NRAO ONLINE 5 Reflectivity of a Proposed Low Level Ionospheric Layer (6 to 60 km) by Watson-Watt and Colleagues in 1936

Epigraph:

"In this way [ionospheric transmitter and receiver at 8.8 MHz] a substantial number of the ghost images noted were found to be due to aeroplanes."[1]

Introduction:

In 1936, a US and then a UK group published descriptions of the discovery of possible radar echoes of a low -level ionosphere layer, well below the D layer (60 to 90 km height). The observations were carried out at 6 MHz using the Chain Home Air Warning Units of the Air Ministry at Orfordness Research Laboratory. The publication supplied information that may have been useful to German scientists and engineers working on radar and countermeasures in the Luftwaffe. The location and some details of the UK system were revealed in the publication.

Within a year, Appleton and his postgraduate student, the Australian Jack Piddington, attempted to confirm the results with an 8.8 MHz system at Cambridge. No low level reflections were observed. "It may be stated at once that no stratum at 10 km height … has been detected by us during three months of observation … Our ideas concerning the normal process of wireless transmission are left undisturbed … Through the courtesy of Mr Watson-Watt we have been able to test our own receiver …" No significant persistent echoes were detected from layers below 60 km. Appleton and Piddington also reported an observation what could have been a major security lapse, "ghost images" due to aircraft (see EPIGRAPH). These events occurred a year before the beginning of WWII, and two years before the Battle of Britain (10 July 1940 to 31 October 1940).

The papers of 1936:

In the weekly publication *Nature* during May 1936, two groups reported the apparent discovery of surprising echoes from low levels in the ionosphere, 10 to 60 km. These levels were much less than the accepted layer of the D layer at 60 to 90 km. R.C. Colwell and A.W. Friend of West Virginia University published in *Nature* a short note on 9 May 1936: "The D Region of the Ionosphere" (vol 137, p. 782). Observations at 1.6 and 3.5 MHz with a pulse width of 10

[1] Appleton and Piddington*, Proc Royal Soc*., 1938 vol 167, p 467 "The Reflexion Coefficients of Ionospheric Regions," a description of data obtained at the Cavendish at Cambridge in 1937.

microseconds were used to detect reflections from low levels; they proposed that the "C region" existed at levels of 2 to 30 km. This work was followed up by an extensive paper in the *Physical Review* from 1 October 1936 by the same authors (vol. 50, page 632, "The Lower Ionosphere"). Additional frequency observations were described (at 2.4 MHz) with shorter pulse times of 3 microseconds; the low ionosphere was observed with "a well defined region … with a C region which lies between 2 and 30 km".

Possibly due to the pressure of publication of the Colwell and Friend results, Watson-Watt and colleagues published a paper in *Nature* a few weeks later (23 May 1936), "Radio Waves from the Middle Atmosphere", vol 137, page 866, by R.A. Watson-Watt, L.H. Bainbridge-Bell, A. F. Wilkins and E.G. Bowen. "We are glad to be able to confirm and amplify the indications given by Prof R. Colwell and A.W. Friend in the letter … of 9 May." Due to the top-secret nature of the Orfordness site, the publication permission granted by the Air Ministry permission remains surprising. No acknowledgement text appeared in the publication.

> [We report] on the initial stages of work for the Radio Research Board [of the National Physical Laboratory of Teddington Middlesex] undertaken at Orfordness, a site the isolation of which permitted the use of substantial powers in short-duration pulses for the closer study of the lower regions of the ionosphere … We have had under intermittent observations the very complex echo-systems which result from the return of radio waves from heights between 6 km and 60 km. We had just before publication of the letter of [Colwell and Friend], completed a preliminary communication on these studies.

The suggestion was made that the echoes from these low heights of 15 to 50 km could be influenced by replenishment from thunderstorms. The observations were made at frequencies in the range 6 to 12 MHz.

Three additional reports on the Orfordness results were reported in *Nature*, two on 13 February 1937 (a "news and views" discussion referring to Watson-Watts talk at the Royal Society on 4 February 1937 and to the two papers of May 1936 in *Nature*) and an additional *Nature* description of the main paper (18 September 1937[2]) of the Watson-Watt group in the *Proceedings of the Royal Society* in 1937, "The Return of Radio Waves from the Middle Atmosphere" by Watson-Watt, Wilkins and Bowen (vol 161, p. 181, 1937).The opening sentence to the major Watson-Watt et al paper of 1937 is noteworthy. Watson-Watt reminded the reader that he had invented a major new scientific term earlier in the 20th century:

> One of us introduced [in 1929] the name "Ionosphere" to designate the region of the upper atmosphere of which the most prominent physical characteristic was the

[2] This "news and views" article pointed out that these low-lying reflecting layers might well have major consequences on the propagation of short-waves and especially on the newly available BBC television broadcasts at VHF (near 40 MHz), the system on which Pawsey worked at EMI.

> occurrence of sustained high ionization densities, and which was, in consequence, of fundamental significance in the propagation of radio waves. The name, after finding its way into many languages … is now commonly applied to the region of the atmosphere above the first 90 km. It is an object of this present paper to show that this sharp distinction, although very broadly justified, is less happy than might have been hoped.

This publication in the *Proceedings of the Royal Society* in 1937 contained a number of details which could well have assisted German scientists in assessing the nature of the top-secret RDF equipment being constructed in East Anglia since 1935, as well as revealing the location of the Air Ministry facility:

> ... Reliance was placed on a substantial increase in the power radiated upward, and, still more important, on the substantial reduction of the duration of the emitted and recorded pulses. Since the wide range of work in progress at the Radio Research Station, Slough, made it undesirable to introduce a new high-power emitter there, the Air Ministry very kindly offered facilities at their Orfordness Research Laboratory, where the least possible disturbance to other radio work was ensured by the isolation of the site. [Of course, it was Watson-Watt's group that had planned and constructed the new equipment, a proto-type RDF that turned out to be suitable for this exploratory ionosphere work using the high power and short pulse intervals.] A pulse emitter capable of giving large instantaneous outputs, and giving well-shaped … flat-topped pulses of 20 microseconds duration was installed … Some 300 m away … a directive receiving system was erected … [thus a bi-static radar]

The region, below 50 km in height, giving these new echoes was, quasi-humorously, designated [the] Z region, since the series F, E and D led naturally through A to Z. In the absence of more detailed knowledge, the authors proposed temporarily to retain the term "Z region" for reference purposes, designating the newly proposed lower regions of ionisation.

Attempts at Confirmation of the Low-level Ionosphere

Within the next year, a number of ionospheric groups around the world attempted to confirm the reality of this new "B" region (yet another terminology proposed by Appleton and Piddington, at 8.5 to 13.5 km heights) or the alternative named "Z" layers (Watson-Watt et al, layers at heights less than 90 km).[3] Watson-Watt asserted that the reflexion coefficient from these 10 km layers was about 0.7, with detectable echoes up to the 10th order. An immediate attempt was made in 1937 by Appleton and Piddington at Cambridge (Piddington was a post-graduate at Cambridge 1936-1938). The results of this investigation were published in 1938 (see footnote 1) From the introduction to the paper, the concerns of Appleton and Piddington were noted: "[The Colwell and Friend and Watson-Watt et al results] are of the greatest

[3] Colwell and Friend (1936) used the term "C" layer for the region 2-30 km which they claimed to have observed.

scientific importance and, immediately they were announced, investigations were begun here in Cambridge to see if we could confirm them."

These observations were made at 8.8 MHz with a power of 2 to 4 kilowatts and a pulse duration of 30 microseconds. The transmitter was near the Solar Physics site at Cambridge University and the receiver was in a private house (perhaps Appleton's home) 7 km distant. With the sensitivity achieved it would have been possible to detect a first order echo from a layer at 10 km with a reflection coefficient of only 0.0001. Appleton and Piddington wrote:

> It may be stated at once that no stratum at 10 km height with a reflexion coefficient of the order of 0.7 has been detected by us during three months of observations. We must conclude, in accordance with our interpretation of the results of [Watson-Watt et al], that the reflexion coefficient must be less than 0.0001. They would therefore play no substantial part in ionospheric alternation or refraction, so that our ideas concerning the normal processes of wireless transmission are left undisturbed.

The publication also contained a surprise. The Air Ministry gave permission for Appleton and Piddington to use the Orfordness transmitter; with this, the Cambridge group detected sporadic echoes from the layers at 10 km at 6 MHz, but with a reflexion coefficient of only 0.00007, a factor of 10000 weaker than Watson-Watt et al had proposed. However, no permanent highly reflecting layer was detected at heights less than 90 km.[4]

These important results from 1937 were reported to Martyn in Australia in mid-1937 (22 July 1937), with a description of Piddington's plans followed by his preliminary, negative results on detecting low-level ionospheric echoes:

> Watson Watt's paper has just come out … I [Piddington] have not seen a low echo yet which could be identified with any certainty; and my apparatus, as far as pulse shortness and CRO [cathode ray tube] delineation, is as good as Watson Watt's. However, plans are afoot and the first thing I will do is to build a transmitter of the same order of magnitude as that used by the authors of the paper. I am starting on this next week. There is another job looming, which is hard to write about. It concerns W. Watt's present transmitter and our use of it as a blind for other uses. This is strictly hush-hush, naturally. [Clearly a reference to the early Air Warning radar trials.][5]

Communication with Australia

[4] The Appleton and Piddington publication did not explicitly mention the site of the transmitter, only the "higher powered sender used by Watson-Watt et al. As discussed above the Watson-Watt paper of 1937 had discussed the site of the Orfordness transmitter. had

[5] Evans, 1973 *History of the Radio Research Board*, p. 139. Letter from Piddington to Martyn from the UK on 22 July 1937.

Likely, Martyn had heard even earlier from Piddington with some preliminary results. He wrote Fred White in Christchurch in New Zealand a month before the letter from Piddington (above) on 14 June 1937: “I have just heard from Piddington that he has completed his high power pulse transmitter and has found no trace of low echoes and is therefore using it for studying the E layer instead.”[6]

No explanation for the likely bogus detection of Watson-Watt et al was given. Possibly the observations of R.L. Dowden in 1957 provide a clue. He observed at 7 MHz from a site at Macquarie Island, in the southwest Pacific Ocean, halfway between New Zealand and Antarctica. He detected echoes from features in the range 20 to 100 km, which earlier groups had interpreted as low-level ionospheric layers. He showed that the echoes arose from coherent backscatter of surface propagated waves by sea waves of length 20-30 meters (of course sea waves were likely present in Watson-Watt’s experiment with the radar located near the North Sea). (Dowden, R. L. (1957). "Short-range echoes observed on ionospheric recorders." *Journal of Atmospheric and Terrestrial Physics 11, no. 2:* 111-117.).

Appleton and Piddington also have a remarkable statement in their paper of 1938. We may ask if the German radar scientists read this statement with some interest in the year before WWII began in 1939, 1 September:

> [Using the British Television service, 69 km from Cambridge at Alexandra Palace], a number of ghost images noted were, however, accompanied by a fluttering of the intensity of the whole television picture, indicating rapid motion of the scattering centre. In this way a substantial number of the **ghost images noted were found to be due to aeroplanes** [our emphasis] and we are not at all sure that any of the cases noted were due to reflection from atmosphere scattering centres.

Clearly, Piddington was primed to begin radar research for the military when he returned to Australia in late 1938, ,From the unpublished Piddington memories (see the Piddington biographical memoir by Melrose and Minnett, *Historical Records of Australian Science,* vol 12, 1998, p. 229):

> So when we came back to Australia, we knew all the principles of radar and we also knew the amount of power we'd need in transmitters and qualities of the receivers to make a set that would be of any use in picking up aircraft.

Bowen planning to Continue Low-Level Ionospheric Research in 1945

Surprisingly, in 1945, Bowen suggested (Chapter 10) that a possible project for the post-war RPL would be an investigation of the Z region. Apparently he was not aware of, or discounted, the Piddington and Appleton negative results published in 1938. In the 2 July 1945 “Future

[6] Ibid, p 285

Programme of the Division of Radiophysics" by Bowen, he suggested a renewed attempt to elucidate the properties of this elusive reflective regions at heights of 12 to 30 km. As Bowen wrote, this region had received

> … practically no attention. It is a region which is fast becoming of very great interest to the aeronautical world since the advent of jet propulsion may result in all transcontinental and transoceanic flight taking place in this region within the next ten or twenty years. A study of the meteorology of the middle atmosphere will therefore be of first importance, and radio provides a method of probing its secrets [such as temperature and velocities] in advance.

In subsequent years, the "Z" of the ionosphere was scarcely discussed.