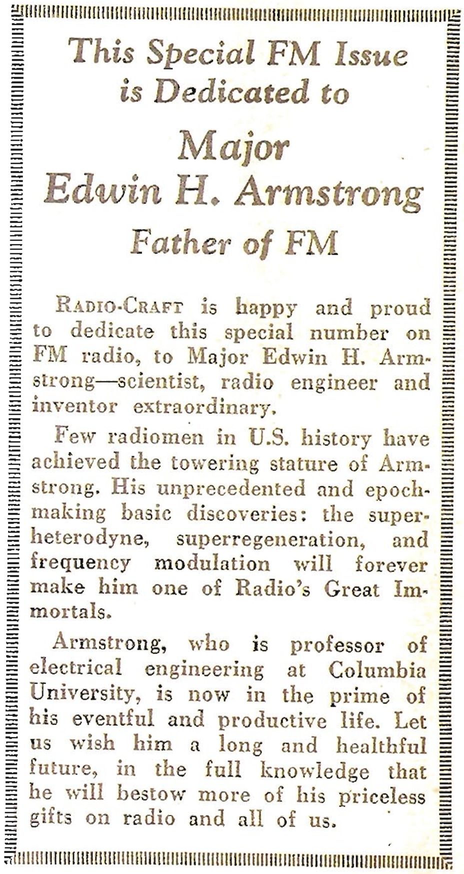
# FM Broadcasting in 1948 by Stef Niewiadomski

In the winter 2009 issue of The Bulletin I described the life, inventions and tragic death in 1954 of Edwin Howard Armstrong, affectionately known as Major Armstrong, retaining his rank title from his service in the Great War. He is credited with the invention of five highly significant improvements to radio technology (regeneration, the continuous wave oscillator, the superhet, super-regeneration and FM broadcasting), which we still benefit from today, and will continue to for many years to come. The breadth of his work in the field of radio resulted in a total of 42 patents.


Figure 1: Front cover of the June 1948 issue of Radio Craft magazine, showing a distinguished looking Major Edwin H Armstrong – The Father of FM - superimposed on a picture of a transmitter antenna mast.



*This Special FM Issue is Dedicated to*

*Major Edwin H. Armstrong*

*Father of FM*

RADIO-CRAFT is happy and proud to dedicate this special number on FM radio, to Major Edwin H. Armstrong—scientist, radio engineer and inventor extraordinary.

Few radiomen in U.S. history have achieved the towering stature of Armstrong. His unprecedented and epoch-making basic discoveries: the superheterodyne, superregeneration, and frequency modulation will forever make him one of Radio's Great Immortals.

Armstrong, who is professor of electrical engineering at Columbia University, is now in the prime of his eventful and productive life. Let us wish him a long and healthful future, in the full knowledge that he will bestow more of his priceless gifts on radio and all of us.

Figure 2: The editor Hugo Gernsback's introduction to the issue, being very complimentary to Armstrong.

In June 1948 Radio Craft magazine, edited by the famous Hugo Gernsback, dedicated a special issue to Armstrong and the state of FM broadcasting in the United States (see Figure 1). I think this is relevant to how FM broadcasting was developing in some parts of Europe at the time, the UK excepted where the introduction of any FM radio services seemed to have a low priority with the BBC and the government.

Gernsback's introduction to the issue was very complimentary to Armstrong, see Figure 2. The precise reason for the dedication of a whole issue of the magazine to Armstrong and FM at that time is unclear, but with the 463 FM broadcasting stations actually in operation in the US, the 564 authorised by the FCC but not quite yet in operation, and 88 broadcasting applications still pending, the total number of potential FM stations had recently exceeded the 1,000 mark. A remarkable number considering that the total number of FM stations at that time in the UK, planned and operating, was precisely zero!

I've tended to use MHz, rather than Mc/s, and kHz, rather than kc/s in the article, though the latter terminology would have been used at the time. The only exception to this is where I am directly quoting contemporary sources.

### FM Broadcasting Begins

During the 1930s there were a small number of experimental stations attempting to broadcast high fidelity audio using wide-bandwidth AM on VHF frequencies. FM broadcasting in the US officially started in 1939 when the FCC allocated the frequency range of 42-50MHz to this service. In that year W1XOJ, located on Asnebumskit Hill in Massachusetts (still a popular location for radio antennas, being well elevated at about 1,400 feet above the surrounding countryside), became the first FM radio station, transmitting to the Boston area with an initial power of about 2kW on 43MHz. It later upgraded to 50kW when a suitable transmitter design became available.

See: http://jeff560.tripod.com/fm2.html for an article which appeared in *Broadcasting* on 1st June 1939 announcing the start of this service. Business executive John Shepard 3rd was the owner and operator of W1XOJ: he believed in and supported Armstrong's work, and recognised a profitable investment when he saw one. Interestingly the programs were transmitted from the Yankee Network studios in Boston to the W1XOJ transmitter site by an FM relay link, designed by Armstrong of course, transmitting on 133.030MHz with a power of 250 watts. General Electric and Stromberg-Carlson built the first radios capable of receiving FM on the 42-50MHz band.

To help 'kick start' broadcasting Armstrong created his own FM station, W2XMN, in Alpine, New Jersey in 1940.

To everyone's surprise applications for FM licenses poured in and the network built up quickly, prompting more and more manufacturers to add the FM band to their sets, and paying Armstrong royalties for the privilege. On 1st March 1941 W47NV began operations in Nashville, Tennessee, becoming the first modern commercial FM radio station, broadcasting on 44.7MHz with 20kW of power. Note that the '47' in the station's call sign indicated the last two digits of its frequency allocation, the leading '4' being assumed.

When the US entered the war in December 1941 production of commercial radio equipment was suspended, which meant a dead stop to the development of FM broadcasting. Existing FM stations, including Armstrong's own W2XMN continued to broadcast, but no new stations or new FM receivers were built throughout the war years. Armstrong dedicated his work during the war to the application of FM to military radios, where it was adopted with great success.

On 27th June 1945 the FCC officially moved FM broadcasting in the US to the frequency range of 88-108MHz, where it still is today. The change in frequency was said to be to avoid possible interference problems between stations in nearby cities and to accommodate more FM radio channels. However, the FCC was influenced by RCA chairman David Sarnoff, who, it is often said, had the covert goal of disrupting the successful FM network that Armstrong had established on the 'old' band by displacing the FM stations with band I TV stations. The move in frequency rendered some half a million FM receivers obsolete overnight, and more significantly caused great disruption and cost impact on the FM stations already broadcasting. Whether this is true or not is unclear, and some sources report that Armstrong himself was in agreement with the change in frequency, seeing the greater potential for more FM broadcasting channels. This frequency band, plus-or-minus a few MHz, pretty much became the FM broadcast band throughout the world.

**Armstrong in 1948**

The cover picture shows a serious looking and distinguished man. In the magazine he looked back at the state of radio broadcasting (all AM or course) in 1922, and as it stood in 1948, looking forward to the era of FM broadcasting. Throughout his life he was always suspicious of mathematicians who 'proved' that certain engineering possibilities had no merit. For example he quoted the 1922 commonly-held view of FM:

'... this method of modulation (frequency modulation) inherently distorts without any compensating advantages whatsoever'. This view was probably based on the analysis of the sidebands inherent to an FM signal. In theory FM sidebands stretch out to infinity on either side of the carrier, and although not all these are necessary to maintain a very good quality demodulated signal, certainly many more are needed than the two required for AM. Presumably the mathematicians had analysed the effect of restricting the number of sidebands, maybe to two, which would have resulted in their conclusion. It was Armstrong who made the leap in understanding by realising that 'all' you had to do was to broadcast a much wider bandwidth FM signal to get the benefits that the scheme promised. There were many implications in transmitting a signal with much wider bandwidth, not least of all that the medium wave band was inherently unsuitable for this.

By 1948 Armstrong had been proved right: FM broadcasting had been proved to be possible and it gave the benefits he had predicted. All the changes needed in the move from AM had been made, at considerable financial and personal cost to Armstrong himself. Transmissions were on VHF, giving the necessary bandwidth, and the infrastructure of transmitters was building at considerable pace. However Armstrong's basic FM patents had only two more years to run. Since 1933 he had taken on himself all the technical and commercial risks of getting FM adopted as a high quality radio service. 1948 is significant because just one month after the publication of this special edition of Radio Craft Armstrong's lawyers began law suits against RCA and NBC for 'wilful infringement, and inducing others to infringe' Armstrong's basic FM patents. Armstrong stood to win damages on all FM radio and TV (TV sound used FM) equipment manufactured by RCA, and its licensees, during the full term of the patents, a vast sum of money by any estimates. The debilitating long term effects of the law suits resulted in his tragic death in 1954.

Figure 3 shows Armstrong revisiting the house in 1032 Warburton Avenue, Yonkers where he grew up, and browsing in the attic room where he performed most of his early pioneering radio experiments as a young man. Close examination of the picture shows that the room has plaster hanging off the walls and littering the floor, and maybe we should assume that the whole house was in similar condition? You can 'fly over' Warburton Avenue on Google Earth and get an impression of the area, bearing in mind that although Yonkers is only a few miles from Manhattan the area was more rural in Armstrong's youth. Sadly 'number 1032' is no more, and is unusual for having achieved listing

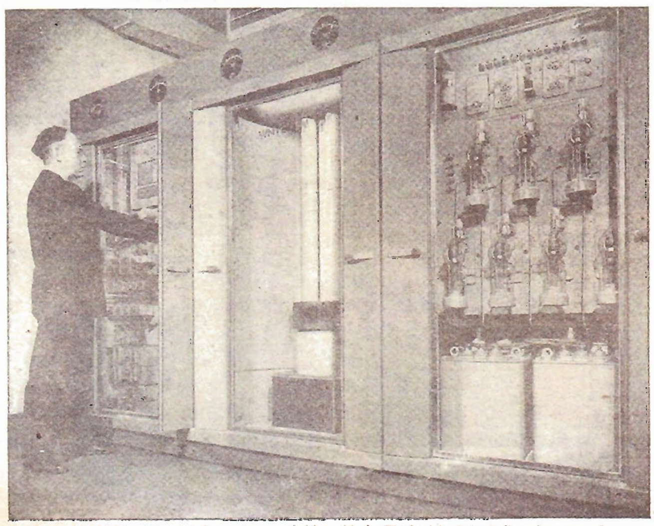
Figure 3: Armstrong revisiting and browsing in the attic room of the house in 1032 Warburton Avenue, Yonkers where he grew up and performed most of his early pioneering experiments as a young man.

*Courtesy of Fortune Magazine; photo by Eric Schaal*

Armstrong revisits the Yonkers room, scene of his early work.

Figure 4: The 10kW FM transmitter of New York City's Municipal Broadcasting station, WNYC-FM.

A MODERN HIGH-POWER FM TRANSMITTER



William H. Pitkin, the chief engineer of New York City's Municipal Broadcasting System, makes an adjustment on Station WNYC-FM's new Western Electric 10-kilowatt transmitter.

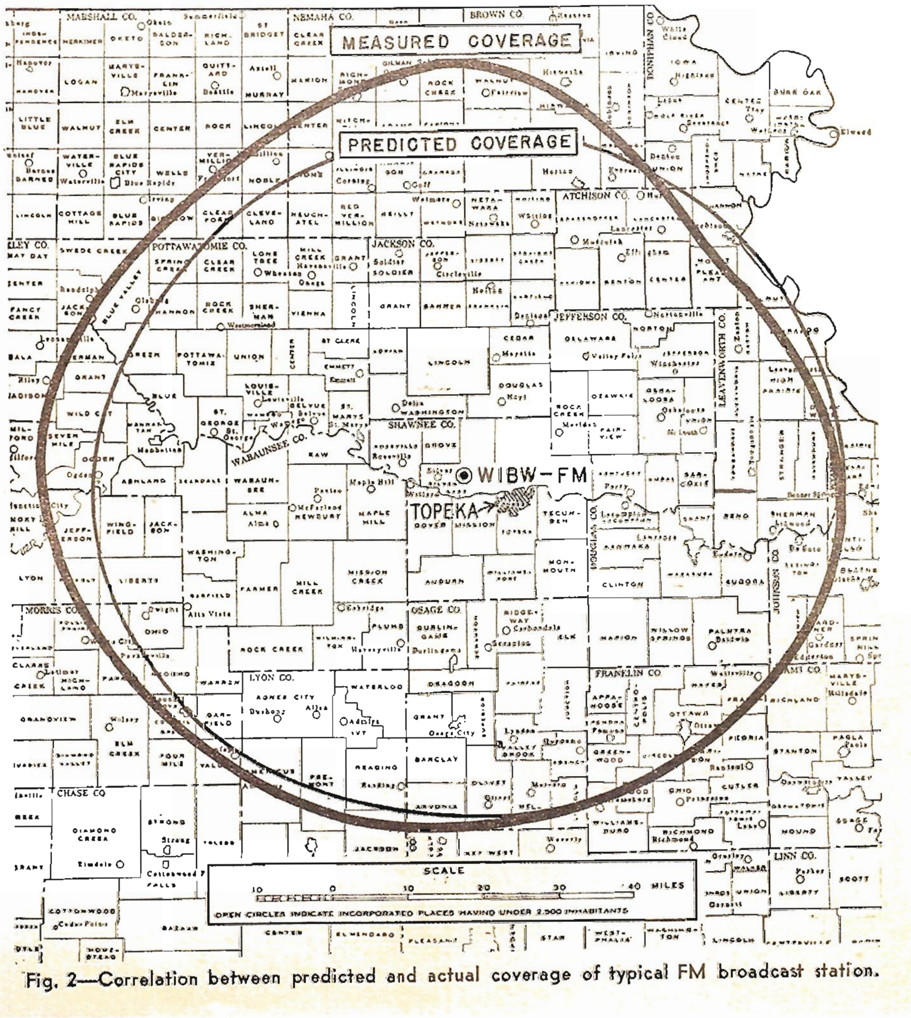



Figure 5

Figure 5: Map of the predicted coverage area in 1948 of one FM station, namely W1BW-FM, in Topeka, Kansas, with the actual coverage obtained. Good correlation between predicted and actual was obtained which helped validate the coverage prediction model used by the FCC.

Figure 6: In anticipation of receivers needing repairing and aligning there was already much suitable test equipment available. McMurdo Silver combined FM and TV servicing gear.

Figure 7: The Heath Company's 5 inch 'scope, using 'surplus tubes', and available only as a kit of course.


Figure 7


Figure 6

on the National Register of Historic Places and even designation as a National Historic Landmark, only to be demolished. Its subsequent removal from National Historic Landmark status is the only such occurrence for a New York State site. It was designated a National Historic Landmark in January 1976, but was demolished in 1983 after suffering fire damage. It was subsequently de-designated as a National Historic Landmark and delisted from the National Register of Historic Places in 1986. The site is now occupied by a block of apartments.

Philosophy Hall, the Columbia University building where Armstrong developed FM, was declared a National Historic Landmark in 2003 in recognition of that fact. See: http://en.wikipedia.org/wiki/Philosophy_Hall for more information on the history of the location.

**Quality of FM Broadcasting**

Armstrong had envisioned two drivers for the move to FM broadcasting. Firstly, freedom from interference, and secondly, improved bandwidth so that the quality of the transmitted audio could be greatly improved over that achievable with AM broadcasts.

The FM modulation technique, or perhaps it's more exact to say that the demodulation technique, gave the promise of freedom of interference from man-made and natural noise. This type of noise is essentially random amplitude pulses which an AM receiver finds impossible to distinguish from the desired amplitude-modulated signal. An FM signal could be amplified and 'limited' (see later for more detail on this) whereby any amplitude variations caused by noise were eliminated and did not appear on the demodulated audio output.

Another drawback of AM broadcasting on the medium wave band that became apparent as soon as the density of stations had reached a certain point was another form of interference. At night medium wave signals travel much further than in the day time as they propagate by sky wave, rather than by ground wave. This caused unwanted distant stations to be super-imposed on the ground wave reception from local stations. Of course this effect is still with us today. This contrasts with the distance VHF signals travel which is roughly the same by day or night. Interference

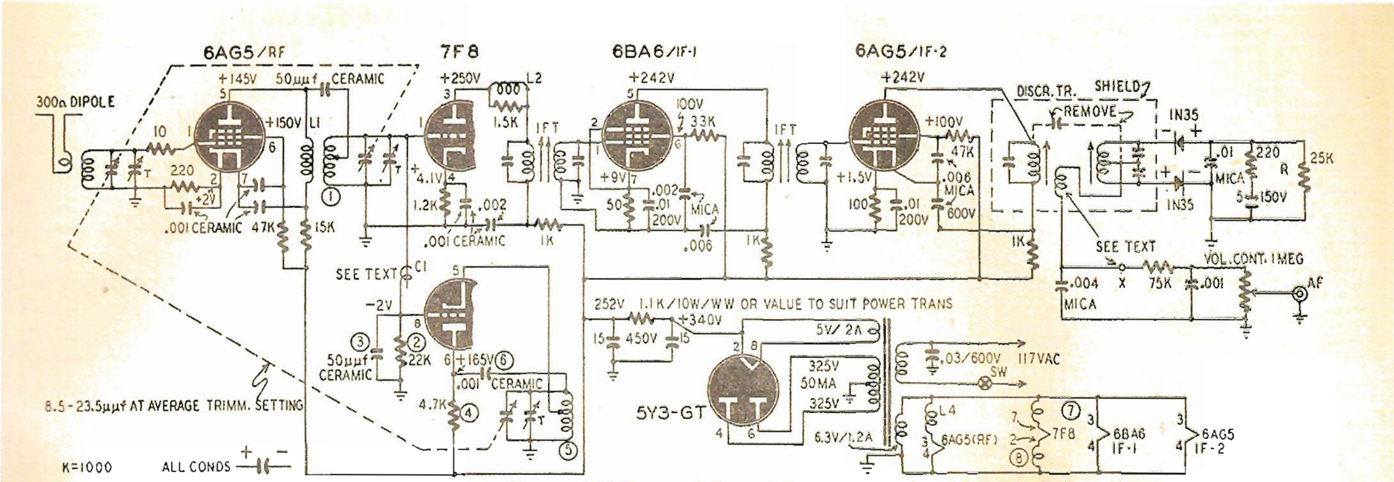



Fig. 1—The schematic. The IN35 crystal is actually two IN34's, carefully matched for equal output. Circled numbers refer to Fig. 2.

Figure 8: Schematic of the receiver described in 'Simplified FM Receiver Uses Crystal Detector'. Rather than use a valve-based pair of diodes the design used a pair of 1N34 germanium diodes (introduced by Sylvania in 1946), or more exactly a 1N35 'dual germanium crystal unit'– a matched pair of 1N34s in a single case.

from other FM stations is much less than with AM because the desired FM signal needs to be only twice as strong as the interfering signal to blanket it entirely. A desired AM signal must be approximately 100 times stronger than an interfering signal for the interference to be unnoticeable.

The available bandwidth at the VHF frequencies used for FM broadcasting meant that high quality broadcasts (for which the FCC set the standard that a station was supposed to achieve) could be made, far in advance of those achievable on 'good old' AM on the medium and long wave bands. It's interesting to read therefore in Gernsback's editorial to the issue that there was 'an unmistakable trend towards a solid duplication of those broadcast by the AM stations ... even though this means sacrificing high-fidelity transmission to ordinary network standards (100-5,000 cycles)'.

Using a process known as multiplexing the wider bandwidth enables the FM broadcaster to send more than one signal over a given FM channel: specifically it held the promise of stereo broadcasting. See later for how and when this was introduced.

**Transmitter Stability and Modulation**

Maintaining frequency stability while transmitting at 100MHz brought its own challenges. One method used was to pass a sample of the transmitter's output frequency through a chain of dividers until a frequency of about 5kHz was obtained. A temperature-controlled crystal oscillator was used as a frequency standard, and its output was also passed through a divider chain whose output frequency was nominally identical to that from the first chain of dividers. The outputs of the two dividers were then applied to balanced modulators whose outputs were 90° out of phase. Each output was then amplified and applied to separate windings of a two-phase inductor motor whose shaft was connected to a frequency compensating capacitor in the tank circuit of the transmitter's modulated oscillator. Any difference between the centre frequency of the modulated signal and the crystal standard produced a beat frequency whose direction of drift operated the motor to adjust the compensating circuit. This sounds very much like a frequency-locked loop (whether the system could achieve phase locking is uncertain) with a mechanical element rather that an all electronic system, probably using a variable-capacitance diode, which we would tend to use today.

Two basic systems were then in use for producing FM at the transmitter: the indirect, or Armstrong method, and the direct method. The indirect system consisted of a crystal-controlled oscillator whose output was split into two paths, one of which was fed through a 90° phase-shifting network, and the other contained a balanced modulator. When these two paths were combined the result was a phase-modulated signal, linear up to ±30°. The frequency deviation was very small. The necessary 150kHz swing was obtained by multiplying the oscillator output to a high frequency, which was then reduced in frequency by heterodyning it with the output of a second crystal oscillator. It was then put through another series of multipliers to raise it to the final frequency. This system allowed a higher order of frequency swing than if simple frequency multiplication had been used.

In the simpler direct method of frequency modulation a reactance valve controlled the master oscillator, which usually operated at one-sixteenth of the output frequency. The oscillator output was fed through multiplier and buffer stages to the transmitter's final power amplifier. A key feature of FM, whatever the exact modulation method used, is that the modulation is applied to the low power stages of the transmitter, which is not the case with AM where the final stages need to be modulated with considerable audio power.

Figure 4 shows the 10kW FM transmitter of New York City's Municipal Broadcasting station, WNYC-FM, in use in 1948.

**Planning the New FM Network**

It was the FCC's responsibility to allocate frequencies and set the effective radiated power (ERP) of FM stations in the 88-108MHz band. Two types of station were envisioned: 'class A' stations, designed to serve small communities and towns, other than the main city of an area and its surrounding rural area. These stations were limited to an ERP of 1kW and an antenna height of 250 feet above the average surrounding terrain. The second type were 'class B' stations, intended to provide service to a metropolitan district or principal city, and its surrounding rural area. The ERP permitted by the class B stations depended on where they were located in the US. Area I was pretty much defined as the Eastern seaboard, including all its major cities of course, and Area II was the rest of the country. Area I class B stations were limited to ERPs of between 10kW and 20kW, depending on the height of their antenna. Area II class B stations were limited to a minimum ERP of 2kW, with no limit on the maximum ERP provided that a new station did not interfere with existing stations. This allowed these stations to serve large sprawling areas, and it was not untypical for them to use ERPs of 450kW or more.

This may sound like a complicated scheme but it should be remembered that FM broadcasting at VHF was in its infancy, and the scheme was conceived to ensure that cities were assigned FM channels on a population basis. That is, the larger the population, then the more channels allocated, and that a balance between large scale and local needs could be achieved. The nature of propagation at 100MHz or so meant that no changes had to be made between day and night. In the New York area the scheme resulted in 20 class B and 13 class A channels being allocated, giving a total of 33 FM stations to serve both broad and local interests. According to http://www.nyradioguide.com/freqlist.htm there are now 44 FM stations in the New York area (most of which can now be listened to on-line), so the original FCC estimate wasn't too far away from what its original propagation estimates and demand for station types predicted. One development not predicted was the appearance of low power (100W


Figure 9 (above): Front view of the 1947 Pilotuner T-601, typical of an FM-only tuner capable of being plugged into the 'gram' input of an existing AM radio.

Figure 10 (right): Table of the more popular FM Tuners available in the US in 1948.

CHARACTERISTICS OF THE MORE POPULAR FM TUNERS

| TUNER AND MODEL | LINE OPERATION | NO. TUBES | R.F. | MIXER | I.F. | LIMITER | DISCRIM-INATOR | OTHER FEATURES |
|---|---|---|---|---|---|---|---|---|
| Approved Electronic Inst. | a.c. 7Y4 | 6 | 6AG5 | 6J6 | 2-6SH7 | 6SH7 | 6AL5 F-S | |
| Brooks | a.c. 6X4 | 8 | 6AK5 | 6BE6 | 3-6AK5 | 2-9001 | 6AL5 F-S | 6U5 tuning indicator |
| Browning RJ-12 | external pack | 8 | 6BA6 | 6BE6 6C4 | 2-7AG7 | 2-6SJ7 | 6H6 F-S | separate AM channel |
| Browning RV-10 | a.c. 80 | 7 | 6AU6 | 7F8 | 2-6AU6 | 2-6SJ7 | 6H6 F-S | 6U5 tuning indicator |
| Collins Audio Products | a.c. 6X4 | 9 | 6J6 | 6AK5 6C4 | 3-6AG5 | 2-9001 | 6AL5 | 6AL7 indicator |
| Collins Audio Products FM-AM Tuner | a.c. 5Y3/GT | 9 | 6J6 | 6AG5 6C4 | 1-6AK5 2-6AG5 | 2-9001 | 6AL5 | V-R tube, audio channel 6AL7 indicator |
| De Wald | a.c.-d.c. 35W4 | 5 | none | 12AT7 | 2-12BA6 | none | 12AL5 F-S | 12SA7 oscillator |
| Dongene | a.c. 5Y3 | 8 | 6BA6 | 6BE6 6C4 | 2-6SG7 | 2-6SJ7 | 6H6 F-S | separate AM channel |
| Edwards Fidelotuner | a.c.-d.c. selen. | 5 | none | 6J6 | 2-6SH7 | 6SH7 | 6H6 F-S | long-lines tuner ckt. |
| Espey 512 | a.c. 5Y3-GT | 6 | 6BA6 | 6BE6 6C4 | 2-6SG7 | none | 6AL5 ratio | also AM tuner 6U5 indicator |
| Meissner 8C | a.c. 6X5-GT | 7 | none | 2-6AG5 6C4 | 2-6BA6 | none | 6AL5 ratio | |
| Meissner 9-1093 | external pack | 9 | none | 2-6AG5 6C4 | 3-6AG5 | 2-9001 | 6AL5 F-S | AM channel, 6U5 indicator separate |
| Pilotuner | a.c. selen. | 5 | 6BA6 | 6BE6 | 2-6BA6 | none | 6AL5 ratio | |

JUNE, 1948

or less) FM stations designed to serve very local, usually ethnic, communities, either legally or illegally. Incidentally there are still 28 medium wave AM stations serving the New York area, so the prediction that FM broadcasting would quickly kill off AM was wildly optimistic.

Figure 5 shows a map of the predicted coverage area in 1948 of one FM station, namely W1BW-FM, in Topeka, Kansas, with the actual coverage obtained. Good correlation between predicted and actual was obtained which helped validate the coverage prediction model used by the FCC. It has to be said that Topeka is a relatively flat area and propagation in hillier cities must have been more complex, with corresponding impact on the placement and coverage of FM stations. According to Wikipedia W1BW-FM still operates, with a country music flavour. A total of seven FM stations now broadcast in the city.

**FM Receiver Servicing and Test Gear**

FM receivers operating at VHF brought new challenges to servicemen used to repairing and aligning medium and long wave AM radios. There was of course the need to generate FM-modulated signals at 100MHz+ for the testing of front ends, and a way of aligning IF stages, operating at 10.7MHz, which was by 1948 the standard for IF transformers and amplifiers in FM radios. With AM sets the IF stages could be aligned 'by ear' but the wider bandwidth of an FM signal meant that more scientific means had to be found to ensure that the IF bandwidth was set correctly for a flat response, otherwise the high fidelity benefit of the transmitted signal would not be reproduced at the output of the receiver. TV broadcasting was being extensively rolled out at the same time and so any service department with an eye to the future was also gaining the skills and test gear to handle TV set repairs. TV sound was broadcast as FM and the skills gained on FM receivers were definitely transferable to TV sets.

The magazine advised service departments to invest in the following test gear: 'a sweep signal generator with frequency ranges from 5-15Mc/s and 80-110Mc/s; a vacuum-tube voltmeter (VTVM); an AM signal generator with a frequency range from 5-125Mc/s; and an oscilloscope'. As they stated, it was possible to repair FM radios with just the VTVM and the AM signal generator, but testing time would be greatly increased and that would cost the service department money. By setting the FM sweep generator to sweep 300kHz above and below the IF centre frequency and monitoring the output of the discriminator with the 'scope, ideally an S-curve with a straight line in the IF pass-band should be obtained. Deviation away from the ideal S-curve generally indicated mis-alignment of the IF transformers which could be tweaked until the curve was satisfactory.

In anticipation of receivers needing repairing and aligning there was already much suitable test gear available. McMurdo Silver combined FM and TV servicing gear, as shown in Figure 6. The fledgling Heath Company (based in Benton Harbour, Michigan) offered a range of test gear kits, including a 5 inch 'scope, VTVM and signal generators, but surprisingly didn't offer a sweep generator. The 'scope (which I think is an O-1, though there is no part number on the advert, see Figure 7) sold for just under $40. At the 1948 exchange rate of $4.03 to the £1 (set at this constant level from May 1940 to September 1949, when it was abruptly devalued to $2.80), this equated to the equivalent of about £10. This was a significant period for Heath as they had only just entered the electronic kit business, having focused on small aircraft accessories before the war. Howard Anthony, the owner of the company, had bought a large stock of war surplus electronic parts, and these were largely what constituted the immediate post-war kits. As you can see the advert for the scope stated 'order today while surplus tubes make this price possible'. This referred mainly to the CRT which is the most expensive part of any 'scope. The kit was a huge success for the company, and as they say 'the rest is history' as the company benefitted from the boom in radio and electronics from the end of the war until the 1970s. The company finally left the electronic kit business in 1992.

This claim and counter-claim between Armstrong and RCA, not just on the nature of the FM discriminator but on all aspects of FM broadcasting, lasted from 1948 until 1954, when it was a significant contributor to Armstrong's suicide.

**FM Discriminators**

In FM receivers the general term used for the equivalent of the detector process in an AM set is an 'FM discriminator'. Armstrong's original concept for an FM discriminator had two distinct stages for the process: firstly a limiter stage where the output from the final IF amplifier stage was greatly amplified and clipped so that any amplitude variations in the received signal were removed, and secondly the discriminator stage, often called the ratio detector, where the limited FM signal was turned back into the original modulating audio. This arrangement needed at least one extra valve in the receiver and so tended to be used in more expensive sets.

Armstrong had developed this concept as the solution to impulse-type noise interference that plagued AM sets. In the 1920s and 1930s the elimination of this type of noise, at a reasonable cost, had been the 'holy grail' of radio designers. This had never been achieved with AM broadcasts. Armstrong's 'back to basics' solution was to change the modulation method from AM to FM, with all the consequences that entailed, including new transmitters, new receivers, a move to VHF, and so on – effectively the creation of a new radio industry.

The other form of FM discriminator used at the time was the Foster-Seeley discriminator, invented in 1936 by Dudley E Foster and Stuart William Seeley. The circuit was envisioned for automatic frequency control of receivers, but also found application in demodulating FM signals. This form of discriminator has no distinct limiter stage and is therefore sensitive to both frequency and amplitude variations, unlike the limiter / ratio detector combination, which from Armstrong's point of view negated one of the major advantages of FM broadcasting. The lack of a limiter stage made any receiver incorporating it cheaper, to the delight of radio manufacturers. It is debatable whether this resulted in any significant degradation of the demodulated audio (as Armstrong argued), especially since most FM reception was more local to the transmitters than with AM, and therefore probably in much stronger signal areas.

The Foster-Seeley discriminator has implications beyond its technical merits (or de-merits) in that Foster and Seeley were working at RCA in 1936 when they invented it. RCA's lawyers saw in it a way of avoiding paying royalties to Armstrong as they claimed that it was fundamentally different from Armstrong's form of FM discriminator on which he held patents. Eventually Armstrong established that the Foster-Seeley discriminator contained an inherent limiting function and was therefore not significantly different from his discriminator design, but that it was definitely inferior in performance in the presence of interference. This claim and counter-claim between Armstrong and RCA, not just on the nature of the FM discriminator but on all aspects of FM broadcasting, lasted from 1948 until 1954, when it was a significant contributor to Armstrong's suicide.

Whichever form of discriminator was used a pair of diodes (in 1948 a 6AL5 dual-diode valve was popular for this function) was needed to produce the final audio. An interesting design, and definitely the shape of things to come, was published in the magazine as 'Simplified FM Receiver Uses Crystal Detector'. Rather than use a valve-based pair of diodes the design used a pair of 1N34 germanium diodes (introduced by Sylvania in 1946), or more exactly a 1N35 'dual germanium crystal unit'- a matched pair of 1N34s in a single case. The circuit of this receiver is shown in Figure 8.

**Use of War Surplus Radios**

As was the case in the UK for many years after the war there was much war surplus electronic equipment around in the US that was suitable for conversion to amateur and broadcast radios. One such piece of equipment was the BC-624, designed for use as a 4-channel crystal-controlled single conversion receiver in the 100-156MHz range, and which was often used by amateurs as an AM receiver on the 2m band. An article in this issue of Radio Craft described its conversion to an FM receiver.

The RF amplifier and mixer made use of 9003 valves, which had been designed in 1943 by RCA as a B7G equivalent of the 956 VHF acorn pentode. The oscillator was converted to be free-running using a 9002, again a B7G valve, equivalent to the 955 acorn triode. The oscillator's frequency determining components consisted of a variable capacitor (with a slow motion mechanism), and trimmers and padders were chosen to give the limited tuning coverage of 88-108MHz.

To make use of as much of the set as possible the original IF transformers were retained, even though their AM bandwidth was too narrow for broadcast FM reception, where the bandwidth needed to be 200-300kHz. For the modified circuit only one winding of each transformer was used in the anode circuit, with capacitor coupling to the grid of the next stage. A relatively low value for the grid leak resistor was used to load the coils and broaden their response. By stagger tuning the transformers the desired wide bandwidth could be achieved.

The trickiest part of the conversion was the winding of the 12MHz (which was the IF of the BC-624) discriminator transformer to replace the original 4th IF transformer. This needed three windings, including a bifilar secondary to drive the discriminator diodes (using a 12H6, an Octal dual-diode). The final receiver was said to result in 'a reasonably good FM receiver. It is sufficiently sensitive to bring in stations to a distance of about 30 miles away, with only a 3- or 4-foot wire as an antenna'.

**FM-only Tuners and AM/FM Receivers**

Introduced in 1947 the Pilotuner T-601 was typical of an FM-only tuner capable of being plugged into the 'gram' input of an existing AM-only radio. Alternatively it could be connected to a stand-alone quality audio amplifier and as such marked the beginning of the hi-fi era when FM tuners and record decks were the audio sources for high quality amplifiers and loudspeakers.

Figure 9 shows a front view of the T-601. The controls are simple: an on/off switch and a tuning knob. We can see that it covers the 'new' FM band of 88-108MHz, and is therefore still usable today. The valve line-up consisted of modern B7G valves, specifically: 6BA6 RF amplifier, 6BE6 frequency changer, 6BA6 1st IF amplifier, 6BA6 2nd IF amplifier, and 6AL5 ratio detector. As I write this article I can see several Pilotuners for sale on eBay.com, so the sets seem to have lasted well and are still sought after today.

10.7MHz was by now commonly accepted as the intermediate frequency of FM sets covering the '100MHz' band. Typically sets which had covered the 'old' FM band had used an IF at 4.3MHz. In 1948 Motorola still used this frequency for some of their early 'new' FM band tuners.

It's interesting that for VHF FM tuners the IF was set to about one tenth of the RF frequency to be received. With medium wave radios there is about a 3:1 ratio between the upper and lower frequency limits, so the 'one tenth' rule of thumb would lead to an ambiguous answer as to where the IF should be placed. The IF frequency of these radios eventually 'settled down' to the range of 450-480kHz where a gap was created between the upper frequency end of the long wave and the lower end of the medium wave.

Figure 10 shows a table of the more popular FM Tuners available in the US in 1948. It's interesting that by this time modern B7G valves such as the 6AG5, 6J6, 6AL5, 6BA6, 6BE6, 9001, etc predominate, but the occasional Octal valve such as the 6SH7 still creeps in. As far as I can see the only B9A valve used is the 12AT7 in the De Wald tuner. The 12AT7 was introduced in the second half of 1947 so De Wald had done well to design it into their tuners for sale in 1948.

There were many AM/FM radio plus record deck (78rpm of course) consoles available in the US in 1948, including ones from Admiral, Crosley, Belmont, Montgomery Ward & Co, Motorola, National, Philco, RCA, Westinghouse and Zenith. The highly-collectable Zenith 7H820 was particularly interesting in that with its 7-valve line-up, it could be tuned to the 'old' Armstrong FM band of 43-48.5MHz, the 'new' FM band of 88-105MHz and the medium wave AM band. I believe this radio was only manufactured very briefly and within a year the 'old' FM band was removed, as broadcasting on this band had ceased.

As far as I can see there were no FM receivers at this time with automatic frequency control (AFC). The concept of AFC was used purely in the context of transmitter frequency stability, as described earlier. My initial thought was that these sets must have needed constant 'tweaks' of the tuning, especially as they warmed up. Then I thought that since broadcasts were in mono only for many years, if the received station drifted around in the comparatively wide IF pass band, any reasonable drift may not have been noticeable. Modern analogue FM sets use an error signal feedback mechanism from the discriminator to the local oscillator to achieve fine frequency control, as the oscillator tries to drift away from the correct frequency.

A table in the magazine shows a total of 71 FM receiver/tuner manufacturers in the US. That's an impressive total for such a new concept in broadcasting and shows that initial doubts as to its viability and longevity had by then been dispelled.

**Stereo Broadcasting**

The FM signals being broadcast in 1948 were of course in glorious mono. In the late 1950s, several systems to add stereo to FM radio were considered by the FCC. Included were systems from many set manufacturers including Crosley, Halstead, Electrical and Musical Industries Ltd (EMI), Zenith and General Electric. The individual systems were evaluated for their strengths and weaknesses during field tests in Uniontown, Pennsylvania using KDKA-FM in Pittsburgh as the originating station.

The GE and Zenith systems, so similar that they were considered theoretically identical, were formally approved by the FCC in April 1961 as the standard stereo FM broadcasting method in the US and later adopted by most other countries. It is important that stereo broadcasts should be compatible with mono receivers. For this reason, the left (L) and right (R) channels were algebraically encoded into sum (L+R) and difference (L–R) signals. The (L+R) main channel signal was transmitted as baseband audio in the range of 30Hz-15kHz. The (L–R) sub-channel signal was modulated onto a 38kHz double-sideband suppressed carrier (DSBSC) signal occupying the frequency range of 23-53kHz.

A 19kHz pilot tone, at exactly half the 38kHz sub-carrier frequency and with a precise phase relationship to it, was also generated. This was transmitted at 8–10% of overall modulation level and used by the receiver to regenerate the 38kHz sub-carrier with the correct phase. The final multiplex signal from the stereo generator contains the main channel (L+R), the pilot tone, and the sub-channel (L–R). This composite signal, along with any other sub-carriers, modulated the FM transmitter.

A mono receiver used just the (L+R) signal so the listener heard both channels in the single loudspeaker. A stereo receiver added the difference signal to the sum signal to recover the left channel, and subtracted the difference signal from the sum to recover the right channel.

On 1st June 1961 FM stereo broadcasting in the US was authorised: on this date the FCC received its first notifications of such regular operation, from WEFM Chicago and WGFM Schenectady (in New York). Both stations had previously experimented with stereo broadcasting, as had others. Apparently WGFM has the honour to be the first to broadcast in stereo, as WEFM had to wait an extra hour because of the difference in time zones.

I used the past tense for the description of how FM stereo broadcasts worked in 1961: in fact it's pretty much the same today, with the addition of other low bandwidth data, such as RDS (Radio Data System).

**Worldwide FM Broadcasting in 1954**

In the years after 1948 FM broadcasting around the world continued to develop and expand. I obtained another snapshot of the state of FM broadcasting around the world from the publication: 'Listener's Guide to the Radio and Television Stations of the World' compiled by B B Babani, picked up at a recent BVWS meeting. This was published in September 1954 by Bernards (Publishers) Ltd, London.

At this date US FM stations numbered 521 in the band from 88.7-107.7MHz, so maybe the full promise of more than 1,000 stations in 1948 had not been fully realised. Outside the US there were a total of 251 stations. In Europe there were 173 stations, of which only one (Wrotham, which in 1954 was still broadcasting an experimental service) was in the UK, indicating the slowness with which the UK adopted FM broadcasting! The leader in Europe was definitely the Federal Republic of Germany (that is, West Germany), with 113 stations. Even Italy had 13 FM stations. The USSR operated two FM stations, one in Moscow on 46.5MHz, and one in Leningrad on 45.8MHz, both on the 'old' FM band.

As a further data point it was reported by the FCC in 2004 that there were 13,476 FM stations in the US.

Official FM broadcasting began in the United Kingdom on 2nd May 1955 (though there had been test broadcasts for several years before this) when the BBC started an FM service broadcasting the Light Programme, Third Programme and Home Service to the south east of England using the sub-band 88.0–94.6MHz. UK stereo broadcasting started in 1966.

His contribution to the science fiction genre is recognised in the Hugo Awards, named after him, first awarded in 1953 and which are still awarded to outstanding science fiction writers today. He even has a crater on the Moon named after him!

**The Editor, Hugo Gernsback**

As well as being an editor and publisher, the editor of Radio Craft magazine, Hugo Gernsback, was a pioneer in amateur radio and public broadcasting. He even founded his own radio station WRNY, an AM radio station operating in New York, to promote his radio and science magazines. The station was the first to have regularly scheduled experimental television broadcasts, starting in 1928. The technique used was a mechanical scanning system, having 48 lines and 7.5 frames per second. This was about the limit that could be transmitted, without sound, on the 5kHz bandwidth of the AM radio channel. The picture at the receiver was about 1.5" square. Gernsback's magazines at the time had described how listeners/viewers to his radio station could build TV receivers for his transmissions.

The March 1937 Short Wave Craft magazine included a training course on Television entitled 'Mechanical Scanning – How It Works'. Of course by 1937, the writing was on the wall for mechanical TV, and the magazine also described positive results of CRT-scanning TV transmissions on six-metres (that is, about 50MHz) transmitted from the Empire State Building in New York City, seen at up to 70 miles away. The article also described what we understand as a modern TV distribution system, using 'concentric' cables (that is, co-ax) to carry the signals between cities to the local transmitters. A possible system for distributing TV signals via co-ax inside steel-framed buildings was also described, overcoming the absorption effect on the TV signal.

Incidentally, Gernsback is also well known for his science fiction writing and publishing, which included Amazing Stories, the first major science fiction magazine, originally published in 1926. It's fair to say that he has a mixed reputation: although he was certainly a visionary and made many predictions of the future of science and society, and sponsored the publishing of many science fiction magazines, he was also know to be a shrewd business man and didn't pay his contributing authors very well.

His contribution to the science fiction genre is recognised in the Hugo Awards, named after him, first awarded in 1953 and which are still awarded to outstanding science fiction writers today. He even has a crater on the Moon named after him! Before you start looking for it through your telescope, it's only fair to point out that it's located close to the edge of the far side of the Moon and is only rarely visible edge-on from Earth. See the Useful References section at the end of this article for a couple of books about Hugo Gernsback.

**The Short Wave Scouts**

In the pre-war period Gernsback had sponsored the creation of 'The Short Wave Scouts' who listened to the short waves and logged the stations they heard. An imposing trophy (silver-plated metal and Bakelite base, standing 22½" high), was awarded every month to the Short Wave Scout who logged the most short-wave stations as possible, amateurs excluded, in a period not exceeding 30 days. At least 50% of the stations logged had to be foreign ones.

In this 1948 issue of Radio Craft the Scouts were expanding to include 'FM Scouts'. Encouraging listeners to report cases of reception of long distance FM stations, Gernsback wrote 'The behaviour of radio waves in the FM band is still understood imperfectly. According to theory, FM signals should not reach much beyond the horizon. Yet they often do. In some cases extraordinary DX reception has been reported'.

Some reports of reception over long distances had already been received: 215 and 190 miles seem to have been the best distances so far, though the editor had to implore listeners to report the 'air-line' distance, as some had reported the road mileage to the station received! This contradicts the 'line of sight' theory of propagation of signals at 100MHz, but the nature of FM demodulation meant that these relatively weak distant signals should not have been audible over the top of local signals on the same channel.

**Tributes**

There are several tributes to Edwin Armstrong on YouTube, including a recording, entitled 'Final Broadcast of Experimental FM Station KE2XCC', of the final broadcast of his experimental FM station in Alpine, New Jersey on 6th March 1954. At that time the station transmitted on 93.1MHz, having moved from its original frequency of 42.8MHz in 1946.

Another delightful set of video clips and photos can be found on YouTube entitled 'Edwin Howard Armstrong: The Yonkers Man Who Made Radio and the Alpine Tower'. The building at the base of the tower, with 'W2XMN' carved over the doorway, is now a museum to Armstrong and the technology he made possible.

So far I've been unable to track down a recording of his voice: if you manage to do this, please let me know.

**In Conclusion**

By 1948 FM broadcasting in the US was well established, supported by the paraphernalia of transmitters, tuners, test equipment, aerials, etc, needed to support the network and its listeners. Europe still lagged behind what was happening in the US, and disappointingly the UK seems to have been in last place in Europe.

Armstrong's view of radio set manufacturers was not always complimentary. In the magazine he wrote: 'It is on the operations of the manufacturer that the spotlight is now focussed. For over two years, as everyone knows, the efforts of a very large part of the industry have been centered on the manufacture and sale of equipment that is already obsolete; that is, AM sets without an FM band. A small part of the industry is engaged in practices which bid fair to bring back the days of the "blooper" – sets which oscillated directly into the antenna. And there have been still others who have engaged in the equivalent of selling an automobile without a gearshift, ie an "FM" set without proper noise-suppressing facilities'.

Armstrong's vision for broadcasting in general was that AM on the long and medium wave bands would die out sooner rather than later in favour of FM broadcasting at VHF. This was a 'purist's' view of *broadcasting whereby the system* capable of the highest quality would prevail and others would fall by the wayside. Clearly even in the 21st century this hasn't happened: the two modulation systems still happily co-exist, and the threat to both today is from new digital modulation systems such as DAB and DRM. AM is still a force in popular broadcasting, with many high power stations still crammed into the relatively narrow medium and long wave bands, just as they were in 1948. FM is generally reserved for high quality stereo broadcasts from a network of relatively local transmitters, and of course mobile broadcasting to vehicles.

Today the most likely method of the demise of AM broadcasting will be government-driven, and not to the benefit of FM broadcasting (which itself may be relegated to the dustbin on the whim of government) but to digital modulation techniques. The mantra that 'digital is good and analogue is bad' seems to drive policy by men who don't know the difference, and AM and FM may die together.

It is perhaps apt to give this update on Armstrong's work in 2012, just 100 years since he, then a 22 year old electrical engineering student at Columbia University, made the first of his many significant contributions to the art of radio when he devised the regenerative or 'feedback' circuit, and thereby amplified the strength of incoming signals by many times. This enabled radio signals to be received over much larger distances than previously possible, and also led to the triode-based oscillator which made stable and tunable transmitters possible, and eventually led to the superhet receiver.

**Useful References**


'Man of High Fidelity: Edwin Howard Armstrong' by Lawrence Lessing. Published in 1956, by J B Lippincott Company of Philadelphia and New York.

'The Legacies of Edwin Howard Armstrong' by various authors. Published by the Radio Club of America. Library of Congress Catalog Card Number 90-63056, 1990.

John Shepard's FM Stations - America's first FM network, See: http://www.bostonradio.org/essays/shepard-fm

'Hugo Gernsback A Man Ahead of his Time' edited by Larry Steckler. Published by Poptronix Inc in 2007

'The Gernsback Days' by Mike Ashley and Robert A W Lowndes. Published by Wildside Press in 2004.

Several histories of the Heath Company can be found on the internet. One is at: http://www.heathkit-museum.com/hvmhistory.shtml

A comprehensive list of all FM only radios, including the very few early 1940s radios covering only the 'old' FM band of about 40-48MHz, can be found at: http://www.somerset.net/arm/fm_only_list.html.

A useful list of links to the history of broadcasting in the US can be found at: http://jeff560.tripod.com/broadcasting.html

http://www.pat2pdf.org/ is a good patent website where you can download pdf versions of many original patents, including those of Armstrong and other radio pioneers.

See: http://semiconductormuseum.com/MuseumLibrary/HistoryOfCrystalDiodesVolume1.pdf for an interesting and informative history of germanium crystal diodes, including the 1N34.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# Obituary: Professor Russell Burns

We regret to announce the death of Professor Russell Burns who died on 4 November 2-11 at the age of 83.

Professor Burns graduated in 1948 with a first class honours degree in physics. Following post-graduate research he joined the Royal Naval Scientific Service. Subsequently he held various appointments in higher education in the UK and abroad and retired in 1989. He has been researching and writing on the history of electrical engineering for more than 40 years. Russell Burns was editor of the major work Radar Development to 1945, and author of the three comprehensive and well-researched IEE histories -

Communications: the Formative Years;
Television: the Formative Years;
Colour TV: the Formative Years;

He also wrote John Logie Baird, TV Pioneer, and The Life and Times of A D Blumlein, amid many other books, and well over 50 papers on radio, radar and TV history. Before his death he had completed a new book Lindemann, Churchill and Science at War which has yet to be published.

Professor Burns, an IET Fellow, has received the Kraszna-Krausz Prize, the IET SET Divisional Premium in 1993 and shared the Maxwell Premium in 1994. He was past chairman of the IET's History of Technology professional Group, Archives Committee, and the Science, Education and Technology Divisional Board.

Many of the older members of the DEHS will remember the excellent talk on the Proximity Fuze that he gave in the late 1990s to what was then CHiDE. He will be greatly missed.


This obituary by Keith Thrower appeared in the December 2011 issue of Transmission Lines, the newsletter of the Defence Electronic History Society, and it is reproduced here by permission of the DEHS.