, the signal then passing through two amplifiers, separated by a SAW delay line. The first amplifier typically provides a gain of 50 dB, the second 30 dB. Despite the design being aimed at implementation at a frequency in the range 300 MHz to 1 GHz, instability is avoided by powering up the amplifiers alternately. Thus whilst the first amplifier is active, the second is off, and the second receives the resultant signal, via the SAW delay line, during its on-period, i.e. the off-period of the first amplifier. Sensitivity is claimed as –102 dBm at a 2.4 kp/s data rate, and the module doubles, as needed, as a transmitter on the same frequency, with an output of 0 dBm.

5. CONCLUSSION

The advanced architectures of different receivers like super heterodyne including IF (intermediate frequency) signal processing techniques in super heterodyne receivers have been clearly explained.

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