HF Propagation And Clandestine Communications During The Second World War

By Brian Austin, G0GSF

Excerpt from “Radio Bygones” No. 120, August-September 2009

HF Propagation And Clandestine Communications During The Second World War

by Brian Austin, G0GSF

Peter Jensen's timely article in *RB118* on the subject of clandestine communications, and the Paraset's part in all of it, reminded me of some calculations I had made some years ago. They concerned the feasibility of establishing radio contact between those incredibly brave radio operators scattered about occupied Europe and the listening stations at Whaddon, not far from Bletchley, and elsewhere in England. Success depended upon a variety of factors amongst which was the transmitter output power, the state of the ionosphere at the time, the electrical noise level at the receiver's input and the radiation efficiency of the makeshift antennas those operators were able to deploy at their various secret sites. Fortunately, for the radio communications historian much of this information can still be traced, while some can also be calculated – based on judicious guesswork, if needs be.

The Ionosphere

Of crucial importance to such sky-wave links is the ionosphere and fortunately the vital data describing its behaviour since the very beginnings of ionospheric sounding have been archived in the World Data Centre (WDC) at the Rutherford Appleton Laboratory near Oxford. Their ready availability on the internet enabled me to find the conditions that prevailed over north-west Europe during the war years. In addition, computer simulations of wire antennas are now commonplace and so the antennas typically used with the so-called 'suitcase sets' operated by those agents could be analysed. Those results, plus the well-understood characteristics of atmospheric noise at the frequencies in question, provided the numbers for the equations I derived to describe the radio propagation path between various parts of north-west Europe and England.

Fig.1. The Paraset and B2 transmitter/receivers (photos by courtesy of Louis Meulstee)

Not surprisingly, my calculated results simply confirmed what we already knew: that such simple equipment as the Paraset, and the somewhat more powerful B2 suitcase set (**Figure 1**) – among many others that were also used – could indeed communicate over distances well in excess of 1000km in some cases. But they also shed a little light on the issues that no doubt had occupied the minds of the sets' designers when they developed these remarkable pieces of equipment without the assistance of any modern computing technology.

The Equipment

Around about 1941 the transmitter/receiver, originally known as the Whaddon MkVII, but soon more famously as the Paraset, was produced. It consisted of the simplest of transmitters using a single, crystal-controlled 6V6 power oscillator, while the receiver contained two 6SK7 valves as the regenerative detector and audio amplifier. The RF output power was typically 5W over the frequency range from 3 to 7.6MHz.

The B2, designed at Station IX, 'The Frythe' in Welwyn, sometime later by Major John Brown G3EUR, contained a more powerful 20W transmitter using an EL32 - 6L6 combination and a reflexed, superhet receiver. It operated from 3 to 16MHz with a pi-coupled output providing considerable impedance matching flexibility. These two sets were among the stalwarts used by the clandestine operators and both have since become very valuable collectors' items.

However, regardless of the sophistication of any radio equipment, it was the state of the ionosphere that would ultimately determine whether it would be possible to 'work' the links between occupied Europe and the various stations across the Channel.

High Frequency (HF) Propagation

Before the advent of the first man-made satellite *Sputnik* 1 in 1957, all long-distance radio communications relied on the ionosphere to return signals to earth and especially to enable them to travel beyond the horizon. Since the distance between most parts of occupied Europe and the receiving stations in the UK were well beyond

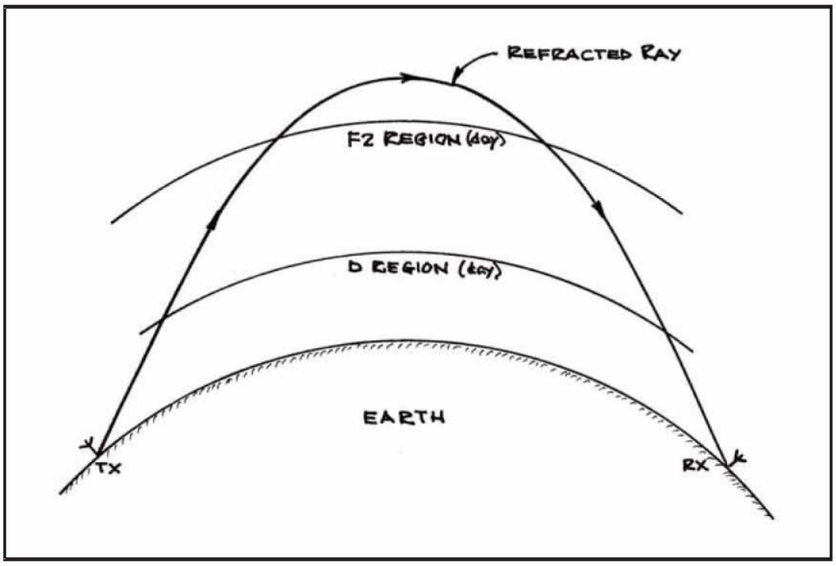

Fig.2. A single-hop path through the inonsphere showing diagrammatically the D and F2 regions.

ground-wave range of 100km at most, it was necessary for the signals from those clandestine stations to make at least one 'hop' off either the E or F regions of the ionosphere in order to cover the necessary distance between transmitter and receiver. Not only that, but they had to be of sufficient intensity or signal strength when they arrived at the receiver to overcome the prevailing electrical noise and so render those signals readable to trained Morse (or CW) operators.

That noise was generated both within the circuits within the receiver itself and was also picked up by its antenna, having emanated in the main from worldwide thunderstorm activity and galactic sources in outer space. The ultimate criterion of performance was therefore the signal-to-noise ratio or SNR at the receiver input.

Whether radio signals will propagate or not is determined by the 'critical frequency' of the ionosphere at the point of reflection. That frequency, written as foE and foF2 for the E and F2 regions of the ionosphere respectively, is seldom constant for long, because its value is determined by both solar and geophysical effects that are themselves variable. The most important of these is the number of sunpots visible on the sun itself.

Sunspots are regions of intense magnetic fields on the solar surface and they are known to have a profound effect on the ionosphere that surrounds the earth. Sunspots were first noticed in 325BC and have been monitored consistently since the early 17th century. There is a direct (if somewhat complicated) relationship between the sunspot count and the critical frequencies, and since they are so important to HF communications they have been monitored in England ever since 1931 at Slough and subsequently in many other places around the world.

Ionosonde

The instrument used to measure the critical frequencies of the ionosphere is an ionosonde. Since its almost simultaneous invention by Appleton and Barnett in England and by Breit and Tuve in the USA in 1924, this technique has been in constant use, first at the Radio Research Station in Slough and then, since 1979, under the auspices of the Rutherford Appleton Laboratory at Chilton near Oxford.

Fortunately, for the study reported here, records of those soundings of the ionosphere are held in an archived database and are readily accessible by researchers. It was thus possible to examine the behaviour of the F2 layer critical frequency – the most important parameter – as it varied on an almost daily basis throughout the war. From this information, and knowledge of the height of the ionosphere, it is possible to calculate the optimum traffic frequency or FOT for communication between any two points either side of the point of refraction.

Such an analysis formed the first part of this study.

The table below summarises these results at midday GMT on the 15th of the month during the later war years. Before this time the clandestine links were most sporadic and their success was limited.

Year	Month	foF2 MHz	FOT Calais MHz	FOT Marseilles MHz
1943	January	5.6	5.3	11.8
1943	June	5.1	4.8	10.7
1944	January	5.8	5.5	12.2
1944	June	4.9	4.7	10.3
1945	January	7.5	7.1	15.8
1945	June	6.1	5.8	12.8

Ionospheric Absorption

As well as reflecting radio signals, the ionosphere can also absorb them and this can severely degrade the SNR along a given path. Absorption takes place mainly within the lowest region of the ionosphere, at around 80km above the earth, known as the D region or layer. It occurs there predominantly because the air density is greatest at lower altitudes and so the ionised particles set in motion by a passing electromagnetic wave experience a loss of energy as they collide with one another.

The physics of the process is highly complicated and will not be discussed here. Suffice it to say that the effect of D layer absorption is most pronounced at lower frequencies and it only occurs during the daylight hours because the D region itself disappears at night.

It is possible to calculate to a high degree of accuracy the amount of absorption that will occur within a specific region of the ionosphere if one knows various factors, such as the position of the sun, the angle of incidence of the radio signal on the D region, the prevailing sunspot number at that time and details of the earth's magnetic field in that region of space. Once again, much of that information can be derived mathematically, or the data may even be readily to hand thanks to those far-sighted enough to ensure that it was all archived. My calculations were made of the absorption likely to have affected single-hop radio signals propagating from places in occupied Europe and England during the years of the Second World War.

Electrical Noise Levels

Electrical noise is always a limiting factor in radio communications and its characteristics have been studied intensively. As is well-known, noise from lightning storms across the globe exhibits considerable frequency-dependence, with a marked increase at the lower end of the radio frequency spectrum. So-called galactic noise exhibits a similar response.

One way of specifying noise is in terms of its equivalent 'noise temperature', which is not quite as unlikely as it sounds if one appreciates that electrical noise is caused by the random motion of charge carriers within a whole variety of substances. Since that motion can readily be related to friction it's not surprising that the more agitated (and hence the 'noisier' those charge carriers), the higher is their effective noise temperature.

Again, it's possible to determine the prevailing atmospheric noise at a particular place and time, and on a specified frequency, given the extensive amount of data that's been published on the subject over recent years. Hence, by knowing both the level of signal and noise at the receiver's input, the signal-to-noise ratio or SNR follows directly.

Clandestine Antennas

The antennas used by the agents secretly operating their 'suitcase sets' were absolutely vital to their success. But they were also the most visible physical feature that could so easily have disclosed their presence to the enemy and their collaborators. This did indeed happen on many occasions and it led sometimes to dreadful retribution at the hands of the Gestapo.

The antennas, therefore, had to be carefully deployed. In nearly all cases they consisted of single lengths of wire, never more than 20m long (and without special feedlines). They were erected in various end-fed configurations in an attempt to achieve as much concealment as possible while not compromising their performance too much by making them either too low or with two many sharp bends and folds.

It was certainly not unknown for some antennas to be accommodated indoors, in which case they had to be bent into various shapes as dictated by the space available. Naturally, optimum concealment like this carried the heavy price of reduced efficiency.

Given the computer-based analytical tools, such as NEC and EZNEC,

Fig.3. Artist's impression of a 'typical' clandestine wireless site, with a far from clandestine antenna.

available to us these days it's possible to determine, to a high degree of accuracy, the radiating characteristics such as the impedance, radiation efficiency and gain as well as the patterns of the lobes generated at any given frequency. From these, and the likely orientation of the antenna itself, one can then calculate the effective radiated power in any given direction. By combining this information with the predictable features of the ionosphere and the known noise and absorption characteristics an estimate can then be made of the signal strength and the signal-to-noise ratio at the monitoring stations in England. These stations, in the main, were equipped with a variety of wire antennas from dipoles to large rhombic and V-beams. These highly directional antennas were aimed in the directions of the various clandestine stations known to be operating in occupied Europe.

The stations in England had available a range of transmitters whose output power varied from as little as 30W (the so-called 'Tinker Box') to the formidable 10kW from the remote transmitters located near Cirencester in Gloucestershire.

As related to the author by Pat Hawker G3VA, one of those wartime operators at Whaddon, the transmitter in Cirencester was frequently within the skip zone so the radio operator was unable to monitor his own transmissions. This caused him to transmit 'blind', or at least deaf, while also having to contend with a slight delay that occurred over the land-line connecting his key to the transmitter. One must assume that the problems facing the operator in some hidden location in France or elsewhere were even more taxing!

The Analysis

All agents operating from occupied Europe were issued with Signals Plans. These highly classified documents gave the times, frequencies and call sign sequences to be used when communicating with 'Central', the station back in England. For example, the 'St Samaria Plan' (possibly for use in occupied Holland), supplied to the author by Pat Hawker (**Figure 4**), lists ten frequencies between 3.320MHz and 6.573MHz as well as the operating times ('skeds') and the strict procedures to be followed, including the

ST. SAMARIA PLAN

CALL SIGNS — ST. SAMARIA
T H N X V U B A F C L E S R Z K W L Q P I Y G O M J

CENTRAL
S E I Y T N U G J A Q L R Z W D K O B V P M H X F C

METHOD OF CALLING — For the first contact you will call using the first three letters of your selection. If contact is established then if a frequency is changed you will use the second three letters and so on. For the next contact you will always use the next three letters to those last used.

You will always change call signs with a change of frequency and must always use a new call sign for each contact. If you should call but not make contact you will continue [illegible] use the same call sign at the next [illegible] until contact is established.

It is most important that the correct call sign should be used.

When the end of the selection is reached the call sign will be completed by taking the required number of letters from the beginning of the selection.

CENTRAL will use their selection in the same way.

CALL SIGNS WILL NEVER BE LINKED

FREQUENCIES	ST. SAMARIA	6573 .. 16	Main Day
		5859 .. 82	
		4723 .. 75	
		3435 .. 20	Main Night
		3339 .. 08	
	CENTRAL	5607 .. 49	Main Day
		6400 .. 91	
		4276 .. 67	
		3320 .. 33	Main Night
		3420 .. 54	

FREQUENCY CHANGE — This will be done by sending the signal QSY followed by the [illegible]
If CENTRAL is wanted to send on two frequencies simultaneously or is proposing to do so, two numbers will be sent.

Fig.4. Part of the original St. Samaria signal plan (by courtesy of Pat Hawker)

method of coding messages. The inherent complexity of the process and its hazardous nature just make one all the more in awe of the remarkable people who undertook it.

One assumes that the choice of frequency to be used at a given time and from a particular geographical location was made with due cognisance of the prevailing state of the ionosphere at that time. However, no 'real time' (in modern parlance) data were available, so the process would have had to rely upon the best possible predictions, or maybe just the best possible guesses! If too high a frequency were selected, the stations may well have found themselves within the skip zone and no contact would have occurred. Equally, too low a frequency during daylight hours (and that's when most of the 'skeds' with agents took place) ran the risk of excessive D-layer absorption and hence weak signal reception. And there was always the risk of interference and fading, since the ionosphere is never stable.

With the huge benefit of hindsight, and the availability of many modern analytical tools, we are able to make some assessment of the feasibility of those 'links' actually working. Two representative locations were chosen for the clandestine stations in France. One was assumed to be in Calais in the north western corner of France, just across the Channel from England; the other was in Marseilles, right down south on the Mediterranean. They represent typical short and long-distance paths to the monitoring stations not far from London and, as a result, will require the use of quite different frequencies for successful propagation.

From our knowledge of the ionosphere, it is safe to assume that propagation will have been via the F2 region during the day. Its height, though variable, can be assumed to be typically 250km. On that basis the path lengths followed by the radio signals from Calais and Marseilles to Whaddon are about 700km and 1200km respectively.

A study of the archived data at the World Data Centre of the Rutherford Appleton Laboratory indicated that between 1943 and the end of the war (which happened to be very close to one

Fig.5. An end-fed inverted-L antenna, typical of some that may have been used

of the periods of sunspot minimum), the foF2 critical frequencies at noon GMT near the points of reflection were in the vicinity of 5 to 6MHz. From those values it is possible to determine the optimum traffic frequencies (FOT) that would have supported communications over those paths. In June 1944, as shown in the table earlier, these turned out to be about 4.7MHz for the Calais-Whaddon path and around 10.3MHz for the longer circuit between Marseilles and Whaddon. The use of frequencies fairly close to these will also have been satisfactory but possibly somewhat less reliable, especially if on the higher side.

The path analysis also provides another important piece of information: the radiation, or take-off, angles required to launch signals over those two ionospheric routes. They are very different, being much steeper, or typically 63 degrees, from Calais but just 28 degrees from Marseilles, based on the assumed height of the F2 layer.

On the rather broad assumption that both clandestine stations employed the same type of antenna in the same configuration, those angles imply significantly different values of antenna gain at the two locations. The gain in each case can be computed by modelling some assumed antenna orientation by using one of the NEC-based computer codes now commonly available.

Antenna Assumptions

In an attempt to be as realistic as possible, and bearing in mind the highly compromised nature of the situations in which those agents found themselves, I have assumed that no more than 10m of end-fed wire was used as the antenna at both sites. Given that restriction, it's unlikely that it would have been mounted too high above the ground unless the clandestine station was set up in an upstairs room and some suitable anchorage point was available opposite a window.

It was possible, too, that the wire might have been in an inverted-L (**Figure 5**) or even an oblique orientation if it ran upwards from a room at ground level before being secured at some point higher up. Such shapes will lead to mixed horizontal and vertical polarisation of the radiated signals, but more importantly, to rather different orientations of the radiation pattern itself. The antenna gain in the required direction of propagation will almost certainly have been less than that obtainable from a well-sited wire antenna.

The computer simulations showed that the gains at their required radiation angles of the Calais and Marseilles antennas, when operating at 4.7 and 10.3MHz respectively, would have been minus 3.3dBi and minus 1.22dBi when completely horizontal and elevated 3m above typical, real ground; or minus 0.46dBi and plus 0.1dBi if both were entirely vertical above such ground. It is, therefore, evident that wires with more of a vertical component in their orientation offered a slight edge.

This can be readily understood if one appreciates that low horizontal antennas (i.e. at heights less than a tenth of a wavelength) produce their maximum radiation straight upwards towards the zenith. By contrast, vertical radiators have much lower take-off angles even when functioning without any form of highly conducting ground plane, as would undoubtedly have been the case here.

The Marseilles to Whaddon path will have benefitted significantly from vertical polarisation since it required a rather low 28 degree take-off angle for optimum performance, while even the 63 degree angle needed at Calais might well have been better served by a predominantly vertical wire.

Since no attempt was made in the simulations to include any losses in the antenna system, other than those due to its own finite conductivity and that within the ground below, the gains quoted above will all be on the high side. Losses due to the proximity of any building and other structures would all serve to reduce the antenna gain and hence the signal-to-noise ratio at the distant receiver.

Absorption Loss

According to Pat Hawker, in a note to the author, most of the skeds between the clandestine operators and 'Central' in England took place during daylight hours. That means that account has to be taken of the predominantly daytime phenomenon of absorption loss that always occurs when radio signals propagate through the D region of the ionosphere. My calculations used the standard technique that now forms the basis of the CCIR (the international radio standards body) procedure for determining this important propagation factor. The method is somewhat tedious to describe, but fortunately less so to carry out as a result of the excellent work done on the problem at the Radio Research Station at Slough by the joint Australian/British team of Peter George and Peter Bradley in 1974.

The starting point is always the prevailing solar conditions as described by the sunspot number, and the archived information at the WDC near Oxford revealed that the mean sunspot number for 1944 was about 10, which is typical of a low point in the solar cycle. Using that value as well as the state of the earth's magnetic field, the sun's position in the sky over northern Europe at mid-winter and mid-summer and the take-off angles of the Calais and Marseilles antennas, the maximum D-layer absorption losses were calculated across those two paths at midday. The results are shown in the table below.

Path	Summer absorption loss (dB)	Winter absorption loss (dB)
Calais-Whaddon	12.1	8.1
Marseilles-Whaddon	5.5	4.6

It's evident that the shorter Calais to Whaddon path suffers a significantly greater absorption loss because of the lower frequency on which it has to operate. In addition, the shorter path also experiences a noticeable increase in loss between winter and summer, whereas the seasonal change is a lot less across the longer Marseilles to Whaddon circuit. Both effects mean that the Calais to Whaddon circuit could well be the more problematic of the two.

Atmospheric Noise

Since the absolute criterion by which any communications link is measured is the received signal-to-noise ratio or SNR, the noise level at the receiver is always of paramount importance. In this particular case, one assumes that the wartime receiving sites in England were chosen with this very much in mind. Therefore, we will assume that locally generated, man-made noise was, to all intents and purposes, not an issue. However, natural noise sources cannot so easily be ignored and, as mentioned before, by far the most prevalent of these is that due to lightning – even when the actual lightning activity is thousands of miles away.

One has to bear in mind that there are typically tens to hundreds of lightning strikes every second around the world and so electrical noise or atmospherics, as they're commonly known, will propagate all around the globe by the same mechanisms as any other HF signals. The effects are cumulative and can be calculated.

At HF (3 to 30MHz) radio receivers are assumed to be dominated by the noise received via the antenna rather than by the internal noise generated within the receiver itself. At any given frequency the former is determined by the atmospheric noise temperature and the efficiency of the antenna, while the latter is set by the receiver's noise figure. As an example, atmospheric noise at 7MHz is typically some 30dB greater than that due to ambient or room temperature, and an antenna only 10% efficient (not unlike those presumably used in occupied Europe), will dominate the receiver's internal noise if it is less than 20dB. Though we have no idea of the noise figure of those 'suitcase sets' (and presumably neither did their designers, since it was not a parameter in vogue in those days), we do know that regenerative receivers, as used in the Paraset, were very sensitive when operating in their self-oscillating mode in order to receive CW. And since these clandestine links 'worked', our modern numerical fancies are but an irrelevance. But they do assist in making the calculations so we'll persist with the approach.

We must also consider the other end of the link if we're to make meaningful calculations of the situation at the receiving stations at Whaddon and elsewhere. The much favoured receiver in use there was the American-made National HRO, but information about its noise figure remains elusive. However, through the good offices of Michael O'Beirne G8MOB, I discovered that the Eddystone 730/4 had a similar valve line-up and its noise figure is typically 10dB, an impressively low value at the lower HF frequencies. The HRO will, therefore, be assumed to be similar.

Of particular importance when making noise calculations is the effective noise bandwidth of the receiver. This will be assumed to be equal to its IF bandwidth which, for the HRO, was typically 6kHz in its AM mode and around 1kHz when its crystal 'noise slicer' was used to improve CW reception.

According to Pat Hawker, not many operators were comfortable with it, so the wider bandwidth may well have been more common and would have produced a 6dB decrease in SNR. The antennas in use in England varied from resonant wire dipoles to massive rhombics and V-beams, and so antenna efficiency in England was not really an issue. Even though a terminated rhombic loses around half its power to that load, the antenna more than compensates for it by its high directivity.

Signals and SNR at Whaddon

The signal-to-noise ratio or SNR at Whaddon was calculated for an assumed typical daytime sked with two clandestine stations: one in Calais and the other in Marseilles. The system parameters used in those calculations are shown in the table on the next page.

These figures represent the optimum conditions of operation at the FOT and with no additional transmitting antenna losses than those due to their finite conductivity. In reality, both assumptions are far too optimistic. Frequency allocation would have been done well in advance of the mission and could only have been based on predicted critical frequencies – a subject that is still as much an art as a science, even in these days of super computers and sophisticated ionosondes. Therefore, it was most unlikely that any of the stations will have been operating at its 'optimum' frequency.

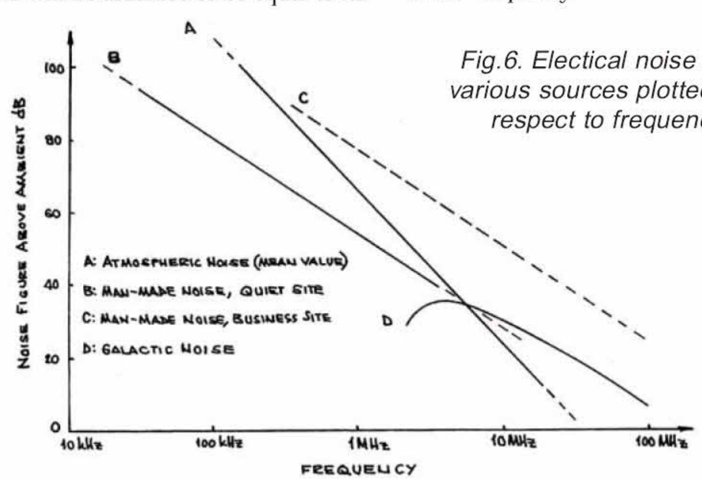

Fig.6. Electical noise from various sources plotted with respect to frequency

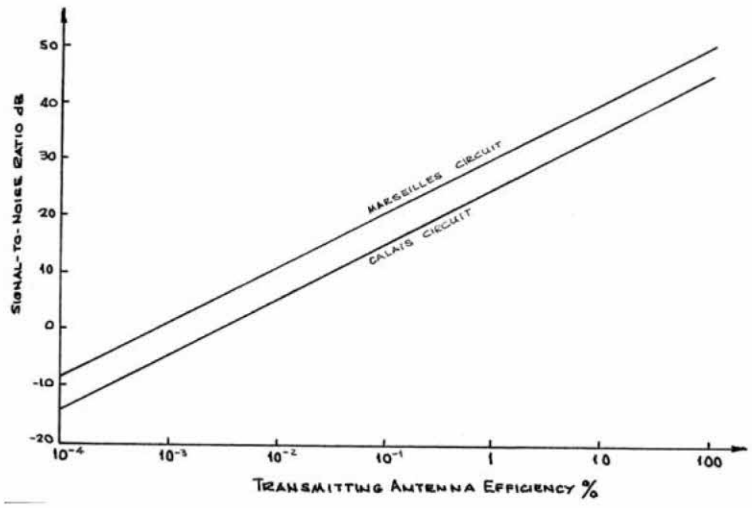

Fig. 7. Calculated signal-to-noise ratios with respect to transmitting antenna efficiency for two likely clandestine circuits using the Paraset from Calais and the B2 from Marseilles.

Link	Calais to Whaddon	Marseilles to Whaddon
Frequency	4.7MHz	10.3MHz
Wavelength	64m	29m
Tx antenna gain	– 0.46dBi	– 0.1dBi
Rx antenna gain	10dBi	16dBi
Tx output power	5W	20W
Path length via F2 layer	707km	1208km
Absorption loss (January)	8.1dB	4.6dB
Absorption loss (June)	12.1dB	5.5dB
Polarisation loss	3dB	3dB
Atmospheric noise	32dB rel to ambient	27dB rel to ambient

The likely outcome, had the chosen frequency been too high, is no contact at all, while reduced signal strengths and SNR would have occurred had a lower frequency been used. And antennas are always affected by their immediate environment so their efficiency will undoubtedly have been somewhat lower.

Even the quoted gain of the rhombic antennas at Whaddon might be overly optimistic since it depends on the elevation angle of its vertical radiation pattern and that, in turn, need not have been the angle required for the actual path lengths in question. Such antenna characteristics cannot be altered on demand, therefore a loss of some decibels in received signal strength is very likely to have occurred at certain times.

And finally, it must be appreciated that atmospheric noise levels are by no means as constant as those figures imply. They are statistical averages over time and can vary by as much as 10dB, at least, in that frequency range. Also, no account has been taken of local lightning activity, which would have increased the noise level significantly and may even have made the circuits completely unworkable. With these caveats in mind, the graphs (**Figure 7**) of SNR plotted against transmitting antenna radiation efficiency make interesting viewing.

An Assessment

The graphs confirm what the sparse records from those wartime days, and the personal recollections of those who were there have already told us. Clandestine radio operation using extremely simple, low-powered equipment and highly compromised antennas was indeed capable of providing the vital link between those agents in occupied France (and elsewhere) and 'Central', their headquarters back in England.

Though based on a number of assumptions which are almost impossible to verify, such as the dimensions and method of erection of the antennas at any of the clandestine sites, and the frequencies in use at any given time, it is evident from this theoretical analysis that antennas with radiation efficiencies of no more than a few percent would be capable of producing signal-to-noise ratios of the order of 20 to 30dB at the receivers in Whaddon and elsewhere in England.

The analysis showed, too, that the more distant transmitters such as those in Marseilles (bearing in mind that the B2 had a 6dB transmitter power advantage over the Paraset), would have had something like a 10 to 12dB edge on signal strength at the receiving stations compared with those much closer in the Calais area. The reasons for this are mainly to be found in the higher optimum frequency required to propagate over the longer distances (and thus the increased antenna gain that follows from that for similar lengths of wire), as well as the lower atmospheric noise levels and decreased absorption losses obtaining at the higher end of the HF band. It was indeed satisfying to know that Pat Hawker's recollections of working those various communications circuits throughout the war confirmed this finding as well.

Conclusion

A theoretical exercise such as this certainly satisfies one's intellectual curiosity. It also helps to shed some light on the many – sometimes conflicting – factors that go to make up a radio communications circuit operating with ionospheric support in the HF spectrum. But what it can never do is bring home the sheer courage and dedication of the radio operators who actually made it happen. What it might do, though, is remind us all of the remarkable feats of radio engineering that made it all possible and which were carried out so successfully at various secret sites across Britain during the war.

Acknowledgements

The author would like to acknowledge all the assistance he received over many years from Pat Hawker MBE, G3VA.

I must also thank the personnel at the Rutherford Appleton Laboratory for their assistance in archiving the relevant ionospheric information. Finally, to Michael O'Beirne G8MOB for the details of the likely receiver noise figure. ***RB***