Colin Horrabin, G3SBI

17 Denbury Ave, Warrington, Stockton Heath, WA4 2BL, United Kingdom; **colin.horrabin7@ntlworld.com**

The HF7070 HF/LF Communications Receiver Prototype

A detailed look at high performance receiver design.

The HF7070 receiver is a double conversion superheterodyne with a first IF at 45 MHz and a second IF that is centered at 44 kHz before going to a 25 bit audio ADC. The output from the ADC goes to an advanced 24 bit fixed-point DSP system. The radio covers dc to 30 MHz and has a noise figure of 12 dB without the use of a preamplifier before the first mixer. Out-of-band IP3 at 50 kHz spacing is 45 dBm, giving an SSB IP3 dynamic range of 115 dB. The IP3 within the 15 kHz bandwidth of the roofing filters is 19 dBm at 100 Hz spacing in an SSB bandwidth, which results in an IP3 dynamic range of 97 dB. This in-band linearity sets new standards for an up-conversion radio and gives superb high fidelity reception of FM, AM, SSB and CW signals.

To complement its excellent technical performance there are all the usual DSP features for the user. These include a sensitive band scope on the LCD panel of the radio. The band scope can also be displayed on a computer connected via a TOSLINK optical cable. With a noise floor of −145 dBm in a 50 Hz bandwidth, it can display sub-microvolt signals.

The receiver analog front end has two H-Mode mixers using fast bus switches. The first mixer is terminated by quadrature hybrid-connected two-pole 45 MHz filters of 15 kHz bandwidth, which is followed by the first IF amplifier. This amplifier, with a noise figure of only 1.3 dB and an IP3 at 40 dBm, drives 4 poles of roofing filter, which is followed by a second amplifier. This amplifier drives the second H-Mode mixer that gives an output centered on 44 kHz. There is a balanced stage of amplification at 44 kHz before the 25 bit audio ADC. The 6 poles of roofing filter at 45 MHz gives 115 dB image rejection at the second H-Mode mixer, so an image rejection mixer is not required.

The HF7070 was designed by the British electronic engineer John Thorpe of JTdesign based in Matlock, England. John also designed the Lowe receivers and the highly acclaimed AR7030 HF/LF receiver manufactured by AOR UK.

In terms of its technical performance the AR7030 represented very good value for money and was made from 1996 until production ceased in 2007 due to the restriction of hazardous substance (ROHS) directive. Over that period some 5000 units were sold, most of which went for export (even the French Navy bought a few).

Originally, John designed the HF7070 receiver for AOR UK, but they ceased trading two years ago. John is a consultant and had other design commitments. So, I designed and built an up-conversion front end for the 7070 a few years ago to help with the development work. John was able to re-engineer this for mainly surface mount components and improve on its technical performance.

Just after John was presented with the front end board, I got to know Martein Bakker, PA3AKE. Martein was keen to build a holy grail version of the CDG2000 transceiver and had made technical measurements on transformers and fast bus switches for H-Mode mixers. These measurements proved quite useful to John. Those readers who are familiar with the CDG2000 Amateur Radio transceiver project will

recognize the similarity of the HF7070 front end block diagram (see Figure 1) to the receiver in the CDG2000. Any reader who is interested in the detailed technical measurements for the HF7070 "proto2" receiver will find them on PA3AKE's website at **http://martein.home.xs4all.nl/pa3ake/hmode/**.

Fundamental Design Issues in the Analog Signal Path

Table 1 shows some of the key parameters of the receiver front end design. It is the job of the two-pole 45 MHz filter to provide some protection to the first IF amplifier for strong signals more than 10 kHz from the selected frequency.

In an up-conversion radio the third order intercept (IP3) usually reduces significantly for off-channel signals within the bandwidth of its roofing filters. The close-in performance of the HF7070 has surprised quite a few people and Table 1 shows how this excellent close-in IP3 performance is achieved. The values in the table of Net NF and Net IP3 are slightly better than the practical measurements on the "proto 2" receiver. In the table, the noise figure (NF) of the receiver at the antenna is 11 dB. This gives a noise floor of −129 dBm in a 2.4 kHz bandwidth. Together with a Net IP3 of 24.5 dBm the result is an in-band dynamic range of 102 dB. The practical results are NF 12 dB and an IP3 of 19 dBm, giving an in-band IP3 dynamic range of 97 dB.

It is necessary for the analog front end to have enough gain so that noise from the analog stages dominates the quantization noise from the ADC in the digital signal fed to the DSP. This gives a smooth, audible transition from noise to signal.

Referring to Table 1, in-band IP3 is limited by the 4-pole roofing filter. As the net IP3 requirement increases, as the signal is amplified the linearity will be degraded if the net value exceeds the stage IP3. This does not happen with the HF7070, but it is interesting to note that the 44 kHz amplifier has an IP3 output of 60 dBm.

A paradox is that a bit of signal path loss at the right place is a design virtue. The IP3 dynamic range at a 100 Hz test tone spacing in a 2.4 kHz bandwidth is 97 dB. The Yaesu FTDX-5000 has an IP3 of −8.5 dBm within the bandwidth of its 9 MHz roofing filters and a NF of 17 dB, which yields a dynamic range of 77 dB. So you can see why people with knowledge of receiver design are impressed with the close-in performance of the HF7070.

The First H-Mode Mixer

The experimental 7070 front end that I gave to John used the Fairchild FST3125 fast bus switch in the mixer. An important result from Martein's experimental work was that the more recent Fairchild FSA3157 actually proved to be the best switch for use in H-Mode mixers. This is a SPDT switch with a 0.5 ns break-before-make action. This SPDT switch is ideal for being driven by a fundamental frequency squarer because it is not necessary for the drive logic to generate a complement signal, as was the case with the

Table 1
Key Parameters of the HF7070 Front End

	Stage Gain dB	Net Gain dB	Stage IP3 dBm	Net IP3 dBm	Stage NF dB	Net NF dB
Antenna low pass filter	−2	−2	45	24.5	2	11.1
First H-Mode mixer	−5	−7	45	22.5	5	9.1
2 pole 45 MHz filter	−1.5	−8.5	24	16	1.5	4.1
First 45 MHz amp	10	1.5	40	26	1.3	2.6
4 pole 45 MHz filter	−2	−0.5	24	24	2	7.7
Second 45 MHz amp	10	9.5	40	34	1.3	5.7
Second H-Mode mixer	−5	4.5	45	29	8	14.02
44 kHz amp	18	22.5	60	47	6	6.02
25 Bit ADC	0	22.5	50	47	4	4

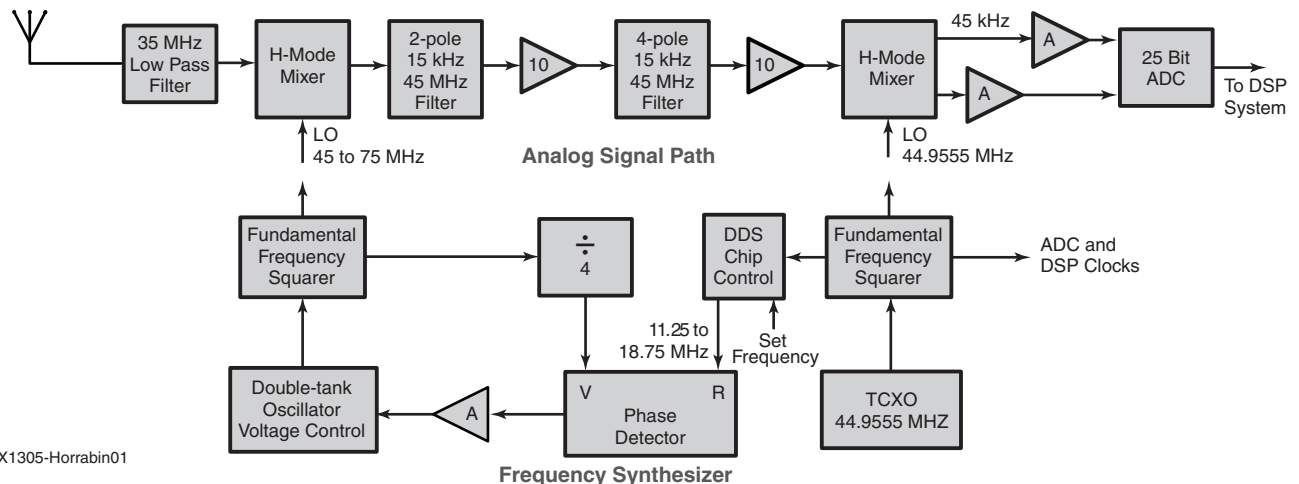| Out of Band IP3 at 50 kHz (dBm)	45	43	38					
Net Gain (dB)	-2	-7	-8.5	+1.5	-0.5	+9.5	+4.5	+22.5
Stage Gain (dB)	-2	-5	-1.5	+10	-2	+10	-5	+18
Noise Figure (dB)	11.1	9.1	4.1	2.6	7.7	5.7	14.02	6.02	4.0

Figure 1 — The HF7070 front end block diagram with Out of Band IP3, Net Gain, State Gain and Noise figure indicated for various stages.

FST3125. The choice of Mini-Circuits transformers used in this mixer gives the radio an out-of-band IP3 of 45 dBm at a 50 kHz test tone spacing with high sensitivity down to an input frequency of 10 kHz.

15 kHz Bandwidth 2-Pole 45 MHz Crystal Filter

Two of these filters are connected via quadrature hybrids to terminate the mixer. The use of quadrature hybrids with two identical filters always presents a nominal 50 Ω termination to the mixer, even when individual filters present a reactive load.

A design goal of the HF7070 was to build a sensitive receiver without a preamplifier before the first H-Mode mixer. Because the HF7070 is a general coverage multimode receiver, it was always our intention to use a 15 kHz bandwidth roofing filter system to accommodate FM and DRM signals. Another reason for this is that narrower bandwidth crystal filters have lower design impedances, which would give a greater insertion loss and therefore require a preamplifier before the first mixer. This filter and its surrounding circuitry introduce a loss of only 1.5 dB.

The First 45 MHz Amplifier

This amplifier drives the second roofing filter and it is the input IP3 of this filter (26 dBm) that limits the in-band performance of the radio.

The amplifier is a 45 MHz version of the 4 × J310 amplifier designed by Bill Carver, W7AAZ, as used in the CDG2000 transceiver. The noise figure of this amplifier is 1.3 dB. Its output IP3 of 40 dBm makes it a particularly important building block in the HF7070 to satisfy the requirement of having a sensitive, linear receiver without a preamplifier before the first H-Mode mixer. This amplifier uses source gate feedback, which gives excellent reverse isolation so that its input impedance is not affected by its output driving a crystal filter, which in its transition region can present a reactive load.

15 kHz Bandwidth 4-Pole 45 MHz Crystal Filter

This filter has an in-band IP3 at its input of 26 dBm and this ultimately controls the in-band IP3 of the radio. Some Amateur Radio equipment manufacturers offer narrower bandwidth VHF roofing filters for their radios. You don't want this for two reasons: (1) the insertion loss increases and (2) the in-band IP3 for a narrower design bandwidth with the same quality of quartz crystals gets worse at roughly 6 dB per octave. This effect was discovered by PA3AKE when he was designing his 9 MHz roofing filters with the fabulously linear crystals supplied by the German firm Quarztechnik.

So what you really need in an up-conversion radio is a wide roofing filter, but the linearity of following circuitry must not degrade the in-band IP3 of the crystal filter. This seems to be a problem area with many transceiver designs.

The second 45 MHz amplifier is similar to the first amplifier and uses the 4 × J310. Its output IP3 is 6 dB higher than the net IP3 at that point.

The second H-Mode mixer gives 115 dB rejection of the image because of the stop band of 6 poles of roofing filter, so an image rejection mixer is not required. This mixer gives a push-pull output centered on 44 kHz.

The 44 kHz Amplifier

John designed this amplifier with a noise figure of 6 dB, a gain of 18 dB and an output IP3 at 60 dBm. A point worth noting is that it is easier to get low-noise, high-IP3 gain at 45 MHz than at audio frequencies. This was an important consideration for the gain distribution of the front end. There is also a potential problem for the unwary that may affect other designs: many operational amplifiers have poor IP3 characteristics.

You get good IP3 results at high signal levels, but the IP3 tones do not fall away as the signal amplitude is reduced; they remain at 60 dB down. There were a few operational amplifiers that gave the correct IP3 behavior.

The reason for this problem may be due to crossover distortion in the output stage of most operational amplifiers. John was aware of this problem when he designed the 44 kHz amplifier. It is interesting to note that the new ICOM IC-7410 with its 36 kHz IF appears to use a version of the TL074 that is known to have the IP3 problem.

Apart from the front panel board, the radio has an analog board and a digital board. After some discussion the 25 bit ADC went on the digital board. The second H-Mode mixer makes the transition from 45 MHz to 44 kHz and it gives a push-pull balanced output. This is followed by a balanced amplifier at 44 kHz located on the analog board whose outputs are connected by a short length of strip cable from the analog board to the balanced inputs of the 25 bit ADC located on the digital board. Whatever common mode noise is present due to the strip cable connection between the two boards is well within the common mode rejection of the ADC.

The 25 Bit ADC

The radio uses a top-of-the-range, stereo, 24 bit audio ADC with both channels driven and the signals digitally added giving a theoretical 25 bit performance, It is worth remembering that the ADC is effectively the main gain block. An estimate of its noise figure

Further Developments

The manufacture of the ten HF7070 production prototypes has been funded by a British company owned by a radio amateur. He was happy to learn that this article was appearing in *QEX*, but he asked that neither he nor his company be mentioned. In view of this it seems unlikely there will be a significant production run because he is concerned that there would be too much competition from SDRs.

Collaboration between British and American electronic engineers during World War II resulted in some great design work. The thing to remember about the HF7070 is that although it has been designed by a British electronic engineer, all the components that really matter, apart from the 45 MHz monolithic filters with their excellent IP3s, were designed in the USA. At least in that sense, history is repeating itself.

It would have been more cost effective to use an MMIC in the 45 MHz IF strip, but nothing was available that met the technical requirements. That has changed recently, however. The American firm Mini-Circuits has introduced the PHA-1+ and the dual-matched version known as the PHA-11+. Although they were designed for microwave applications, the noise figure (NF) and IP3 out is at its best between 45 MHz and 100 MHz, making them useful in IF amplifiers for up-conversion radios. Typical performance at 45 MHz is: NF 2.2 dB: gain 18 dB: and IP3 out 42 dBm.

The vector network analyzer designed by Paul Kiciak, N2PK, together with the *Windows* software for the VNA written by Dave Robert, G8KBB, was used to measure the PHA-1 input impedance at 45 MHz, which is 80 Ω in parallel with 25 pF. The best way to use this part in the existing HF7070 IF strip is to use two in parallel with an output attenuator to replace the first 4 × J310 amplifier, and one to replace the second amplifier, again with an output attenuator.

A change to the HF7070 front end architecture by having all 6 poles of roofing filter connected via quadrature hybrids immediately after the first H-Mode mixer could, in principle, further increase close-in receiver dynamic range. Obviously, careful shielding around the filters is required. All the mechanical and electronic components for this experiment have been obtained and I hope to report the results in a future *QEX* article. From a practical printed circuit point of view, rather than use the matched pair the thermal affect on amplifier noise figure would have been reduced if two individual PHA-1s could have been used. Unfortunately, this did not fit well with the circuit board design. Another version of the PHA-1 where the input and output pins are transposed could be useful. Perhaps Mini-Circuits will consider this.

(NF) is 4 dB, but if it was 12 dB the effect on receiver noise figure would be to increase it by only 0.1 dB.

Overall Front End Performance of the Signal Path

The HF7070 has excellent technical specifications and this is reflected in its outstanding on-air performance. This didn't happen by chance; a lot of thought has gone into the receiver front end architecture.

It is unusual to have a sensitive up-conversion receiver that does not use a preamplifier before the first mixer. In many ways the front end architecture makes use of the principles established by Bill Squires, W2PUL, in the 1960s in his SS-1R receiver. His receiver used the 7360 beam-switching tube in the mixers and, although it was a tunable IF design, gain distribution was carefully controlled before the main crystal filter. It also lacked a preamplifier before its first mixer.

Just like PA3AKE's holy grail receiver with a 9 MHz IF, the HF7070 is only as good as the in-band and out-of-band linearity of its crystal roofing filters. Martein has made IP3 measurements on a number of different manufacturers' 15 kHz bandwidth, 45 MHz fundamental-mode monolithic crystal filters. Only one makes the grade in terms of IP3 and its 3rd order law compliance with input signal level.

A Low Phase Noise Local Oscillator for the HF7070

The local oscillator in the HF7070 is a DDS/PLL design using a double-tank VCO. This was designed by John Thorpe and it is similar to the one used in the AR7030 receiver, but with improved performance. The basic double-tank oscillator is shown in Figure 2. The principle involved is that this circuit can only oscillate if the cold end of the active tank (the one with the J310) is a low impedance to ground. This can only occur if the dummy tank is series resonant at the same frequency as the active tank. This means that as you move away from the carrier two resonators are active, which increases the rate of phase noise fall-off with offset frequency. This circuit has never been analyzed from a phase noise point of view by a mathematician, but measurements show phase noise falls off at 30 dB/decade compared to 20 dB/decade in a single resonator oscillator.

In a superhet receiver local oscillator, sideband noise causes reciprocal mixing and, as a result the dynamic range associated with good close-in IP3, can be limited by the sideband noise of the local oscillator. The frequency reference used in the HF7070 frequency synthesizer is a 44.9555 MHz TCXO that has a good phase noise profile. The TCXO is used for the local oscillator feed to

The Double-Tank Oscillator

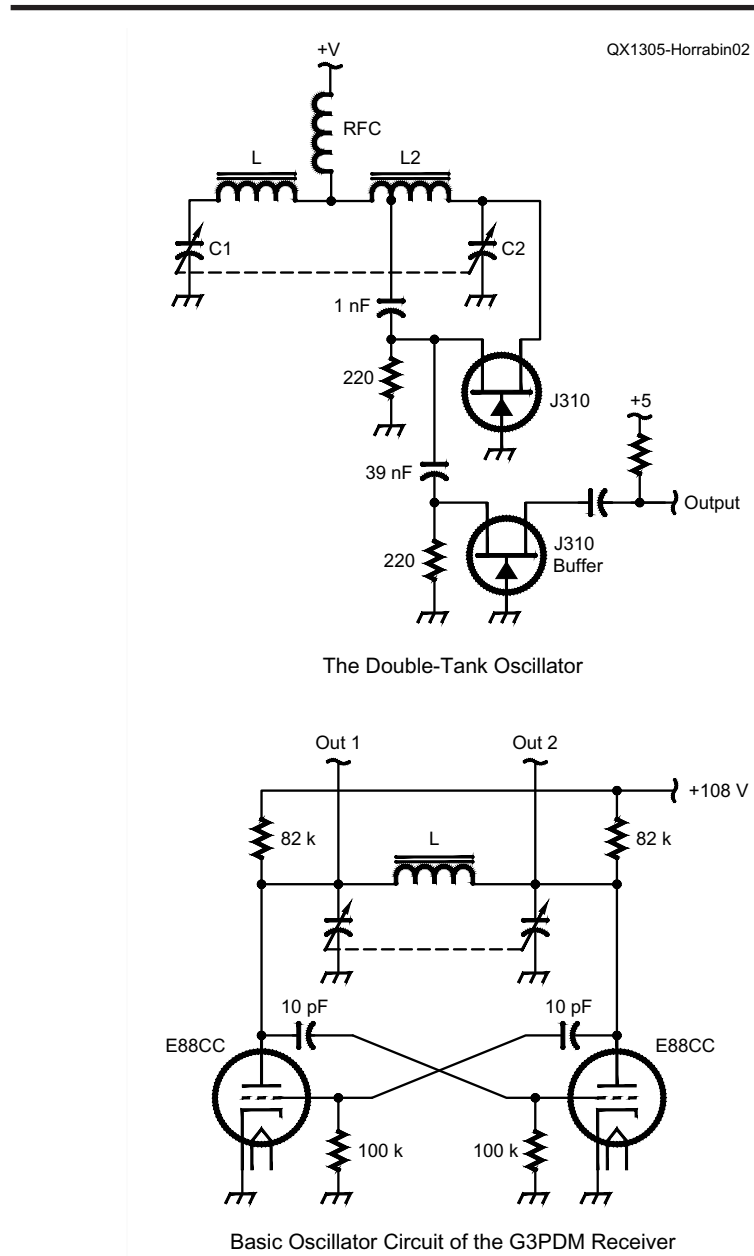
Basic Oscillator Circuit of the G3PDM Receiver

Figure 2 — The HF7070 double-tank oscillator (top) compared to the tube-based oscillator used in the G3PDM/W1 receiver designed by Peter Martin in 1970.

the second H-Mode mixer and it also clocks an AD9951 DDS chip. Other divided outputs from the TCXO are used to provide clocks for the 25 bit ADC and the DSP system.

Operation of the local oscillator frequency synthesizer is as follows. The output frequency from the double-tank VCO is divided by 4, which is then phase locked to a DDS-generated reference frequency in the range of 11.25 to 18.75 MHz. The result is that the VCO tunes 45 to 75 MHz in small steps. The VCO is buffered and goes to a fundamental frequency squarer whose output drives the FSA3157 switches in the first

H-Mode mixer. The loop bandwidth of the PLL system is about 1 kHz, within which VCO oscillator phase noise is reduced by the action of the loop.

A measured value of phase noise for the HF7070 at 200 Hz to 1 kHz offset on the 7 MHz band is a −116 dBc/Hz plateau falling to −128 dBc/Hz at 7 kHz. Six SSB signals could be present within the 15 kHz bandwidth of the roofing filter and would be separated in at least an 82 dB dynamic range because of reciprocal mixing

For CW reception with a 250 Hz DSP, the bandwidth dynamic range would be at least

Frequency Offset (kHz)	3	5	10	20	30	50	100	200
AR7030 dBc/Hz	−113	−118	−128	−137	−142	−147	−155	−160
HF7070 dBc/Hz	−116	−122	−133	−142	−145	−150	−158	−162
HF7070 at 7 MHz	−120	−126	−138	−147	−150	−154	−159	−162

92 dB. If the DSP bandwidth was reduced to 50 Hz you could resolve CW signals in at least a 99 dB range.

Outside the PLL bandwidth the phase noise profile is that of the double-tank oscillator itself. The HF7070 is not phase noise limited beyond 7 kHz from the carrier, reaching −150 dBc/Hz at 30 kHz from the carrier on the 7 MHz band. According to Leeson, phase noise in a single-tank oscillator reduces beyond a corner frequency at 20 dB per decade as you move away from the carrier. In the double-tank oscillator our measurements have shown that phase noise decreases by about 30 dB per decade.

By examining Table 2 you'll see that phase noise falls at around 30 dB per decade of frequency offset in both the AR7030 and the HF7070. The results for the AR7030 are calculated from the Peter Hart review of the AR7030 receiver in the July 1996 *RadCom*.

The results characterize the basic phase-noise profile of the AR7030s double-tank VCO, which is the result of the very narrow PLL bandwidth used in the AR7030 receiver. The HF7070 is added for comparison and adjusted to compare with the AR7030 measurements at 21 MHz.

I developed the double-tank circuit in 1994 to complement my design of the H-Mode mixer and John developed it further for use in the AR7030 receiver. The owner's manual for the AR7030 includes a complete circuit of the radio, so it is surprising that John's version of the double-tank oscillator has not been copied for use in other commercial developments (such as other Amateur Radio equipment). In fact, the real origin of the double-tank circuit goes back a bit further than 1994, all the way to the G3PDM receiver designed by Peter Martin in 1970. His receiver used a 7360 as the mixer and he had a push-pull double-triode local oscillator VCO to drive it. There was only one resonator, each end of which went to the plate of a triode. Each triode plate was connected to the high-voltage power supply through an 82 kΩ resistor. You can't do that with J310s, but if you compare the two circuits they do a similar job. So, it is fair to say that Peter got there first.

Semiconductor designers appear to have a love affair with band-gap voltage references in what they consider to be low noise systems. These usually have a voltage of
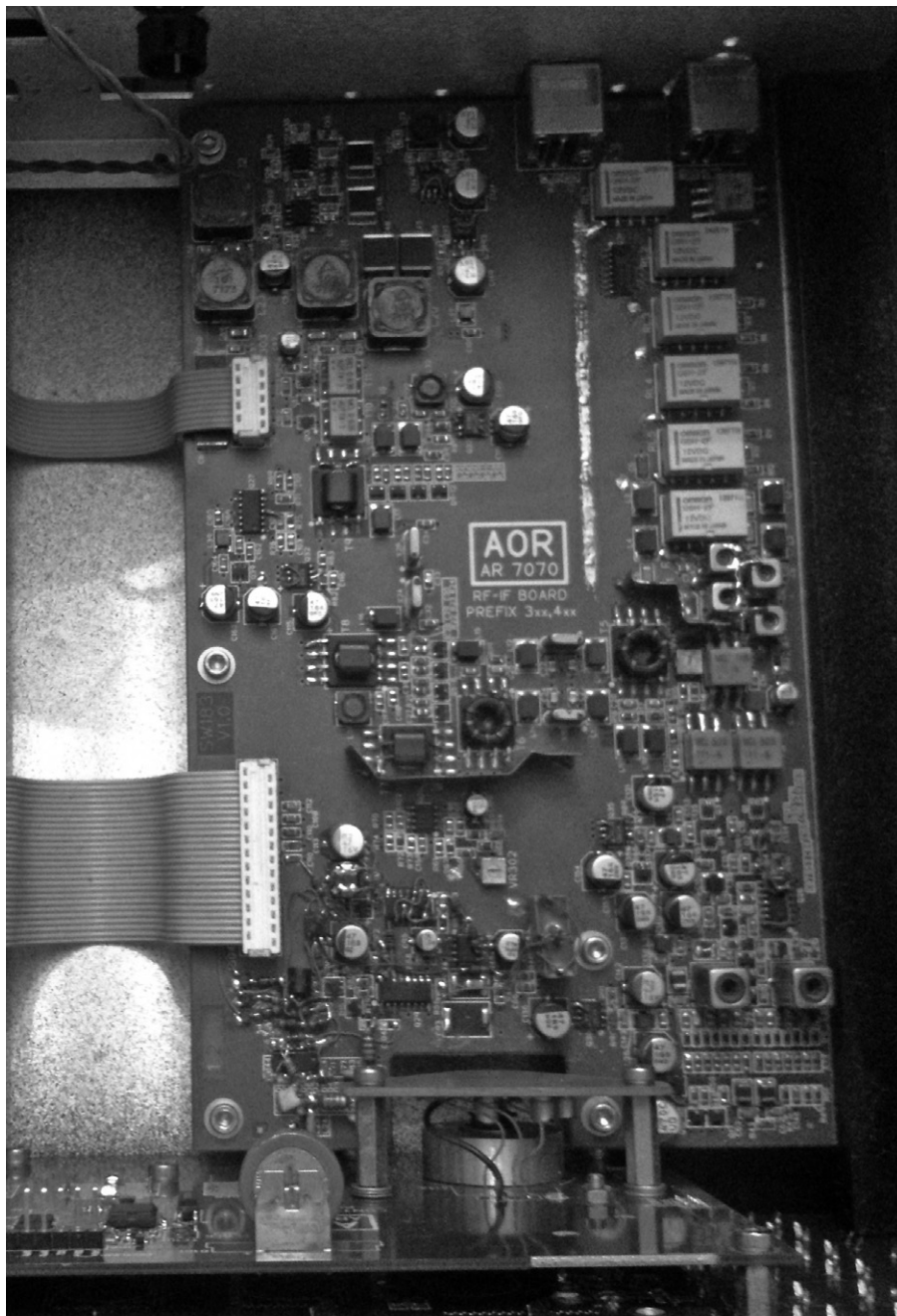
Figure 3 — This photo shows the RF/IF circuit board in the prototype HF7070 receiver. The signals enter at the top right, and the white blocks in that section of the board are relays for an input attenuator. Below the relays are the low pass filter inductors and then the Mini-Circuits transformers of the first H-mode mixer. To the left is the first toroid of the quadrature hybrid, two poles of filtering and the second quadrature hybrid. To the left of center is the 4 × J310 amplifier. In the top left quarter of the board there is a four pole filter, the second 4 × J310 amplifier, the second H-mode mixer and the 44 kHz push-pull amplifier. The narrow cable strip carries the amplified signal to the analog-to-digital converter on the digital circuit board. The bottom section of the circuit board includes the frequency synthesizer and low-noise voltage regulators.

1.2 V and an RMS noise of about 10 µV in a 10 kHz bandwidth. They have a characteristic noise profile with a noise plateau that extends out to about 300 kHz before it falls sharply to the thermal noise floor. Most chip designs that make use of band-gap references fail to provide a pin to which a large capacitor can be connected to reduce low frequency noise from the reference.

There is suspicion that close-in phase noise within the PLL bandwidth on the HF 7070 is limited by band-gap noise on the phase detector chip made by Philips: the 74HCT9046. To improve this situation it is necessary to know how band-gap noise on the chip may be turned into noise that would affect the charge pump. This turned out to be easier said than done.

In the old days manufacturers of integrated circuits would show internal circuits on their data sheets. Philips was contacted to see if they would provide a circuit of the chip so it could be established exactly what effect band-gap noise could have on the charge pump, but a circuit was not forthcoming. They were again contacted, but finally told us they were not interested in pursuing the issue further because no other '9046 users had asked these questions before and the chip was selling well. As far as Philips was concerned, this was a non-issue.

In truth, these issues have only recently arisen because state of the art up-conversion HF receivers are approaching 120 dB dynamic range, and in the case of PA3AKE's holy grail down-conversion receiver, *exceeding* 120 dB. Semiconductor designers really need to take notice of the shortcomings of band-gap references in ultra low-noise systems and provide a pin to deal with low frequency noise from the reference.

On-Air Performance of the HF7070 Receiver

The technical performance of this radio is what Pat Hawker, MBE, G3VA, (SK) would call "superlinear." Not only does the radio have an SSB IP3 dynamic range of 115 dB at 50 kHz, its design answers the problem of how to get good IP3 dynamic range in an up-conversion radio for signals within the bandwidth of its 45 MHz roofing filter (effectively achieving a dynamic range of 97 dB in an SSB bandwidth). What was unknown was how a radio with this built-in in-band linearity would actually sound on the air.

The answer is "amazing." The fidelity is remarkable and what is particularly noticeable is the way selected signals seem to stand out above the noise floor and adjacent signals. The first time you hear this radio you know you are listening to something special. Unless you hear it yourself, the performance is impossible to describe.
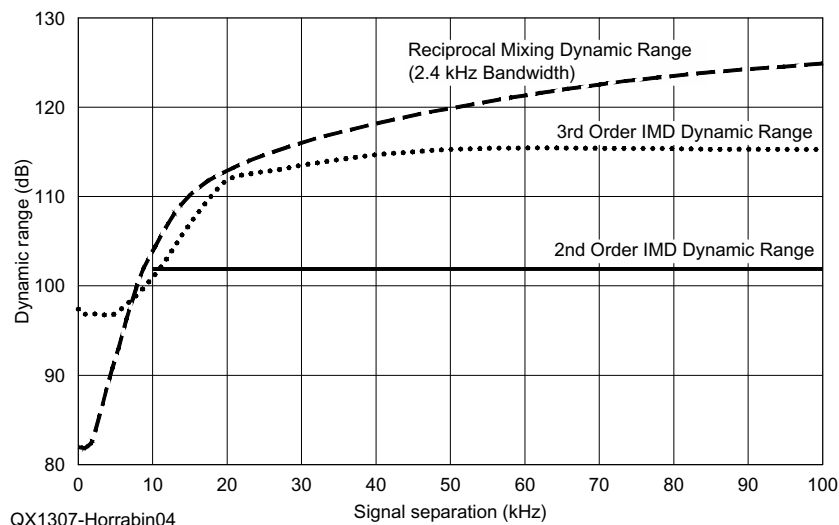
Figure 4 — This graph shows the measured dynamic range (DR) of the HF7070 prototype receiver. The reciprocal mixing dynamic range was measured with a 2.4 kHz bandwidth. Notice that the 2nd order IMD DR is completely flat across the entire measured range. The 3rd order IMD DR increases rapidly above a signal spacing of about 5 kHz and then becomes quite flat at a signal spacing of 20 kHz. Ideally, the IMD DR should not change as the signal spacing of the input signals changes. This radio has a 3rd order IMD DR that is better than 110 dB at 20 kHz spacing, and levels off at 115 dB, which is quite remarkable. This graph was copied from Martein (PA3AKE) Bakker's website: http://martein.home.xs4all.nl/pa3ake/hmode/ar7070-proto2.html.

How I Came to be Involved in the Design of the HF7070

In 1995 I had suggested to John Thorpe that he consider the double-tank oscillator for use in the AR7030 receiver. We had spoken many times on the phone, but we didn't meet until 1998.

In 2000 Dave Roberts, G8KBB, George Fare, G3OGQ, and I started to design the CDG2000 transceiver that used an H-Mode mixer with the FST3125 fast-bus switch. As an analog radio, it made use of the 4 × J310 amplifier and the 9 MHz IF amplifier design that Bill Carver, W7AAZ, presented in *QST*.

When we were discussing the frequency synthesizer, I suggested that we ask John and AOR UK if they would let us use John's VCO design. They did. Since the CDG2000 receiver section uses a 9 MHz IF, the output of John's VCO was divided by at least two, giving –150 dBc/Hz at 25 kHz on 20 meters and –150 dBc/Hz at 12.5 kHz on 40 meters.

The divider was a 74AC74 bistable, so it produced a square wave output, giving both not-Q and Q signals to drive the mixer, and required no adjustments to give a receiver IP3 of 40 dBm.

On one of my visits to John I stopped by AOR UK to thank them for their help. While I was there, Mark Sumner told me that John was investigating a DSP based receiver then known as the AR7070, but progress had been slow. Originally John intended the signal path to be 45 MHz/455 kHz/20 kHz to the 24 bit audio ADC.

Mark supplied me with some of the Hertz Technology 15 kHz bandwidth, 45 MHz fundamental mode crystal filters to test. Their transmission characteristics were very good with low insertion loss and a good stop band. I realized that if 6 poles of filter were used you could go straight down from 45 MHz to 44 kHz, simplifying John's original design and reducing the second H-Mode mixer image by 110 dB. Also the very good in-band IP3 of these filters offered the promise of hitherto unobtainable close-in dynamic range. I designed and built the prototype up-conversion front end and gave the design information to John along with the prototype board.

One of my hallmarks at Daresbury Laboratory was the tendency to push any given technology to the limit. That is why I am now experimenting with the use of the Mini-Circuits PHA-1 MMIC, which in principle could put 10 dB on the in-band IP3 and give 45 dBm at 20 kHz in a front end like that used in the HF7070. I don't really see John making use of this development because it is unlikely he will design another up-conversion receiver. Together with a local oscillator using the AD9910 DDS chip with a 1 GHz low-phase-noise clock, however, this development would represent the ultimate up-conversion receiver technology.
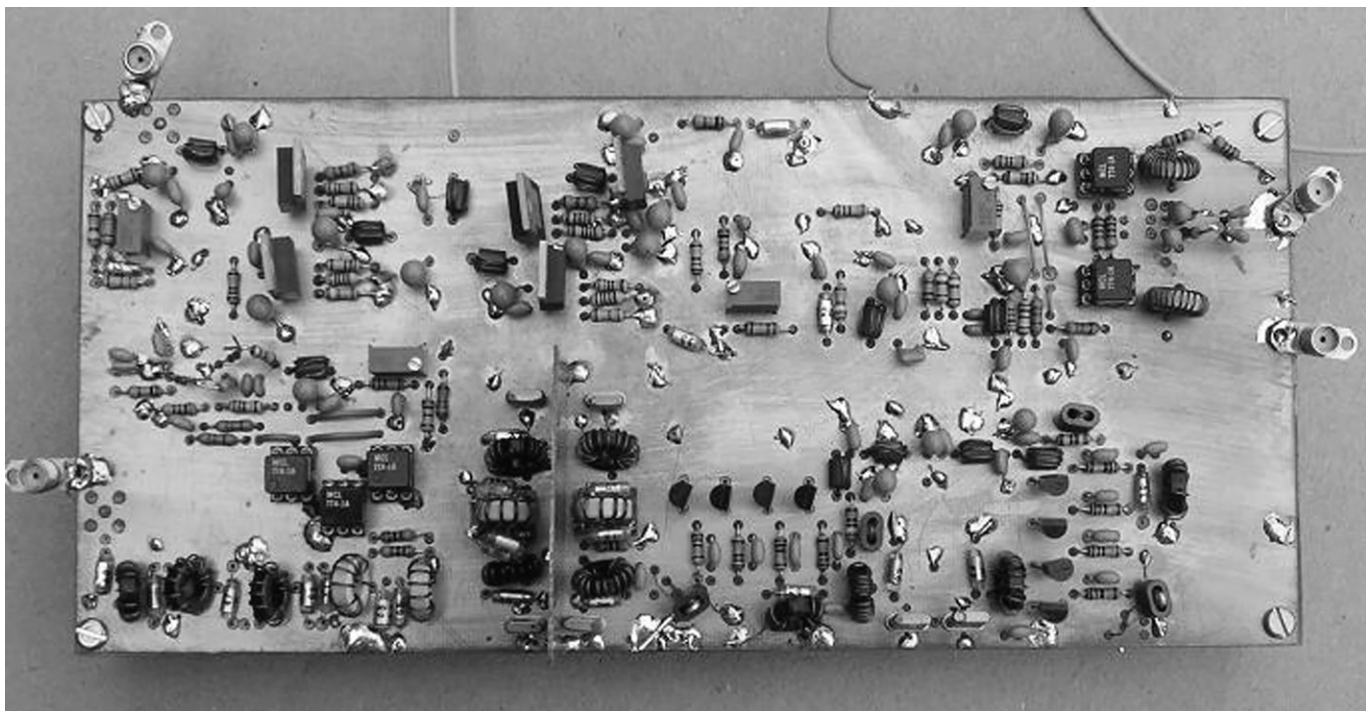
Figure 5 — This photo shows the first prototype receiver front end. It proved the author's design before it was adapted for the HF7070 receiver. This photo is courtesy of Martein Bakker, PA3AKE: http://martein.home.xs4all.nl/pa3ake/hmode/g3sbi_intro.html.

In the 15 kHz wide roofing filter, the signal you are listening to is in the center of the pass band where its group delay characteristics are at their best. This is one factor in the exemplary performance of the radio.

John knows I am a CW enthusiast so my personal agenda was to make sure that the HF7070 was a good CW receiver, and it is. When I first had the opportunity to listen to the HF7070 proto1 receiver, John had a lap top computer connected to display the bandscope. Apart from the larger display, it updates much faster than the LCD display on the radio front panel and I could read CW off the screen. I was watching a DX station on 15 meters working split, and I could see other stations replying. This is remarkable stuff !

Acknowledgements

Useful Reading Material

• "Super-Linear HF Receiver Front Ends," (Colin Horrabin, G3SBI, evaluates the N6NWP high performance mixer), *RadCom,* "Technical Topics," Sep 1993, pp 54-56.

• "G3SBI's High Performance Mixer," (H-Mode mixer), *RadCom,* "Technical Topics," Oct 1993, pp 55-56.

• "Crystal Filters for High Performance Mixers," (H-Mode mixer termination with crystal filters using quadrature hybrids), *RadCom,* "Technical Topics," Jan 1994, 37-39.

• Reed Fisher, W2CQH, "Twisted-Wire Quadrature Hybrid Directional Couplers," *QST* Jan 1978, pp 21 to 23. More consistent results can be obtained by using bonded bifilar wire to build your own quadrature hybrids. Such wire is available from the Scientific Wire Company (**www.wires.co.uk/acatalog/bb_wire.html**).

• The CDG2000 transceiver description at the Warrington Amateur Radio Club website at **www.warc.org.uk/proj_cdg2000.php**.

• The G3PDM receiver, as described in the *Radio Communication Handbook* Fifth Edition, 1982, pp 4.50-4.57.

• Wes Hayward, W7ZOI, Rick Campbell, KK7B, and Bob Larkin, W7PUA, *Experimental Methods in RF Design* ARRL, 2009. ARRL Order No. 9239; $49.95. ARRL publications are available from your local ARRL dealer, or from the ARRL Bookstore. Telephone toll free in the US 888-277-5289 or call 860-594-0355, fax 860-594-0303; **www.arrl.org/shop**; **pubsales@arrl.org**.

• Wes Hayward, W7ZOI, and Doug DeMaw, W1FB, (SK), *Solid State Design for the Radio Amateur*, ARRL, 1986. This book is out of print, but it occasionally shows up at Hamfests, on eBay and other used book sites.

• William Sabin and Edgar Schoenike, *Single Sideband Systems and Circuits*, 2nd Ed, McGraw Hill, 1995.

• Peter Hart, G3SJX, "Review — The AR7030 VLF to HF Receiver," *RadCom*, July 1996, pp 44-46.

has led to the high performance receivers found in PA3AKE's holy grail version of the CDG2000 and now the up-conversion HF7070 receiver designed by John Thorpe.

"Technical Topics" also brought together Bill Carver, W7AAZ, Harold Johnson, W4ZCB and Gian Moda, I7SWX. Their contributions to radio technology have been used in the design of the HF7070 as well. The influence of Wes Hayward, W7ZOI, expressed in his various books and articles in *QST* and *QEX* have contributed significantly to the detailed design of the signal path. Research work by Martein Bakker, PA3AKE, presented on his website has been important for the technical status of our hobby and has helped John Thorpe to firm up the choices of some critical components.

I retired in 2000 and it would not have been possible to research and build the prototype up-conversion front end were it not for the good will of former colleagues at Daresbury Laboratory. George Fare, G3OGQ, was recruited to help with circuit board design work and Mark Sumner, G7KNY, formerly of AOR UK (now at MWS Technical Services), provided components needed for experimental work associated with the front end design.

When Martein Bakker, PA3AKE, became involved in testing various H-Mode mixer configurations (transformers and switches), Mark supplied all the bits. It was a real shame that AOR UK ceased trading before the project reached the production stage. The purpose of my experimental front end design was to establish the circuit techniques that John Thorpe was then able to improve upon for his commercial design.

Colin Horrabin, G3SBI, was born in 1941. His father provided him with a World War II BC348 radio receiver for his 12th birthday, followed by a copy of the ARRL Handbook for Christmas. After years building various projects using government surplus equipment, he obtained his Amateur Radio license in 1963. He has a degree in electrical engineering and a degree equivalent qualification in mechanical engineering. Following an apprenticeship with the British Aircraft Corporation in the early 1960s, he spent over 30 years working at Daresbury Laboratory as an electronic engineer. Colin is interested in small DX antennas for the LF bands, and intends to do some work on small multi turn spiral wound loops that are self resonant containing ¼ wavelengths of wire, which are suitable for transmitting.