CAMBRIDGE WIRELESS - WIRELESS HERITAGE SPECIAL INTEREST GROUP

History Archive - Issue 1: May 2009

LANCASHIRE CONSTABULARY'S DEVELOPMENTS IN MOBILE COMMUNICATIONS

Author John Davies

John Davies joined the Lancashire Wireless Workshops in 1948 as a radio engineer. He retired in 1984 and lectured for a number of years on private mobile radio system design and implementation.

He remains exceedingly active and has maintained a very close interest in radio engineering including recent involvement in a local radio planning enquiry.

In this article he describes the pioneering work undertaken by Lancashire Constabulary on wide area coverage systems and the parallel evolution of mobile and portable transceivers.

The innovations introduced by Lancashire had very tangible benefits in terms of operational efficiency. John's story, a mix of personal and professional observation, provides a fascinating insight into forty years of radio design experience.

Lancashire Constabulary HQ
With thanks to the Pye Telecom Historic Collection

The Foundation

The Lancashire Constabulary Wireless Workshops – or as it was often referred to – Workless Wire shops, was founded in 1929 with the recruitment from the Royal Air Force of Frank Gee, later to become Superintendent Gee.

Frank Gee was a very far-sighted man. In 1980 following the World Administrative Radio Conference, all police and fire service radio equipment had to be replaced to clear the broadcast band 2.

The Lancashire Constabulary Radio Engineering Branch (Lancon) as it had then become known needed to make a decision on whether to re-equip with an amplitude modulated system or remain with a frequency modulated system. The Home Office would have preferred a change to AM to fit in with their systems.

When I told him we were staying with FM, Frank, then into his eighties, said "Don't!" Shocked, I asked "What?" His reply was "Go digital. That's the modulation of the future."

How right he was. However, digital modulation was then at a very early stage of development and no equipment was available so Lancashire Police, Lancashire Fire Service and the Isle of Man Police and Fire Service, for whom we were to oversee the change over, stayed with FM.

Early Days

In the early nineteen thirties all the police forces were using medium frequencies and telegraphy for what little mobile communications they possessed; most of it provided by the Home Office. Under the then Chief Constable, William Trubshaw, Mr Gee decided to work on VHF and telephony.

The other forces then not under the Home Office's wing were the Metropolitan, Manchester City led by Superintendent Octaloni, Liverpool and Birmingham cities and they also were attempting to use VHF and telephony. With the exception of the Metropolitan Police and Lancashire all were eventually swallowed up by the Home Office.

Using VHF was not easy. The valves at that time were not designed to work at frequencies of sixty to seventy MHz. To improve their VHF performance they had to be de-capped (the lossy plastic bases removed) and other components, particular condensers, now called capacitors, were comparatively large with a high inductive element.

The first VHF AM system was operated from a base station close to the centre of Preston and could reach the only four radio equipped cars as far as the Blackpool boundary, some twenty miles.

These achieved considerable success in recovering stolen cars which had been taken by revellers to get home after the last bus or train – a common practice - and encouraged the spending of more money to further develop the system.

Sir Archibald Frederick Hordern became Chief Constable in 1935. During 1936 a manned base station using a higher power transmitter was established on Barnacre Fell, north of Preston. The aerials were manufactured in the Wireless Workshops own machine shop.

The original dipoles were later replaced with a home-made four stack dipole and reflector which gave radio coverage over the Fylde from Carnforth and the detached portion of Lancashire which is now in Cumbria into Preston.

The coverage was extended by the later introduction of manned stations at Billinge near Wigan, Higham near Burnley and Newhey near Rochdale.

These stations provided coverage over most of Lancashire, a much larger county before Local Government Reorganisation in1974. The system used simplex amplitude modulation with, I believe, originally home-built mobile transmitters which were later replaced with a model built by Eddystone Ltd.

Loudspeakers were built into the control panel – a different type made up for every model of car – and the microphone and transmit switch was in a heavy standard black telephone handset.

The mobile receivers were American National 1-10. The National 1-10 was a tuneable super-regenerative receiver which had to be tuned to the station through which the mobile operated and the level of re-generation set up by the driver for maximum sensitivity without self-oscillation. I believe it operated on 70-80MHz. I remember the two RF valves were 'acorn' types 954 and 955.

After the war the mobile receivers were replaced by Eddystone type P40, originally designed as an aircraft receiver. The transmitter/receiver combination required a huge amount of power including a high DC voltage for the valves. They were very heavy and filled most of the car boot.

The valve HT was supplied by a large motor generator also mounted in the boot. If a car to be fitted with radio was taken to a tame blacksmith, Ted Porter in Preston, he would bend a few lengths of welding rod around the rear axle casing and the next day from his ramshackle workshop in the back yard of a public house he would hand over a perfectly fitting mounting frame which spread the load over the boot floor and axle housing.

Police cars were supplied directly by the manufacturers – and models from different manufacturers were used to Lancon specification with larger batteries and high wattage generators.

Even then the 12 volts vehicle supply was conveyed to a 15amp socket in the boot by a heavy cable. In use the radio equipment was plugged into the socket and after a tour of duty a Davenset charger provided at every police garage was plugged into the socket to recharge the battery.

A notable use of the system was when the Liverpool telephone exchange was bombed out of operation in WW11 and a terrific amount of communication was carried out from a Lancashire mobile station at the site and the Lancon base station at Billinge.

The Introduction of Frequency Modulation

Apart from the forces mentioned earlier the Home Office provided all the mobile communication which by wartime was amplitude modulated telephony. There was great rivalry between Lancon and the H.O. and Lancon were permanently under the threat of take-over.

Frank Gee read of the benefits of frequency modulation from the experience of America and decided that that was the modulation to use. He oversaw the conversion of the AM Eddystone P40 receivers to FM.

This was achieved by installing a second oscillator and mixer in the set where the demodulator had been accommodated to produce a 2nd I.F. of 1.2MHz. This was conveyed by a piece of feeder cable to a mu-metal box mounted on top of the P40 which contained a limiting I.F. amplifier to cope with variations of signal strength, a discriminator and a squelch or mute circuit to prevent the receiver noise from reaching the audio amplifier in the absence of a signal.

The resultant audio signal was sent back to the original amplifier in the P40. The mobile transmitters at this stage remained AM. The base station transmitters carried common modulation, FM and AM simultaneously; another first. This system worked successfully for several years.

Mr Davies joins the police force

I joined the force in 1948 intending to be a policeman but before reporting for duty I was called to Headquarters at Hutton for a second interview. The interviewer looked at my application and asked

"Radio Mechanic, eh? Know anything about FM?"

"Yes."

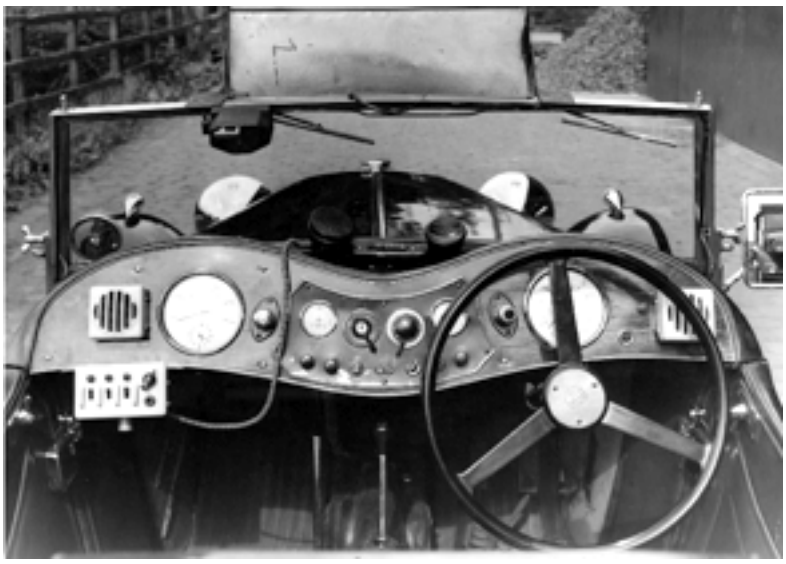
"Where did you get that?"

I stretched a point and told him that whilst in the Royal Navy I worked on American ships which used FM ship-to-shore communications in Hong Kong shortly after the war.

He made a 'phone call and then asked "Would you mind going into our wireless workshops for three weeks to help install our first commercially built FM sets before going to the training school?''

I stayed for nine months before going to the training school at Bruche near Warrington and on my return stayed thirty six years so all memories from here on are my own.

The first commercial sets referred were Mullard type GME501 with a transmitter power of 25watts. I was employed in the fitting shop installing these and the older AM equipments in vehicles. The Mullards were much smaller than the older sets but were still quite large and heavy although the valves were more modern, glass based types.



Mullard GME501 installation in MG TC Midget c.1948

The transmitters which included the motor generator and the receivers were in separate housings so they still occupied a lot of boot space. They had, however, a neat control unit which was much easier to install than the old panels we made ourselves. They were also two-channel, the crystals being selected from the control panel and they operated duplex from two aerials mounted on the roof of the car.

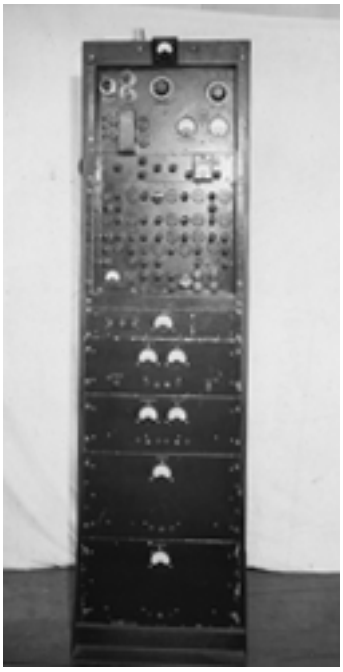
The second generation of mobile sets, still boot-mounted, were supplied by Hudson Electronics Ltd. and were less power-hungry. Later models from the same company were largely transistorised.

Wide Area Coverage

Around 1946 a number of developments took place. The site at Winter Hill, which now looks like a small telecommunications town, was developed. At that time it was bleak moorland without even a proper road. The Wireless Branch made the road themselves.

Along with the introduction of FM Superintendent Gee dreamed of a synchronous wide-area coverage system to enable large areas to be covered on a single frequency from more than one base transmitter.

The Mullard company were involved in its development and in 1948 the system was almost ready for installation at Barnacre and Winter Hill although there was still laboratory work to be done and the Mullard engineers lived with us for weeks at a time.



Mullard Synchronous Slave Transmitter c.1948

The transmitters did not demodulate and we were fortunate that the up-link from the control room at H.Q. to the two sites was exactly 3/2 times the broadcast frequency. In the synchronisation panel – which contained thirty EF42 valves! - the link frequency was divided to 100 KHz.

That frequency was then used to control a 3.4MHz impulse-governed oscillator to provide the broadcast frequency. So, the output from the two transmitters was exactly synchronised in both RF carrier and audio modulation. The distance between the control room and the two stations was very similar.

The system worked mostly satisfactorily until about 1953 but there were problems with complete synchronism. In an area of equal signal strengths from both stations it was possible to stop the car in an area of no signal where the two signals were anti-phase. Of course, moving about one and a half metres produced a signal of twice the power from one transmitter. A driver moving comparatively slowly along a road where these conditions applied experienced a severe fluttering sound as the car moved between in-phase and anti-phase signals.

To overcome this defect, Lancon developed in-house a quasi-synchronous system. The base receivers in both the base sites and control room were by now of G.E.C. manufacture. More of these were purchased and modified to form the basis of the transmitters. The mixing of the up-link to create the standard G.E.C. IF of 8.0MHz with the multiplied output of the same oscillator used to produce the broadcast frequency resulted again in synchronisation of the RF output and the system did not demodulate.

Fortunately, the new link and broadcast frequencies were no longer exactly 3/2 so an additional frequency had to be introduced into the IF. To do this a very high specification, ovened and voltage-regulated low frequency crystal oscillator provided the 550 KHz to be added to the IF.

The low frequency oscillator was then adjusted to give a difference of between 10 and 20Hz between transmitters. This overcame the problems of exact synchronism.

More base stations were later added where there was an appreciable difference in link path lengths between them making the modulation non-synchronous. This was overcome by adding a RF delay line in the transmitters to equal the path lengths.

A further development of this system came much later after the introduction of UHF, 450MHz personal radios for the police. These operated on a Divisional or Sub-divisional basis where a number of Sectional areas had to be covered simultaneously.

The link between Divisional control and the Section base station had to be over a BT line. In this case

the output from a very low frequency crystal oscillator just below 3 KHz was sent over one BT line to all the base stations and was then multiplied up to 450MHz.

The obvious problem was then the amount of FM noise produced on the carrier by the multiplication of the 3KHz signal from control. I was not personally involved at that time and am unsure how this was filtered out but it was successfully achieved.

The speech was transmitted to the base stations over a separate line where, if necessary, an audio delay was introduced to equalise the path lengths. The system was known as Lanpacs (Lancashire Police Area Coverage System).

Lancon-built HQ Control panel. pre 1957

Extension of Responsibilities

In 1955 the branch took on responsibility for the provision of mobile radio for the Lancashire Fire and Ambulances Services where none had existed previously. Later responsibility for the Lancashire Highways and Bridges Department was added. Even the maintenance of audio and visual aids in schools came under the Radio Branch.

The original equipment for the Fire and Ambulances was EKCO, E.K.Cole Ltd, Wide area coverage was not provided at the start although it was later for the Fire Service. The EKCO equipment was exceptionably well-engineered. It may have been thought too well when the weight of the mobiles is considered. They used miniature valves but built on four individual strip chassis mounted in a very heavy duty main frame within an equally sturdy case.

Each chassis containing the power supply, audio circuits, receiver RF and IF circuits and transmitter RF section, was fitted with a 24pin connector at the end of the strip. The connectors in fact gave very little trouble.

There was a problem at first with the IF bandwidth, unfortunately I can't remember the details but it may have been ripples occurring within the pass-band. Lancon modified them with components supplied by EKCO. No crystal filters in those days, just a line of individually tuned circuits.

Sometime during the 1970s, I think, I received a call from the ambulance service that the cardiac pacemaker fitted to a patient failed twice during passage to hospital in an ambulance. Fortunately, the attendant re-started it but the second time noticed that it had occurred when the driver had been transmitting on the radio. She told him not to use the radio and everything was then in order.

On examination of the vehicle the aerial standing wave ratio was found to be very high. The vehicle bodies were built to specification and Lancon insisted that two strips of aluminium 8"wide be built into the fibreglass roof from corner to corner to form an artificial ground for the aerials.

A metal detector showed there to be no strips but, on removing the aerial, four pieces of aluminium were present. The manufacturer had cut a corner and placed four off-cuts in the aerial position. The aerial feeder cable carrying twenty five watts ran in a duct about six inches from the patient's left side. After that episode the roofs were routinely checked with a metal detector and the feeder cable re-routed.

The Move from Hutton Hall

In 1957 the workshop moved from the old 18th century Hutton Hall which was demolished to make way for the training school into a purpose-built shop at the rear of the main Headquarters building.

This was luxurious even equipped with two screened rooms, one for the laboratory and one for the repair and testing of mobile sets. Additional to the radio side of the job we had a machine shop and joiner's workshop as many items were still hand-made; base station aerials, 600watt transmitters and many small items.

Lancashire Constabulary HQ Hutton

One item which was required and not available commercially was a high power aerial relay. All base station equipment was duplicated to provide main and standby and remotely switched from Headquarters.

The switching of the 600 watt transmitters to the aerial was a problem. It was overcome by positioning the transmitters one half wavelength apart. The aerial connection was on the top of the case and a rigid 1/2 transmission line made of brass tubing in the workshop was mounted with the ends above the aerial connections.

The connection to the aerial was from a socket mounted at the centre of the line. At each end was a mercury-filled glass tube relay. When, say, the main tx was selected the inner conductor was connected to the aerial output of the tx. The relay at the other end of the line short-circuited the inner to the outer conductors of the line presenting an effective open circuit at the central aerial connector. When the standby tx was selected the relays rocked to reverse the situation. This was still in use when I left in 1984.

The Motor-cycle Set

The first project in the new workshop was the design of the first largely solid-state motor-cycle transmitter/receiver. The problems were size, temperature, weight and battery drain - design issues that remain with us today.

Transistors at the time were limited to 55°C and it was found that a black box, needed to dissipate the heat generated inside, rose to 48°C when parked in the sun without any internal heat. Too close for comfort!

The only thing that could be done to reduce the battery drain was to use the minimum number of valves and use transistors as far as possible given their then limited frequency response. The receiver RF amplifier and mixer were miniature valves as was the crystal oscillator frequency multiplier. The transmitter output stages of course had to be valve.

The size and weight problem was overcome by splitting the set into two parts. An aluminium case

containing the transmitter and receiver was mounted on a sandwich of two sheets of steel with a polyurethane filling and installed on the rear carrier of the ‘bike.

In use it was found necessary to include vibration dampers on the sandwich. The case had to be designed to both radiate the internal heat and insulate it from the sun’s radiation. For a start the electronics were divided; all the valves were mounted on a horizontal chassis to one side of a vertical spine. The semi-conductor components were on a chassis at the other side of the spine.

The spine itself was made of two aluminium sheets separated by a sealed air space. The case was painted matt black but with two 3/4inch top-hat section aluminium spacers attached around the outside. On top of these was a white fibre-glass cover. This cover was in two halves with a gap along the top surface to allow warm air to circulate into the atmosphere. This lowered the internal temperature by 11°. No problems were experienced with overheating.

The aerial however, mounted in a bracket on the rear face of the case repeatedly snapped off at the base. I forget the exact length but it was longer than ¼ wavelength. Following a ‘bike along the road it was seen that the aerial whipped back and to almost through 180°. The cure was to fit a sleeve over the lower few inches of the rod.

The power supply, loudspeaker and the unique connector for the headset was mounted in a special recess in the petrol tank of the Triumph Speed Twins that we were using at the time.

Being mounted immediately above the engine created a problem of its own. The lead-out wires of the H.T. transformer started breaking after a few months in service. At certain engine speeds, the windings of the transformer rotated back and forth around the core to the full extent of the lead-out wires. The answer was to pot the complete transformer in Epoxy resin.

In addition to these installation considerations it was essential that the equipment was useable on the move and the rider safely connected to the radio.

Several types of microphone were tried, throat and cheek but eventually we settled for a boom microphone. I know of no one else using them at that time. The microphone itself was large and today would probably not be permitted on Health and Safety grounds. A single earpiece clipped into a light plastic ear curl was used. But how do you connect the rider to the radio? The cable from the headset was clipped to his belt and below that point was curly and springy so that should the rider and ‘bike part company, the connector would fly to his belt without going into the wheels.

The actual connection to the equipment was a magnetic, contactless connector which sat on its other half mounted on the power supply in the tank well. The two halves would separate with a pull in any direction but never came apart with vibration.
These connectors were comprised of two coils of wire each in one half of a Mullard ferrite cup core which, when the connector sat on its other half, mated up with the other half of the cup core producing a very satisfactory transformer.

In one half of the assembly a pair of flat magnets mated up with an identical arrangement in the other half except that the magnets were replaced with soft iron.

Two semi-spherical humps on the surface of one half fitted into two recesses on the other allowing the units to separate if pulled in any direction.

Later the ‘corker’ helmets were replaced with bone domes and the headsets were built into the helmet. Much safer!

At the start of the development of the motor cycle set we obtained a lattice crystal IF filter from Hycon Eastern in the U.S.A. This was a revolution compared to the line of tuned transformers in use then. Superintendent Gee decided we make our own.

I was seconded to the HF crystal laboratory of the Automatic Telephone Equipment Company in Liverpool for nine months to assist in the development. We produced a few good filters but could not replicate them well enough for production. In the meantime Standard Telephones and Cables had overtaken us and their filters were ideal. They were used in a transistorised progressively limiting IF amplifier chain. The other item which was new was a transistorised high frequency third overtone crystal oscillator.

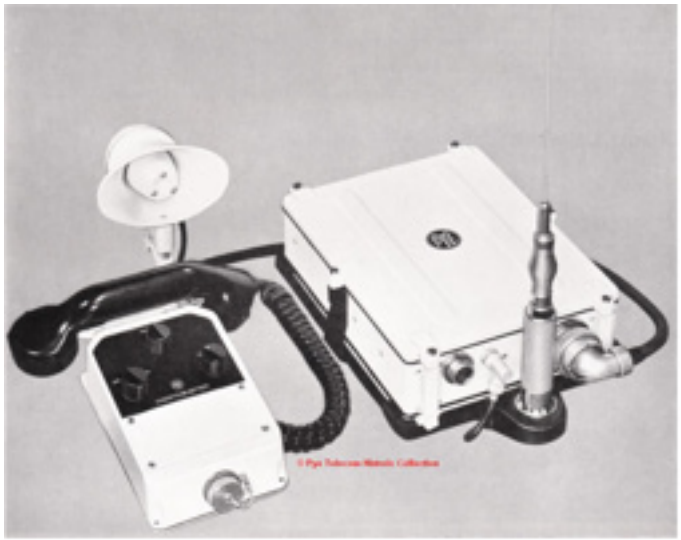
Police motor bike with installed radio set
With thanks to the Pye Telecom Historic Collection

Four patents were taken out merely to protect our user rights and I was given to understand that this was the first time a local authority had taken out a patent. They were for the magnetic connector, the case design, the progressively limiting IF amplifier and the crystal oscillator.

The production equipment was made for us by G.E.C. Ltd. at Coventry and gave many years good service before being replaced by a PYE Westminster I think, which was modified to use Lancon's magnetic connector.

Personal Radio

In 1959 a demonstration of a very small VHF receiver and transmitter by Motorola were imported from the U.S.A. by an agent who demonstrated it to us. A temporary base station was erected on the roof of Stretford police station at Old Trafford. The performance of the equipment encouraged Lancon to import a number of the mobile pairs to assess their effectiveness in policing.



Pye Police Radio - similar to equipment supplied to Lancashire police
With thanks to the Pye Telecom Historic Collection

The receiver was a beautiful piece of engineering that worked perfectly. The transmitter used a small number of sub-miniature valves. Both operated from dry batteries, the one for the transmitter also supplying the valve HT, thus they were expensive to run but gave virtually no trouble and proved the value of mobile communications to the man on the beat.

They were installed in Chorley Division operating at 150MHz via a Hudson Electronics 10W base station sited at Chorley Police Station. This trial

system worked extremely well and proved beyond doubt the value of instant communication with beat officers.
Another personal radio was one made by A. C. Cossor Ltd. and was trialled at Fleetwood but for some reason was considered impractical.
The success of the Chorley scheme encouraged Lancon to eventually extend the network to cover the whole county and some 25 Hudson base stations were purchased which gave good service for many years.

The acquisition of the personal radios themselves was a problem; none were available in the UK. It was therefore decided to make our own and a prototype of the Lancon was made.

The Lancon was formed in a compartmented plastic egg box giving great strength (We did have one run over by a car that still worked). The transmitter and receiver were combined in one box about six inches by four and carried on the belt. It was powered by a Nicad battery and operated at about 150MHz. The microphone, audio transducer and transmit switch were in a small case attached to the lapel of the tunic and the aerial was part of the cable from the tx/rx.

PC using Motorola personal radio c. 1960

The receiver audio was conveyed to the ear by an acoustic plastic tube to a flat plastic ear curl so there was nothing that could be driven into the user's ear.
G.E.C. Ltd. produced the unit in quantity at their Coventry factory and I believe later exported some to Russia. I shudder to think about what may have happened to the cable to the microphone in their low temperatures!

PC with Lanson personal radio Tx/Rx 1963

The Lancon gave several years of good service but we were the first to discover the memory effect in Nicad batteries. The routine duration of a policeman's tour of duty discharged the battery to a constant level and if a man had to exceed his normal tour the battery saw itself as discharged and stopped working. A special discharger/charger was produced and at the end of a tour of duty when the batteries were routinely placed on charge they were first automatically discharged to a pre-determined low level before charging commenced. This solved the problem.

A few years later the Pye Pocketfone came along. This operated at UHF, 450 MHz. It comprised of a transmitter and receiver intended to be carried separately but Lancon mounted them both on a plastic chest plate. This brought the microphone to a point where it could be spoken into directly although an earpiece had to be re-introduced. The big advantage of combining the tx and rx was that the drain on the batteries could be shared. In service it was found that the receiver which was in use permanently ran its battery down much faster than the transmitter which was for most of the time used only spasmodically.

The unit was used in this form for several years until it was replaced by the Burndept, again modified at Lancon's suggested modifications. The Burndept included an in-built aerial. By now many policemen were working from inside a car with a less reliable signal. We therefore arranged for a connection on the set for the attachment of a car gutter aerial.

This introduced the problem that when the car aerial was in use the signals from the internal aerial and the car aerial could be anti-phase so it was arranged that the connection of the car aerial automatically prevented the internal aerial from functioning.

Operational benefits of personal radio

The combination of 'all informed' wide area coverage providing coverage to mobiles in vehicles and policemen on the beat transformed the operational effectiveness of policing and emergency response not only in Lancashire but in police forces around the world.

Today we take these innovations very much for granted but in practice the world is a safer place thanks to the many thousands of man hours invested in radio design and development.

We were always proud of our work at the Lancashire Constabulary Wireless Workshops and we look back on our years there with fondness.

Lancashire Constabulary HQ
With thanks to the Pye Telecom Historic Collection

Acknowledgements
The photographs of Pye equipment in this article are used with the kind permission of the Pye Telecom Historic Collection.

The photographs of Lancon equipment used in this article were supplied by the Lancashire County Museum and are used with the kind permission of the Chief Constable.

A series of pictures of the LanCom set can be found here on this website.
http://www.qsl.net/gm8aob/pages_2/lancon.htm#LANCON

Addendum - August 2010

I have recently been given this photograph by a retired Assistant Chief Constable.

It is of a very early mobile police station/incident room. It must be either late 1930s or early 40s. The operator seen through the window is wearing headphones so it was probably equipped with radio although no aerials are visible but its successor, a converted Leyland Tiger bus, carried a guyed mast flat on the roof until reaching the scene when we erected it there. If it did contain radio it would have been amplitude modulated and probably consisted of an Eddystone P40 receiver of which Lancon had many and either an Eddystone transmitter of which I forget the number or a home made model. We used both in the forties.

The Leyland Tiger was later replaced by another converted Leyland bus. In the 70s-80s this was again replaced by a trailer, a Kabmobile made by Portakabin, with a retractable undercarriage to allow easy access for visitors. It also provided a sleeping compartment and cooking facilities to provide for an officer to remain in constant contact during siege operations as several occurred around that time. In the event I don't remember it ever being used for this purpose.

We used to take the Leyland Tiger a few times each year to the Police College which was then at Ryton-on-Dunsmore to demonstrate the use of mobile on-scene radio. Not many forces then had the immediate availability of hand-portables.

Early Hand-portables. (Walkie-talkies)

In the late 1940s Lancon owned no hand-portables. They were rented by the day from the Home Office depot at Billinge. I forget just which models these were but they were AM, as was all H.O. equipment (a bone of contention between Lancon and H.O.) about 8inches square and 4 inches deep using valves and 'dry' lead-acid rechargeable batteries and very heavy to be worn on the chest. They were very sturdy and I remember on one occasion saving a colleague from serious injury. At a Grand National meeting my colleague was kicked on the chest by a Police horse. The 'walkie talkie' as they were called then was so badly dented that it had to be written off as it was impossible to remove the set from the case! I can't remember what we used a base station, probably the same as mentioned in the early mobile police station. Later, we purchased our own Marconi 'walkie-talkies', even heavier than the H.O. models but they were reliable and gave good service. About the same time we bought Pye Rangers for use as base stations. The Marconi sets were later replaced by a lighter model made by B.C.C. (British Communications Corporation?). These were used until the Pye Pocketfone came along. On one occasion when several important sporting events, including the Grand National, occurred on the same day we installed the BCCs in two helicopters at Kidlington airport to give an overview of the traffic situation.

As part of a UK based Wireless Heritage initiative in association with the Pye Telecom Historic Collection we would very much like to produce a collection of articles based on personal reminiscences of radio system design and implementation.

If you have a story to tell or would like to join the Cambridge Wireless - Wireless Heritage Special Interest Group - then please contact

Geoff Varrall
0208 744 3163
geoff@rttonline.com