Direct Conversion Receivers—Some Amateur Radio History

Wes Hayward, W7ZOI October 20, 2018 …. **(Appendix added, March 22, 2019.)**

Definition — Direct Conversion: A type of radio receiver wherein a signal is applied to a mixer and is *converted directly* to a baseband, typically audio. There is no intermediate frequency. The method is sometimes called **zero IF, homodyne, or synchrodyne**.

> The **75-50-25 Years Ago** column in the November 2018 QST, edited by W1AB, mentioned a paper that Dick Bingham and I wrote a half century ago. The column said W7ZOI and W7WKR looked ***to the past*** to build a receiver using "**Direct Conversion—A Neglected Technique**." This note reviews that paper, some personal history , some experience with DC receivers, and the role of direct conversion since that paper appeared. I would submit that we were looking **to the future** rather than the past.

1961

I had just taken a job with Varian Associates in Palo Alto, California in June, 1961. We had rented an apartment in nearby Mountain View. I was on the air (40 CW) with a homebrew vacuum tube clunker and a clandestine antenna, enabling me to meet local hams. It was a totally new life and lifestyle for us.

Solid State ham gear was quite rare in 1961, but there was great interest. Without commercial transistor equipment to purchase, hard core hams resorted to building. The lore of the day said that vacuum tubes would never be replaced, but not all of us were convinced. **QST** had frequent articles about the emerging technology. A new magazine, **73,** had some useful offerings. **73** had a savvy technical editor in Jim Fisk, W1DTY (later W1HR). **Ham Radio** appeared in 1968, a magazine completely devoted to the technical end of the hobby. Fisk was a **HR** founder (with Skip Tenney) and served as their technical editor until his death.

I was very disenchanted with amateur radio by 1962 and almost dropped out. But the solid-state lore lured me with the thought of combining ham radio with my growing interest in backpacking. Once committed, I dismantled my vacuum tube gear to obtain parts for an all solid-state station. A superhet receiver was functioning in December, 1962, followed by a 1 watt output, crystal controlled CW transmitter in February, 1963. It was great fun to get on the air at that time, for virtually every contact was a "first transistor station" for the folks I worked. People were interested and they really cared about the technical details.

K6DMW

One of the hams I met at Varian was Chuck Wilcox, K6DMW. Chuck had a circuits background and was a wealth of knowledge. We would often eat lunch in his office and talk about circuits. I learned a lot from him, including a glimpse at a formal core of circuit design, well outside my experience. My naive approach to circuit design at that time was to copy standard circuits from magazines or handbooks. It was at one of these lunch sessions that we began discussing gain distribution in receivers of the day. Why was there so much gain in the IF? How much gain was needed and did it depend upon the nature of the signal? We concluded that high IF gain was best for AM, supplying a signal to drive the nonlinear detectors. Modest gain at a low intermediate frequency enhanced freedom from system oscillation. The IF was also a good place to perform gain control.

A good AM receiver might actually be more complicated than a simple SSB or CW design. AGC aside, SSB and CW need **no IF gain at all**. A product detector, essentially just a mixer, is a linear block. That is, the audio output is a frequency shifted linear replica of the CW or SSB signal at the input.

It was this point in the discussion that the direct conversion receiver idea emerged. Could one build a receiver that had no front end at all? Could we effectively apply antenna signals directly to a product detector? The local oscillator (LO) for the detector would have to be changed, but that should not present a problem. [1]

I begin to construct a "DC" receiver sometime in 1963. The result was interesting, but generally a failure for reasons that I didn't fully understand at the time. My DC receiver was nothing more than a crystal set with an audio amplifier. LO and antenna signals were both applied to a 1N34A detector diode. The antenna signal was filtered with a LC bandpass circuit. The receiver worked, but results were severely compromised. 80 meter CW and SSB signals from all over the country were heard. But the receiver was extremely microphonic. Adjusting the input filter was almost impossible. The direct conversion idea was set aside for the moment, mentally filed away for another time.

W7WKR

Chuck left Varian in the mid 1960s to join a Bay Area start-up. I left Varian in 1966 to return to the Pacific Northwest to take a job with Boeing. While there, I met Dick Bingham, W7WKR. He was a devoted backpacker and mountaineer, having done some very intense treks in the North Cascades. Dick was interested in building a small rig to take with him in the mountains, so he was interested in my experiences. By then, I had taken my super-heterodyne monster to summits in both California and Washington. I described my DC receiver experiences to Dick and he immediately understood the problem and saw the solution: Replace the single diode with a balanced detector. Balance would keep LO energy away from the antenna. He suggested a diode ring mixer, a circuit with four diodes and a pair of RF transformers.

A lunch-time experiment was planned. Dick had a commercial diode ring in the lab where he worked. I brought a high gain audio amplifier and headphones from home. A pair of HP-606 signal generators were used, one as a LO and the other as an RF source. The DC port on the diode ring was routed to the audio amplifier. The results were extremely encouraging with no hint of the microphonic problems that had plagued my earlier efforts. Dick returned home and built an 80 meter CW transceiver using these ideas. I did similar things on 40 meters. Our on-the-air, home experiments reinforced what we had observed on the lab bench.

Enter ARRL

Dick and I knew that we had a good thing going here, something that might even have major impact. We concluded that we should write a QST paper on the concept. In that vein, I wrote to QST technical editor George Grammer, W1DF, to ask him if he had any interest in a QST article on a new, yet simple receiver. Grammer's response was less than enthusiastic. League policy discouraged regenerative receivers, and that was his view of our effort. They would consider a paper, should we submit one, but insisted that the readers wanted several bands and the ability to receive all modes.

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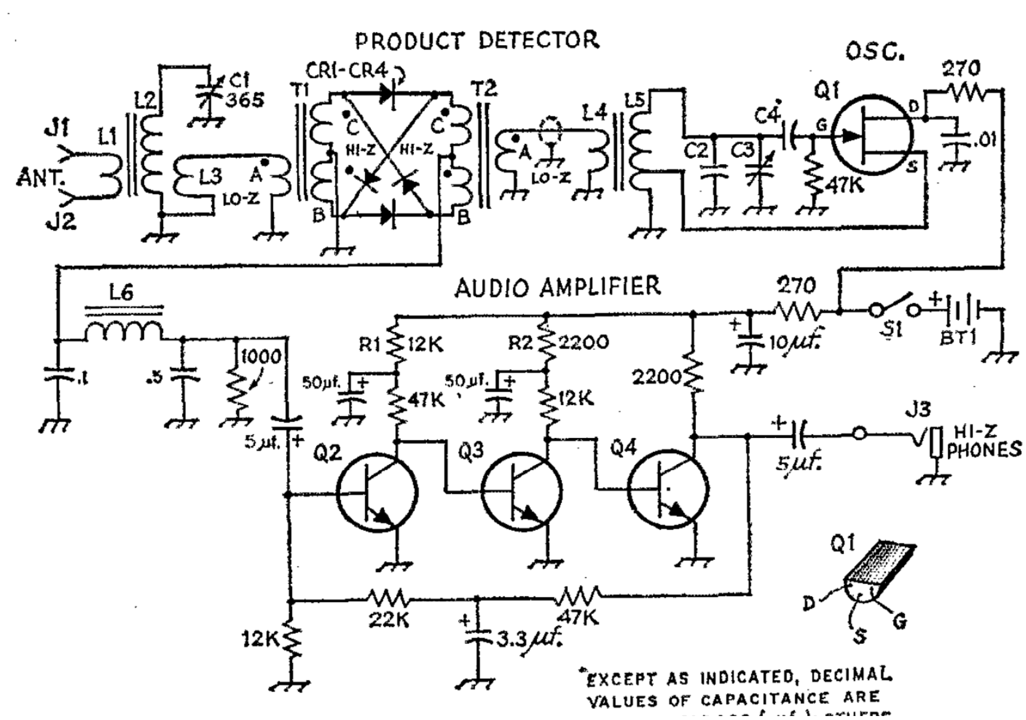
[1] The direct conversion concept was certainly not a new one. An excellent vacuum tube example is a design by White in QST for May, 1961.

Clearly, I failed in my attempt to present the idea to Grammer. He was treating our work merely as a potential construction project that happened to use transistors. It never registered with him that we might have something partially new. We decided to ignore George's advice about multiple modes and several bands. Instead, we selected a single band design for the QST piece, a circuit that was as simple as we could possibly make it. Our receiver used only four transistors and four diodes. An internal 9 volt battery provided the needed power. Yet the receiver was capable of detecting sub microvolt CW and SSB signals while suffering none of the familiar difficulties of earlier *simple* receivers. It even held it's own in a strong signal environment.



DC RECEIVER FROM 1968 PAPER.

Dick and I appreciated that we had **not** invented this method. That was implicit in the title of our paper. Direct conversion of a signal to audio had recently been done by White.(see ref 1) Some pre WW2 TRF receivers had used the method. What we saw was a way to do it with transistors and diodes in a very simple, hence practical implementation. We felt that this was an idea that was just waiting to be born anew and we wanted to be part of it

My Deception — A confession:

I remained skeptical, afraid that a submitted article would be rejected if it didn't incorporate the features suggested by Grammer. Still, we did not want to present a receiver that was loaded with bands and modes, for that would obscure the simplicity offered by the method. A possible, albeit devious solution then came to mind: The paper would need photographs. I didn't have time to get them taken, for my family and I were in the middle of a move from Washington to Oregon where I would take a job with Tektronix. My devious thought was to send the receiver itself to ARRL *so they could take the photographs*. They would then have the box in their hands and would hopefully listen to it. I sent the receiver, the manuscript, and a cover letter that said I didn't yet have a return address, which was true. They were stuck with the receiver. This happened in June of 1968.

Once settled in Oregon, I sent a note to ARRL with my new address. A terse return note from Grammer said that the paper had been accepted and that the photography and editorial chores would be done by a relatively new guy on their staff, Doug DeMaw, W1CER (later W1FB.) Nothing was said about a publication date.

In 1968, the normal time lag for publishing a QST article was a year or more, so I was quite surprised to see our paper appear in print by November, a mere five months after submission. A further surprise followed in April, 1969, when a DeMaw QST article appeared with the title "Some Notes on Solid-State Product Detectors" where Doug evaluated other detectors that might work for DC receivers. Another DeMaw paper followed in May 1969 QST describing a complete DC receiver. W1DAX (from MIT) presented an **outstanding** but now largely forgotten phasing version in QST for September, 1969. Clearly some of the technical folks at ARRL were also enthused by direct conversion.

What Really Happened

Dick and I knew that keeping things simple had worked at ARRL. My deception to place a receiver in their hands to be heard and tested had worked. But this was all inference; we had no direct details about what had actually happened at Newington.

DeMaw and I started regular correspondence in April of 1969 after his product detector paper appeared in QST. I finally met him in person a few years later and we spent some time comparing notes. It was then that I heard the full story of their introduction to direct conversion.

First, Grammer was very unhappy with my decision to ship the receiver to them. The photography was an extra, resented chore for them, even though they were set up with a photo room just for such things. Further, the receiver had none of the features that Grammer had specified. It was "too simple and couldn't possibly work". He was on the verge of rejecting the paper and sending it back, but decided to dump it in DeMaw's lap to let him see if the receiver actually worked. Expecting little, Doug took the receiver into the lab and attached an antenna. There was a faint hiss in the phones, but nothing more. He peaked the antenna trimmer, producing an increase in noise output. Hmmm, a good sign. Doug started turning the main frequency control and found a CW signal. But it was not at all the sound that he expected. The signal was clean. Peaking the antenna trimmer changed the amplitude, but nothing more. There was no interaction between controls. When another CW signal appeared in the passband, both could be copied. Tuning was smooth, almost textbook in character. This was the epiphany, the moment when Doug realized that solid-state technology had produce a new way to build a simple receiver. Doug tuned the receiver higher in the band and found some SSB. Again it was like nothing he had ever heard. It was as if the voice came from the same room. Doug used the term ***presence*** in his description.

Doug was now excited. He had thought he was going to hear something like a casual regenerative receiver, complete with the usual pops, plops, and squawks. But our little *toy* sounded "like a real receiver." He went back into the office area to find some of the other Headquarters staff, especially the contesters. He told me there was a steady stream of listeners and that by day's end, all interested folks in the building had heard it. The common comment was an exciting "you hear both sides of a signal, but it otherwise sounds as good as my home S-Line." There was another surprising observation—the receiver still functioned when W1AW came on the air with code practice. It was not perfect, but it survived. Many superhets that were tested for product reviews totally failed this test. (Dynamic range testing didn't start at ARRL until 1975 or 1976.)

A Half Century Later

Direct conversion soon became a staple for the experimenters and builders within amateur radio. Many hams built simple receivers like ours. Doug's designs with CA-3028 front end detectors were also popular.

Commercial direct conversion receivers and CW transceivers also appeared. The first of these was from Ten-Tec, a new company from Tennessee. Their PM-1 advertisements appeared in September of 1969, suggesting that they may have had working prototypes at about the same time that we did. Heath came out with the HW-7 in January, 1973. Both the PM-1 and the HW-7 used unbalanced dual gate MOSFET detectors. A few years later, Heath introduced their HW-8, which now used a MC-1496 balanced detector.

There are certainly things we could have done better in our 1968 design and in the paper. The diode ring could be terminated better for lower distortion. The paper could have done more to explain the function of detector balance. Some of our construction recommendations were redundant or just wrong. For example, cheap switching diodes would have been fine in the detector. Almost any bipolar transistor would have worked in the audio chain. These details were all resolved over time.

Hams in the QRP community were busy through the 1970s in building and using direct conversion. Dozens of DC receiver articles were published and literally thousands of such receivers were built. Some workers have done elegant work in improving the ideas. The premier example is W7EL's Optimized QRP Transceiver in QST for August, 1980. Diode ring mixers remain popular, but most in use today are modules from MiniCircuits containing the four diodes and two transformers. Many direct conversion receivers have been built using other balanced detectors, such as the NE602 or MC1496, and unbalanced circuits such as the dual gate MOSFET. The circuits using diode rings continue to offer the better performance.

Hams have taken the concept even further by using phasing methods, which yield a single sideband response. This produces a "single signal" when listening to CW. A variety of other detectors have appeared. Some using integrated circuit MOSFET switches have yielded good performance with a quadrature sampling detector. Both analog and digital methods have been used to do the related audio processing. One manufacturer, Elecraft, has produced some very high performance CW and SSB transceivers based upon this work, but in the final analysis, it's still a variation of direct conversion.

The DC scheme has moved beyond the amateur radio world. Several integrated circuit makers produce custom chips that include direct conversion. Mixers at an IF of several hundred MHz produce a baseband output. On-chip phasing is common. The typical application is a cell phone. These circuits are sometimes described in the journals of the microwave engineering community. More often, they are proprietary designs. We may use the phones daily, but know nothing of the inner workings.

Appendix (Added on March 22, 2019)

A few folks have, by now, seen the posting that I put on my web site in late 2018. Some of them thought that it might be fun to duplicate the original circuit, just to see how it would sound. But there were problems, for there is little information available about some of the parts that are years out of date. This is especially true for the semiconductors.

The three audio transistors, RCA 40233 in the original design, are extremely rare. But that does not matter, for almost any small signal NPN will work well in this application. The 2N3904 is a good choice. The earliest versions of this amplifier that I built used 2N696 power parts, the same things used in some QRP transmitters.

The oscillator used a MPF-102 JFET. I was curious what was in the original receiver, for the MPF-102 is known to have widely ranging parameters. So I opened the original receiver and extracted the FET to measure the parameters. It turned out to be a very middle of the road part with a pinch off voltage of 3.02 volts and an Idss of 8.2 mA. Almost any common N channel JFET should work here, ranging from the 2N4416 to the J310. The J310 is still available at this writing from Mouser in a TO-92 leaded package, but it a bit expensive. It is much more affordable in SMT. Adding the usual biasing diode from gate to ground is recommended.

It is important to keep the VFO in it's own shielded box. Without this isolation, antenna signals may find their way to the oscillator where subtle problems may occur.

The hot carrier diodes used in the product detector are specials that are probably no longer available. A good substitute would be the 1N5711, which is inexpensive and still available as a leaded part from Mouser. There are many interesting diodes available in SMT form.

High impedance headphones were common in 1968, but are now rare, having been replaced by low impedance elements. A transformer will be needed between the audio output and these low impedance phones. We used to get these transformers at Radio Shack. Junk box parts from portable BC receivers are one common source. Also, Mouser lists many transformers. The Xicon 42TL003-RC steps from 1.2K down to 8 Ohms and should do the job. I've not tried this part.

Another unusual element is the 88 mH toroid used in the audio low pass filter at the detector output. A viable substitute would be a 100 mH inductor with radial leads. The muRata 19R107C (from Mouser) should work. Bourns also offers a variety of similar parts.