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George A. Campbell

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Dr. George A. Campbell

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ON the first of December next, after thirty-eight years of active and unusually productive service as a mathematical physicist and inventor, Dr. George A. Campbell retires from active membership on the staff of the Bell Telephone Laboratories.

As the history of an art can often be written most effectively in terms of the personalities who have been responsible for its upbuilding, I feel that I am not departing from the objectives of the *Bell System Technical Journal* in bringing to the attention of its readers a brief note concerning one of the chief artificers of telephone transmission. Dr. Campbell's achievements in this field entitle him beyond question to rank first among his generation of theoretical workers in electrical communication. Yet, in common with many truly great minds, it has been his nature to avoid publicity, so that outside the circle of his immediate associates and a few of the more mathematically gifted students of his chosen branch of electrical science, his fame is far from being commensurate with his achievements.

In 1897, thirty-eight years ago, the art of telephone transmission was in its infancy. Circuits of even a few hundred miles' length were rare, and the longest distance over which communication had been held was that separating New York and Chicago. It was at this time that Campbell, as a young man, after graduating from Massachusetts Institute of Technology and spending four years in graduate study at Harvard, Göttingen, Vienna and Paris, joined the staff of the American Telephone and Telegraph Company to engage in research. Familiar with the work of Rayleigh and Heaviside, Campbell's early studies sought some method of mitigating the attenuation, which levied heavy toll upon the voice currents and formed a theretofore unyielding barrier against telephone communication over very long distances.

Heaviside had suggested that inductance, if properly applied in a long telephone circuit, should diminish rather than increase the attenuation. Campbell followed this suggestion and developed a theory of loading, but in his case there occurred one of those coincidences—fortunately rare in the history of science—of two investigators arriving at substantially the same result at the same time. Independently of Professor M. I. Pupin, he worked out a complete theory of the telephone loading coil. They both applied for patents, with the result that an interference was declared, and Pupin was able to establish a slightly earlier date of conception. The loading coil interference was decided in Pupin's favor and the famous patents issued to him. The fact should be recorded, however, that Campbell's analysis of the problem—actually more detailed than Pupin's—led him to formulate rules for the design of loading coils and their spacing which were, from the very beginning, the only ones employed in this country.

As the effectiveness of telephone instruments increased and the lengths of circuits grew, noise and crosstalk became an outstanding obstacle to telephone advance. It had been shown that this crosstalk was a complex effect resulting partly from electromagnetic and partly from electrostatic induction. In unpublished memoranda written between 1903 and 1907, Campbell pointed out the importance of Maxwell's capacity coefficients in the calculation of crosstalk and coined the much-used term "direct capacity," now modernized to "direct capacitance." It was also at this time that he designed his well-known "shielded" balance, which in one form is a bridge for measuring direct capacities. He showed in these early memoranda that crosstalk between two circuits depends, to a considerable extent, and particularly in the case of loaded circuits, on a function of the various direct capacities between the wires of two circuits. He termed this function the "direct capacity unbalance." This work led to the invention of the well-known capacity unbalance test set, hundreds of which have been used in countless measurements in the manufacture and installation of toll cables.

This study of Campbell's marked an important advance since, for the precise but unwieldy theory of crosstalk, it substituted a simple approximation—an approximation which was to remain adequate until the advent of carrier systems with their higher frequencies and shorter wave-lengths.

As control was gradually extended over the characteristics of telephone circuits, both from the standpoint of their transmission effectiveness and their freedom from crosstalk and noise, the art reached the point at which development emphasis shifted to the telephone repeater. Here, an entirely new line problem arose,—namely, that of avoiding singing when repeaters are adapted to two-way amplification. Up to 1912, the only type of repeater circuit used was the so-called 21-type, in which a single repeater element amplifies messages which reach it from both directions and which requires that the two associated sections of line have very similar characteristics. A well-known limitation of the 21-type repeater is its tendency to "sing" when line unbalance or amplification exceed certain rather low limits.

On the other hand, the 22-type repeater has two amplifying elements and two artificial lines, one to balance each associated section of actual line. While the basic idea of the 22-type was old, it remained for Campbell, in a memorandum dated March 7, 1912, to reveal its properties of inherent stability. He points out that "singing will not be introduced by any possible unbalance however large, in either of the lines, provided the unbalance of the other line does not exceed a certain critical magnitude." Also his words, "the use of a compensating device such as an artificial line, to reduce the amplification at the resonant frequencies to the level of the amplification at other telephonic frequencies" suggest broadly the idea of equalizing for amplitude-frequency distortion which is brought in by the selective characteristics of the line circuits or other apparatus in a long system. Furthermore, "if it became necessary merely to eliminate certain frequencies lying outside of the range required for telephony, the use of an artificial selecting circuit" is definite anticipation of the use, subsequently common in all repeaters, of low-pass filters to cut off frequencies outside of the band transmitted and thus minimize line balance difficulties.

Campbell also indicated that the stability of a circuit as regards singing could be improved if the amplification were distributed among a number of properly spaced points along the line rather than concentrated at a single point.

Moreover, the great amplification made possible in telephone circuits by the perfection of the vacuum tube and its associated circuits permitted the use of cables for long distances with manifest advantages for congested routes. The great amplifications required for the longer cable circuits, however, could most effectively be handled by the use of "four-wire" circuits both for voice frequencies and later for carrier systems. Campbell was the originator of this type of circuit. In the same memorandum of 1912, which discussed the 22-type repeater, he suggested it as the logical extension of the one-way paths in the 22-type repeater, each path containing as many one-way amplifiers and line sections as desired.

The present situation in transmission, particularly toll transmission, is characterized by the growing use of high frequencies, the transmission of broader frequency bands and the use of the so-called "carrier" method. This we find in the most advanced form in the proposed very broad band cable circuits of the coaxial and other types. Transoceanic telephony and broadcasting are other outstanding uses. The electrical wave-filter in its many forms is one of the most important elements in all such systems. The filter appears as a means of sharply separating the currents of different continuous bands of frequencies in carrier telephone and telegraph systems, for sharp selectivity in radio systems and for various other uses in these and other forms of transmission such as telephone repeaters, telephotography, composite sets and testing apparatus. Indeed, the filter has, within the last few years, become almost as ubiquitous as the vacuum tube. The fundamental conception of the electric wave-filter arose out of Campbell's analysis of loaded lines. The patent was issued to him in 1917. It is evident to one reading his famous paper on "Loaded Lines in Telephonic Transmission," published in the *Philosophical Magazine* of 1903, that even at that time he had begun to envisage the high-pass and low-pass wave-filters.

Effective station sets are fundamental to all good transmission. In a memorandum dated October 8, 1906, Campbell disclosed the single-transformer anti-sidetone station circuit which is achieving almost world-wide acceptance. Later, he carried out a comprehensive and conclusive piece of work in revealing all of the possible circuit arrangements for doubly conjugate branches and in setting down the impedance relations of the line, network, transmitter and receiver of these various branches. This systematic analysis of the problem greatly facilitated a comprehensive survey, giving assurance that all types of circuits would be considered and that those which best fitted the available transmitters and receivers would be selected. The work was summarized in an extensive paper entitled "Maximum Output Networks for Telephone Substation and Repeater Circuits" by Campbell and Foster in the *A. I. E. E. Transactions* of 1920.

It would appear that Campbell also originated the articulation test which now finds a use wherever telephone development work is in progress. In a paper entitled "Telephonic Intelligibility," which appeared in the *Philosophical Magazine* of January, 1910, he describes how, in connection with tests he had been conducting, he made up and employed successfully articulation lists consisting of meaningless monosyllables.

This brief note is intended only to enumerate without elaboration the more outstanding of Dr. Campbell's contributions to the art of electrical communication as they fit into the history of that art. Their diversity is such as to establish the unusual versatility of Campbell's genius. His is a career unusually productive of discoveries, inventions and patents. Many of his important memoranda, however, were never worked up in the detailed form which would render them suitable for publication, and still reside only in the Company's engineering files. It would be regrettable to pass this occasion by without some notice being taken of these unpublished documents, and perhaps as fitting a commemoration as any is to print a few of the briefer ones just as they were written. Choosing somewhat at random, we are selecting the above cited memorandum of March 7, 1912, in which the 22-type repeater and the four-wire circuit are suggested, and two memoranda of earlier dates discussing capacity unbalances and crosstalk. The memorandum on repeaters is perhaps particularly interesting because of its historical flavor. Written twenty-three years ago, it refers to the measurement of attenuation in miles of cable, not decibels, and to such considerations as the natural period of the mechanical repeater diaphragm.