THE INTRODUCTION OF FREQUENCY MODULATION FOR SOUND BROADCASTING IN BRITAIN

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Abstract: **The paper traces the origins of VHF sound broadcasting in Britain, the background to the choice of wide-band FM, and the subsequent technical developments.**

Index Terms: **VHF Broadcasting, Frequency Modulation, Audio Quality, BBC Engineering.**

I. THE 'LATE START' IN BRITAIN

Britain played a pioneering role in the development of television, with the introduction of the world's first high-definition (405-line) broadcast service in 1936 [1]. This was a major advance over many competing systems in USA, Germany and Britain. By contrast, FM sound broadcasting in Britain did not begin until 1955, initially only for listeners in the south-east of England. This was long after the FCC in USA had, in 1940, allocated 40 channels for FM broadcasting in the 42-50MHz range (changed in 1945 to 88-108MHz), and after West Germany had re-built the whole of its broadcasting network from 1945 (at the end of World War Two) using VHF/FM, having 30 transmitting stations by 1951. Other continental European countries (such as Switzerland) had also adopted VHF/FM well before Britain.

The concept of FM had been known for many years, and its advantages and disadvantages discussed extensively in the scientific and engineering literature. It has a well-documented history of controversy and disagreements, extending over much of the first half of the 20th century (see Appendix I). However, all the essential methods needed for a broadcast system were described succinctly by Armstrong in 1936 [2]. Armstrong's life, his inventions and the litigation surrounding them, and the dramatic events of his career and eventual death, are well-known. In retrospect it seems surprising that the introduction of VHF/FM in Britain was associated with much uncertainty over the merits of FM over AM.

Sound broadcasting in USA developed in a framework of a large number of low-power 'local' radio stations using AM on the medium waveband (535kHz to 1705kHz in North America). When VHF/FM transmissions commenced, the regulatory environment of the FCC resulted in the same programme material being used for AM and FM, which led to a slow development of public interest in changing to FM.

In Europe, the norm was a much smaller number of high-power transmitters for 'national' programmes (e.g. there were no 'local' stations). The net result was a severe shortage of channels. Each channel was 9kHz wide (cf. 10kHz in USA), and because of the long range of the high-power transmitters, frequency re-use on a geographical basis was almost impossible. Interference between transmissions was therefore severe, especially after dark when the sky-wave dominated. It was made even worse by a few continental transmitters which did not comply with the official frequency allocations and power limits.

Reception in some parts of south-east England was unacceptably-poor during winter evenings. Interference from electrical appliances such as vacuum cleaners was also common, especially on long-wave, because legally enforceable standards for acceptable levels of electromagnetic. interference had not been introduced.

Consequently, in Britain, there was an urgent need both for more channels and for a method of reducing interference, and a general realisation that any solution required a move to VHF. At the time, all legal broadcast transmission was a monopoly of the BBC, and the freedom of action of the BBC was constrained by government policies. Moreover, the economy was still in recovery from the effects of World War Two, and the finance required to set up a completely new broadcasting system was not readily available (both from the transmission side, and the ability of industry to produce a new range of receivers based on totally new principles and of greater complexity).

II. INITIAL TESTS AND FIRST TRANSMISSIONS

It was against this background that, from 1945, the BBC Engineering Department began tests to decide whether AM or FM would be preferable in the case of VHF transmission being adopted. A transmitter at Wrotham, Kent, built in 1949, with a 470 ft (143m) mast, was used from 1951 to make comparative tests of the two methods. Three alternatives were considered (a) conventional AM (b) AM with an impulse-noise limiter in a wide-band

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receiver, called AML and (c) wideband FM [3]. Finally, in January 1954, a report of the Television Advisory Committee (established in 1935 to oversee TV development) recommended the use of FM [4]. It appears to have been chosen by a narrow margin, with little enthusiasm, and there was a widespread view that moving to VHF was an unwelcome complication. The capital cost of transmitters to provide 97% national coverage on VHF was estimated to be three times greater (£9M) for AM than FM.

The document includes a 6-page 'minority report' written by one committee member, C.O. Stanley (who was one of two representatives of the Radio Industries Council on the Committee and was also owner of the Pye company) in which he states '…VHF sound broadcasting has been a failure in practically every country…', and advocates narrow band AM.

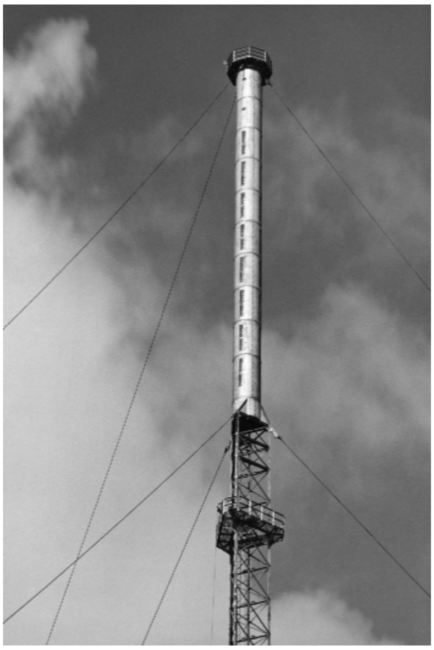


Fig. 1a Cylindrical VHF slot-antenna at Wrotham

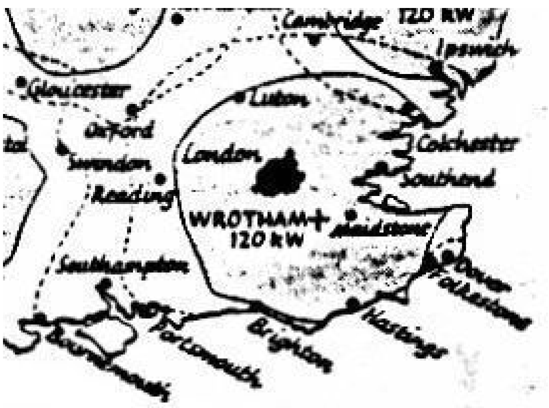


Fig. 1b Initial Service area from Wrotham

The broadcast FM service commenced in May 1955. The transmitter at Wrotham used a cylindrical antenna with vertical slots (Fig. 1, [14]), which radiated a 25kW horizontally-polarised signal (later increased to 120kW) in Band II (87.5-108MHz), with a deviation of ±75kHz (Appendix II). The need for a horizontal dipole for reception was a novelty, transmissions for the 405-line television broadcasts in Band I (47-68MHz) being vertically polarised. A 200kHz channel spacing as used in USA was chosen, instead of the Continental-European spacing of 300kHz. The transmission area (at 1mV/m) included London, and after a short while, it seems that doubts about the wisdom of introducing the service disappeared. The contrast between hearing music from one of the usual medium wave AM receivers and the new VHF/FM receivers was an unforgettable experience. The actual contrast was probably greater because most AM receivers were not designed with low distortion as a priority, and they typically included substantial low-pass filtering of the audio output (to reduce the predominantly high-frequency interference from adjacent channel transmissions). The VHF/FM receivers, on the other hand, were designed to make the best of the new method, and intended for owners who would appreciate better sound-quality. The impact of the difference was as least as great as that between 78 rpm shellac records and 33 rpm vinyl records, which were still a novelty, having been introduced by Columbia in USA in 1948, and soon after by Decca in Britain. Together these two developments started to create a new public interest in 'Hi-Fi'and several British companies (for example H.J. Leak and Acoustical Manufacturing Co.) began to achieve an international reputation for their audio products.

Fig. 2 Advertisement (1957) for FM Tuner Kit for home-construction

The supply of FM receivers was initially quite limited. Imported table-top receivers (typically with LW, MW, SW and VHF/FM) from companies such as Grundig became available (at a time when most domestic radio and TV receivers were of British manufacture, and importing such products was considered rather unusual). 'Construction kits' for 'FM Tuners' became widely available, and could be made by any handyman with soldering iron and a moderate knowledge of electronics (Fig. 2). Typically these used the miniature EF91 (Z77, 6AM6) h.f. pentode valves or the readily-available military equivalent CV 138, (Fig. 3) and comprised r.f. stage, mixer, local oscillator, 10.7MHz i.f. stage and a ratio-discriminator, and provided a low power audio output for which a separate power amplifier and loudspeaker were needed.

Fig. 3. CV138 pentode

A power supply to provide 6.3V a.c. for the valve heaters and 250V d.c. for the valve H.T. supply was also needed, so that the 'FM Tuner' itself was significantly less than a complete receiver. The choice of a ratio discriminator (rather than the Travis or Foster-Seeley discriminators) was probably made because it provided some amplitude-limiting, and because of the comparative ease of alignment by those without professional test-and-measurement equipment. One-valve super-regenerative convertors were initially suggested as a cheap form of tuner for VHF/FM in areas of good signal strength, but fortunately seem not to have been adopted.

It has to be realised that in 1955, audio 'system-components' for consumer use were not available in the way that they are today. Now anyone can assemble a system by separately purchasing a power amplifier, a tuner, record player, a tape-recorder, and a pair of loudspeakers, together with compatible connecting leads, but in 1954, finding an existing radio receiver or record player to which one could safely connect the output of one's newly-assembled FM tuner was not an easy task (see Appendix III).

A few audio power amplifier designs for which associated 'kits of parts' could be purchased were available and well known to electronics and radio 'hobbyists' – and so this provided a another route to construction of a complete receiver. Examples were the Williamson Amplifier (from 1947) and the Mullard 5 10 amplifier (5 valves, 10 watts). The sound quality from these amplifiers depended very much on the output transformer used.

Although FM offered a much-improved signal to noise ratio, it was associated with some new forms of interference in areas of low signal strength or when the receiver had an unsuitable or inadequate antenna. Multi-path propagation could result in the cancellation of the signal, and although this could usually be overcome by a small change in antenna location, this was not the case for signal reflections from low-flying aircraft, which could result in signal cancellations accompanied by bursts of wide-band noise, repeated at a varying rate around 1Hz . Interference from vehicle ignition systems and from inadequately-suppressed electric motors and thermostats in domestic equipment was significant but because it also caused interference to TV reception, legislation and enforceable standards were soon to reduce this to an acceptable level.

III. DEVELOPMENT OF THE FM BROADCASTING SERVICE

After a short while, the one transmitter at Wrotham Park was supplemented as more transmitters were brought into operation – initially Pontop Pike (NE England), Divis (Northern Ireland), Meldrum (Aberdeen), and Wenvoe (S. Wales). These were followed by North Hessary Tor (South Devon), Sutton Coldfield (Midlands), Tacolneston (East Anglia), Blaen Plwy (mid-Wales), and Holme Moss (Manchester), and later Rowridge (Isle of Wight) and others. These generally-unknown small places in key high-altitude positions became 'household names' for a generation of electronics engineers! Within a few years most of the UK had been covered by the transmissions, and low power transmitters began to be installed to 'fill in' gaps in coverage of small centres of population. Currently, the BBC transmits FM from over 200 sites in UK, with 40 transmitters classified as 'main stations'. Output powers range from only 4W (at Combe Martin, near Ilfracombe) to 250kW for 11 of those in the 'main station' category.

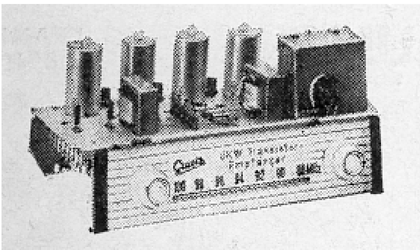
It was found that although VHF had been regarded as 'line of sight only' (therefore needing very high masts on high ground for transmitting antennas), in practice acceptable reception was often achieved well outside the recommended service areas.

The programmes transmitted were identical to those concurrently transmitted on medium wave AM – however, in contrast to the situation in USA, there was public demand for and appreciation of FM because of the improved quality and especially the almost total elimination of interference. Predictions of pessimists that the British public would not appreciate good audio quality if it were offered to them seem to have been false.

For each service area there were three programmes and therefore three carrier frequencies were needed. The carrier spacing was 2.2MHz (e.g. a separation of 11 channels) for each service area. Therefore it was possible to have a switched-frequency receiver, with a single preset adjustment for each service area. Such receivers did not use crystal-controlled local oscillators and so automatic frequency control was then almost essential, but overcame the difficulty which some users experienced in correctly tuning FM receivers (it being no longer sufficient to adjust the tuning for the 'loudest signal', as was normal with an AM receiver). Suitable varactor-diodes for frequency control by a d.c. bias were not available at this time.

The FM transmissions were in Band II but only the lower half of the band was used, because the upper half continued to be used for such applications as police and fire services. At the time, a licence was needed to receive any broadcast transmissions and it certainly did not permit the reception of these other transmissions. Yet the public was being supplied with receivers which could receive such transmissions (although the reception was normally poor and often unintelligible because of the use of different modulation methods, including narrow-band FM). It seems that the problem was resolved by concluding that it was permissible to listen to such transmissions ‘accidentally’ provided that the content was not passed on to other persons. There were suggestions that criminals engaged in burglaries used FM receivers to monitor police radio communications.

It was many years before the upper half of Band II was cleared to make way for broadcasting. By then, commercial radio broadcasting from the UK mainland had become legal and acceptable, and a large number of non-BBC transmissions were filling the band, including some having no corresponding transmission in medium wave AM (for example, Classic FM).



Prototype all-transistor v.h.f. receiver (Graetz).

Fig. 4. prototype transistor FM receiver (1957)

In the early years of the VHF/FM service, although transistor radios became widespread the transistors available for consumer electronics could not be used for either the r.f. or i.f. stages of VHF receivers, and so could only provide medium wave and long wave reception. In 1957, the upper frequency limit of transistors for consumer products was around 1MHz. In August 1957 a prototype all-transistor VHF receiver was exhibited by Graetz (Fig. 4) at a radio exhibition in Frankfurt am Main, using 2N247 transistors and a reduced i.f. of 6.75MHz [5]. A detailed circuit design for affordable home-construction was published by Harvey in 1960 [7] using the 2N247 as local oscillator, the OC170 for i.f. stages using and two GET115 transistors for a push pull output providing 1W. For cost reasons there was no r.f. amplifier stage.

After various experimental broadcasts in stereo from the Wrotham transmitter, regular stereo transmission of FM broadcasts began in UK in 1966 (in USA the FCC approved stereo in 1961).

VHF/FM reception was for many years considered impracticable for vehicle radios, mainly because of reception problems with multi-path signals.

In December 1981, a new higher (177m) transmitter mast at Wrotham was brought into use, output power was increased to 250kW and mixed-polarisation replaced the previous horizontal polarisation. The mixed polarisation was intended to improve reception by car radios and portable radios, and was the first step towards making similar improvements nationally. This indicated a recognition that VHF/FM would be the predominant sound broadcasting method, with no significant further development of AM.

The advances in solid-state electronics, the much improved sensitivity of modern receivers, and the ability to produce at very low cost much more sophisticated receiver designs (with crystal controlled local oscillator and phase-lock loop tuning systems) has made good quality VHF/FM reception widely available and affordable for portable and vehicle receivers, and reduced even further the need for AM reception.

Now there is Digital Audio Broadcasting (DAB) and broadband internet streaming-audio, both capable of delivering interference-free high-quality stereo to the home; these were unimaginable developments when the arguments over the relative merits of FM and AM were raging. They may in due course make AM short-wave broadcasting obsolescent, and perhaps will eventually result in the obsolescence of VHF/FM.

IV. RETROSPECTION AND HINDSIGHT

The narrow margin by which FM was chosen instead of AM for the British VHF service in 1954 raises the question of how developments might have differed if the opposite choice had been made. Clearly this would have been out of line with practice elsewhere – but at the time the need for international standards was less compulsive. Most receivers were manufactured by small companies, with very little import or export of consumer electronics products.

The 405-line TV standard on VHF Bands I (47-68MHz) and III (174-230MHz), which used AM for the sound channel, persisted for a long time and the final transmitter was not closed down until 1985, though it had been effectively superseded by the introduction of the 625-line TV PAL standard on UHF Bands IV and V (470-854MHz) in 1964, which uses an FM subcarrier for the audio channel. Thus it is conceivable that a VHF/AM sound broadcasting system could also have persisted for many years.

Although there was long experience of audio VHF/AM broadcasting as the sound channel of the 405-line TV broadcasts which generally gave interference-free reception, it was never associated with quality because the majority of TV receivers used small 3 inch (76mm) loudspeakers, with no design emphasis on the audio reproduction.

Substantial improvements would have been possible using the same technology. However, the provision of a nationwide sound broadcasting service might have been much more difficult to achieve with AM than with FM because of the capture effect of FM [6, 12]. This provided well-defined and much larger service areas for the transmitters and permitted much more frequency re-use, since interference between transmitters using the same frequency was not significant – the strongest signal almost always dominates completely.

Prior to the decision to use FM for sound broadcasting, narrow-band (±5kHz) FM was in use for some commercial and emergency service communications, and the British army had narrow-band (±15 to ±35kHz deviation) FM transceivers in the 38-45MHz range for battlefield use, so it is not the case that there was no previous British experience of FM. However, the ability of FM to achieve a better signal to noise ratio by increased deviation (e.g. widening the bandwidth) was clearly understood by only very few people at the time. Eckersley's often quoted analogy ('the wider you open the window the more the dirt blows in') was generally felt even by technically-qualified people to be a universal law.

The need for a wide-bandwidth discriminator in order to achieve a good capture ratio had been explained by 1949 [6], but apparently was not generally realised even in the mid-1950s.

It seems that no amount of engineering innovation in a VHF/AM service could have compensated for the benefits which FM provided as a result of (a) the ability to increase signal to noise ratio by increasing bandwidth and (b) the capture effect (even though the receiver designs of the time did not achieve a good capture-ratio [6]).

Acknowledgement

The BBC Research Department is thanked for permission to use Fig. 1a

Appendix I

An early proposal for using FM was by Zenneck in 1908 [8], for a telegraphy arc transmitter. Tucker [9] attributes the invention of FM to Ehret in 1902 (US Patent 785804). Many technically-inaccurate suggestions soon followed based on the idea that by using FM, the transmission bandwidth could be reduced in comparison to AM (widely understood to need a bandwidth of twice the highest modulating frequency). The fallacy that FM could use a lower bandwidth persisted for many years. Many investigators started from the assumptions that FM was a way to reduce bandwidth and that the only way to detect an FM signal was to use the (non-linear) side of a resonance curve to convert frequency variation into amplitude variations. Not surprisingly, from this perspective they found FM to be inferior to AM. Carson [10] concluded in 1922 that '…*[FM]* inherently distorts without any compensating advantages whatsoever'.

Armstrong's work, presented in 1935 and published in 1936 [2] was thus a major and exceptional breakthrough, yet despite the clarity of his paper, was not widely accepted.

In 1940, an editorial in Wireless Engineer [13] suggested some fallacies in Carson's work, but Carson responded that he still held the same views. It was not unusual for those who had not understood Armstrong's work or who had other reasons to wish to criticise it to claim that the demonstrated interference reduction of FM was not due to the FM itself so much as the use of an amplitude limiter in the receiver.

Although now sometimes regarded incorrectly as the 'inventor' of FM, Armstrong's actual inventions and his innovative work on all aspects of FM broadcasting laid the foundation for FM transmitter and receiver development for decades.

The lack of enthusiasm for FM during the BBC comparative tests was evident. In 1951, Brinkley [11] presented the 'case for AM' and it seems that many people shared his opinion at the time. Brinkley worked for the Pye company, and therefore may have been under pressure to present 'company policy' His paper includes assertions that since AM/MW sound quality was 'better than telephony' it was 'good enough', 'the majority of listeners were reasonably satisfied', 'majority of programmes … would benefit little from the extension of the frequency response'. He also expressed the opinion that the conclusions (favouring FM) from the BBC tests were '…practically valueless'. In the published discussion following the presentation of the paper a need for 'balance' in the audio frequency response was suggested, proposing that if the audio response did not extend below 120Hz, then there was no need to go above 4kHz, while a 10kHz upper limit would be useful only if the lower limit went down to 50Hz.

Appendix II

The Wrotham FM antenna was a 32m hollow steel cylinder, 2m diameter, with 32 slots in 8 tiers, each slot being 2·4m high and 0·3m wide [14]. The transmitter output comprised a cascade of a 1·5kW tetrode (4H/181E), then 2kW and 9kW grounded-grid triode stages (3J/161J and 3J/210E), with a 2·5kV anode voltage to stages 1 and 2 and 6kV to stage 3. The valves were air-blast cooled. The final valve weighed 10 kg and required a cathode heater power of 625W at 5V. With an anode current of 2·3A, and operation in Class C, an anode efficiency of 70% was achieved, delivering 10·5kW r.f. output into a 51·5 ohm coaxial line of 41mm diameter. A coaxial transmission-line filter was used to remove the 2nd and 3rd harmonics of the carrier frequency. Three such transmitters fed into a shared antenna via bridge-ring combining filters [15].

Appendix III

Up until the mid 1950's domestic AM radios were in four main categories:

1. Large 'radio-gramophones', often with an 'automatic' record player capable of playing several records in sequence, and a single loudspeaker, of 8 or 10 inch (200 or 250 mm) diameter. A few of these had push-pull audio output stages and so were capable of greater power output, but since there was no stereo, there was no incentive to have external loudspeakers.
2. Table-top receivers, normally kept in a fixed location, with a loudspeaker of 5 or 8 inch (130 or 200 mm) diameter.
3. Portable mains receivers, with an internal loop (or, later, ferrite-rod) antenna, and a 3 or 5 inch (76 or 130mm) diameter loudspeaker.
4. Portable battery receivers, using directly-heated valves (which needed less power)

Only the first two categories could be considered as appropriate to develop for the new VHF/FM broadcasts, because of the need for a correctly-positioned dipole antenna, often mounted out of doors at roof level and because there was little expectation of good audio quality from the last two. The portable mains radios and some of the table-top radios used a live-chassis construction, with the valve heaters connected in series across the mains supply. They were often marketed as a.c./d.c. universal sets, though almost never used with a d.c. supply. This design method avoided the cost and weight of a mains transformer but meant that the internal metalwork was connected directly to the mains neutral. In practice, because of use of symmetrical two-pin mains connections or incorrectly wired three-pin plugs, this meant that the chassis was often connected to the mains live, and so was actually at 240V a.c. with respect to ground. Connecting external tuners, loudspeakers, headphones or antennas was thus seriously hazardous.

Except for the portable receivers, the antenna was often a short piece of wire positioned by 'trial and error' to give adequate reception of AM. Few people installed any kind of outdoor antenna except in remote areas where signal strength was very low. Outdoor antennas were thus almost exclusively associated with TV reception, the 'H' type (one dipole, one reflector) for vertically polarised Band I transmissions being in widespread use. Multi-element Yagi antenna arrays did not become common until the start of independent (commercial, non-BBC) TV in Band III.

Although there were many British radio manufacturers and considerable variations in the appearance and mechanical construction of the mains-operated AM receivers, almost all used a similar 5-valve superhet design (pentode-triode mixer/oscillator, pentode i.f amplifier, double-diode-triode demodulator / a.f. amplifier, pentode or beam-tetrode a.f. output, rectifier – for example, 6K8, 6K7, 6Q7, 6V6, 6X5). Printed-circuit construction methods were not used until the mid 1950's.

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http://tx.mb21.co.uk/gallery/ source of data about UK Broadcast Transmitters and much more

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