

## BK1198 SINGLE-CHIP AM/FM/SW SUPERHETERODYNE RECEIVER

The BK1198 is specifically designed as the basis of a high-performance low-parts-count radio receiver system. Unlike many competing receiver solutions, the BK1198 is particularly suitable for low-setup-cost manufacturing, in particular avoiding the need for complex firmware programming and microcontroller interfaces. This also makes it ideal for hobbyist use.

The BK1198 is still firmware-programmable for manufacturers who have suitable facilities, but it comes factory-pre-programmed with range of user-selectable options that will suit most cost-conscious designs.

The BK1198 is available in two versions, a 22-pin SSOP with full FM stereo outputs and a digital data bus for full-sized stereo systems, and a 16-pin SOIC version with mono only-output, designed for portable low-cost applications. Jaycar only stock the 16-pin version, and the rest of this sheet will refer to that.

Note that there is no standard size 16-pin DIP version of this chip. If you are not using a circuit board specifically designed to take the BK1198 SOIC-16, we recommend the use of an SOIC to DIP adaptor board, which are readily available.

Although the manufacturer recommends the use of tuned circuits on the AM and FM inputs, in reasonable reception areas quite good results can be had with just a simple piece of wire connected to both

the AM and FM inputs. In general, however, best results on AM are had with a conventional ferrite rod with a wound coil.

Apart from those two coils and the crystal reference oscillator, the rest of the receiver is entirely implemented on silicon; there are no external coils, ceramic filters or other bandpass-shaping components.

At first glance it may look like a voltage-tuned system similar to earlier designs using varicap diodes, but actually the only purpose of the “tuning voltage” is to inform the control processor of the angular position of the tuning pot. Once this is established, the frequency synthesizer/decoder system works identically to a button-selected model.

A cheap 32.768 KHz watch crystal is used as a frequency reference to stabilize the internal VCO.

Band selection is achieved in a similar manner to station selection. 18 different bands can be selected by connecting pin 15 to one of the 18 tapings on the voltage divider string connected to the same regulated voltage as the station select pot. The manufacturer suggests 18 x 20K resistors with a 10K at the top and bottom of the chain, but this is not critical.

The values of 10K and 20K are chosen simply because 20K is exactly twice the value of 10K. It is also not necessary to use all 20 resistors. In the example circuit shown below only four bands are used, and the resistor values have been calculated by adding together all the resistors that are “skipped”. Also, by making “2R” equal to 22K, all the “lumped” resistor values - 33K, 22K, 220K, 56K, 68K – work out very close to E12 preferred values.

**Page 1**

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The frequency coverage of each band is controlled by values set in flash memory. The chip comes pre-programmed with a good set of ranges, but they can be re-programmed via the serial interface.

FM3 has been chosen because it covers all the FM frequencies used throughout the world, and you may pick up something interesting in countries that don't use part of the band .

Similarly, AM3 has been chosen because it covers the widest frequency range, and works in 1kHz steps. In Australia that means it can receive the "narrowcasting" ethnic stations above the normal AM broadcast band. Similarly, SW 10 and SW 11 cover almost the entire shortwave band up about 22MHz and are labelled as SW1 and SW2 as far as the receiver is concerned. There is nothing to stop you constructing a complete R-2R resistor string and wiring up a switch to select whichever of the frequency ranges best suit your own preferences.

Once the circuit has been constructed, there is no alignment or other setup required; it should work at full performance automatically. The AM input pin features an internal varicap diode which automatically peaks the AM aerial coil each time a station is selected.

**CRYSTAL OSCILLATOR** The master frequency reference is a standard 34.768kHz crystal, of the common type used in clocks and watches. This is used as the reference for the internal "sub-master", from which all the other processing signals are derived. The receiver will still work without the crystal, although there will be some drift, and the dial scale may not track. (Another problem is that the receiver may not always return to the frequency it was tuned to when it was switched off).

**RECEIVER DESIGN** The receiver design is a superheterodyne, but with an unusually low Intermediate Frequency (IF) of about 70kHz (the exact figure is not given in the original data sheet). Such a low IF allows the bandpass shaping to be carried out by precision digital filters; there are no external IF bandpass shaping components at all. While this design approach has become commonplace with VHF and UHF receivers, (FM radio, digital TV etc), it has not previously been seen in AM receivers, due to the challenges of getting an adequate signal-to-noise ratio.

However, there has been considerable pressure on manufacturers (mostly from US retailers), for them to treat AM reception more "respectfully," as in large areas of the country, AM is basically "the only game in town...."

Experienced readers will know that such a low IF would normally cause "Image Interference" problems (see explanation below). This issue is overcome by the use of a more complex circuit technique known as a "dual quadrature balanced mixer." While this technique is now almost universally used in "all silicon" VHF and UHF tuners (Digital Radio and TV tuners, FM radios and transceivers), until recently it was not employed for AM and shortwave, because the required digital processing circuitry was not "quiet" enough.

Recent advances in "mixed signal" chip design (fabricating both analog and digital circuitry on the same chip) has now made high-performance single-chip AM possible.

Page 2

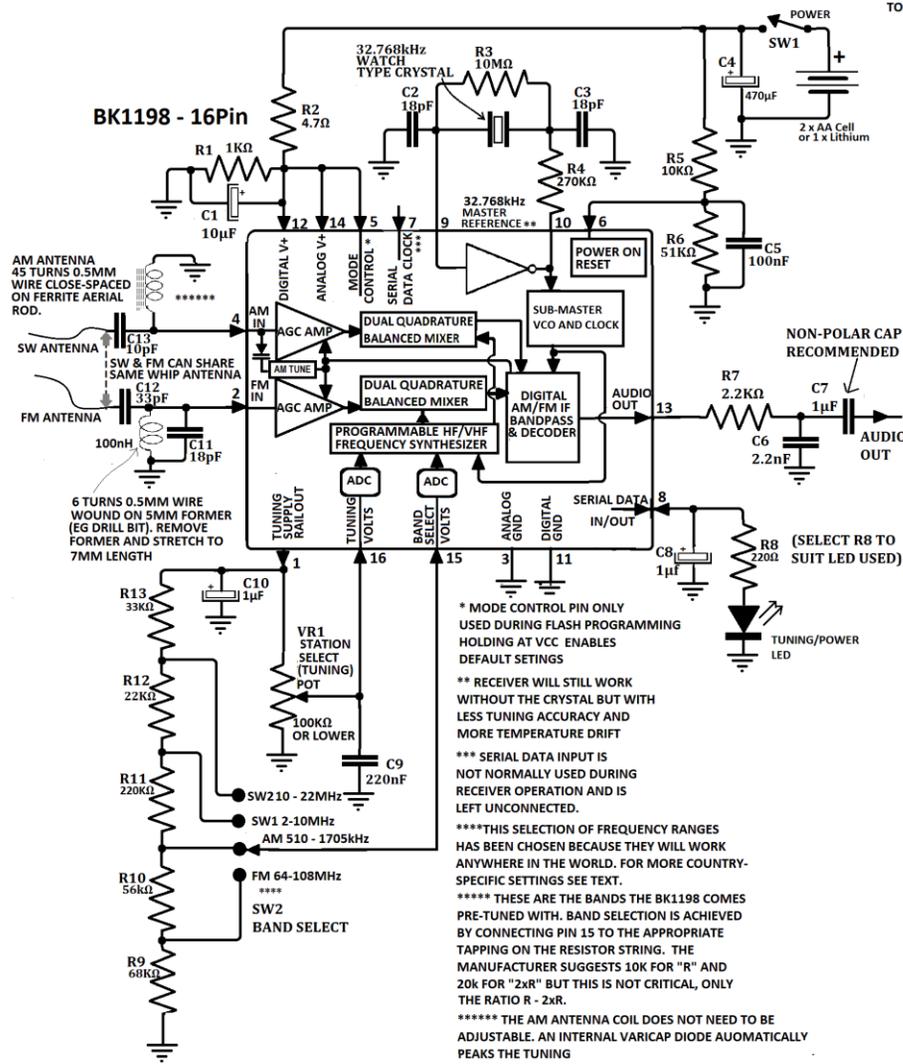
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**BK1198 - 16Pin  
BASIC APPLICATION CIRCUIT**



- SW12 7.8 - 16.2MHz
- SW11 9.8 - 22MHz
- SW10 2.7 - 10.25MHz
- SW9 21.1 - 22.1MHz
- SW8 17 - 18.1MHz
- SW7 14.9 - 16MHz
- SW6 13.3 - 14.3MHz
- SW5 14.4 - 12.30 MHz
- SW4 9.1 - 10.1MHz
- SW3 6.7 - 7.7MHz
- SW2 5.5 - 6.5MHz
- SW1 4.7 - 5.1MHz
- AM3 513 - 1730 (1kHz steps)
- AM2 513 - 1629 (9/10 kHz steps)
- AM1 510 - 1730 (9/10kHz steps)
- FM3 64 - 108MHz (50kHz steps)
- FM2 87 - 108.5 MHz (100kHz steps)
- FM1 87 - 108MHz (100kHz steps)

R1	1KΩ
R2	4.7Ω
R3	10MΩ
R4	270KΩ
R5	10KΩ
R6	51KΩ
R7	2.2KΩ
R8	220Ω
R9	68KΩ
R10	56KΩ
R11	220KΩ
R12	22KΩ
R13	33KΩ
VR1	100KΩ
C1	10μF
C2	18pF
C3	18pF
C4	470μF
C5	100nF
C6	2.2nF
C7	1μF
C8	1μF
C9	220nF
C10	1μF
C11	18pF
C12	33pF
C13	10pF

PRE-PROGRAMMED FREQUENCY RANGES

## 100 YEARS OF THE “SUPERHET” 1918 - 2018

**THE SUPERHETERODYNE EXPLAINED.** The term “superheterodyne” is a contraction of “supersonic heterodyne” and was originally conceived by Major Edwin Armstrong of the US Army Signals Corps during the First World War, to solve a problem inherent in the early triode valves used at the time.

(Note: There are many other claimants to this title, and in fact Armstrong’s patent was later overturned on the basis of one of them, but Armstrong was the *only* person shown to have actually built such a receiver at the time. Many such claims of “historical priority” turn out to have originated with attempts by lawyers of rival companies to invalidate lucrative patents. Patents eventually expire and are forgotten, but unfortunately the “I was first” tales have no such expiry dates... Also, the commercial potential of many major inventions was *not at all obvious* at the time they were patented, the gramophone and motion picture film being just two more examples).

In 1914 British Intelligence had discovered that the German Navy were using so-called “Short-Wave” spark transmitters for in-fleet communications. In those days, “Short-Waves” basically meant anything above about 500kHz, and the detected signals were around 1MHz, which is the middle of what we now refer to as the present-day AM radio band. (AM radio broadcasting as we know it didn’t start until 1920).

The Germans had assumed that such signals could not be detected much beyond the horizon, so they could be used as a reasonably secure medium for everyday communications traffic.

Completely unbeknown to them, British intelligence soon discovered that the signals *could* in fact be intercepted from the UK with a sensitive enough receiver, and by using direction-finding antennas,

they could accurately determine both the position and speed of the German fleets, which was of enormous strategic importance.

However, the then-state-of-the-art “pliotron” high-vacuum radio valves they were using, only date from around 1912-13, and understanding their actual operation was still very much a work in progress. They worked well as Radio Frequency amplifiers up to around 100kHz, but above that, they could only provide a small amount of amplification (“gain”) before going into uncontrollable oscillation. Under pressure of wartime emergency, for “short wave” amplification British Intelligence adopted the brute force approach of simply stringing a large number of such low-gain stages together, (each with a typical gain of 5-10%) to produce a stable high-gain amplifier that was reasonably reliable. This cost a huge amount of money, consumed a large amount of electrical power and occupied most of a room. However, the results were so successful that the Admiralty thought it was money well spent.

In 1918 Armstrong was permitted to visit one of these top secret installations, and immediately appreciated the value of the system, but he could also see that it would be totally impractical for a mobile installation such as on a ship. Then he suddenly had a brainwave; perhaps the problem could be solved in a single stroke by using a “Heterodyne” device to convert the Short-Wave signals down to a lower frequency that could be more efficiently amplified by the primitive triodes of the day.

The “heterodyne” process, where two frequencies are mixed together to produce other frequencies was already well-known, but was mainly used to make “CW” Morse Code signals audible. Spark transmitters produced a nice clear buzz or chirp in the earphones, but with the pure sinewave carrier waves (“CW”) from the newer (and much more

Page 4

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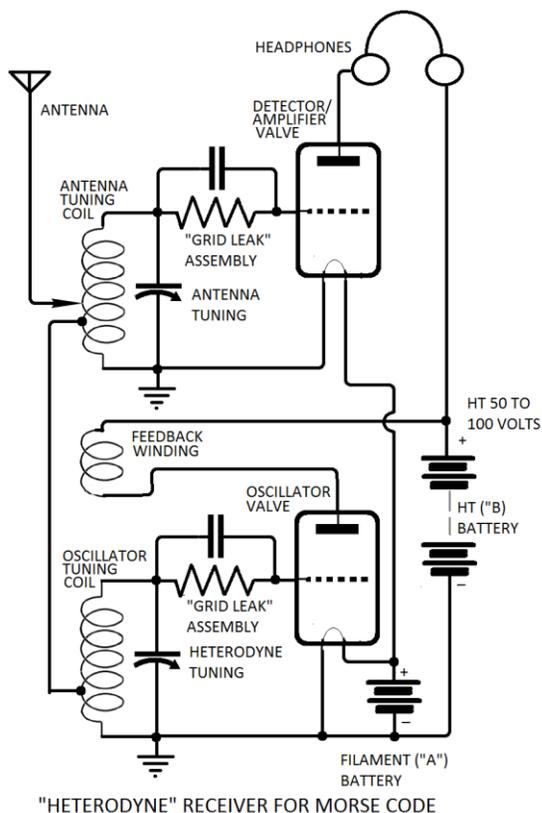


efficient) types of transmitters using Poulsen Arcs or high frequency alternators, the Morse code would be heard a series of clicks or thumps. With alternator-type transmitters an elegant solution to the problem was to actually have two alternators on the same shaft, producing frequencies 3kHz or so apart, which would result in the Morse dots and dashes being heard as a 3kHz "beat note" in the earphones. This was called a "heterodyne" basically Greek for "generated by a difference (in frequency)".

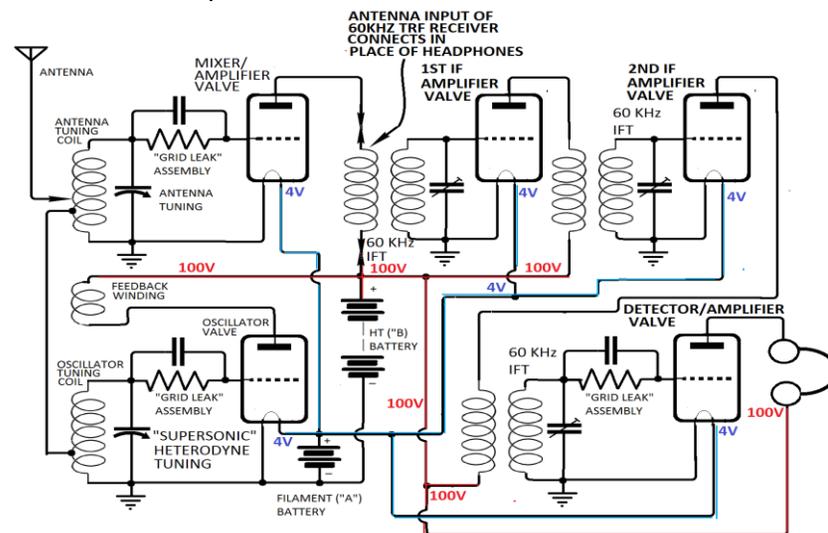
When valve receivers became available, it was more practical to use a single carrier frequency, and have a valve-based "local" oscillator to provide the heterodyne signal at the receiver. This also allowed operators to adjust the pitch to suit their own preferences. (Nowadays this is referred to as a "Beat Frequency Oscillator" or "BFO"). Operators had noticed that if the local oscillator frequency was moved too far from

the carrier frequency, the received signals would increase in pitch until they were no longer audible. They had become "supersonic" (which at that time meant: "above the range of Human hearing" not: "travelling faster than sound" as it does now).

Until Armstrong's invention, there was no practical application for this phenomenon, but he was soon able to verify that the incoming signals had in fact been shifted to a different "supersonic" frequency, and were otherwise unchanged. For example, to receive a 1MHz signal on an existing 60kHz receiver, he only needed to connect the 60kHz receiver's antenna input to the heterodyne receiver's headphone socket and set the oscillator to 1.06MHz. A new version of the original 1MHz signal would then appear at 60kHz, (1.06MHz - 1MHz) where it could be efficiently amplified by a separate existing 60kHz "Tuned Radio Frequency" (TRF) valve receiver. Such receivers were readily available then, as up until the 1920s, most communications were carried out on frequencies well under 100kHz.



"HETERODYNE" RECEIVER FOR MORSE CODE



"SUPERSONIC HETERODYNE" RECEIVER Copyright © Jaycar 2018

Actually the "mixing" of two different signals like that, produces so-called "sum and difference" frequencies, so in the above example, there would be signals on both 60kHz and 2.06MHz (1.06MHz +1MHz). This is normally not a problem in itself as the 60kHz filters will completely reject the 2.06MHz signal. The problem is, in this case, where there might be another station transmitting on 1.12 MHz (that is; 1MHz + 60kHz + 60kHz). In that situation both frequencies will produce a 60kHz heterodyne:  $1.06\text{MHz} - 1\text{MHz} = 60\text{kHz}$  and  $1.12\text{MHz} - 1.06\text{MHz} = 60\text{kHz}$ . The unwanted signal is known as the "image" frequency.

In early superheterodynes, in that particular case this problem could be reduced by setting the local oscillator to 60kHz *below* the incoming frequency instead of above it (ie to 940kHz). That would still give the 60kHz IF, since  $1\text{MHz} - 940\text{kHz} = 60\text{kHz}$ , but this time the offending "image frequency" would produce  $1.12\text{MHz} - 940\text{kHz} = 180\text{kHz}$ , which would be rejected by the 60kHz filters. However, if there happened to be another signal on 880kHz, that would also act as an image frequency since  $940 - 880$  also equals 60! In practice the operator would simply "surf" between the two settings for the clearest signal.

Another approach is to heavily pre-filter the incoming signals so that only the desired frequency actually gets to the mixer, using a separate tuned circuit for the "Antenna Tuning". While this does help, with low IFs such as 60kHz, the "image" frequencies are too close together to be effectively filtered out by the filtering circuit. However, for Armstrong's original application, there weren't that many image frequencies to worry about; it was only when radio broadcasting got underway that it became a problem.

By the early 1920s engineers had worked out what was making triode amplifiers unstable, and Louis Hazeltine is generally given credit for developing the technique of "neutralization", which made home TRF

radio receivers reasonably practical and affordable for the first time. Superheterodynes certainly gave better results, but at greater cost and operating complexity and so they were mostly used by the military and in remote locations. For domestic radios, the TRF approach was adequate and was both cheaper and easier to use.

Anyone only familiar with modern, (or even not-so-modern) superheterodyne receivers would barely recognize a 1920s version. They typically didn't use air-cored coils for the IF amplifier circuitry, most 1920s superhets used specially-wound iron-cored transformers with a natural resonant frequency of around 60kHz. This is the reason they are still often called IF "transformers"

However, by the 1930s totally new types of valves had been developed which greatly reduced the cost and complexity of superheterodynes. The problem of image interference was almost completely eliminated by shifting the intermediate frequency up to around 450kHz. This made the desired frequency and the unwanted image frequency around 900kHz apart, meaning a single aerial tuned circuit was more than enough to suppress the unwanted frequencies. (Ironically, the new "high" ~450kHz Intermediate Frequencies were in the original "short wave" range that early triode designs had problems with, and which the superhet circuit was designed to solve!)

Eventually, by international agreement, the standard AM receiver IF in most countries became 455kHz or very close to it. In the 1970s manufacturers started to use non-adjustable 455kHz ceramic resonators, which eventually made exactly 455kHz the de-facto standard everywhere.

When FM broadcasting started on the 88-108MHz VHF band, an IF of 455kHz was not feasible both because of the wide FM deviation and

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the inability of practical VHF tuned circuits to reject the +910kHz image frequencies. For FM a standard IF frequency of 10.7MHz was eventually chosen.

To meet the requirement for remote control-operated tuners in HiFi systems and car radios, the mechanical tuning capacitors in many systems were replaced by varicap (varactor) diodes, where the capacitance changes were effected by changing the reverse bias on the diodes, rather than simply rotating the capacitors. Other than that, receivers were generally similar to designs using mechanical tuning capacitors.

However, the requirement for more compact receivers in personal stereos led to the development of “coil-less” receiver designs, where all of the signal processing and filtering is carried out by circuitry etched onto silicon chips instead of using external components. While this was relatively easy to do with VHF FM and TV receivers, it remained a major challenge for AM reception. Where AM reception was required, those receivers tended to revert to the traditional varicap tuned design with external tuning components, for both AM and FM

The ancestor of the “silicon tuner” was the Philips TDA7000 chip introduced in the 1970s. It still had external aerial and oscillator tuning, but almost everything else was implemented in analog silicon. It used a very low IF of about 70kHz, as that was all that could be achieved using active RC filters at the time. Of course the FM deviation of +/- 75kHz is much wider than that, but the TDA7000 got around this with an ingenious circuit that used negative feedback from the audio output to “cancel out” some of the deviation, by modulating the local oscillator frequency.

Such a low IF would be expected to create major problems with image interference, particularly since no antenna tuning was used, however, modulating the local oscillator frequency has the fortuitous effect of “scattering” potentially interfering frequencies so they appear as low-level noise which is ignored.

Much the same circuitry is still used in the miniature receivers incorporated into mobile phones and the like, except that they are now truly “coil-less”. The local oscillator is actually a special type of crystal-locked multivibrator which can have a range of 30MHz to 1GHz!

While the “Image-frequency-scattering” technique works well for FM, it is not applicable to AM receivers, so more complex techniques are needed to avoid image interference. This is particularly the case with all-silicon TV tuners, which may have to operate in crowded cable TV environments with hundreds of channels.

This is most commonly achieved using a circuit known as a “Dual Quadrature Balanced Mixer”.

An ordinary superhet mixer was usually just a valve or transistor which was basically switched on and off by the local oscillator signal. The output of this type normally contains a “fruitcake” mixture of the incoming desired and interfering signals, the oscillator signal, the upper and lower sidebands, plus varying amounts harmonics of all these. Generally, most of this is filtered out by the IF tuned circuits, leaving just the lower sideband, which forms the IF signal.

With a correctly operating balanced mixer, all that appears at the output are the upper and lower sidebands, everything else is suppressed.

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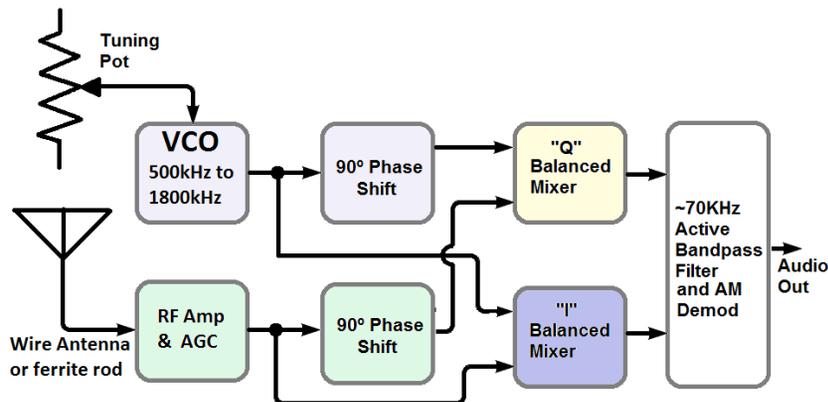
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But if you set up a second balanced mixer, where both the incoming signals and the oscillator signal have been shifted by 90 degrees, and then combine the two sets of output sidebands, a remarkable thing happens: Only one sideband is produced. This can be either the upper or the lower sideband, depending on how the system is configured. (Radio amateurs may recognize this is the heart of many low-cost Single-Sideband transmitter designs).

Again, let's assume you want to receive an AM station on 1MHz. With a 70kHz IF, that will mean setting the local oscillator to 1.07MHz. With a conventional mixer, that will mean that if there is also a signal on  $1 + 0.07 = 1.14\text{MHz}$ , that too will produce an unwanted 70kHz lower sideband.



With a dual quadrature mixer, it can be configured so that the only output signal frequency is the incoming signal frequency subtracted from the oscillator frequency. So  $1.07\text{MHz} - 1.0\text{MHz} = 0.07\text{MHz}$  (70 kHz), which is what we want, but as for the image frequency, we get  $1.07\text{MHz} - 1.14\text{MHz}$ , which comes out as *minus* 70kHz!

So what does “minus 70kHz” mean? Well, nothing of any importance to the 70kHz IF filter! Like the frequency-scattered signals on the coil-less FM receiver, the unwanted image signal appears as low-level noise spread across the AM spectrum.

How effective is this? In the case of the BK1198, extremely effective. You don't really even need an AM antenna tuned circuit; in reasonable reception areas, a short length of wire soldered directly to the AM input pin will work quite well. The ferrite antenna has lower noise pickup which is why it's recommended (plus it's nice and compact).

It's not quite as effective on shortwave, but you still really have to look for image interference to find it.

## Page 8

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