Communications for Artillery Location in the British Army, 1914 - 1970

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Abstract

The advent of indirect fire in the Royal Artillery at the beginning of the 20th century brought with it the need to employ technical means for locating the enemy's batteries. These fall under three headings; Survey, Flash Spotting and Sound Location, the latter two of which are considered in this article. This article is not intended to be in any sense a mathematical treatise on the principles of artillery location but of necessity there is some mention of those principles, in general terms. References are given for those readers who may wish to investigate the theories in detail.

The main purpose of this article is to present such information as is currently known on the communication technologies which facilitated the use of artillery location in wartime. Research continues into this subject and it is expected that updates and amendments to this document will be made over the coming years.

The article was prepared using the TexNicCentre editing system for the LaTeX typesetter. It will be available online at www.royalsignals.org.uk – the web site of the Wireless-Set-No19 email list group. For further details visit the site, or go to Yahoo Groups.

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Version 2, July 2007 : Added information on Carrier Link, SR and SR Radio Link No 2.

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1 Indirect Fire and its Consequences

Up to the end of the 19th century, gunners could always see their targets and engaged them by pointing the gun barrels in the right direction and tilting them upward to achieve the correct range – this is known as *Direct Fire*. However, various technical advances such as the introduction of rifled barrels and more effective propellants, served to increase the range of guns of all types. Consequently, they could be sited further away from their targets and hidden from the enemy (who would, of course, be using weapons with similar ranges to attempt to knock out our batteries). The first example of this was the use of howitzers[1] firing from behind cover such as a crest, during the Boer War.

Firing from out of sight of the target is known as *Indirect Fire* and by 1906 it had been accepted by the British Army as the primary mode of fire. The big problem with indirect fire, of course, is how to point ("lay") the guns at the target when you can't look down the barrel and see it. The means of achieving this took some time to stabilise and continues to evolve to the present day.

Before the First World War, it was envisaged that future wars would be characterised by movement and that cavalry would play a vital role in exploiting breaks made in the enemy's lines. At this time, the Royal Regiment of Artillery was composed of two separate organisations, mounted (the Royal Horse Artillery supporting Cavalry and the Royal Field Artillery supporting infantry) and dismounted (the Royal Garrison Artillery, providing siege and coastal artillery). During WW1, the RHA and RFA supplied the lighter guns, while the RGA supplied the mediums and heavies. They were not in fact merged until 1927.

As we now know, WW1 in Europe was mainly a war of "position" and the methods for controlling indirect fire had to become very sophisticated. Put simply, indirect fire required a great deal of trigonometry and surveying. After all, the target must be definable in some way other than direct view, and the only suitable approach is to have an accurate drawing which covers both gun and target – in short, a map. Hence the trade of surveyor (a Royal Engineer trade at this time) rose to paramount importance.

The other aspect of indirect fire which came to the fore in WW1 was the location of hostile guns. Generally speaking, gun batteries firing indirectly would be out of sight of the enemy and his guns would be out of our sight. However, it was very desirable to be able to fire on his guns to put them out of action. The two means developed during WW1 for gun location form the main subject of this article.

2 Artillery Survey

In 1914 as war began, the British Army's surveying resources were just two map officers, followed in early 1915 by a ranging section of 19 which became the 1st Ranging and Survey Section RE in April 1915 [1]. Initially this group worked with aeroplanes which, lacking wireless, had to drop a smoke bomb on the proposed target. Observers would then find bearings to the smoke and hence the range but, of course, the observers and the guns had to be surveyed onto the map for this to be usable. At the same time Harold Hemming, a Canadian gunnery officer, is generally credited with having invented Flash Spotting, which originally used the "flash to bang" time for range along with a compass bearing. Unfortunately it was found that to be useful, the timings had to be accurate to less than a tenth of a second whereas even a trained observer had a reaction time which was more like a fifth of a second.

In October 1915 a Royal Horse Artillery officer called William Lawrence Bragg was sent to France. Lawrence Bragg (later Sir Lawrence Bragg CH) was at this time in his twenties and already a Nobel Prize winner for his work on X Rays and Crystal Structure. He perfected the method of gun location known as Sound Ranging, having famously noticed that he was lifted from his seat on the privy when a nearby gun fired. This "gun sound" was the pressure wave produced when the exploding propellant emerged from the barrel and could be detected by a suitable microphone. There was at this time in Bragg's unit, a Corporal Tucker who, before the war, had worked at Imperial College on the cooling of platinum wires by air currents. To be effective, any microphone used for sound ranging had to be sensitive to the very low frequencies

[1] Howitzer: A gun which fires its shell on a much higher trajectory than a field gun and has a relatively short barrel (less than 30 times the bore). The plunging trajectory of the shell makes the howitzer an ideal weapon for use against fortifications.

of the gun sound (from a few Hertz to a few tens of Hertz) and relatively insensitive to higher frequencies. Using the principle of the Helmholtz resonator (see Appendix B), they stretched a thin wire across a hole cut in an ammunition box, and the Tucker Microphone was born. By the end of WW1, 34 sound ranging sections were detecting gun sounds in this way [2].

In 1920, it was decided that survey, flash spotting and sound ranging should be transferred to the Royal Artillery in a single Survey Company, RA. All but one of the officers who had been involved in flash spotting and sound ranging had left the service, most returning to academia. The one officer who remained joined the Air Defence Experimental Establishment and it is noted in [2] that his capabilities were not highly regarded by his ex-colleagues in sound ranging! Technical developments slowed dramatically in the inter-war years and the equipment produced for sound ranging was poor. It seems that much of it was abandoned in the withdrawal through Dunkirk, which is perhaps just as well. With the outbreak of WW2, Hemming was back in uniform heading Flash Spotting and Bragg had, from the late 30s, been advising the government on Sound Ranging.

In 1939, Survey Regiments were organised with three Batteries, one each for survey, flash spotting and sound ranging but during the war this changed to a two Battery arrangement, each Battery containing three troops for the three duties. The 1943 regimental establishment shows 31 officers, 4 warrant officers, 45 senior NCOs, 124 junior NCOs and 404 gunners/privates – a total of 608 men. There were in addition 14 attached REME other ranks operating a Light Aid Detachment, led by a Warrant Officer [3]. By the end of World War 2, there were nine Survey Regiments in action.

2.1 Maps and Grids

It was mentioned above that artillery survey, which formed part of the work of the Survey Regiment, RA, involved map making. It may be useful, before moving on to Flash Spotting and Sound Ranging, to spend a few moments considering this in more detail, because survey was the basis of the rest of the artillery's operations.

The generally accepted geographical framework of measurement is latitude and longitude but unfortunately this is not particularly useful on the battlefield, in particular because the lines of longitude converge at the poles and are therefore not parallel to each other. The most convenient coordinate system for use by artillery is a rectangular grid effectively overlaid on a standard map. The grid system is defined in terms of a number of parameters including the latitude and longitude of the grid's origin, the units of measurement (yards in the British Army until relatively recently) and the orientation of the grid with respect to North. Note that because of the curvature of the earth's surface, a rectangular grid cannot be sustained over great distances.

For artillery purposes, an error of less than one metre in position and the same in height above some reference (usually mean sea level) is required. But it is no good applying a grid to an inaccurate map, and maps were a problem in both World Wars – in WW1, some of the French maps were based on a Napoleonic survey! However, the German maps of the Western Front were also conveniently inaccurate. In WW2, the British view was that the German maps of Germany were unsuitable for military operations! Where necessary therefore, new maps had to be created by aerial photography and surveying on the ground, although in 1944, a set of modern German maps of Holland fell into Allied hands and made it unnecessary for further work to be done on our own versions.

Artillery survey fixes features on the landscape, as well as the guns, observers, etc., in relation to the grid, allowing any position to be quoted in terms of x and y co-ordinates (known as *Eastings* and *Northings* respectively). This is initially done by regimental surveyors who are part of the artillery regiments, and progressively improved by the men of the Survey Regiment, as time permits. In WW2, it was the job of the Gun Position Officer (GPO) to know exactly where his unit was at all times while on the move, so that his guns could deploy at short notice and with the expected positional accuracy. The aim of the subsequent refinements carried out by the Survey Regiment was to bring all the guns in first a division and then a corps and finally across the whole theatre into known relationship. In this way, large concentrations of fire from numbers of batteries could be accurately called down on particular targets.

3 Flash Spotting

Now we turn to the first of the two methods of locating enemy artillery which remained unchallenged until the arrival of SHF radars late in the Second World War and the dramatically increased speeds of calculation made possible by the electronic computer from the 1960s. It may be difficult for a modern reader to appreciate just how big the computer revolution has been and to realise that fifty years and more ago, *all* scientific and engineering calculations had to be done by means of slide rule and printed mathematical tables. The theory and practice of artillery location is based on science and mathematics, particularly trigonometry. Generally, everything had to be worked out manually and plotted on a variety of charts. And yet, it is recorded that by the end of WW2, a located hostile battery could be fired on before its shells had fallen! [1]

3.1 Principles and Deployment

The principles of flash spotting are simple; two or more observers take bearings on a gun flash and, providing the positions of the observers are accurately known, some simple trigonometrical calculations will fix the position of the gun. For those interested, the theory of this calculation is shown in Appendix A.

Today, a computer with a suitable program and fed with the observer positions and the observed bearings would produce the hostile gun's position in microseconds, using calculations roughly like those in Appendix A. However, before computers these calculations would have been onerous, slow and open to errors. Happily there was a much better way – by plotting. Given a map overlaid with a grid on which the positions of the observers were accurately marked, observed bearings could be plotted and their intersection would identify the hostile gun's position, at least in theory.

Much valuable information on the conduct of flash spotting can be found in the 1937 publication "Manual of Flash Spotting" [4] which, given its date, was probably produced under the guidance of Harold Hemming as the country moved towards rearmament. It is also a reasonable assumption that it contains descriptions of the best practices worked out during WW1 and it is known that it was still current in 1939[2].

Each flash spotting troop could deploy up to four observation posts but normally used three, which was the minimum permitted number. Although the principles are simple, the practice is less so and it was found that using just two observers was unreliable. Indeed, the observations from up to six posts could be combined but that appears to have been rare.

Flash Spotting posts had to be manned and with their observers alert twenty four hours a day, seven days a week in action. Given some of the locations suggested, this cannot have been easy.

> . . . it will be evident that the sites which best fulfill the conditions are commanding positions some 1,500 to 2,000 yards from the front line. A flash spotting post requires a large arc of view, if placed further forward than this, it will be difficult to conceal, and the enemy will be able to disturb the observer with machine gun and rifle fire. Accurate observation can hardly be expected of an observer under such conditions ([4] p 52).

That must rate as one of the greatest understatements of all time! It is also interesting to note that most assumptions in the Manual favour position warfare and there seems to have been little thought that flash spotting could be employed in mobile warfare. For example, on the tactical employment of flash spotting in the advance:

> As long as the advance continues without halts, there will be few, if any, opportunities for action by the group ([4] p 74).

Observers clearly had to take accurate bearings on the flashes they saw, both in azimuth (in the horizontal plane) and in elevation[3]. Highly sophisticated optical instruments were provided

[2] An amendment dated March 1939 exists.

[3] Up to this point, we have assumed that the landscape is flat, but this is obviously not always the case. However, for the fixing of hostile gun positions, height is not an issue as bearings are all that are needed. Some other uses of flash spotting, such as the plotting of air bursts when ranging friendly guns, do require an elevation reading. These

for taking the bearings (see 3.2 below), but the big problem in flash spotting is making sure that all observers are looking at the same flash, particularly at night.

(a)

(b)

Figure 1: Instrument, Flash Spotting, No4 Mk.II

3.2 Spotting Instruments

The optical instrument used by flash spotters throughout the inter-war years and WW2 was essentially a set of accurately calibrated binoculars known as the Instrument, Flash Spotting No 4 (which implies that there were at least three earlier versions, of course). Figure 1 shows front and rear views of the instrument, of which each observation post was equipped with two. Aside from accuracy and the ability to exactly calibrate bearing and elevation, the instrument had quick release arrangements which would allow the observer to quickly swing it to a different bearing to begin making detailed observations on a different gun.

It is noted in the Manual [4] that flash spotting posts should not only observe gun flashes, etc., but must take every opportunity to make general observations on troop dispositions and movements in the their area of observation. This information would be passed back to headquarters in regular reports for which a form was provided. In order to assist in this intelligence gathering work, a post would also be equipped with ordinary binoculars and a telescope.

3.3 Communications

Usually, flash spotting posts were connected to the flash spotting headquarters by line. The process of surveying a post into the grid was presumably fairly lengthy but, of course, essential for operation of the post, so there would have been at least a certain amount of time to lay lines. The Manual [4] lays stress on the use of what appear to be fairly permanent structures for observation posts and their construction would have added to the preparation time, allowing even more time for line laying. How accurately that describes the actual conditions in WW2 is not currently known and hints about the use of R/T in various sources might be taken to indicate that flash spotting posts were in practice put into operation much more quickly than may be inferred from the Manual [4].

In May 1916 Hemming, knowing that the most essential feature of successful flash spotting was to ensure that all observers were concentrating on the same flash, invented the arrangement which was to be used from then, as far as is known, until the eventual demise of flash spotting. He realised that each observer could be given the ability to signal to HQ whenever a flash was seen, by means of a telegraph key, using the existing telephone lines from the posts to the HQ. Bragg suggested the means by which this might be achieved, a sensitive relay, and while on

other uses of Flash Spotting are not further considered in this article as they have little bearing on the communication requirements.

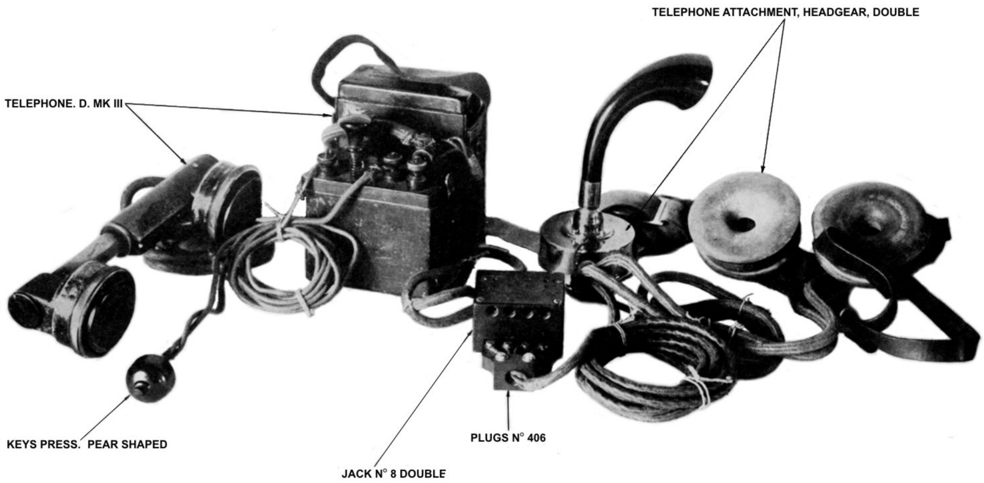


Figure 2: Flash Key and flash Spotting Post Telephone Equipment

leave, Hemming bought some relays, keys and buzzers in London's Lisle Street[4]. He returned to France after only four days of a fortnight's leave (his fellow officers thought he was mad) and constructed a prototype device. Subsequently, the GPO produced the design as the "Flash and Buzzer Switchboard" which was used with a modified standard "buzzer" field telephone.

It should first be explained that buzzer telephones were field telephones without a bell which used a simple buzzer at the calling end to make a noise in the headset or receiver of the telephone at the receiving end (generally a single headset called a watch receiver was provided, in addition to the handset). The telephone used in flash spotting was originally a modified version of the Telephone Set, D, Mark III [5] but that may have been replaced later in WW2. The "D III" telephone with the flash spotting modifications is shown in Figure 2. The modifications were:

1. A "flash key" was fitted between the L and C terminals of the telephone. This was originally a spring loaded bell push type of switch as shown in Figure 2 but it will be seen from the picture of the Instruments, Flash Spotting in Figure 1 that a toggle switch is fitted to the instrument stand and this could be substituted for the bell push. The function of the flash switch was to complete the DC circuit through the telephone by shorting out the blocking capacitor which was wired between the L and CL terminals. This operation is further explained below.

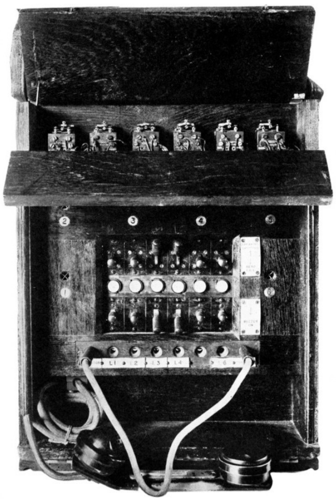
2. In the standard DIII telephone, the handset and the watch receiver are wired directly to terminals on the main unit. For the flash spotting version, the watch receiver is directly wired, along with a double four-pin jack socket, the Jacks, No 8, Double. The hand set is supplied with the appropriate four-pin plug, the Plug No 406 (used in numerous later telephones and, in fact, for connecting teleprinters).

3. An additional headset (Telephone Attachment, Headgear, Double) was plugged into the other socket in the double jack. This headset, which carried a breast microphone, was normally worn by the observer.

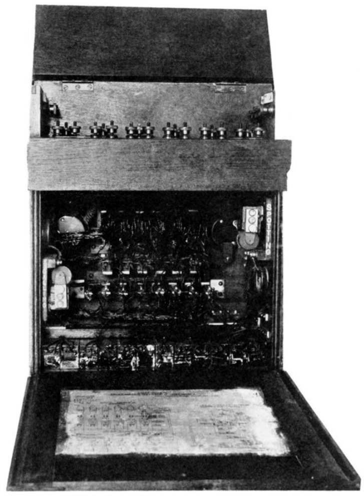
The buzzer telephones at the observation posts were connected to the Flash and Buzzer Switchboard (see Figures 3 and 4) which, apart from use as a standard six line exchange, allowed the observation post to indicate to the Flash spotting HQ exactly when a flash was observed. Each of the switchboard's six lines were equipped with:

- A watch receiver, also known as a "hooter" to receive an incoming buzz call.
- A black, three position speak and ring key.
- A red flash buzzer key.

[4]To become famous in the 50s and 60s as the centre of the surplus electronics trade.



(a) Front



(b) Rear

Figure 3: Flash and Buzzer Switchboard

- A 15v battery and flash relay.
- A 4v lamp.
- An audio jack socket for connecting an observation post circuit to an external line.

In addition, the switchboard contained a handset and speech circuit with battery, a battery for operating the lamps, a sending buzzer for calling posts, a receiving buzzer operated by the flash switch at any post and terminals for connecting an external line or, more usually, a standard switchboard.

The operation of the switchboard was similar to that of normal switchboard if the black key only is considered. The normal position of the key is horizontal, when an incoming buzz call would operate the appropriate hooter. To answer the call, the operator would lift the black key, connecting the speech circuit and disabling the hooter and lamp. To call a post from the switchboard, the black key would be pressed down against its return spring and released. This action would send a buzz call from the sending buzzer to the post. Finally, to connect several posts together, their black keys would be lifted.

The red keys had a simple function related to the reception of flash calls - only when a post's red key was down would operation of the flash switch at the post cause the appropriate flash relay to close, lighting the lamp and operating the receiving buzzer.

3.4 Flash Spotting in Action

The operation of flash spotting communications will best be described by outlining the procedure used to obtain a position. The following is paraphrased from [4] and represents the situation at the beginning of World War 2 – procedures before and after that date will no doubt have differed, but probably only in detail. First, the two main plotting tools, the Concentration Board and the Parallel Ruler Board[5] must be mentioned.

The Concentration Board was a rectangular map board with either a map or a standard grid mounted on its surface. On the map or grid were plotted the accurate positions of the flash spotting posts in use, as well as all hostile positions already found, all suspicious areas, etc. Each observation post was plotted in a different colour and corresponding to each post, a coloured pre-printed arc was stuck to the board, extending 10 degrees on each side beyond the field of view of the post[6]. A pin was carefully driven into the board at the location of each post

[5] There was a third board, the Large Scale Plotter, but as this was only used for very accurate location and followed on from the use of the other boards, it is not covered further here. A full description of its theory and use is given in [4].

[6] These pre-printed arcs were subdivided to 10 minutes of arc and were provided in 50cm, 60cm and 70cm radii, so that they could be arranged to avoid too much crossing on the board. Once positioned, the arcs were labelled every 5 degrees, with zero corresponding to grid North.

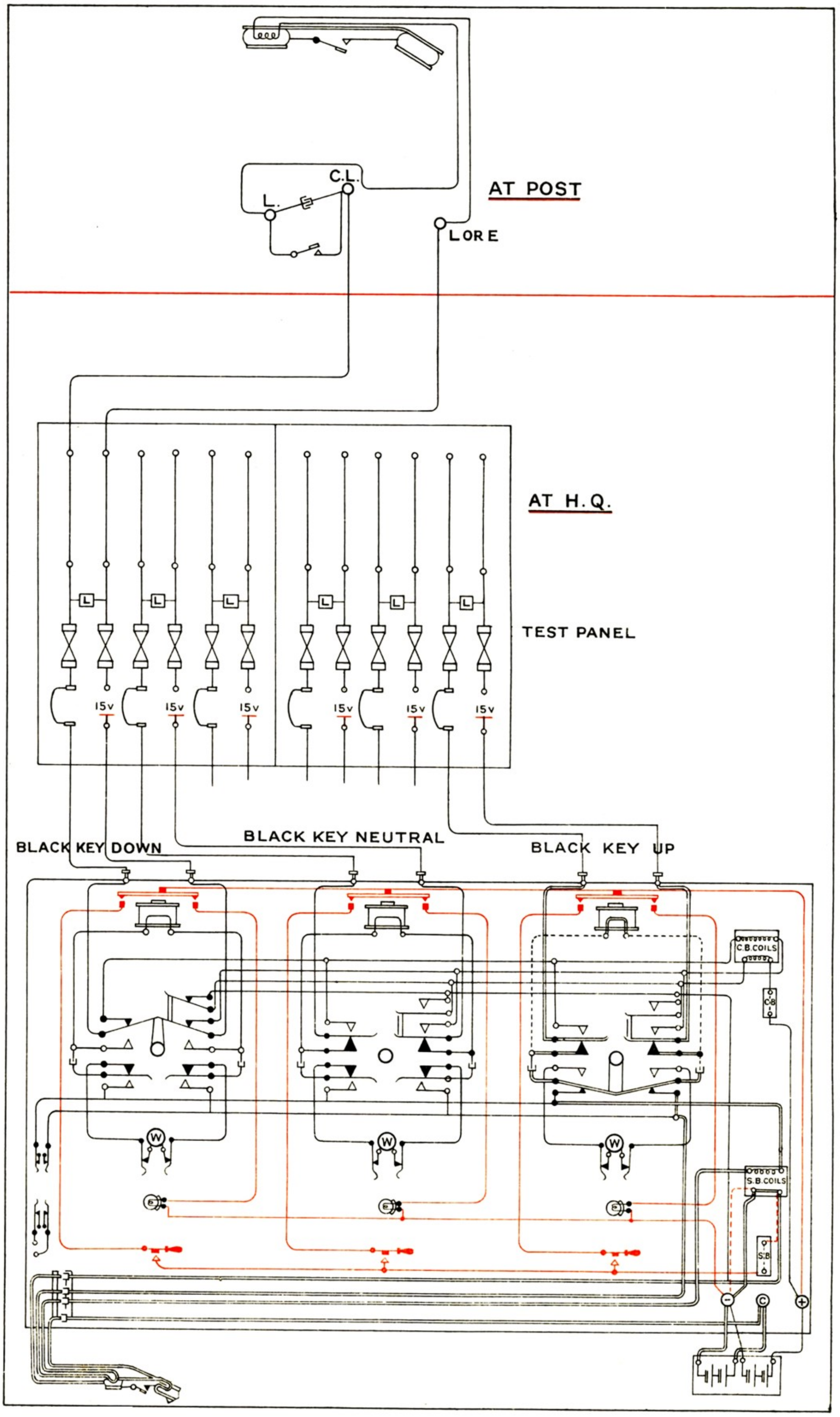


Figure 4: Flash and Buzzer Switchboard - Circuit

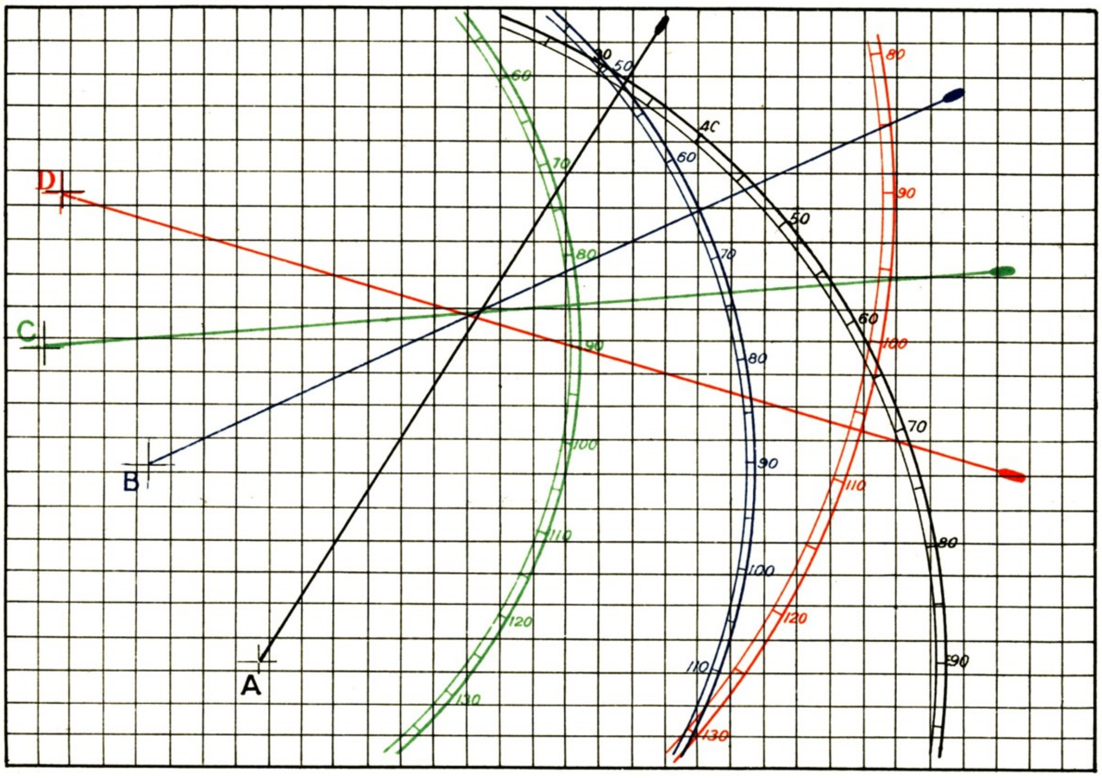


Figure 5: Concentration Board

and a thread (normally gut) was attached it. The other end of the gut thread was attached to a lead weight, coloured to match the post's colour, so that the thread could be stretched across the board to indicate a bearing on the post's arc. An example of a concentration board is shown at Figure 5.

The Parallel Ruler Board (see Figure 6) was again a map board with a standard grid ruled on it, but this time a circle of as large a diameter as possible and divided every 10 minutes of arc, was added. The positions of the posts were accurately plotted but no pins or threads were used. Instead a parallel (or "rolling") rule was used to set a post's observed bearing from the centre point of the circle and the rule was rolled across to line up with the post's position. Thus the bearing from the post could be accurately plotted without the use of individual arcs. Obviously, the intersection of bearings from several posts gave the location of the hostile gun or battery – provided that all the posts had been observing (or "concentrating" on) the same flash. The purpose of the Concentration Board was to ensure that happened, as will now be described.

The initial setup on the switchboard when engaged in spotting was all black keys up and all red keys down. When an observer saw a flash, he laid his optical instrument on it and reported it by pressing his flash switch, giving a buzz and a lamp signal at HQ. The HQ operator would request the bearing which would be laid out on the concentration board. If the thread passed through a known position, the plotter would direct the other posts to watch on the bearings from their posts to the position. If the thread passed through more than one known position, the plotter would direct at least one post to watch each known bearing. Then, if the position was indeed known, this would be confirmed by the simultaneous[7] lighting of more than one lamp.

Alternatively, if only one lamp was lit on each round, the position was previously unknown and a search procedure was initiated. Each post, other than that reporting the flash, would be given a sector to watch, based on an approximation of the range from the first post, from the "flash to bang" time – not at all accurate, as mentioned earlier. The post originally reporting the flash would then "lead" the operation and all red keys, except the key for that post, would be raised to the horizontal position. This disabled the flash keys at the other posts, but allowed

[7]In fact, the lighting might not be quite simultaneous, particularly if observing smoke puffs during the day as the smoke could be affected by wind.

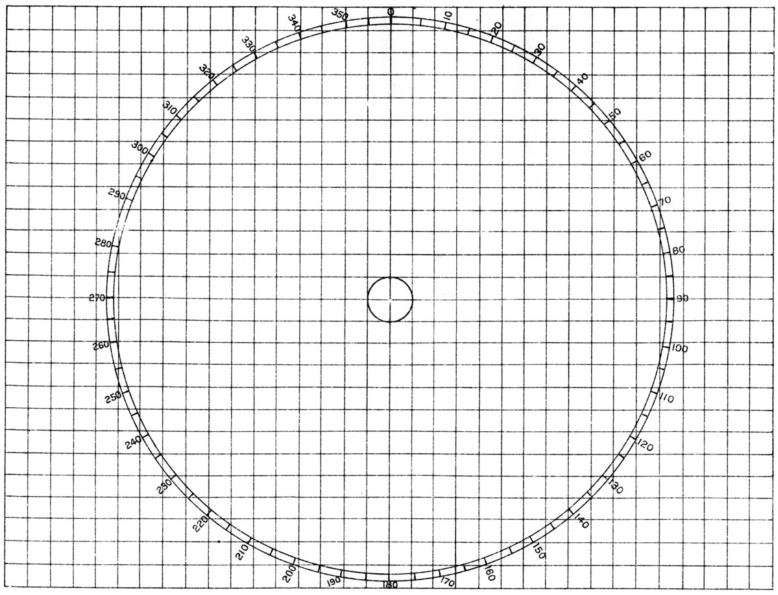


Figure 6: Parallel Ruler Board

them to hear the first post's flash report as a buzz.

If this had been properly controlled, one of the other posts would soon see a flash corresponding to the original report and would send bearings to HQ. The red keys would then be returned to the down position and synchronisation could be checked by the HQ. Assuming the plot on the concentration board indicated that a concentration had been achieved, the bearings would be transferred to the parallel ruler board to give an accurate location for the hostile gun or battery[8].

3.5 Use of Wireless

It is clear from [4] and earlier versions of this handbook, that line with the Flash and Buzzer Switchboard was the normal means of communication although a very short Appendix 4 "Use of Wireless" mentions that wireless can be used in mobile warfare when there is insufficient time to lay lines; unfortunately no detail is given. Correspondence in the National Archive indicates that during the procurement process of the Radio Link, SR Mk.I (see 4.7.2 below), this was to be the equipment used for Flash Spotting wireless communication. Thereafter, it must be assumed that the successor system, Radio Link, SR Mk.II was also used. Training pamphlets from 1954 [6] and 1956 [7] describe the full wireless procedure used during Flash Spotting operations.

3.6 Conclusion

Flash spotting was, with hindsight, the most obvious development in artillery location once indirect fire became the norm. It was based on simple scientific principles which made it a particularly accurate tool – once proper instruments were designed and procedures worked out. All of that, of course, was thanks to the work of Harold Hemming during the two World Wars.

Some time after the end of World War 2, Flash Spotting was abandoned, probably for a number of reasons, including better flashless propellants, longer ranges, the use of radar and, possibly most importantly, the advent of fire and run mobile artillery operations. In 1948 [8], two Flash Spotting or "Observation" troops, each capable of fielding four OPs, were part of the Corps "Observation Regiment", as the Survey Regiment was then known. In a document of 1955 [9], a Flash Spotting troop is noted as part of the Locating battery of the Corps Locating Regiment, in another change of name. In both cases, the regiment also contained Survey, SR and Radar units. However, in the Royal Signals Pocket Book of 1954 [10], there is no mention of flash spotting in the Corps Locating Regiment wireless diagram. We must therefore assume that during the latter half of the 1950s, Flash Spotting was disappearing.

[8]In many cases, the plotting accuracy was sufficiently good that individual guns in a battery could be located.

4 Sound Ranging

The location of hostile guns from the sound they produce when fired is, in comparison to flash spotting, more complex in both theory and practice. To begin with consider the sound itself, actually one of three sounds made by a firing gun:

- Gun Sound – the noise made by the expanding hot gas, product of the ignition of the propellant, as it bursts from the barrel immediately behind the shell. Gun sound travels at the speed of sound – 337.6 metres per second, and is the sound used in sound ranging.
- Shell Sounds – noises made by the shell as is flies through the air. If the shell is travelling supersonically, there will also be a shell wave or "sonic boom". Because the shell does not travel at a known speed, any attempt to use shell sounds for ranging will fail.
- Shell Burst – the noise made by the exploding shell. Somewhat similar to gun sound, it can confuse the situation. The shell burst may, of course, be used for ranging our guns, although this will not be considered further in this article.

Unlike the gun flash, which is light and travels almost instantaneously from gun to observer, gun sound is a pressure wave which travels much more slowly. This is both the most useful feature in that the whole sound ranging operation replies on measurable travel time differences, and the source of a good deal of complication.

The boom of the gun sound travels as an expanding spherical pressure wave at a nominal speed of 337.6 metres per second. However, this speed only applies in still air of average humidity at a temperature of 50 degrees Fahrenheit! We will consider this issue after a discussion of the general principles of sound ranging.

4.1 Fundamentals

We will assume for now that the speed of sound is a constant. The momentum achieved by the gases emerging from the barrel is such that the gas bubble will expand past atmospheric pressure and will then "recoil" back through atmospheric pressure and would continue to oscillate for ever, were it not for the fact that the wavefronts produced carry away energy. In practice, it takes only one or two cycles of compression and rarefaction for the oscillations to die away. The result is a highly damped oscillation with a very low fundamental frequency – below 20Hz, down to perhaps 2 or 3Hz. However, the energy contained in the wavefront is very large (hence Bragg's observation that he was lifted off the privy seat by the gun sound from a local gun) and thus gun sound can be detected at great distances.

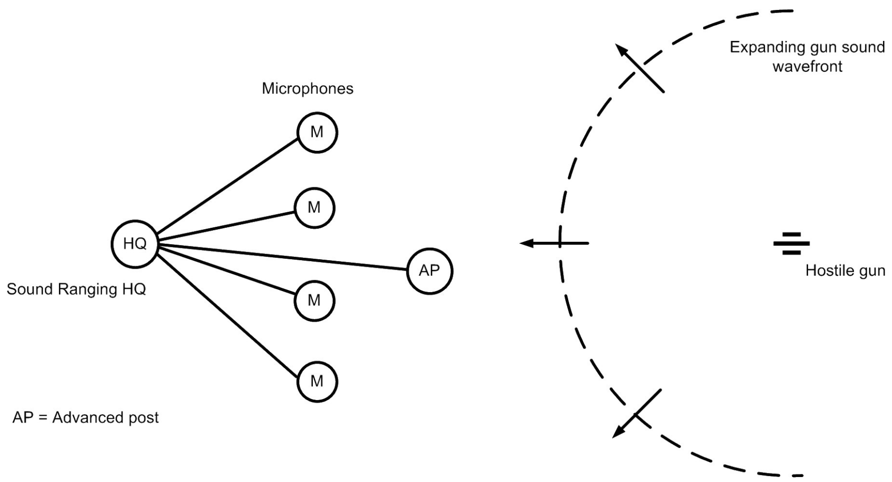


Figure 7: General arrangement of SR microphones.

Sound Ranging relies upon measuring the time differences between the times of arrival of the gun sound at a number of accurately surveyed microphones of the Tucker hot wire type (see Appendix B). The general arrangement is as in Figure 7 which shows four microphones laid out roughly in a line, a sound ranging HQ, where the computation and plotting are done, and an Advanced Post which controls the observation, as will be described later.

The following explanation of the principles of SR is based on the information given in the Manual of Sound Ranging (1937) [11] but is deliberately simplified. Those readers who wish to investigate the mathematics in detail should read the Manual or any instructional work dating from before around 1960[9].

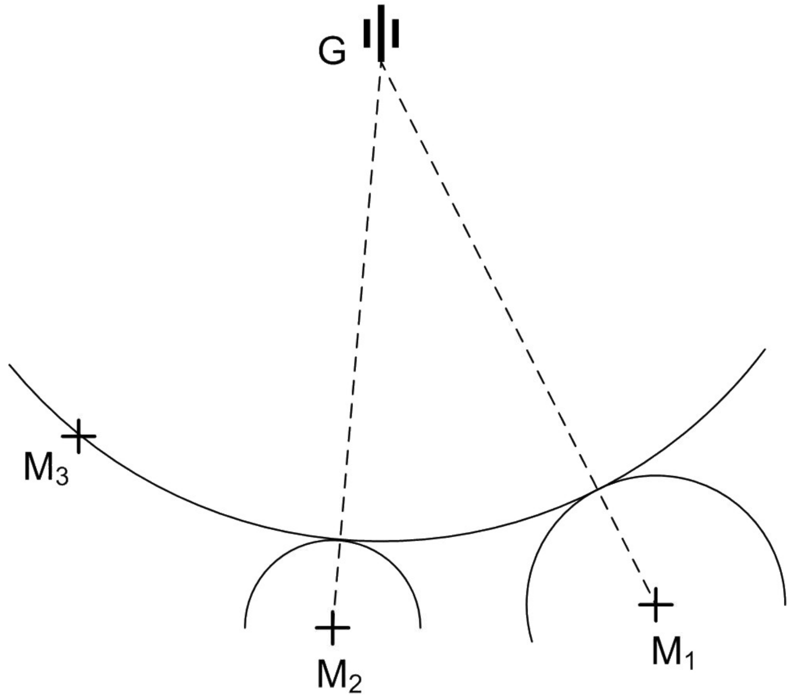


Figure 8: Arrival timings

Consider a simple arrangement of just three microphones as shown in Figure 8. The sound from the gun G arrives first at microphone M_3, then at M_2 and finally at M_1. If the speed of sound is V, the arrival time at M_3 is T_3 and the arrival time at M_2 is T_2, then M_3 is closer to G than is M_2 by $V(T_2\text{-}T_3)$. Similarly using M_1 and T_1, M_3 is closer to G than M_1 by $V(T_1\text{-}T_3)$. Graphically, as in Figure 8, circles showing these differences in distance may be drawn around M_2 and M_1. Now it is clear that G must lie at the centre of the circle which passes through M_3 and touches the two difference circles, as shown.

Unfortunately, drawing the circle centred on G accurately is not so simple[10]. Having drawn the difference circles to scale on tracing paper, it is possible to graphically find the circle centred on G with a set of concentric circles drawn on a sheet of paper, placed under the tracing paper. This method was in fact used, probably in WW1, but may not have been particularly accurate and was certainly quite cumbersome.

There were other, more accurate methods, most of which relied on some more complicated geometry. If we consider M_3 and M_2 only, there are an infinite number of circles which pass through M_3 and touch M_2. However, the centres of these circles lie on a hyperbola which is a "*plane curve such that the difference between any point on the curve and two fixed points is a constant*". This complicated statement describes a curve which looks like those in Figure 9. The foci of the hyperbola, incidentally, are the positions of the two microphones. The circles defined by M_3 and the difference circle have centres which lie on a different hyperbola and the gun is located at the intersection of the two hyperbolas. In practice, at least three hyperbolas (four microphones) were required to provide an accurate location, mainly because localised atmospheric irregularities would produce small errors.

There were several plotting methods based on hyperbolae, the most obvious of which was to

[9] After that date, and particularly in more modern times, a different principle will most likely be found. This later arrangement, the three microphone group, is described below.

[10] In fact, to produce Figure 8, it was necessary to start with that circle and then add the arcs centred on M_1 and M_2

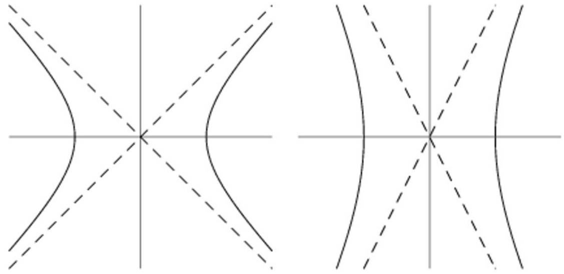


Figure 9: Hyperbolas

draw a family of hyperbolae in different colours for each sub-base [11]. The appropriate hyperbola for the time difference measured was selected for each sub-base and their intersection should give the gun's location. However, this required three or more sets of hyperbolae in different colours and produced a very confusing plot. It seems that between the two World Wars a method based on hyperbolae, but much much practical in operation was developed. This used a chart known as the Ostroid Graph containing only two sets of curves but at present, no example of this can be found.

A third method, involving asymptotes and developed in World War 1, appears to have been used in World War 2 for manual plotting. Asymptotes are the straight lines to which the hyperbola approaches, but never meets, even if extended indefinitely. They can be regarded as tangents to the curve at infinity and are shown on Figure 9 as dashed lines. Since the distance from the microphones to the gun is normally much greater (typically four or five times greater) than the length of the sub-base, the appropriate asymptote can be used as an approximation to the hyperbola for each sub-base. Being straight lines, the asymptotes are much easier to work with than hyperbolae.

The principle behind the production of asymptote scales is outlined in Appendix C. In practice, the angle made by the asymptote to the line of a sub-base is dependent upon the difference in sound arrival time for the microphones at each end of the sub-base. A gridded board was set out with the surveyed positions of the microphones and around the edge of the board, a set of time difference scales, one for each sub-base. A string (normally gut) was pinned to the centre point of each sub base and a lead weight was attached to the other ends of each string. The strings could then be laid across the appropriate points on the scales and the intersection would give the gun location. A World War 1 example set out for a six microphone, curved, regular base is shown at Figure 10.

4.2 Corrections

At this point we must return to the speed of sound and the reasons why it cannot be assumed to be constant. A number of meteorological factors must be taken into account and in Sound Ranging, as in all artillery, regular and accurate met. reports (commonly referred to as "meteor" reports) are essential[12]. Since the measured time differences were inversely proportional to the actual velocity of sound, corrections were converted to, and applied as a percentage of the differences.

The factors which must be included in the corrections are listed below.

4.2.1 Barometric Pressure

Providing the temperature remains constant, Boyle's law states that the product of the volume of a given mass of gas and its pressure is a constant. The velocity of sound (V) is given by:

[11] The length of the line of microphones is known as the "base" and the distance between an adjacent pair of microphones is known as a "sub-base".

[12] The flight of a shell is affected by a large number of factors, from the wear on the barrel's bore to the temperature of the propellant. However, most of the corrections made are based on the meteor report and meteorologists have long been essential to the operation of artillery units. The theoretical basis for meteorological corrections in sound ranging was originally published in early 1918 by Harry Bateman, one of Bragg's colleagues [12]. In modern times, automated met. stations provide continuous meteor data to the gun control systems.

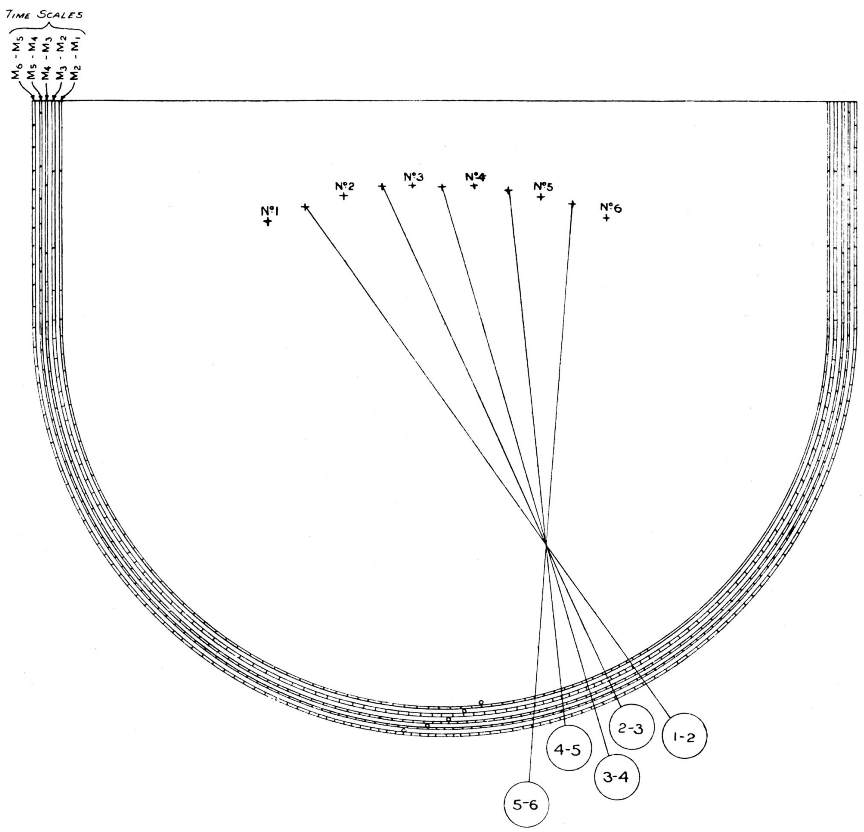


Figure 10: Asymptote Plotting Board.

$$V = \sqrt{\frac{kP}{d}}$$

where k is a constant, P is the atmospheric pressure and d is the density of the air.

So from Boyle's law, a change in pressure is accompanied by a change in density such that the changes cancel out and thus barometric pressure changes make no difference to the velocity of sound.

4.2.2 Humidity

On the other hand, the density of the air varies with humidity and a correction to the velocity of sound should therefore be made for humidity. However, the correction would be very small and in practice it was customary to take 337.6 metres per second as the velocity in still air at 10°C, rather than 337.16 metres per second, which is the velocity in dry air at that temperature. This assumed that the air has a constant humidity but errors introduced by this assumption are negligible[13].

4.2.3 Temperature

Sound travels faster in warm air than cold, the velocity of sound being proportional to the square root of the absolute temperature. Appendix D provides the theoretical basis for the use of a time difference correction of +0.18% per degree Centigrade above 10° and -0.18% per degree below that temperature. In Fahrenheit, these approximate to ±0.1% per degree above/below 50°F.

[13] This explanation comes from [11] and it is likely that in 1937, when it was written, no account was taken of operation in very dry (e.g. the Western Desert) or very humid (e.g. Burma) conditions. As yet, no evidence on this has come to light.

4.2.4 Wind

Sound, being a pressure wave, can be affected by wind – for example, a uniform wind blowing in the same direction as the sound is travelling from gun to microphone will increase the sound velocity by an amount equal to the speed of the wind. But, of course, such a uniform "following" wind will only act in this way for one microphone - the others will experience a lesser effect. In addition, not only are winds not normally uniform but they vary with height, resulting in an effect shown in cross section in Figure 11 which, as will be readily appreciated, is complex. It would appear that a set of graphs was produced as a result of experiment and that these were used to apply corrections to the time differences, based on the strength and direction of the wind at each microphone.

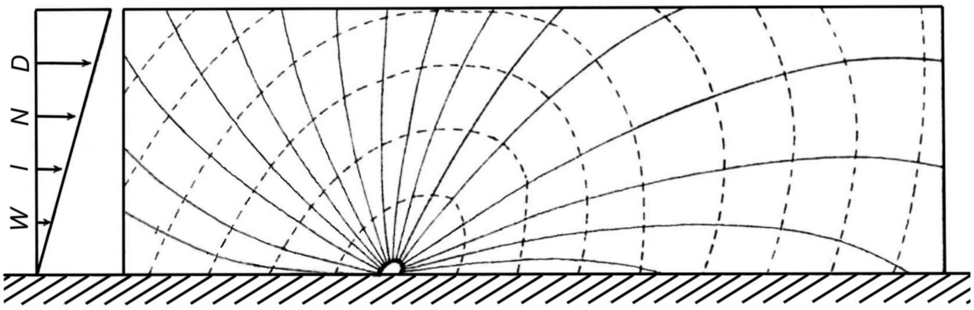


Figure 11: Effect of Wind

4.3 Measurement of Timing Differences

Up to now, it has been made clear that sound ranging relies on the differences in time between the appearances of the gun sound at each microphone in the SR base, but there has been no indication of how these differences were measured. Although at present no corroborating evidence can be found, it is likely that Bragg developed the original recording arrangement of a string galvanometer, a light source and a light sensitive recording film.

The "string", or "Eindhoven" galvanometer was invented Willem Eindhoven, professor of physiology at the University of Leiden and was originally used for the display of rapidly occurring transient changes of current, such as produced by the heart muscles[14]. The instrument used a conductive "string" under tension in a magnetic field which, when a current is passed through it, would deflect. Expanding the concept produced the "harp" galvanometer where a number of thin wires under tension (six in SR) were placed in a strong magnetic field. When a current passed through any of the wires, it would deflect and this deflection could be made to interrupt a beam of light.

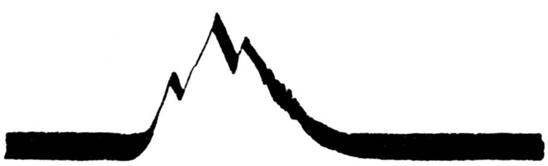


Figure 12: A "Break".

In practice, light was focussed through a slot, past the wires of the harp and onto a moving, light sensitive film, which showed a set of six straight lines when no current passed through the wires. If the microphones of the SR base were connected to the wires of the harp, the arrival of a gun sound would be seen on the recording film as a deflection of the image of the harp wire, known as "break" – see Figure 12. If the film travelled at a known, constant speed, then there

[14]Eindhoven was awarded a Nobel Prize for his work on the electrocardiogram in 1924

was a direct relationship between length on the film and time. Therefore the time differences could be read as lengths between deflections on the recording film and translated into time intervals. In addition, the shape of the break could be used to provide other information such as an estimate of calibre.

4.4 The Microphone

Having developed from the prototype made out of an ammunition box, it is reported that the microphone was

> "... similar in size to a dustbin, but double skinned ... dug in with just the lid protruding, covered with coco matting and [with] earth sprinkled on top" [13].

Diagrams from the period however tend to show the microphone unit to be roughly as wide as it was high, so a "half dustbin" might be a better description. A number of arrangements were used for covering the microphone from the coco matting to little canvas tents, but the essential feature was that it had to be protected from the direct affects of moving air, which would have tended to desensitise it or add "noise" to the wanted signal.

There are indications that the original experiments used the galvanometer strings connected at the balance point of a bridge containing the microphone (which is essentially a variable resistor) with a balancing resistor and two sources of EMF as shown in Figure 13. This is consistent with the frequent use of the Wheatstone Bridge for measurement and the connection of galvanometers in bridges during the early part of the 20th century.

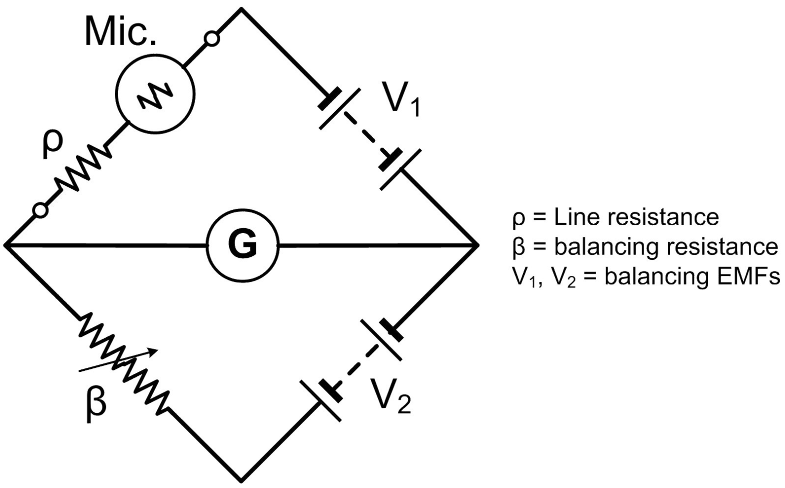


Figure 13: Bridge Connected Microphone

It seems that the bridge arrangement was used throughout the first World War but in 1921, perhaps with the use of radio in mind, a transformer was designed to provide a more stable and easily adjusted connection. The microphone's varying resistance in the presence of gun sound gives rise to an alternating current at the balance point of the bridge, albeit a very low frequency AC, requiring careful transformer design [14]. Figure 14 shows the use of a transformer (part of Recorder, SR No1 Mk.II).

The current in the microphone (normally set to between 30 and 40mA) is dependent upon the battery voltage and the resistances of one leg of each section of the attenuator, the line current adjustment potentiometer and the combined resistance of the microphone and the line. Current in the primary of the transformer is kept approximately constant by the arrangement of the attenuator sections and the whole circuit is balanced.

4.5 Recorder and Plotter

Before going on to consider the communications required for Sound Ranging, mention must be made of the destination of the microphone signals and the automated means of finding locations developed during World War 2. In contrast to the lack of surviving information on

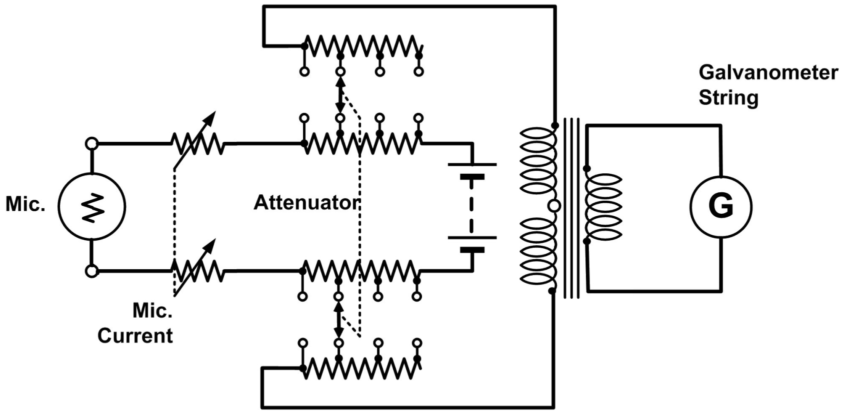


Figure 14: Transformer Connection

the equipment used in the Great War, a great deal is known about the instruments used in the Second World War. Right through the War and beyond, the recording equipment was the Recorder, SR No 1 [15]. The Mark I version of this device was developed prior to the outbreak of the war and the Mark II appeared in 1940, in turn being replaced by the Mark III later in the war.

The Recorder, SR, No 1 (see Figure 15) was a complicated device consisting of several systems:

- Transformer unit. This contained six interface circuits similar to the circuit shown in Figure 14 for connection to the microphones.
- Galvanometer. Six string Eindhoven type using 20μ copper wires mounted on springs for easy replacement and with gaps between the strings of just 0.67mm (see Figure 16). A permanent magnet produced a field at ten degrees to the plane of the strings and the optical axis so that deflections of more than 0.67mm would not cause the strings to touch their neighbours.
- A timing motor driven by a tuning fork and amplifier (see Figure 17). The motor produced marks on the recording at precise intervals which could be related to distance via the corrected velocity of sound, allowing measurement of time differences between breaks to be accurately performed.
- Optical path. A lantern provided the illumination which allowed the movement of the harp strings to be projected on to light sensitive film in a camera. The optical path was complex, since it provided magnification of the harp and the addition of the timing marks.
- Automatic developer. The "film" used appears to have been fairly standard bromide photographic paper in a roll which, after exposure in the camera, passed to a one pint developing bath containing a solution of Metol, Sodium Sulphide and Caustic Potash. From the developer, the film passed to a fixing bath containing six pints of a solution of Hypo and Metabisulphite. There was even an electrically operated knife to cut the film!

In 1944, the Recorder, Sound Ranging No. 2 was introduced and this simplified the process considerably because it used a pen recorder and a plain paper roll. A pen recorder is, of course, much less sensitive than a string galvanometer and whereas the No. 1 recorder used line current directly, the No. 2 had to use amplification to produce readable deflection. It appears that a six pen device was tried but proved insufficiently sensitive and the No. 2 recorder was a four pen system. According to a training pamphlet of 1948 [8], SR Troops were equipped with one Recorder, SR No.1 and two Recorders, SR, No.2, the former used for long base operations (up to six microphones) and the latter for short base (four microphones) location of relatively close guns.

It was assumed in Section 4.1 above, that gun locations based on the differences between arrival of the gun sounds were found by plotting and this does seem to have been generally true. However, at some point an instrument was devised to do the calculations automatically,

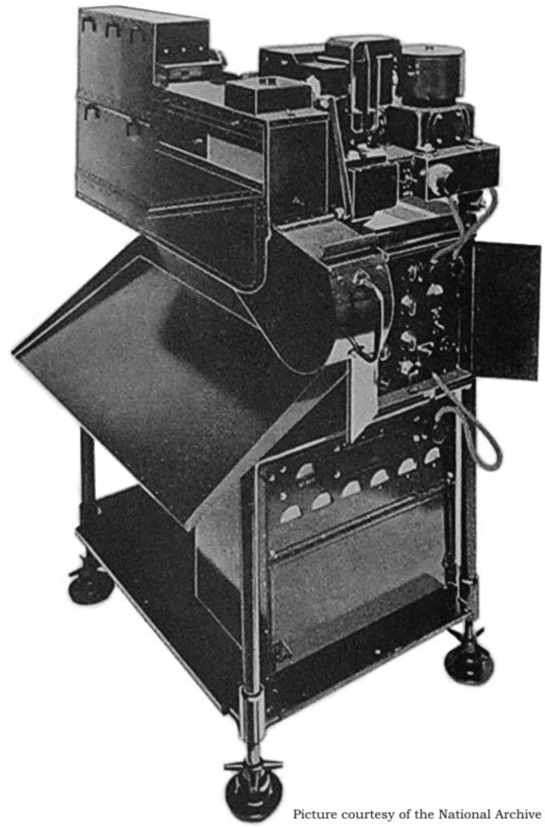


Figure 15: Recorder, SR, No 1 Mark II

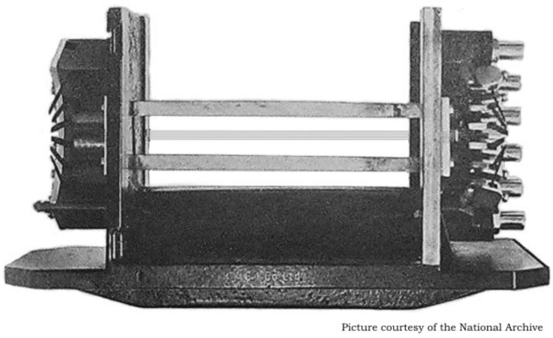


Figure 16: Galvanometer Harp Unit

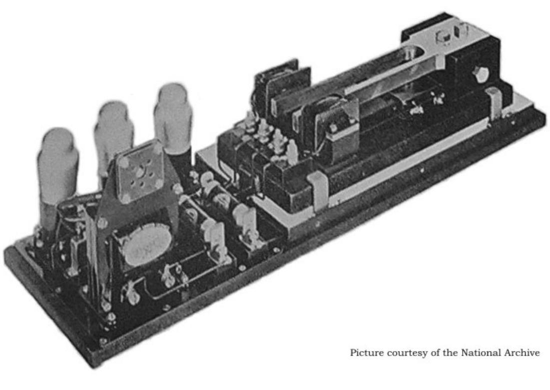


Figure 17: Tuning Fork and Amplifier

the Plotter, Sound Ranging, Mark I [16]. This device (see Figure 18) was a precision instrument which could be used with any sort of microphone base, regular or irregular, provided that the ratio of location range to base length was no more than 3:2.

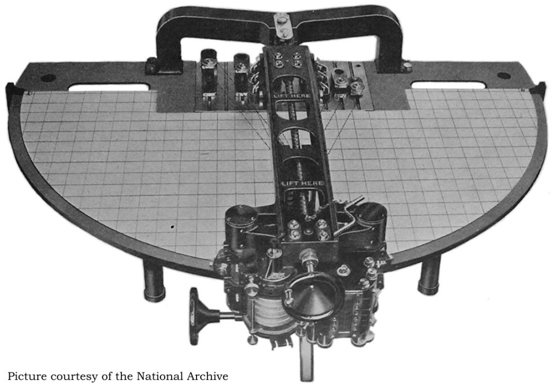


Figure 18: Plotter, Sound Ranging, Mk I

Being entirely mechanical, this instrument was extremely complex (see the drawing at Figure 19) and a full explanation of the intricacies of its operation is well beyond the scope of this article. In summary, there was a miniature but very accurate model layout of the microphones in correct relationship to each other (this model consists of the pegs which may be seen at the rear of the instrument in Figure 18 and to the left of Figure 20). A wire is anchored at each peg (which represents a microphone position) and the time differences are entered by means of setting drums (see Figure 21). Via a complicated arrangement of pulleys, a pointer was caused to travel over the gridded surface of the instrument, coming to rest at the hostile gun location, relative to the map grid.

4.6 Deployment

Establishing a sound ranging unit in the field involved laying out the line of four to six microphones normally about three to five kilometres behind the front line. In most cases, the base would be sited behind friendly artillery, thus halving the interference they produced, since the microphones could not pick up their shell waves, only their gun waves. There are computational advantages to using a straight line with the microphones regularly spaced along it, but many other layouts are possible and in any case, the topography may preclude a regular base. In general, the longer the base, the greater the location range but there are complications. Thus, a 3Km straight base had a range 12Km with an area of location which can be described as a segment of a circle of 12Km radius, centred on the middle of the base. With an 8Km straight base, the range is 15Km directly in front of the base but the shape is different, as shown in Figure 22.

Regular, straight bases were not always possible, as mentioned above, and many arrangements were used to suit the terrain and the tactical situation. Curved bases produced greater accuracy forwards, at the expense of flank performance and it was possible to use a cross shaped base where flank location was required.

Once the microphone positions had been determined following reconnaissance, the microphones would be "dug in" and connected to the recorder at headquarters. Also set up and connected to the HQ were (normally) two Advanced Posts well in front of the microphone base, with good observation of the front and any areas likely to come under hostile fire. This latter requirement was prompted more by a secondary use of SR to locate the fall of enemy shells than the location of hostile guns.

The Advanced Post (AP) played a vital role in sound ranging, controlling the whole operation. At least one AP was manned round the clock and when an enemy battery fired, the AP heard its gun sound and started the recorder at the SR headquarters. It was necessary for the AP to be sufficiently far in front of the microphone base to hear the gun sound a few seconds before it reached the base, so that the recorder could be started in time to give a clear record of the breaks from each microphone.

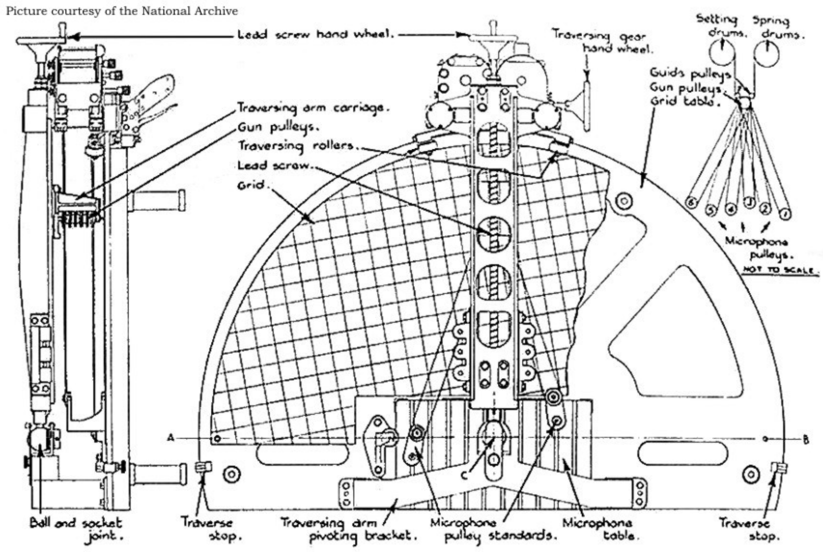


Figure 19: Mechanical layout of Plotter

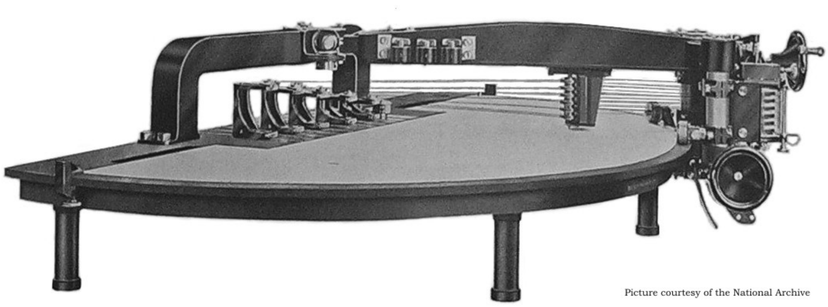


Figure 20: Left Side View of Plotter

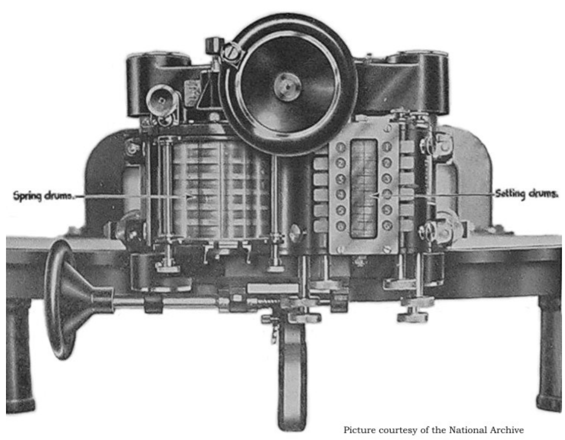


Figure 21: Plotter Settings

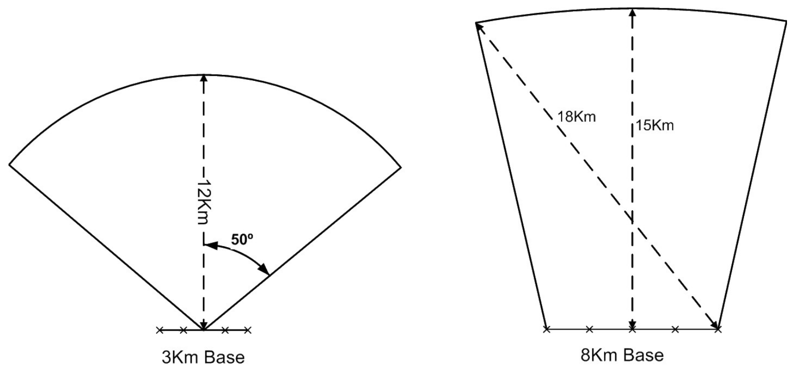


Figure 22: The effect of base length

From the inception of SR, line communication was used to connect microphones and APs to the SR headquarters. As will be explained below, wireless connection became possible once radio telephony developed but by far the most common means of connection remained line. So with microphone bases of five kilometers or more and APs perhaps five kilometers in front of the base, a considerable amount of field cable had to be laid. We have already seen that twin cable was necessary for the microphone connections, given the balanced connection required, and the same was true of the AP circuits, because of the design of the AP equipment.

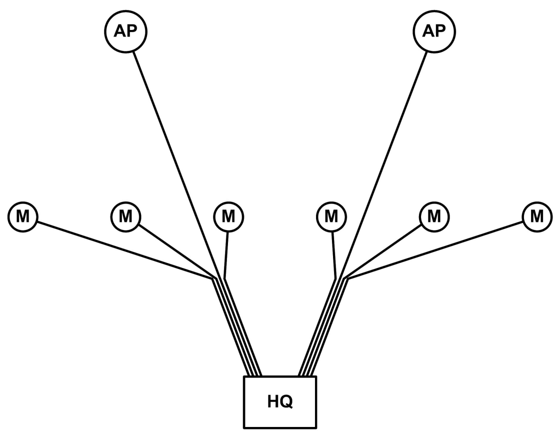


Figure 23: Possible line connection arrangement

4.6.1 Control Unit, SR

As mentioned above, the AP controlled the making of a recording by starting the Recorder at Sound Ranging HQ when the hostile gun was heard firing. The equipment used was the Control Unit, SR, shown in Figure 24.

This unit is essentially a modified buzzer telephone, similar in construction to the Telephone Type D, Mk.IV, and appears to have several components, such as the handset and the buzzer, in common with that unit. Recall that the telephone used in Flash Spotting was an unmodified Telephone type D Mk.III with an external flash switch. In the case of the equivalent SR unit, the modifications were considerable. Reference to the circuit (Figure 13) shows that it uses "phantom" signalling to operate the relay in the Recorder at SR Headquarters, while operating normally as a telephone (which the Flash Spotting telephone could not do). Current to operate the Recorder relay is derived from a 24v. battery via the switch plus a variable line current resistor and applied between earth and both legs of the line. A centre tapped bridging inductance removes AC (speech and buzz) from the Recorder switching circuit and a 0.5μF capacitor blocks the switching voltage from the telephone.

Figure 24: Control Unit, SR, Mk.II

The working instructions for the Control Unit may be of interest:

1. Unscrew screws in hinged back and see that the 3 volt (two Cells, Dry X) and the 24 volt battery (two 12 volt units) are correctly connected.
2. Plug in 4 pin plug of handset.
3. Connect lines to terminals L1 and L2.
4. Remove earth pin from sling, push into ground and connect to terminal E.
5. See that connector switch is connected and metal slide in place.
   NOTE This slide is pushed in from terminal side and prevents the wires being pulled off the terminals.
6. To prove the instrument
   (a) Short circuit terminals L1 and E.
   (b) Turn increase line Current control anti-clockwise.
       If the indicator lamp does not light press connector switch when lamp should light. Press connector switch to extinguish lamp.
7. Remove short circuit from terminals L1 and E and give buzzer call by pressing Buzz Call key. Communications should now be possible with headquarters.
8. Press connector switch to light indicator lamp then by communication with headquarters adjust Increase Line Current control by stages until line current is sufficient to switch on recorder unfailingly.
9. To adjust buzzer
   (a) Loosen collars marked lock then unscrew centre knobs to clear armature contacts.
   (b) With Buzz Call switch pressed down, advance either know until buzzer commences to operate irrespective of quality. Lock this knob then advance the other knob until a clear higher note is obtained. Lock this knob. Check adjustments by operating the Buzz Call key and readjusting if necessary. When adjusting buzzer do not force contact screws hard on to armature or buzzer will be put out of action.

It is known that the control relay in the Recorder, SR No 1 Mk.III was a "polar" relay which would allow the the AP to turn on the recorder with a single press of the control switch, with a local switch on the recorder turning it off. It would appear that this arrangement was not available with earlier Recorders and the AP operator may have had to hold the switch pressed until informed by the HQ that a recording had been received. Perhaps this is the reason the telephone had to work with the button pressed.

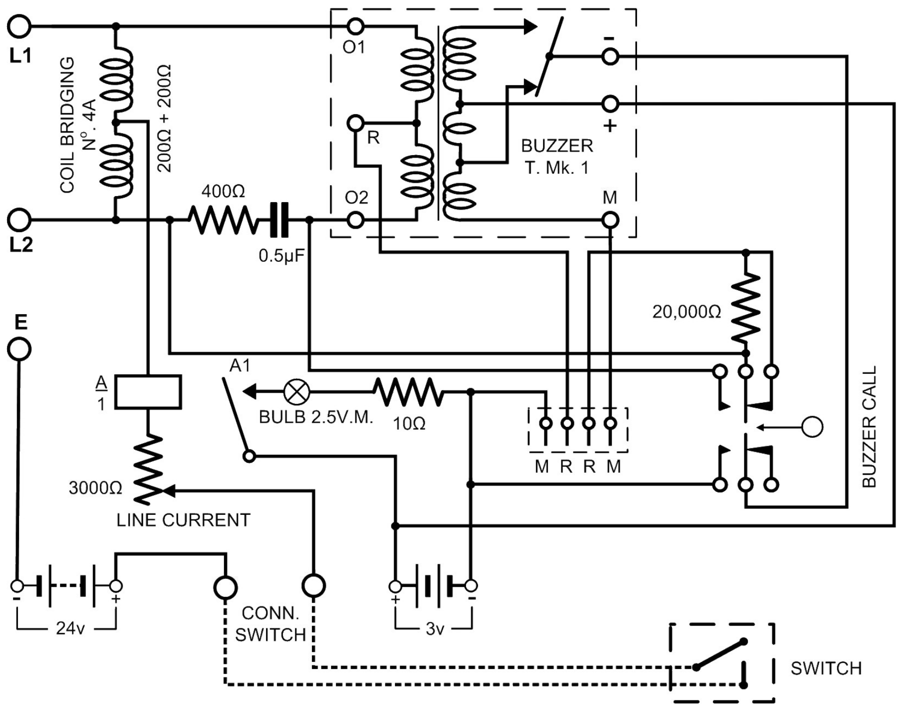


Figure 25: Control Unit, SR, Mk.II - Circuit

The Mark II control unit appears to have been in service from at least the beginning of World War 2 to 1944 when, along with the arrival of the Recorder, SR No.2, the control unit was replaced by the Control Unit, SR No. 2[15]. At present, no details of either the earlier Control Unit, SR Mk.I or the Control Unit, SR No.2 are available. There is also no information to hand as to what equipment was used in the first World War and it is not even certain that early APs were able to start the recorder. Possibly they simply reported the sound to HQ by telephone.

A fitting conclusion to this section is Figure 26, the wonderful caricature of D Troop Headquarters, 7th Survey Regiment, RA in action by Gordon Brown. Gordon was officially a film reader and the unit's photographer, but his artistic talents are clear from this work, one of a series which can be seen at the regiment's web site.

4.7 Wireless

Because of the relatively static nature of war on the Western Front, presumably SR bases had no need to move at short notice and therefore the time taken to lay the lines would not have been a problem. As we know, at the end of that war, the mobile conditions which had been expected at the beginning did return. By the end of the war also, CW wireless was commonly in use and radio telephony, although in its infancy, was clearly going to be important in military communications. A wireless connection could be set up in little more than the time it took to drive to the desired location and it must have been clear that if the principle could be applied to SR, the set up time (a minimum of six to twelve hours) could be avoided.

4.7.1 Early Attempts

In 1922, experiments into the use of wireless instead of line to connect the microphones to the recorder were carried out by the Signals Experimental Establishment [17]. A five microphone base of 15,000 yards (13.72Km) was set up with a recorder some 10,000 yards (9.1Km) from them, and used to attempt the location of large calibre guns at ranges of 30,000 to 40,000 yards (27.43 to 36.58Km). A Major Fuller, RE – undoubtedly the officer who invented the Fullerphone – had designed a 'Turner' trigger circuit operated by the Tucker hot wire microphone and arranged

[15]At this time, the SR microphone was also replaced.

Figure 26: SR Troop HQ in action - by Gordon Brown

to transmit a dash on 1300m. The string galvanometer at the recording station responded with a similar dash.

The report states that this arrangement proved unsuitable because of the loss of information conveyed by the normal break and that a close approximation to the actual sound must be transmitted. However, a transformer capable of dealing with the very low frequency components of gun sound had been designed [14], as we have already seen above, and this could be used to modulate the transmitter.

Over subsequent years, developments clearly occurred and it seems that a 195 metre radio link was used in the late 1920s but unfortunately no further information on the system is currently available. It is however possible that it was based on the "A" set which is the only member of the 1920s inventory which covered 195m. In 1931, another SEE report [18] documents a proposed new link to replace the 195m system, evidently because that wavelength had been allocated to other services (probably broadcasting). The range requirement for the new link was 4,500 yards (4.1Km).

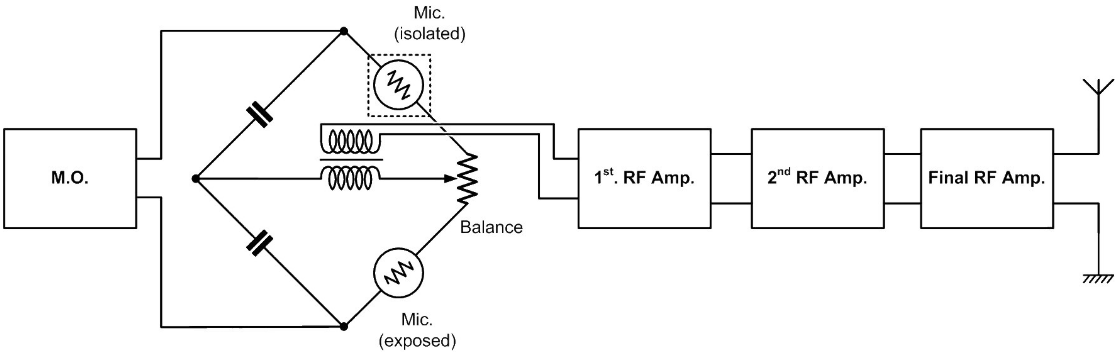


Figure 27: SR Link Transmitter for 1931 Trials

The equipment used is described in some detail:

Wavelength 650–2000m (460–150Khz)

Microphones The standard Tucker microphones were used but at each microphone position there were in fact two microphones, one exposed to gun sounds and the other isolated from noise. This appears to have been done to achieve balance in the bridge modulator used in the transmitter.

Transmitter (See Figure 27). Hartley M.O. driving a bridge amplitude modulator. This fed three RF amplifier stages; a pair of S625 tetrodes in push-pull then a single AT26 triode and finally a pair of AT50 triodes in parallel.

Receiver 2-stage T.R.F. with controlled regenerative detector and a step down transformer driving the galvanometer string.

The trials of 11th February were successful, giving ranges of more than 6,000 yards (5.5Km) and the report notes that the now Colonel Fuller was in attendance. Various recommendations were made in the report:

- R/T communication is required between AP, microphones and recording station. It would appear that the AP had to call the shot, instructing the microphone stations to switch to transmit and the HQ to start the recorder. It was noted that one possibility was that a modification to the microphone transmitter might work but could possibly need a separate R/T receiver.
- A more selective receiver was needed and a superhet with "simple controls" was recommended.
- The sender should be boxed with the microphone and its resonator (this recommendation does not appear to have been adopted).

The next development took place around 1937 when the Air Defence Experimental Establishment[16] produced a system operating in the frequency range 1.5 – 2 Mhz [19] also known as "Radio Link, Long Base", for which no detailed information is currently available. It is not known if this equipment went into service and there is no evidence in the available correspondence [20] that any wireless equipment was on general issue before the Radio Link, SR Mk.I (see below). However, it is known from [2] that

> "...sound ranging equipment that was remarkably ponderous, cumbersome and troublesome ... was abandoned on the continent at the Dunkirk evacuation..."

Most likely however, this refers to large microphones and complex line-connected recording equipment.

4.7.2 Radio Link, SR Mk.I

In 1938, following a suggestion from S.E.E. that a higher frequency might be more suitable for SR radio links, trials were carried out using a modified Wireless Set No 11, the standard vehicular HF set at that time and, indeed, during the first half of the second World War. The tests were successful, and a decision to proceed was made on 11th November 1938, with an initial contract placed with E.K.Cole in May 1939. One set consisting of eight senders and one multi-channel receiver was delivered in October 1939. This system was further developed up to early 1940 and a production design was tested at Larkhill, culminating in a successful demonstration in February at Foulness. The Radio Link, Sound Ranging Mk.I entered production later that year[17].

Refer to Figure 27 which shows the deployment of a five microphone base using the Mk I link. Each location (AP(s), Microphones and HQ) was equipped with a Wireless Set No.11SR, a WS11 modified to cover the frequency range 5 – 8.5Mhz (the standard WS11 covers 4.2 – 7.5Mhz) for normal R/T operation. The WS11SR could also be coupled to a Sender SR, No.1, for use at the microphone sites. The Sender SR, No.1 was very similar in appearance to the WS11 and used many of the same components. However, it was a transmitter only, with a special DC modulator to reduce timing instability and distortion of the low frequency gun sounds, and it covered the 7.5 – 8.5Mhz range allocated for SR. A line drawing of the WS11SR/Sender SR, No.1 is shown at Figure 29.

[16]Between the wars, SR seems to have been treated as an inter-service matter. The Admiralty in particular had a stake in SR, generally at sea, and many documents exist on the subject of ranging by sound above and below the surface. Although the Signals Experimental Establishment had a major role, as might be expected, the ADEE were also involved in ranging by sound (the Dungeness sound mirrors, made redundant by RDF, are a testament to the importance of sound ranging in air defence). Remember also that the one remaining WW1 SR officer had joined ADEE.

[17]The correspondence covering the procurement still exists in the National Archive [20]. Further detailed information may be found in Wireless for the Warrior Volumes 1 and 3 by Louis Meulstee [21], to whom the author is indebted for information on the Radio Link, SR Mk.II and permission to reproduce the figures in this section.

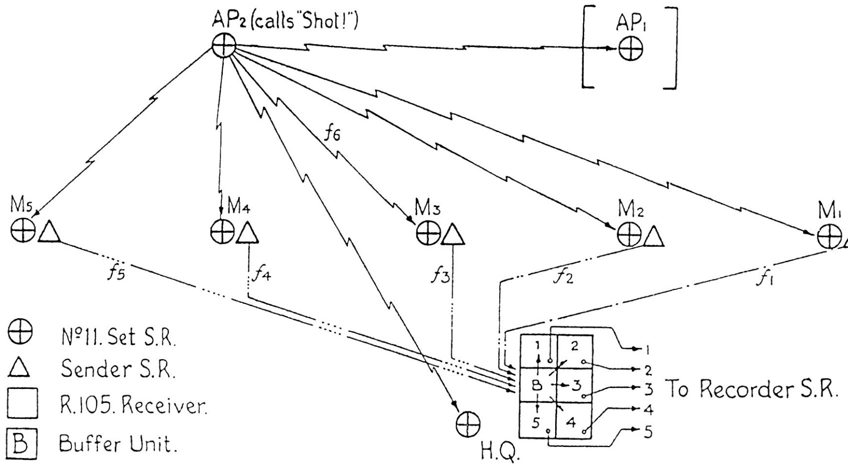


Figure 28: SR base deployed using the Radio Link, SR Mk.I

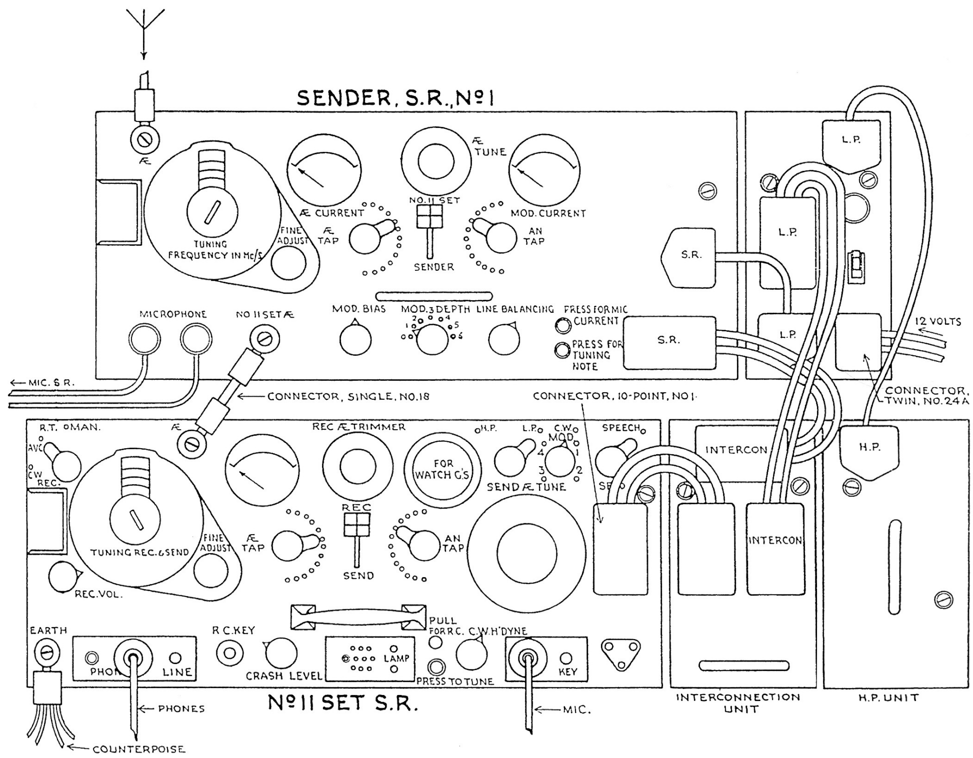


Figure 29: WS11SR with Sender SR, No.1

The remaining element in the Radio Link, SR Mk.I was the multi-channel receiver known as the R105 (see the photograph and line drawing at Figure 30). This device contained an aerial pre-amplifier or 'buffer' which distributed the incoming signal from the aerial to five identical receivers covering the 7.5 – 8.5Mhz range of the Senders SR, No.1. Each receiver could drive either headphones via a transformer or one input of the Recorder, SR.

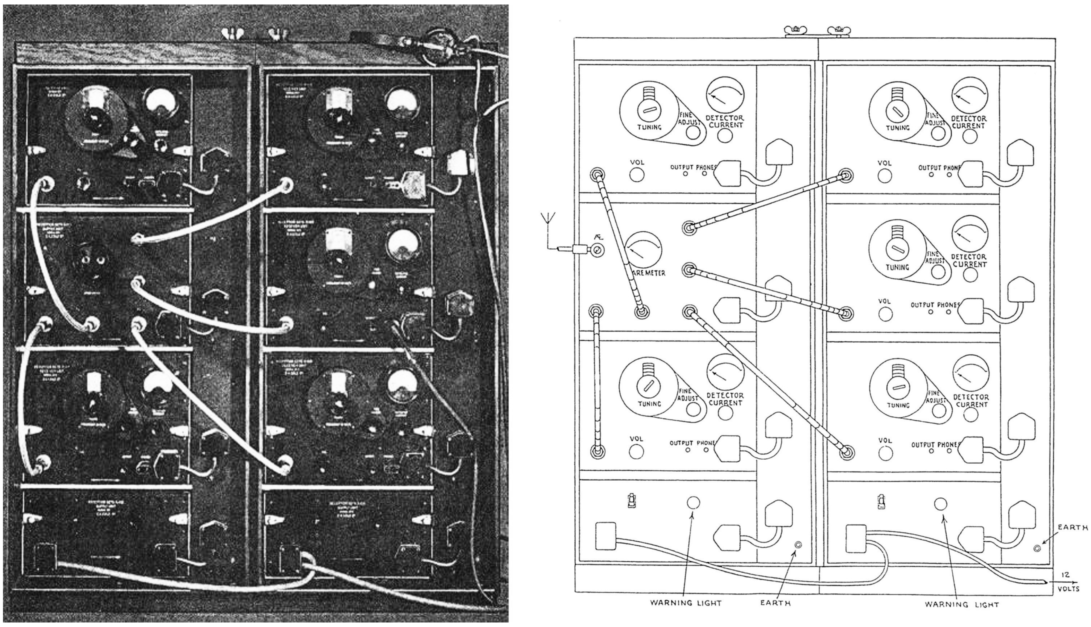


Figure 30: Receiver SR, R105

The transformer unit attenuators in the Recorder SR described above each had an additional direct connection position (not shown in Figure 14) marked "Radio" for connection to the recorder output of a receiver unit. Because this was provided at each attenuator, a combination of line and radio link could be used; particularly useful when a base was being initially set up and not all lines had been laid, or when a line was put out of service by enemy fire.

In operation, the WS11SR net was set up to give communication between all locations and then each channel of the R105 was netted to its microphone sender. At this point, the switches on all the Senders SR, No.1 were set to "No.11 Set". When an enemy gun was heard by the AP, he would call "Shot" on the R/T net, all the microphone site operators would switch to "Sender", powering the sender, and the HQ operator would start the recorder. After an agreed interval, the recorder would be switched off and the Senders SR, No.1 returned to "No.11 Set".

4.7.3 Radio Link, SR Mk.II

In 1943, a new set of radio link equipment, the Radio Link, SR Mk.II was introduced. In many respects this equipment, which was manufactured by Pye, was a great improvement over the Mk.I. The size, weight and battery drain were all reduced considerably as only one unit plus power supply was needed at each site.

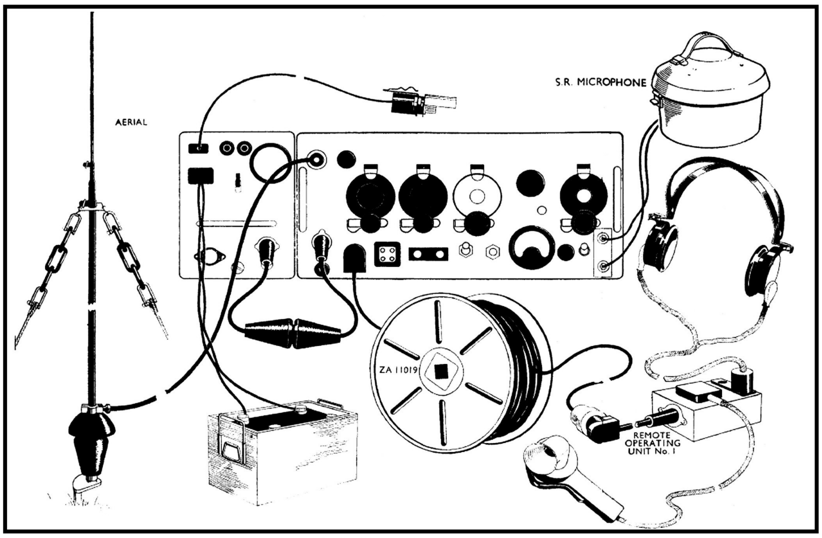
There were two types of set, the Wireless Set SR OS (the microphone site or "outstation" set) and Wireless Set SR HQ (the recording site set) – see Figure 31. A striking similarity to the Wireless Set 22 will be noticed and it appears that both sets are built into a WS22 case, with many components being common with the WS18, WS19 and WS22. However, the electronic design is novel.

Each set had a tunable master oscillator covering the 9 – 10.5Mhz frequency range and they could be netted together with the HQ set on R/T in the normal way. However, the OS sets could be switched between five channels, differing from the nominal frequency by -20Khz, -10Khz, 0, +10Khz and +20Khz for the transmission of gun sounds from the SR microphone when the "SR" button was pressed. The HQ set contained five separate IF and detector units, tuned to the five channel offsets of the OS sets. Note that the offsets were not operator variable, all that was necessary was for the R/T netting (on the nominal, centre frequency) to be carried out.

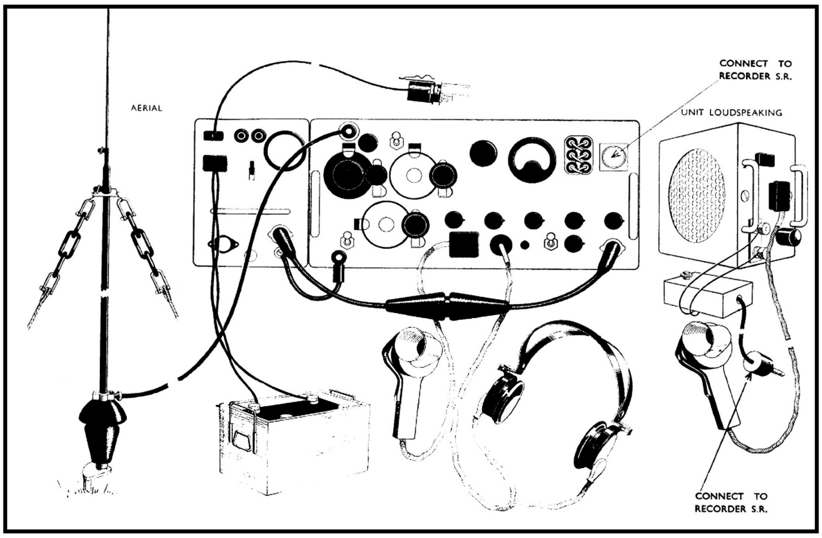
(a) Outstation

(b) H.Q.

Figure 31: Radio Link, SR Mk.II



(a) Outstation



(b) HQ Station

Figure 32: Station layouts

Further detail may be found in Colin Guy's excellent article, originally published by VMARS, but available on the internet [22].

Deployment of the Radio Link, SR Mk.II (see Figure 32) was very similar to that of the Mk.I version in that up to five microphone sites could be set up and equipped with OS sets, as were one or two APs. In this case, of course, normal R/T intercommunication and gun sound transmission were combined into one set. The HQ set was connected to the Recorder, SR via a multicore connector.

The Mk.II link was in use up to the early 1950s, probably through the Korean War but there are indications that there was a period thereafter when no SR radio link was available.

4.8 General Wireless Communications

No description of the wireless communications used for Artillery Location would be complete without touching on the less specialised aspects of unit communications. Generally the wireless net structure reflected the organisation of the unit and its place in the command structure, for obvious reasons. Given the changes in structure which the Survey Regiment underwent over the years, it is necessary to be specific about date. Happily, the situation in late 1943 is known from a Royal Signals Pocket Book [23] and Figure 33 shows one configuration of wireless within the regiment. Note that the "OPS" are Flash Spotting posts manned by the Observation Troop.

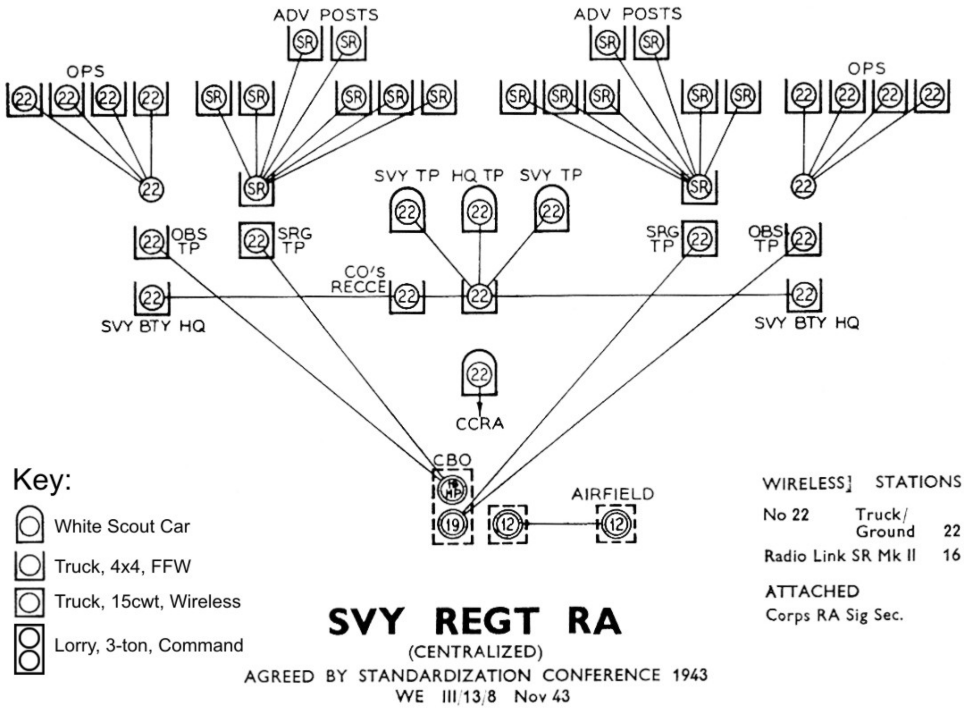


Figure 33: Survey Regt. Communications

This diagram is labelled "centralized" and also shown in [23] is a similar diagram labelled "decentralized", signifying the placing of command at respectively a higher and lower level. In this case, the centralized version describes the regiment operating as a whole whereas decentralization involved the two batteries operating independently.

5 Postwar Developments

Unlike Flash Spotting, location and ranging of artillery by sound did not disappear after the second World War, and several interesting systems were produced, as will be seen below.

By the late 40s and early 50s two different arrangements for setting up a sound ranging operation were defined:

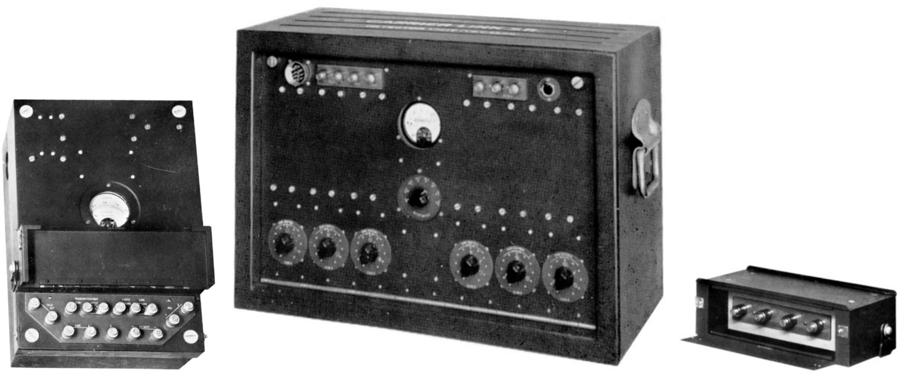
"Long Base" working: For locating distant guns, five to seven microphones were laid out from 1000 to 2000 metres apart. Two APs were normally positioned around one sub-base in front of the base on the right bisector of the flank sub-bases.

"Short Base" working: To locate mortars or relatively close guns, a base of four microphones could be deployed. In this case, the sub-bases were from 300 to 700 metres with one AP, 600 to 1000 metres in front of the centre of the base.

It should also be remembered that at the end of the war bases of up to six microphones could be connected to the Recorder, SR No 1, while only up to four microphones could be used with the No 2 recorder. This was about to change, with the introduction of seven-pen recorders in the 1950s.

5.1 Carrier Link, S.R.

The first major advance concerned the line connection of microphones to the command post, and its recorder. There had been many developments in VF telephony during the war and it is likely that the Carrier Link, S.R. (also known as the Carrier Link, Base) was a spin-off from this work. It appeared in early 1945 and was used to carry up to six microphone connections to the command post via a single cable.



(a) Transmitter (b) Detector (c) Filter

Figure 34: Carrier Link, S.R.

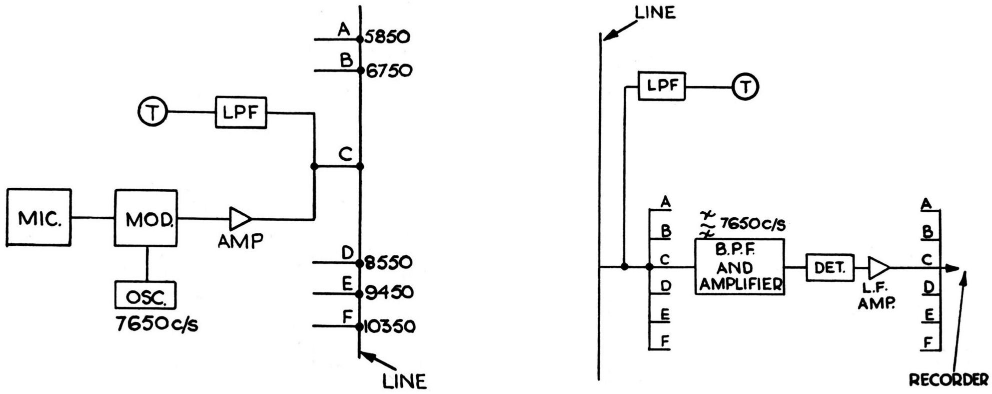
The complete equipment consisted of six transmitter units for use at the microphone positions, a detector unit installed at the SR command post and a number of low pass filter units. These can be seen in Figure 34.

The transmitters each operated on a different VF channel as shown in Table 1.

Channel	Frequency
A	5,850c/s
B	6,750c/s
C	7,650c/s
D	8,550c/s
E	9,450c/s
F	10,350c/s

Table 1: Carrier Frequencies

The transmitters used two valves, an oscillator and a screen-grid modulated amplifier, while each of the six channels in the detector again used two valves, a VF amplifier and an output amplifier which drove a channel of the SR Recorder directly. Both units were powered by a six volt secondary battery and had a vibrator HT supply circuit. The circuits of all the transmitters were identical as was each channel of the detector, except for the frequency determining and filtering components.



(a) Transmitter

(b) Detector

Figure 35: Carrier Link, S.R., Block Diagrams

The really clever feature of this system was not the use of VF telephony technologies, but the fact that it used an "omnibus" line connection, as can be seen in Figure 35. A single line circuit (which would normally be twisted pair, but could be earth return if necessary) was laid past all the microphone points and the command post and each unit was "tee-ed" onto it. The order of the units and where the detector was positioned were both immaterial, providing an extremely flexible system. The transmitter and detector units were all equipped to allow the line to be properly terminated, used when the unit was at either end of the line. It is noted in [24] that the time to deploy was around 8 hours, dependent upon conditions. According to the EMER[18] on the system[25]:

> The power handling capacity of the system is adequate for use with any length of transmission line likely to be used but, in presence of induction currents or adverse weather conditions, operation of the system may be impaired if the distance between the detector unit and the furthest transmitter unit exceeds six or seven miles.

It will have been noticed that the transmission of gun sounds by the Carrier Link, S.R. does not occupy baseband frequencies and this was to allow the use of normal telephones on the line. Each transmitter unit and the detector unit contains a low pass filter designed to permit the connection of a standard field telephone to the line without interference from (or to) the VF channels. In addition, a number of the separate low pass filters shown in Figure 34(c) were provided to allow the connection of field telephones at other points on the line.

When issued in 1945, the Carrier link, S.R. was meant to be used with the six channel photographic recorder described above. However, a modification instruction dated 1959 [27] described how the detector unit could be modified to drive the Recorder, S.R. No 5. This device was clearly a pen recorder, and the modification connected the output of each channel demodulator via a capacitor directly to the recorder, bypassing the output amplifier valve. Note that the system described in the next section is almost certainly the Recorder, S.R. No 5 – it was not unknown for the same system to be known by slightly different names.

5.2 Equipment, Recording, Sound Ranging, Long and Short Base, No 5

By the late 1950s, the technology of the Radio Link, SR Mk.II was becoming outdated and, as mentioned above, it seems that it went out of use well before 1960. The next radio link system

[18]Electrical and Mechanical Engineering Regulations were the technical manuals used by the Royal Electrical and Mechanical Engineers (after 1942) when servicing equipment. A discussion of the EMER system will be found in the author's article "EMERs - A Valuable Resource".[26]

would not appear for more than another decade and when it did arrive, it was utterly different from anything which had gone before (see below). It has been suggested that there may have been a failed project in the 1950s to design a replacement for the Radio Link, SR, Mk.II, but this has yet to be proved either way. The replacement which did emerge in the mid-950s was a line-only system, the Equipment, Recording, Sound Ranging, Long and Short Base, No.5 [28]. This equipment had six main elements:

1. Microphones (hot wire or moving coil).
2. AP Control Units, No.1 and No.2.
3. Amplifier, SR, Mk.I. This unit had eight amplifiers (one was a spare) with three push-pull stages using CV820 valves. The response was flat to within 3dB between 10 and 80 Hz. when the input impedance was less than 1500 ohms.
4. Recorder, 7 Pen, Mk.I.
5. Test Unit, Lines, SR Mk.2.
6. Supply Unit Vibratory, 12 volt, SR No.1.

Interestingly, the deployment diagram in the User Handbook [28] shows one microphone connected by what appears to be a radio circuit. However, there is no mention of radio in the text. This could be seen as further evidence that by 1955, radio was no longer in use. It is likely however, that up to six channels could be connected to the Carrier Link, S.R. described in the previous section.

The author is currently searching for a copy of the user handbook or the EMER for the No 5 SR Recording Equipment and will add further information to this article if it becomes available.

5.3 Sound Ranging Set, Radio Link No 2

In the 1960s, a new sound ranging radio link system was designed and was taken into service in 1967. According to a document in the National Archives [30], the system underwent electrical QA testing in 1970, but that must have been after release because the EMERs [29] carry earlier dates.

Like earlier radio link systems, the No 2 link could be used in a mixed environment of radio and line connection – however that was really the only similarity, full advantage having been taken of solid state logic to produce a system completely unlike anything which had gone before.

The major items of equipment were externally similar to the "Larkspur" range of wireless sets current at the time, built in hermetically sealed cast aluminium cases. A complete set of equipment allowed the setting up of one or two APs, up to seven MPs and one Command Post – Figures 36 to 38 give a general idea of what the system looked like.

Advanced post (Figure 36) The AP system was the simplest and contained a Transmitter, a Control Unit, a Remote Switch Unit and an Aerial (plus cabling and supply components).

Microphone Point (Figure 37) Each MP was equipped with a Microphone (second item from the right in the top row - standing upside down in the picture!), a Transmitter, an MP Receiver and an Aerial.

Sound Ranging Command Post (Figure 38) The Command Post was equipped with the most complex system comprising a Transmitter, a Control Receiver, a Data Receiver, a Power Supply and System Selector, a Recorder Amplifier, a Recorder and two Aerials. In addition, if line connections were to be used for some microphones, a Lines Test Unit was added (not in the picture).

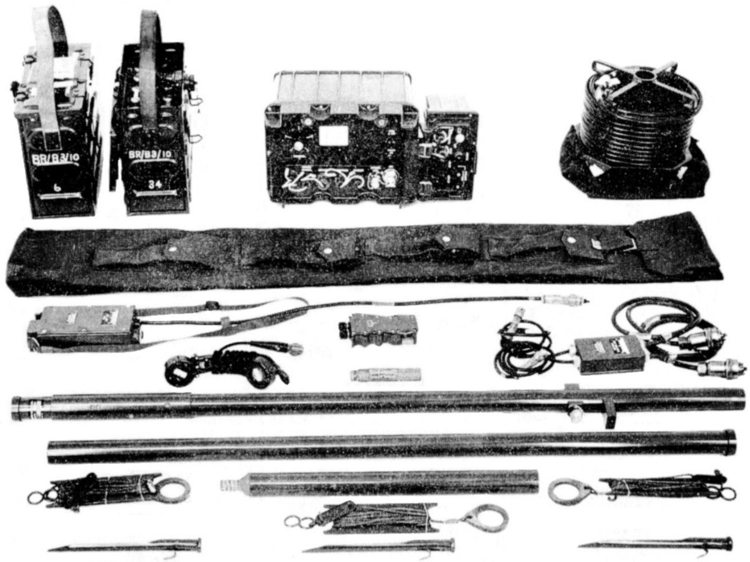


Figure 36: SR Radio Link No 2 – Advanced Post equipment

The system operated on 57 channels spaced at 250Khz in the frequency range 70 – 84 Mhz, crystals for five channels at a time being fitted. Each transmitter and receiver unit had a five position channel selector on the front panel. In operation, three of the channels were used as described below, and two channels were spare, presumably in case of interference. There was only one type of transmitter, despite the three roles (which in fact differed only in the signal transmitted) but there were three types of receiver (MP, Data and Control). However, the RF and IF stages of the receivers were common.

Refer to the System Diagram, Figure 39 when reading the following description.

When a gun sound was heard at an AP, the remote switching unit (also known as the remote "trigger") was pressed, or the Start switch on the control unit was operated. This caused a half second Start tone to be sent to the control receiver at the command post. Once sufficient time had elapsed for a recording to be made, the trigger was released or the Stop switch operated. This in turn caused a half second Stop tone to be sent to the CP – see Table 2 for the tone frequencies. If required, a handset could be used to allow the AP to send speech to the CP via the control receiver.

	Start	Stop
AP1	4Khz	6.5Khz
AP2	10Khz	15Khz

Table 2: Control Tone Frequencies

Reception of the Start tone triggered two events; the starting of the recorder (which would subsequently be stopped by a Stop tone, or manual operation) and the initiation of a series of actions at the data receiver:

1. The CP transmitter switched on for 292.5μS and sent a synchronising pulse to the MP receivers. The off period of the transmitter was 607.5μS, giving a total frame period of 900μS (a pulse repetition rate of 1.1Khz). The sequence repeated for as long as the recorder was running.

2. The synchronising pulse had a positive excursion of 126μS and it's positive to negative trailing edge was used to phase lock the control clocks in the MP receivers.

3. At each MP receiver, the synchronising pulse reset a counter chain and phase locked the crystal oscillator driving the chain.

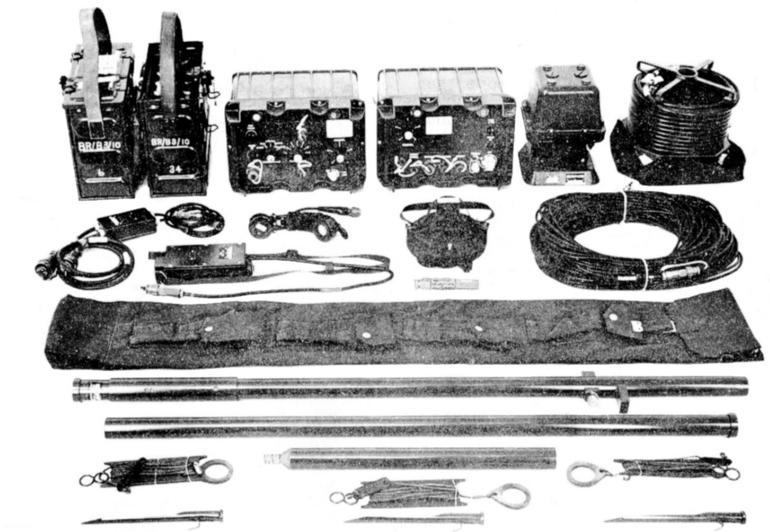


Figure 37: SR Radio Link No 2 – Microphone Point equipment

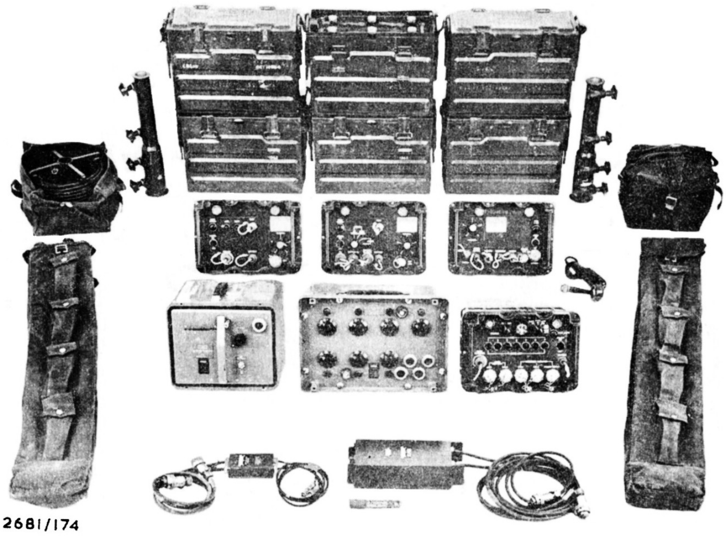


Figure 38: SR Radio Link No 2 – Command Post equipment

4. The counter chain produced a train of seven gating pulses, each 90μS in duration. By means of a "Trace" switch (trace refers to the pen recorder channel), the gating pulse to be used at each MP was selected.

5. The selected gating pulse switched the MP transmitter to send, modulated by the microphone output.

6. An identically phase locked counter chain in the CP data receiver produced gating pulses synchronised to the MP transmissions and directed them to the appropriate integrating detector which formed representations of the microphone signals. Note that the repetition rate of the system was relatively high (1.1Khz) compared to the microphone output frequencies and the integrators could produce valid outputs.

7. When a Stop tone was received from the AP, or the recorder was manually stopped, the whole system was reset and returned to stand by.

Because the timings were critical, the MP receiver had a five position "Range" switch which allowed the gating pulses to be shifted in steps of 22.5μS relative to the equivalent pulse in the

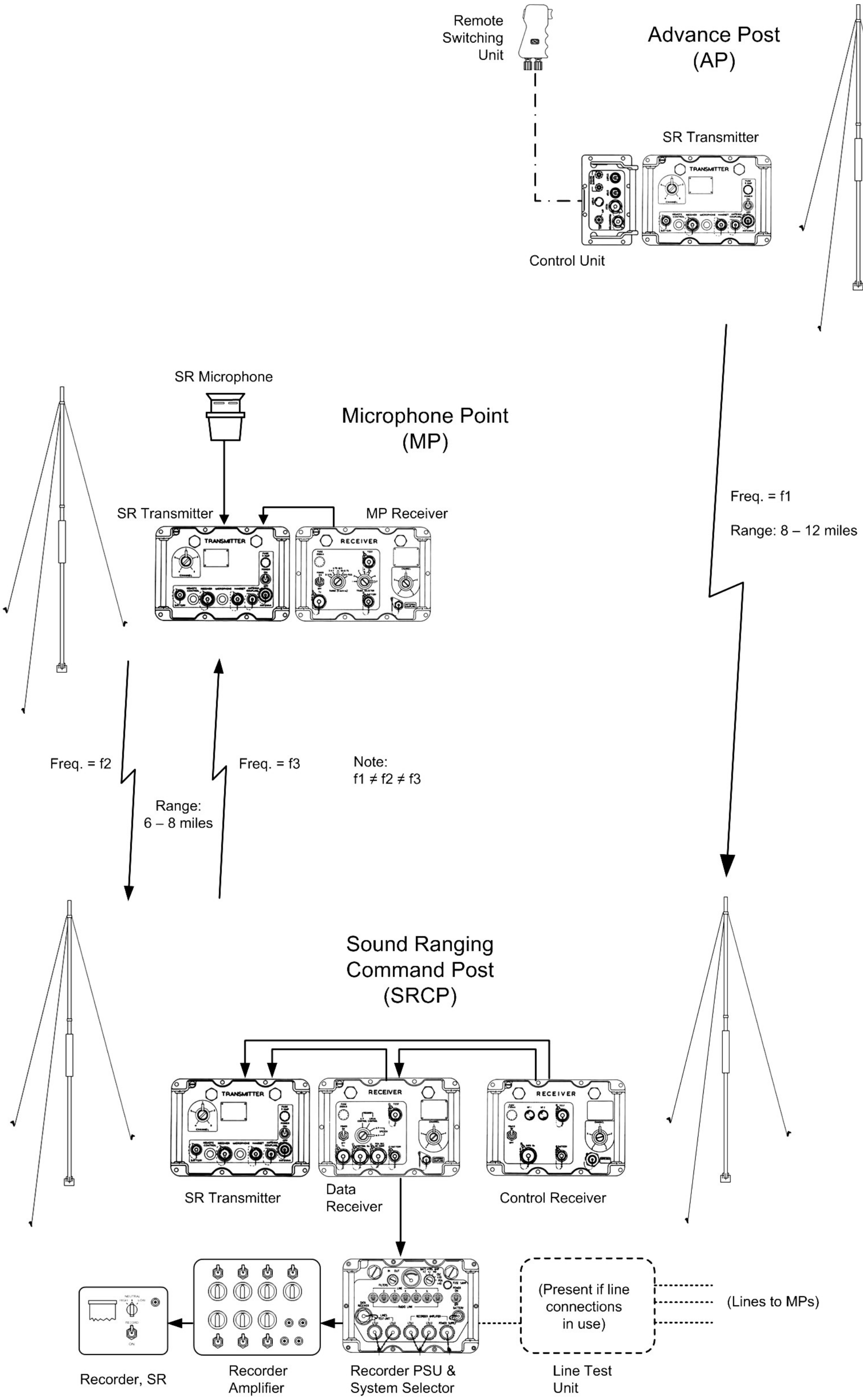


Figure 39: SR Radio Link No 2 – System Diagram

CP data receiver, to overcome propagation delays.

Finally, handsets could be connected at the MPs and the CP, allowing two-way speech communication. However, this would only have been used during setup as the MPs were normally unmanned in operation.

6 Current Systems

Introduced in the late 1960's, the Sound Ranging Radio Link No.2 remained in service for around thirty years. Over that time the recorders were replaced as technology developed, but the radio equipment remained essentially unchanged. It was eventually replaced by a system called HALO (Hostile Artillery LOcator) and then by ASP (Advanced Sound ranging Project) which is current in 2007, when this article is being written. Some information on ASP may be gleaned from the various Army web sites.

Also available on the web, this time on the site of the Royal School of Artillery at Larkhill, is a Basic Science and Technology handout on Sound Ranging [31]. In this document will be found an explanation of the three microphone, triangular base arrangement used in modern sound ranging.

Three microphones are arranged in an equilateral triangle with sides of just 10 metres! At a velocity of 337.6m/s, sound takes just 29.62mS to travel 10m and so this system has to be highly accurate to deal with time intervals much shorter than 30mS. The triangular arrangement of the microphones is designed to make the base equally sensitive to sounds arriving from any direction. On the other hand, three microphones cannot give a location with any degree of accuracy, only a bearing. But, of course, set up two of these clusters of three microphones, survey them and determine their alignment, and location is possible. The clusters are small enough to be set up quickly and easily, say on a flat roof, and these days surveying is a simple matter of taking a GPS location.

7 Conclusions

Indirect fire as the standard means of artillery operation is a little over one hundred years old and only a few years younger is the science of artillery location. Long before the birth of radar, location was by means of the flash or the bang of the gun, both methods invented by brilliant men who also designed the supporting technology required.

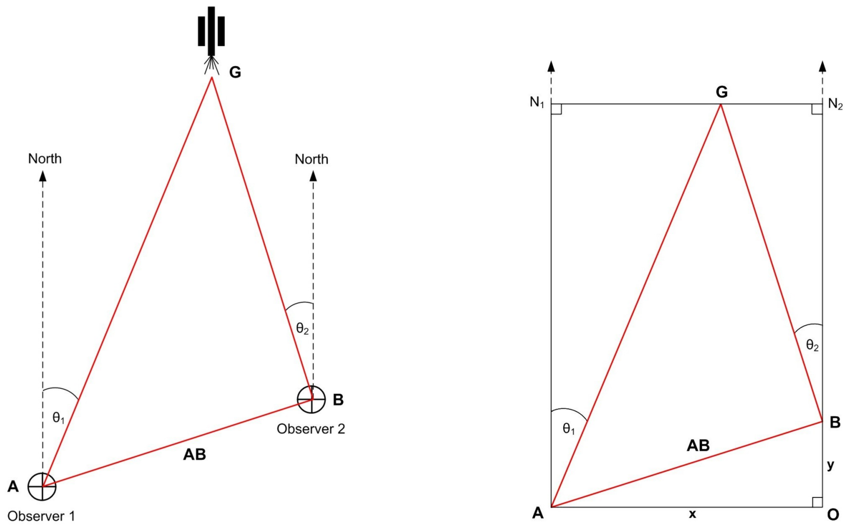
For those interested in military communications, the highly specialised equipment used over the last ninety three years in artillery location has its own fascination. The fact that so relatively few locating units have ever existed makes physical examples of the equipment exceedingly rare and even the documentation is difficult to find. Therefore there are still gaps in our knowledge which may, hopefully, be filled over time.

And finally, although (as far as is known) Flash Spotting ceased in the 1950s, Sound Ranging is alive and well – and may be in a city near you (Google "gunshot detection")!!

Appendices

A Solution of Triangles for Flash Spotting

The observations are shown in Figure 40a. [19]



(a) Observation (b) Calculation

Figure 40: The Geometry of Flash Spotting

In Figure 40b, two East–West lines (AO and N_1N_2) and two North–South lines (N_1A and N_2O) have been added, to construct three right angled triangles around the observation triangle, which is shown in red. The object of the calculation is to determine the grid position of point G, which can be in the form of Easting and Northing offsets from point A. Thus the required lengths are N_1A and N_1G.

We will use the position of the first observer, point A, as the reference and since we know the position on the grid of both observers, we know the distances AO and OB (shown as x and y respectively, in Figure 40b). So from Pythagoras' Theorem, we can find the distance between the observers, AB:

$$AB^2 = x^2 + y^2$$

thus

$$AB = \sqrt{x^2 + y^2}$$

We can now find the two unknown angles in △ABO using sines:

$$\begin{aligned} \sin O\hat{A}B &= \frac{y}{AB} \\ \sin A\hat{B}O &= \frac{x}{AB} \end{aligned}$$

thus

$$\begin{aligned} O\hat{A}B &= \arcsin \frac{y}{AB} \\ A\hat{B}O &= \arcsin \frac{x}{AB} \end{aligned}$$

Given these angles it can be seen by inspection that the angles θ_1, $O\hat{A}B$ and $G\hat{A}B$ sum to 90° while θ_2, $A\hat{B}O$ and $G\hat{B}A$ sum to 180°. Remember that we know θ_1 and θ_2 from the observed bearings. Thus

[19] For those who feel the need of a refresher at this point, Stan Brown's excellent *Trig Without Tears* website is recommended [32].

$$\begin{aligned} G\hat{A}B &= 90 - (\theta_1 + O\hat{A}B) \\ G\hat{B}A &= 180 - (\theta_2 + A\hat{B}O) \end{aligned}$$

From the sum of angles in any triangle, we can write the value of $A\hat{G}B$:

$$A\hat{G}B = 180 - (G\hat{A}B + G\hat{B}A)$$

From the Sine Rule, we could now find the ranges to the hostile gun from each observer, but it is in fact only necessary to find one. We will find AG:

$$AG = AB \cdot \frac{\sin G\hat{B}A}{\sin A\hat{G}B}$$

Finally, we can find the required Easting and Northing offsets, N_1G and N_1A:

$$\sin\theta_1 = \frac{N_1G}{GA}$$

so

$$N_1G = GA \cdot \sin\theta_1$$

and similarly

$$N_1A = GA \cdot \cos\theta_2$$

B The Hot Wire Microphone

The "Tucker" microphone was, as mentioned above, invented by W. S. Tucker (who rose to the rank of Major by the end of the war), based on his earlier work at Imperial College. It was the subject of patent applications in 1916 (13123) and 1918 (8948), and Tucker continued to work on the design after the war, publishing his results in 1921 [33].

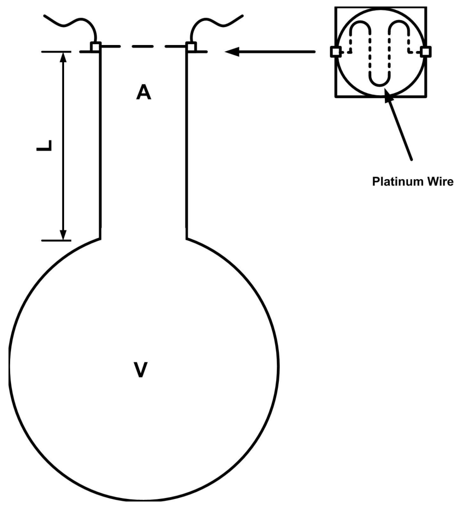


Figure 41: Helmholtz Resonator

The hot wire microphone is unlike many other microphones in that it is not intended to reproduce sound as electrical variations. Rather it is a device for measuring the energy contained in a sound wave, specifically at very low frequencies, otherwise known as "infrasound". There is a similarity with the hot wire anemometer used to measure wind speed but it differs from that device in having a degree of frequency selectivity achieved using a "Helmholtz Resonator" (see Figure 41).

A thin platinum wire, typically 6μm in diameter, is fixed across one end of a tube, the other end of which connects to a closed cavity. When sound of a particular frequency arrives at the outer end of the tube, air rushes in and out of the tube, cooling the wire by forced convection and decreasing its resistance. The amplitude of the variations is greatest at or around the resonant frequency of the device, which is given by:

$$f = \frac{c}{2}\sqrt{\frac{A}{VL}}$$

where c = speed of sound
A = cross sectional area of the tube
L = length of the tube
V = volume of the cavity

The variations in the resistance of the platinum wire may be found by connecting it in a balanced bridge configuration. It should be noted that the signal thus produced gives one cycle of resistance change from nominal to a lower value and then back to nominal on both the rise and fall in pressure at the tube entrance. Thus the fundamental frequency of the microphone output is twice that of the gun sound.

C The Asymptote

(This explanation of asymptote plotting is reproduced from The Manual of Sound Ranging [11].)

In order to draw the asymptote scale on a plotting board, it is necessary to know the angle between the right bisector of the sub-base and the asymptote, for a given time difference. In Figure C, if a circle is described with M_1 as centre and radius (T_1-T_2), the hyperbola (dashed) is the locus of the centre of the circle which touches the circle with centre M_1 and passes through M_2.

Suppose the gun is at a very great distance. The arc OM_2 of the circle whose centre is the gun position is then almost a straight line and, in the limit, when its centre becomes infinitely distant, will be a straight line passing through M_2 and touching the circle whose centre is M_1 at O, while the gun will lie on the right bisector of the tangent M_2O. The right bisector of the tangent will pass through the midpoint of the line M_1M_2 and will touch the hyperbola at infinity. It is therefore the asymptote of the hyperbola.

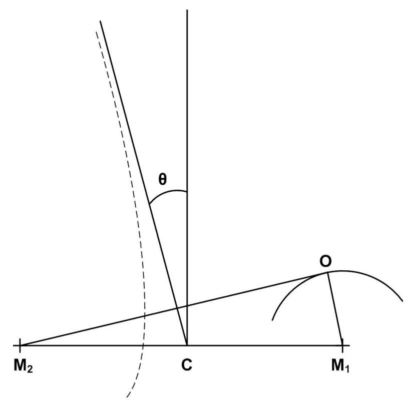


Figure 42: The Asymptote.

Let l represent the distance between the microphones M_1 and M_2, for which T_1–T_2 is the time difference and θ is the angle between the right bisector of the line M_1M_2 and the asymptote of the hyperbola corresponding to the time difference T_1T_2.
In Figure C, $\theta = O\hat{M_2}M_1$.

Therefore

$$\sin\theta = \frac{OM_1}{M_1M_2} = \frac{(T_1 - T_2)}{l}$$

If

$$t = T_1 - T_2$$

Then

$$\sin\theta = \frac{t}{l}$$

From this formula, the angle θ can be calculated for a series of time differences t.

D SR Correction for Temperature

Let V_θ be the velocity of sound at temperature θ and V_{10} the temperature at 10°C.
Since the velocity of sound is proportional to the square root of the absolute temperature.

$$\frac{V_\theta}{V_{10}} = \sqrt{\frac{273+\theta}{283}} = \sqrt{1+\frac{\theta-10}{283}}$$

If t_θ is the time difference at temperature θ and t_{10} the time difference at 10°C,

$$\frac{t_\theta}{t_{10}} = \frac{V_{10}}{V_\theta}$$

and

$$t_{10} = t_\theta \frac{V_\theta}{V_{10}}$$

Thus the measured time difference at temperature θ must be multiplied by the factor

$$\frac{V_\theta}{V_{10}} = \sqrt{1+\frac{\theta-10}{283}}$$

to reduce it to the time difference at 10°C.

Finally,

$$\sqrt{1+\frac{\theta-10}{283}} = 1+0.5\frac{\theta-10}{283}(approx.) = 1+0.0018(\theta-10^\circ)$$

E The RF Capacitor Microphone

The "standard" condenser or capacitor microphone was invented by E.C. Wente at Bell Labs in 1916 and consists of a capacitor, one plate of which is the microphone's diaphragm. The principle is based on the equation which relates charge to capacitance and voltage:

$$Q = C \times V$$

where:

Q is charge (in Coulombs), C is capacitance (in Farads) and V is voltage (in Volts)

As the distance between the capacitor plates changes with the sound vibrations, the capacitance changes and assuming the voltage is roughly constant, the charge must vary. The applied or "bias" voltage across the capacitor is connected via a high value resistor (10MΩ or so) in order to keep the rate of change of charge slow. The result is that the voltage across the capacitor varies with the audio at the diaphragm.

However, the use of relatively high bias voltages in the field is somewhat unreliable and a variation on the capacitor microphone was used. The RF capacitor microphone uses an RF bias from a low-noise, high frequency oscillator (several Mhz.). In simple terms, this oscillator is fed to a bridge circuit which, under no-signal conditions, is balanced and produces no output. When the capacitance value of the microphone capsule changes, it unbalances the bridge and produces an audio signal. The importance of this system for Sound Ranging is that the microphone produces a very good response down to frequencies well below 1Hz.

The following description of the principle is reproduced from EMER Telecommunications B822 Part 1:

Microphone Unit

335. The heart of the equipment is the Sennheiser microphone, MKH 110/P. This is a capacitor pressure transducer with a built-in amplifier employing an r.f. bridge technique, which gives a substantially flat response down to below 1c/s. Figure 43 illustrates the basic principle of the microphone.
336. The output of the r.f. oscillator O is periodically switched at the r.f. frequency by the diodes S to the capacitor C via resistor R. The switching phase is shifted 90°

from that of the r.f. oscillator by means of loose coupling and aligning the resonance of the microphone circuit M under no-signal conditions. As a result, the voltage across the capacitor is zero. As soon as sound causes a deflection of the transducer element diaphragm, the switching phase changes in a manner proportional to the sound pressure and a corresponding audio voltage appears across capacitor C. A d.c. supply of 8V is required to energise the the capacitor microphone and operate the r.f. oscillator. A detailed circuit of the microphone is not given as it is not intended that this unit should be serviced. In the event of failure, the unit should be replaced.

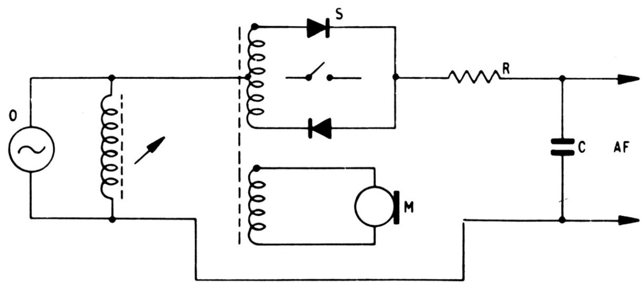


Figure 43: RF Condenser Microphone, basic circuit

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Note that several of the documents listed above are available for download from the Wireless-Set-No19 site http://www.royalsignals.org.uk

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