Errors in Radiotelegraphy


Various articles on telegraphy in Point to Point Telecommunications, particularly that by E. G. Copper, in the February 1959 issue, discussing some aspects of the use of automatic error correcting systems, have given rise to correspondences. It was felt, therefore, that an authoritative article on the history of the development of automatic telegraphy on radio systems would be of interest, and J. A. Smale, as a well-known authority on this subject, was invited to review this field.

1 INTRODUCTION

It is often assumed, with considerable justification, that errors were introduced into telegraphy by the advent of radio. Certainly, atmospherics (static), dropouts due to fading, and distortion due to variable multi-path transmissions have complicated the problem of providing adequate accuracy, and have tended to obscure the errors made by operators and those caused by equipment failures. Nevertheless, the problem existed on landline and submarine cable telegraphy, due to signal distortion and interference of one sort or another and, with the introduction of higher speeds and mechanization, resulted in the development of various schemes of signal selection and regeneration. The final responsibility for accuracy resided in the skilled operator and the human faculty for detecting errors, although the human frailty of guessing sometimes resulted in the inaccurate correction of errors. With the increase in error-rate on radio-telegraph circuits, the burden on the operator became a heavy one. Albeit, this bred a particular skill, but with the establishment of a world-wide radio network, the high cost of suitably skilled operators gave impetus to mechanization and the adoption of printing telegraphs, already common in line telegraphy.

The early radio circuits employed Morse Code signalling, dating from 1835, which could be read at slow speed and at least checked manually at high speed. Mechanization was possible to some extent by the adoption of the high speed Wheatstone system using Morse perforators and printers but the liability to errors, due to atmospherics on long-wave signals and later to fading and interference in addition on short-wave signals, was even greater than when using undulator or recorder signals transcribed manually; the system was therefore still expensive in terms of skilled operators capable of checking the Wheatstone signals and perforated tape.

The alternative system of printing telegraphy in use on wire circuits employed the Baudot or Murray code from which was developed the 5-unit start-stop teleprinter using the International Alphabet No. 2. This is a code having the same length of signal for each character and using all of the 32 possible permutations of five elements. The Baudot code dates from 1874 and the real growth in the use of the 5-unit teleprinter dates from 1926 when the code alphabet was standardized by international agreement. (The alternative proposal at that time was a 6-unit code, giving 64 possible permutations, and it is perhaps a pity, having regard to availability of characters and the need for error detection, that the 5-unit code was adopted on the score of maximum traffic speed for a given signalling speed.)

The first really successful teleprinter was brought to the United Kingdom by Donald Murray in about 1922; it was the Morkrum No. 11 Teletype, working at 30 bauds, and the first pair of machines was used on a private wire circuit in London between the Marconi radio control office in the City and the branch telegraph office at Marconi House in the Strand.

Murray had already been interested in mechanized telegraphy for many years and, in a pamphlet published in 1915 entitled ‘Press-button Telegraphy’, forecast very closely the present world-wide network of 5-unit printers, public and private subscriber teleprinter systems. Under the name ‘Autoplex’ he proposed a synchronous automatic-multiplex system, and in adopting this name for the present series of automatic ARQ equipment, the Marconi Company is happy to honour the memory of a great pioneer of printing telegraphs.

Attempts to use the 5-unit start-stop teleprinter on radio circuits date back to about 1923, when test transmissions were made from London to Berlin from the Marconi long-wave transmitter, GLO, at Ongar. The
early experiments using this teleprinter produced some interesting results. Unlike the Morse code, the 5-unit code provides only 32 possible permutations, all of which are allocated to meaningful characters and this lack of redundancy, in relation to the signal-noise ratios frequently encountered in practice, resulted in the printing of good-looking characters which were wrong, that is, in undetectable errors, particularly in code traffic. Such an additional liability to errors was quickly recognized as a menace to the telegraph system, capable of putting clients to considerable inconvenience and expense and this, coupled with the inability of the operator to check the signals on a recorder undoubtedly created a serious prejudice against the system. However, the advantages of the teleprinter as a standard machine gave impetus to the search for a solution; firstly by improving the quality of the radio circuit by raising the signal-noise ratio of the received signal; secondly by making the apparatus less susceptible to errors, and thirdly by refining the process of correcting errors by making it automatic.

By the outbreak of the Second World War, the 5-unit start-stop teleprinter was in widespread use on wire circuits. The availability of a standard equipment coupled with a shortage of trained radio operators at a time when traffic was increasing rapidly, led to something of a landside towards the use of teleprinters on radio circuits. Furthermore, the possibility of integrating inland and overseas circuits greatly favoured the adoption of a readily available machine, for which automatic switching systems were already in common use.

2. IMPROVEMENT IN THE RADIO CIRCUIT

The improvement in quality of the radio circuit is really another story, but there are a few historical facts associating frequency shift or 2-tone signalling with the introduction of teleprinter working.

Prior to the introduction of short-wave working there was not much that could be done to reduce further the effects of atmospherics on long-wave signals. But in 1924, when early experiments were being carried out with teleprinters, the first effort, as far as the writer is aware, was made to employ frequency-shift signalling using the Ongar long-wave transmitter.

In 1933, Bakker and Van Duuren, of the Netherlands P.T.T. proposed to detect mutilation of signals by using one frequency for mark and another for space. At the same time they made the first mention of ARQ, that is the automatic request for the repetition of a signal that had failed and the automatic transmission of the repetition.

In 1936, Cable & Wireless engineers proposed a 2-tone system called Double Frequency Keying, whereby ‘extras’ (due to atmospheres) and ‘drop-outs’ (due to fades) resulted in failures of the same sign, so that a system based on comparison could cater for both types of failure simultaneously.

The Second World War saw a rapid development of the frequency-shift signalling system. The improvement was particularly beneficial on circuits using low-power and elementary aerials and this improvement was considered by many organizations throughout the world sufficient to justify the use of ‘unprotected’ 5-unit code and teleprinters. ‘Radioteletype’ and frequency-shift operation became almost synonymous. However, some organizations, using higher power and directional aerials, and already mechanized but using other systems of regeneration and direct printing, were less attracted by a change in the form of mechanization unless it were accompanied by error detection and correction, that is by the use of a ‘protected’ code.

3. IMPROVEMENT IN TELEGRAPH TECHNIQUE

The story of the reduction in susceptibility to errors of the telegraph apparatus and the development of automatic means for doing this can be combined with a brief description of some of the methods employed since 1919, leading up to the present ARQ system already described in this journal.

In the first transatlantic radio-telegraph circuit between Clifden in Ireland, and Glace Bay in Nova Scotia, which in 1919 was still operating mainly on a simplex basis, the receiving operator pressed his transmitting key if a word needed repeating, and under bad conditions every word was repeated until he pressed his key to indicate satisfactory reception. High speed Wheatstone transmission, when possible, was received on a wax cylinder which was subsequently slowed down for aural
transcription. Even at speeds of 60 wpm the receiving operator was able to assess the quality of reception and, by pressing his key, initiated repetitions to prevent too many errors piling up at the receiving end.

By 1924, a form of diversity reception was in use, by which the operator listened to an audio signal and also had unobstructed view of the writing point of an undulator recording the same signal (an alternative method used a double-pen undulator recording the same signal from two different receiving stations). Operators were capable of typewriter reception at a speed of 40 wpm by this method, under conditions which made aural or undulator reception alone impossible.

About the same time, the French Administration was using the Baudot synchronous 5-unit system on radio circuits. Verdan proposed a method by which each character was repeated after a short interval of time. The first reception was stored and automatically compared with the second reception; if they differed, the printer accepted only those marking elements which appeared in both. In this way spurious marks caused by atmospherics were largely eliminated. This was the system later used in conjunction with the Cable & Wireless double-frequency keying experiments in 1936, enabling simultaneous correction of failures due to ‘extras’ and ‘drop-outs’.

In 1926, when the first short-wave Beam came into use with generally much higher speeds of working, reception of Morse signals on undulators was common practice. During adverse conditions, the circuit resorted to ‘slips twice’, the Wheatstone tape of each message or batch of messages being transmitted a second time. The undulator tape of the two receptions were either pasted down on sheets in the correct relation or the two tapes were drawn across a typewriter in front of the transcribing operator. Creed reperforators and printers were sometimes used but the handling of errors still required the services of a skilled operator and the production of clean message copies was not too satisfactory. Furthermore, the speeds often attained on short-wave Beam circuits were too high for the wholly satisfactory operation of the reperforators.

In 1928, with the merger of the British cable and wireless services, a common method of operating the two media, using the regenerator and direct printing techniques of the cable system, was introduced. Double Current Cable Code, due to H. V. Higgett of Cable & Wireless, is a modification of 3-position Morse code code suitable for the 2-position signalling adopted on radio circuits. Two-channel time division multiplex, operating at aggregate speeds up to 90 bauds, was installed first on the London-Cape Town Beam in 1939 and subsequently on many circuits in the Cable and Wireless system. This code employs space-mark for a dot, mark-space for a dash and space-space or mark-mark for a space in the Morse code. Consequently, as complete inversions are unlikely, there is a degree of error detection in the code. The Verdan system of automatic repetition and comparison was made available using the two channels of the multiplex signal, but as the Verdan system catered for errors of one sign only, the receiving equipment had to be set for either ‘extras’ or ‘drop-outs’.

In 1932, Siemens & Halske demonstrated a 4-channel time-division multiplex on which the Verdan principle was used when necessary to transmit one, two or three repetitions with subsequent comparisons. The system was used on a long-wave circuit between Berlin and Moscow.

Also in 1932, the Radio Corporation of America introduced the 5-unit teleprinter on the San Francisco-Honolulu circuit. This experience led J. B. Moore, in 1934, to propose the ‘constant ratio’ code. Redundancy, which is lacking in the 5-unit code, can be increased to any desired extent by using more than five elements for each character so that there are more permutations than characters. Moore in fact proposed a code of 7 or 8 elements. With a 7-unit code, coupled with the imposition of a pattern such that every character used must have three spacing elements and four marking elements, there are 35 valid permutations. Errors in reception can be detected by a simple counting device except in the case of certain multiple inversions, that is, a mark changed to a space and a space changed to a mark in the same character, a comparatively rare occurrence. Detected errors can then be dealt with by a request for repetition. Moore subsequently wrote that this proposal was made while he was a member of the Riverhead laboratory group working on the development and design, not of printer systems, but rather of radio receiving systems. He said: ‘Since we could not seem to make the radio system good enough to handle the 5-unit code, it occurred to me that
the thing to do would be to make a printer system that could be operated over the short-wave radio circuits then available to us.' It seems that frequency-shift operation was not considered.

In 1933, Bakker and Van Duuren, when proposing to detect errors by a 2-frequency signalling system, made the first proposal for automatic request for repetition. In these two basic inventions we have the fundamentals of the present ARQ systems.

In 1936, the Radio Corporation of America carried out tests of a 7-unit multiplex system, incorporating the Moore code, on the New York-San Francisco circuit. It was put into commercial use on that circuit in 1939 and shortly afterwards on the New York-London circuit. Entirely new 7-unit perforators, transmitters and printers were used and the system therefore had the disadvantage, perhaps only subsequently realized, of non-standard telegraph apparatus.

In 1938, Van Duuren described a system combining ARQ with an error detecting code of the 'constant ratio' type. The desirable, if not essential, feature of employing standard 5-unit teleprinter equipment was already apparent and Van Duuren who, in the period following the Second World War has become the acknowledged leader in this field of development, first proposed a 7-unit code designed to facilitate the automatic conversion from the 5-unit code of certain 'rules' of conversion (the mere addition of two units to the 5-unit code is not admissible as this does not produce a constant ratio).

By 1947, the Van Duuren ARQ system was in commercial use between New York and Amsterdam and between Amsterdam and Berne. At this time, also, R. G. Griffith, now with the Canadian Overseas Telecommunications Corporation, produced what amounted to a 10-unit code system in which each element of the 5-unit code was converted to two signal elements, mark-space for a marking unit and space-mark for a spacing unit, an arrangement similar to that used in the Higgitt Double Current Cable Code. The Verdan system of character repetition and comparison was also incorporated.

Other types of 5-unit to 7-unit convertors were proposed in 1946 by Van Duuren, in 1947 by Higgett, in 1951 by Cook of the British Post Office, and in 1953 by Wheeler and Fyfield, also of the British Post Office.

These proposals aimed at having the smallest number of exceptions to the 'rules' necessary for automatic conversion.

Saunders and Warburton of Cable & Wireless proposed a wholly mechanical means of converting 5-unit to 7-unit and vice versa, which did not need to conform to any rules. This system, which is in use on a number of circuits in the British Commonwealth network, has the advantage of simplicity and compactness, but it is not compatible with the electronic and electro-magnetic systems now more generally in use.

In 1956, the International Radio Consultative Committee at Warsaw recommended the standardization of the Van Duuren error detecting code and certain other features of his ARQ system. The Autoplex system already described in this journal conforms to these standards.

4 CONCLUSIONS
And so, 25 years after the basic proposals of Van Duuren and Moore, we might parallel the opening sentence of this article and say with considerable justification that the liability of telegraph circuits using radio to errors is now well under control.

J. A. SMALE joined the Marconi Company in 1919. In 1921 he was responsible for the installation in the City of London of the first central telegraph office for wireless circuits. He transferred to Cable and Wireless in 1929 and was appointed Engineer-in-Chief in 1948, when he assumed responsibility for 155,000 miles of submarine cable and some 130 radio circuits. Before the onset of World War II he organized a system of world-wide emergency wireless circuits which later proved to be invaluable to the Allies. He was also responsible for the development of the system of wireless relay stations as a means of overcoming much of the effects of fading and atmospheric interference on long-distance wireless routes.

Mr Smale, one of the authorities on world communications, has been largely responsible for providing the British Commonwealth communications system. On his retirement from Cable and Wireless in 1957 he rejoined Marconi's as Technical Consultant on Telecommunications Engineering.