

From Effect to Artifact : The Case of the Cymometer*

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사이모미터 (cymometer) 를 통해 고찰한 과학 기기와 실험적 실천의 관계

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요 약

최근 과학 기기 (scientific instruments) 에 대한 역사적 고찰들은 두가지 조금은 상반된 결론을 제시하고 있다. 하나는 과학 기기가 수동적인 도구가 아니라 “그 자체의 생명” 을 가지고 있다고 할 수 있을 만큼 능동적이고 독자적이라는 것이며, 또 다른 하나는 과학 기기가 과학과 기술, 이론과 실천을 매개한다는 것이다. 이 논문의 목적은 이러한 두가지 결론을, 특히 이 둘의 관련을, 비판적으로 고찰하는 데 있다. 필자는 물리학에서의 공명 (resonance) 현상으로부터 어떻게 초기 무선전신에서 과장측정기로 널리 쓰였던 사이모미터가 나왔는지를 분석함으로써, 과학과 기술을 매개했던 것은 기기가 아니라 실험실에서의 과학자의 “실천” (practices) 이었음을 강조할 것이다. 이와 함께 필자는 과학 기기가 수행하는 역할은 서로 다른 이론과 실천이 만날 수 있는 “인공물의 공간” 을 만드는 것임을 보일 것이다.

I. Introduction

The recent “turn to instruments” in the history of science has created radically different images of scientific instruments from those that were commonly shared among historians of the 1960s and 1970s. At that time, when the main interest of historians of science was in the development of theories and ideas, instruments were simply identified with measuring devices, or regarded, at best, as things that embodied theory. Current studies have revived, however, instruments’ complex, autonomous, and “fuzzy” nature, epitomizing their findings in a kind of postmodern dictum that “instruments have their own lives.” According to these studies, instruments are said to often actively create new phenomena that are unexpected even by their original makers. It has been also shown that the use of instruments is not transparent, but usually involves the issue of “authority” and depends upon

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"audiences."¹

In addition, it has been pointed out that instruments mediate the interactions between science and technology. Derek de S. Price has long emphasized this role. His concern is both with the long term benefits of the inflow of technical instruments into science that has proved essential for its development (like Galileo's telescope), and with the relatively short term evolution of technological artifacts from laboratory effects (such as the transformation of the Edison effect to Fleming's thermionic valve). Norton Wise has insightfully depicted how in history some machines (such as the steam engine and telegraphy) and some instruments (such as the balances) have mediated between the domains of science, technology, and social philosophy. Taking up Price's maxim, Nathan Rosenberg, an economic historian, has recently argued that the outflow of scientific instruments from scientific laboratories to industry contributes much to the techno-economic innovative capacity of nations.²

1) See, for example, articles in Albert Van Helden and Thomas L. Hankins eds., *Instruments* (*Osiris* vol. 9, 1994), and especially Helden and Hankins, "Introduction: Instruments in the History of Science," *ibid.*, pp. 1-6; Simon Schaffer, "Glass Works: Newton's Prisms and the Uses of Experiment," in David Gooding, Trevor Pinch, and Simon Schaffer eds., *The Uses of Experiments: Studies in the Natural Sciences* (Cambridge: Cambridge Univ. Pr., 1989), pp. 67-104; Peter Galison and Alexi Assimus, "Artificial Cloud, Real Particles," in *ibid.*, pp. 225-274; Timothy Lenoir, "Models and Instruments in the Development of Electrophysiology," *Historical Studies in the Physical and Biological Sciences* 17 (1986), 1-54. The motto, "instruments have their own lives," is quoted from Peter Galison, "History, Philosophy, and the Central Metaphor," *Science in Context* 2 (1988), 197-212. See also Galison, *How Experiments End* (Chicago: Univ. of Chicago Pr., 1987); Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton Univ. Pr., 1985); Gyeong Soon Im, "The Formation and Development of the Ramsauer Effect," (forthcoming in *Historical Studies in the Physical Biological Sciences*, 1995). Ian Hacking's new insight on the role of experiments, as well as Latour and Woolgar's emphasis on the "inscription device," helped historians to examine instruments in more detail. See, Ian Hacking, *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science* (Cambridge: Cambridge Univ. Pr., 1983); Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Facts* (Sage Publication, 1979). For instruments and authority, see Sungook Hong, "Efficiency and Authority in the 'Open vs. Closed' Transformer Controversy," (forthcoming in *Annals of Science*, 1995), and for an interesting analysis of instruments and their audiences, see Schaffer, "Measuring Virtue," in A. Cunningham and R. French eds., *The Medical Enlightenment of the Eighteenth Century* (Cambridge: Cambridge Univ. Pr., 1990), pp. 281-318.

2) Derek de S. Price, "The Science/Technology Relationship, the Craft of Experimental Science, and Policy for the Improvement of High Technology Innovation," *Research Policy* 13 (1984), 3-20; "Notice towards a Philosophy of Science/Technology Interaction," in R. Laudan ed., *The Nature of Technological Knowledge: Are Models of Scientific Change Relevant?* (Dordrecht: Reidel, 1984), pp. 105-114. M. Norton Wise, "Mediating Machine," *Science in Context* 2:1 (1988), 77-113; "Mediations: Enlightenment Balancing Acts, or the Technologies of Rationalism," in P. Horwich ed.,

However, the two preceding considerations of instruments—the postmodern idea of instrumental autonomy and the more traditional account of instrumental mediation between science and technology—are not likely to share many interfaces. If instruments are so unpredictable in their nature, how are unstable laboratory devices transformed into technological artifacts with definite functions? How can such unstable instruments mediate the interactions between science and technology? My concern here lies in suggesting a way out of this seemingly contradictory situation. I shall try to show that it is the scientist's practices, rather than the instrument itself, that mediates the interaction between science and technology, and that simultaneously transforms instrument into stable(technological) artifact. The role of instruments is thus to create a kind of "artifactual space" in which various theories and practices meet. This artifactual space created by instruments also acts like a "buffer zone" located somewhere between laboratory effects and technological artifacts. Only by paying too little attention to a scientist's laboratory practice, have instruments been rendered into living animated actors.³⁾

To look into the relationship between instruments and laboratory practices I shall analyze the "cymometer," the wave-length measuring device used in early wireless telegraphy, and first devised in 1904 by British scientist-engineer John Ambrose Fleming(1849-1945).⁴⁾ The cymometer fits my purpose for the following two reasons. First, it grew out of a curious laboratory effect with Seibt's long, spiral coil, and was then used in the technological field of wireless telegraphy. Second, Fleming's laboratory notes and published papers allow us to follow in great detail the laboratory practices that led him to the construction of the device. In the following pages, I shall first examine the various requirements for, and constraints in, the construction of a wave-length measuring device. Next, I shall delve into the process of how Fleming changed the laboratory effect into a technological artifact. Finally,

World Changes: Thomas Kuhn and the Nature of Science (Cambridge, Mass. : MIT Pr., 1993), pp.207-256. Nathan Rosenberg, "Scientific Instrumentation and University Research," *Research Policy* 21 (1992), 381-390.

3) For the detailed historical analysis of the scientists' laboratory practices, see Jed Z. Buchwald, *The Creation of Scientific Effects: Heinrich Hertz and Electric Waves* (Chicago : Univ. of Chicago Pr., 1994); Frederic L. Holmes, *Lavoisier and the Chemistry of Life: An Exploration of Scientific Creativity* (Madison : The Univ. of Wisconsin Pr., 1985). A good account for the historiographical importance of scientific practices is Mi Gyung Kim, "Labor and Mirage : Writing History of Chemistry," (forthcoming in *Studies in the History and Philosophy of Science*, 1995).

4) For the life and the work of Fleming, see J. A. Fleming, *Memories of a Scientific Life* (London : Marshall, Morgan & Scott, 1934); J. T. MacGregor-Morris, *The Inventor of the Valve: A Biography of John Ambrose Fleming* (London : The Television Society, 1954); Sungook Hong, "Forging the Scientist-Engineer : A Professional Career of John Ambrose Fleming," unpublished dissertation (Seoul National University, 1994).

I shall make some general remarks concerning the science-technology relationship based upon my analysis of the cymometer case.⁵⁾

II. Necessities and Constraints in Wavelength Measurements

John Ambrose Fleming, Pender Professor of Electrical Engineering at University College London (UCL), became a scientific advisor to the Marconi Company in 1899. After 1899, Fleming's electrical engineering Laboratory at UCL was increasingly involved in the research of high-frequency oscillation phenomena. In 1900, experiments related to the transatlantic telegraphy, as well as measurements of the capacitance of small antennas, started there. In 1901, measurements of the capacitance of various condensers occupied an important place among the laboratory's work. In the next year, experiments on the oscillatory character of the Duddell Arc, on Rutherford's magnetic detectors, and on the use of an ionized flame as a relay were conducted. Though Fleming's position as scientific advisor to the Marconi Company was not renewed in December, 1903,⁶⁾ the high frequency measurement of current, capacitance and inductance became a central part of laboratory researches in 1904. The same year, the laboratory obtained a licence as an experimental wireless telegraphy plant that was granted under the Wireless Telegraphy Act (1904). It was, in fact, the first radio-engineering laboratory among all British university laboratories.⁷⁾

During the 1900s, several research assistants helped Fleming. Arthur Blok worked as Fleming's assistant between 1901 and 1904. He conducted laborious measurements during this period, and designed an ingenious device for high-frequency AC measurement. Fleming's former assistant, J.C. Shields, performed capacitance and inductance measurements in 1904. After 1904, many experiments were designed and performed by G.B. Dyke, who became Demonstrator in 1906. W.C. Clinton, Demonstrator from 1893, and Assistant Professor from 1906, performed most of the routine duties of the department such as undergraduate lectures and laboratory demonstrations. Clinton also designed a useful commutator for capacitance and inductance measurements.⁸⁾

5) I have analyzed how the Edison effect evolved into the thermionic valve in my forthcoming paper, "From Effect to Artifact: The Case of the Valve," (*Physis*, 1995).

6) This has not been widely known. For this episode, see Hong, "Forging the Scientist-Engineer", p. 263.

7) For early works in Fleming's Pender Laboratory, see Fleming et. al., *Laboratory Book*, Vol. I, UCL MS Add 122/21, Fleming Collection.

8) MacGregor-Morris, *Inventor of the Valve* (cit. n. 4), on p. 45; Blok, "Some Personal Recollections

The Laboratory's first wireless research was on the measurement of the capacitance of antennas and condensers. For this purpose, Fleming used J.C. Maxwell's tuning-fork method in 1901-2. The method utilized an equilibrium of the Wheatstone bridge containing an unknown capacitance in one branch under the action of an intermittent current, which was created by the vibration of the tuning fork. Though portable, the intermittent effect of the tuning-fork was far from regular and continuous. In the 1890s, therefore, several rotating commutators had been designed and employed in experiments at the Cavendish Laboratory, Cambridge. Following this line, Fleming and Clinton, in early 1903, constructed a more stable rotating commutator, which they claimed to have been "designed more from the point of view of an engineer than an electrical instrument maker."⁹ They also found that, with this commutator, the inductance of the antenna could be easily and rapidly measured.

The measurement of the capacitance C of an antenna, when it was combined with the inductance L , bore an important meaning. From these values, the natural frequency of radiation f could be deduced by using the formula $f = 1/2\pi\sqrt{LC}$. Either wavelength or period T could thus be calculated by $\lambda = c/f$ and $T = 1/f$, where c is the velocity of light. The calculation of these values was crucially important for exact tuning. After the introduction of Marconi's syntonic wireless telegraphy (British Patent 7,777/1900), in which antennas were inductively coupled with the discharge circuit of the transmitter and with the coherer circuit of the receiver respectively, the tuning of these four circuits became a central concern. In particular, while experimenting (with much difficulty) on the second transatlantic communication between Poldhu and Glace Bay in the winter of 1902-3, Marconi and his associates realized that their lack of knowledge about the wavelength was profound. As one of Marconi's engineers, R.N. Vyvyan, confessed, "we did not have means or instruments for measuring wavelengths, in fact we did not know accurately what

tions," *ibid.*, pp. 124-134.

9) For Fleming-Clinton commutator, see J. A. Fleming and W. C. Clinton, "On the Measurement of Small Capacities and Inductances" (read at the Physical Society on 27 Feb. 1903), *Proceedings of the Physical Society* 18(1903), 386-409. Two different commutators—a buzzer and a rotating commutator—had been used in the Cavendish Laboratory after Maxwell. For the former, see J.J. Thomson, "On the Determination of the Number of Electrostatic Units in the Electromagnetic Unit of Electricity," *Philosophical Transactions* 174(1883), 707-720, on p. 719; R.T. Glazebrook, "On a Method of Measuring the Electrical Capacity of a Condenser, and on the Determination by Electrical Observations of the Period of a Tuning-fork," *Philosophical Magazine* 18(1884), 98-101. For the latter, see J.J. Thomson and G.F.C. Searle, "A Determination of 'v,' the ratio of the Electromagnetic Unit of Electricity to Electrostatic Unit," *Philosophical Transactions* 181 A(1890), 583-621, on p. 607; R.T. Glazebrook, "On the Air Condensers of the British Association," *British Association Report* (1890), on p. 107.

wavelength we were using."¹⁰

There were, however, several laboratory methods to determine the wavelength or the frequency. First, for a very simple circuit, to calculate C and L was sufficient. Hertz calculated these values to estimate the wavelength of the radiation emitted from his dipole radiator. This was, however, impossible for a complex circuit or a complex antenna. In many cases, measurements were impossible as well. To measure L and C of the antenna, one had to connect the antenna into one branch of the Wheatstone bridge, but this was very difficult with an antenna 60 meters in height. Second, for short waves, parallel straightwires—the so-called Lecher's wire—could be used for a direct determination of wavelength. But this also required too much space for long waves. For wavelengths of several hundred meters, for instance, this method was thus practically impossible. Third, J. J. Thomson, in 1893, proposed to use a double-shunted (one resistance and the other inductance) circuit to determine the frequency of oscillation. This method was once employed by Rutherford with the magnetic detector as a current-measurer in 1896, but it had another problem of measuring high-frequency alternating currents, which was as difficult as, or certainly more difficult than, that of inductances and capacitances. The Wheatstone bridge method, Lecher's wire, and J. J. Thomson's double shunt circuit were practical only in the laboratory; they would be no longer so in the "field."¹¹

For long waves, it was eventually learned that the Lecher wire became more manageable by "spiralling" it. Hertz had already discovered a considerable diminution of the wave's velocity on the spiral. George Seibt in Germany devised a long coil, with which the phenomenon of resonance could be easily demonstrated. The "Seibt's coil" consisted of a long insulated wire wound around a wooden frame in a compact way and an earth (ground) wire stretched parallel to the coil. It was then connected to the condenser circuit with a variable inductance. When the oscillation was created by discharging the condenser, a standing wave could be created by varying the value of inductance. The wavelength of this standing wave was observed by the location of bright glow discharge between the helix and the earth-wire. The brightest point corresponded to the peak, and the darkest point corresponded to the

10) R. N. Vyvyan, *Wireless over Thirty Years* (London: Routledge, 1933), on p. 37. For Marconi's syntonik system, see Hong, "Forging the Scientist-Engineer" pp. 241-248.

11) For Hertz, see H. Hertz, "On Very Rapid Electric Oscillations," in *Electric Waves* (London: Macmillan, 1893), on pp. 51-52. For the Lecher's wire, see E. Lecher, "Eine Studie über electrische Resonanzerscheinungen," *Annalen der Physik* 41 (1890), 850-70. For J. J. Thomson and Rutherford, see J. J. Thomson, *Recent Researches in Electricity and Magnetism* (repr. London: Dawsons, 1968), pp. 512-517; E. Rutherford, "A Magnetic Detector of Electrical Waves and some of its Applications," *Philosophical Transactions* 189 A (1897), 1-24, on 20-24.

node of the waves.¹² A typical demonstration of resonance with Seibt's coil is shown in figure 1.

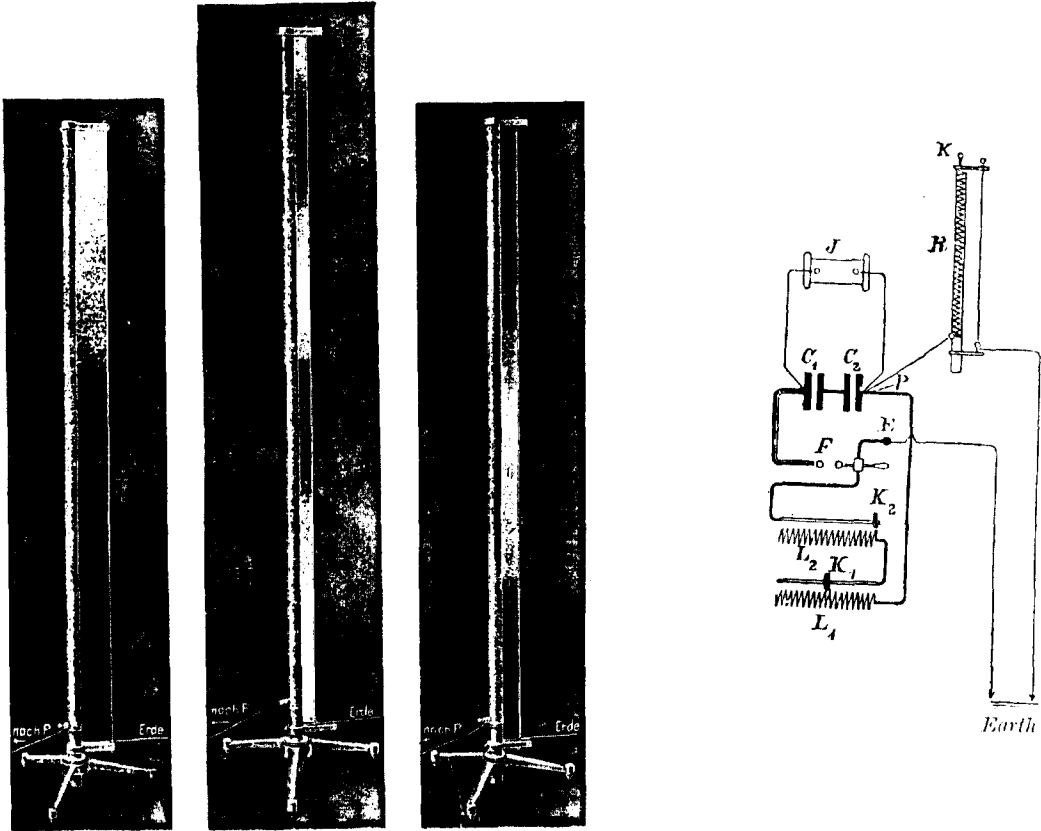


Figure 1. The Seibt Coil and the Resonance Circuit. From *Elektrotechnische Zeitschrift* (5 Feb. 1903), pp. 106-107.

Like Lecher's wire, the Seibt's coil could be used for measurement of the wavelength on the basis of the following procedure : The oscillatory discharge creates waves in the air whose frequency and wavelength satisfy the relation $f=c/\lambda$; under a certain resonant condition, it simultaneously creates a standing wave on the helix whose frequency and wavelength satisfy $f=v/\lambda_h$, where λ_h is the wavelength and v is the velocity of waves along the helix. The velocity v is equal to $1/\sqrt{C_h L_h}$ where

¹² I have consulted for Fleming, *The Principles of Electric Wave Telegraphy* (London : Longmans, 1906), pp.257-260. See also G. Seibt, "Vorführung von Experimenten über schnelle elektrische Schwingungen," *Elektrotechnische Zeitschrift* (5 Feb. 1903), 105-108.

C_h and L_h are the capacitance and inductance of the helix per unit length. From these, $\lambda = c \lambda_h / v$ or $\lambda = c \lambda_h (\sqrt{C_h L_h})$. Suppose we observed the fundamental harmonics of the wave along the helix, that is, a node at the beginning and a peak at the end of the helix, such that $\lambda_h = 4l$, where l is the length of the helix. Under this condition, we can obtain the wavelength of original oscillation from $\lambda = 4cl / (\sqrt{C_h L_h})$. When we obtain the first harmonics, that is, two nodes and two loops on the helix, then $\lambda = 4l/3$, and in this case, $\lambda = 4cl (\sqrt{C_h L_h}) / 3$. In the case of higher harmonics, the procedure would be the same.¹³⁾

The Seibt coil became one of the essential pieces of experimental apparatus in Fleming's laboratory. It was because the coil provided a good sample of inductance and capacitance to be measured, and because phenomena of harmonics caused by the electromagnetic wave could be visualized on the long coil. In December 1903, Arthur Blok measured the capacitances and inductances of 5 different Seibt coils, one of which was 200 cm long. In early 1904, these values were again measured with the Fleming-Clinton commutator. Then, Fleming moved to a more practical end. From May 1904, Fleming and his assistants performed a series of experiments with the long coil in order to test its validity as a wavelength measurer that could be used not only in the laboratory but also in the field, which was a far more demanding goal.¹⁴⁾ Yet Fleming here noticed a strange anomaly, which obstructed its fulfilment. From that time on, Fleming tried all attempts to stabilize this anomaly, and when this was finally stabilized, the practical wavelength measurer was born.

III. Battle with the Seibt Coil. May-June 1904

The Seibt's coil was used as a wavelength measurer on the basis of the relation $\lambda = c \lambda_h / v$, where $v = 1 / (\sqrt{C_h L_h})$. In this equation, v must be fixed, because it was determined by the inductance and capacitance of the helix. But it was at the same

13) Count Arco had employed the coil as a device to check tuning between the transmitter and the receiver. See Count Arco, "On a New Process for Tuning Spark Telegraph Stations," *Electrician* 50 (27 Feb. 1903), 777-778. In 1903, measurement of the wavelength with the Seibt's coil was already popular in laboratory experiments. See, for example, T. Mizuno, "On Resonance Coils," *Electrician* 51 (7 Aug. 1903), 654-655; (21 Aug. 1903), 730-732; A. Slaby, "Der Multiplikationsstab, ein Wellenmesser für die Funkentelegraphie," *Elektrotechnische Zeitschrift* 24 (10 Dec. 1903), 1007-1012.

14) A. Blok, "Measurement of Inductances of Seibt Coils," (10 Dec. 1903), *Laboratory Book*, Vol. I, (cit. n. 7), pp. 106-113; Fleming, "Note on the Measurement of Small Inductances and Capacities, and on a Standard of Small Inductance" (read at the Physical Society on 25 March, 1904), *Proceedings of the Physical Society* 19 (1904), 160-171; "Experiments on Stationary Electric Waves on Spiral Wires," (7 May-June, 1904), *Laboratory Book*, Vol. I, pp. 124 ff.

time determined by $v=c \lambda_h/\lambda$ or $v=f\lambda_h$. Thus, a check on whether v is constant in the case in which f and λ_h are varying could be used as a means to verify the validity of $\lambda=c\lambda_h/v$ on the helix. This was Fleming's starting point.

The experimental setting is shown in figure 2. Here, 1 and 2 are Leyden Jars of 0.00153 and 0.00125 microfarad (mfd). When these two were connected in series, the total capacitance was 0.00071 mfd and when connected in parallel, it was 0.00278 mfd. "Coil" was the Seibt's coil of 200 cm in length, of which the inductance had been carefully determined by Shields. " d " was the distance between the Seibt coil and the earth-wire, and " C " was the variable inductance. Shields had also carefully calibrated the scale of this variable inductance, and Dyke measured the capacitance of the long coil with respect to the earth-wire at various distances.¹⁵⁾

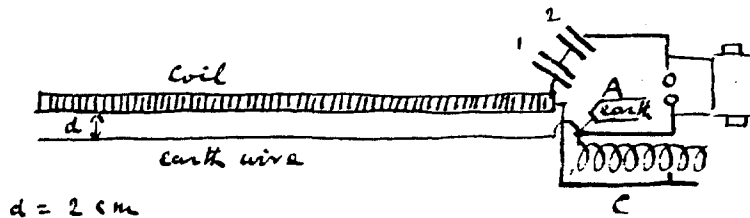


Figure 2. Fleming's Experiments with the Seibt's Coil. Fleming, *Laboratory Book*, MS UCL Vol. I, p. 124.

Fleming obtained the velocities from $v=f\lambda_h$, in which f was determined by $f=1/2\pi\sqrt{LC}$ and λ_h was measured by a vacuum tube filled with rarefied (i.e. low-pressure) carbon dioxide gas. Here, λ_h ought to *decrease* as the series of odd harmonics (that is, as the ratio of 1 : 1/3 : 1/5 : 1/7 : 1/9 : 1/11 as we move from the fundamental, first, second, third, fourth, and the fifth harmonics) which f ought to *increase* as the ratio of 1 : 3 : 5 : 7 : 9 : 11, rendering the product $f\lambda_h$ constant.

The first measurement was made with $d=2$ cm on 7 May, 1904. The values of λ_h were quite consistent with theory, but the values of f were deviating considerably. They were not increasing as 1 : 3 : 5 : 7 : 9 : 11, but rather as 1 : 3 : 5 : 6 : 7 : 8, i.e., its value fell off rapidly with increasing frequency. The velocity $v=f\lambda_h$ was therefore far from constant. For example, the frequency(f_t) and the velocity(v_t) for the

15) J.C. Shields, "Results of Inductance Measurements of Long Seibt Coil," (7 Jan. 1904); "Results of Inductance Measurements on Short Coils," (9 Feb. 1904); "Measurements of Inductance of endless Solenoid," (7 Mar. 1904); "Measurements of Inductances used in Connection with Seibt Apparatus," (5 May 1904); G.B. Dyke, "Capacity of Long Coil," (6-9 May, 1904) in *Laboratory Book*, Vol. I.

fundamental harmonics was $0.23 \cdot 10^6$ and $184 \cdot 10^6$ cm/s respectively; for the first harmonics $f_1 = 0.69 \cdot 10^6$ and $v_1 = 187.3 \cdot 10^6$ cm/s; for the second harmonics $f_2 = 1.15 \cdot 10^6$ and $v_2 = 185.61 \cdot 10^6$ cm/s; for the third harmonics $f_3 = 1.38 \cdot 10^6$ and $v_3 = 160.2 \cdot 10^6$ cm/s; for the fourth harmonics $f_4 = 1.61 \cdot 10^6$ and $v_4 = 145.1 \cdot 10^6$ cm/s; finally for the fifth harmonics $f_5 = 1.84 \cdot 10^6$ and $v_5 = 133.6 \cdot 10^6$ cm/s. On the basis of J. J. Thomson's prior research on the decrease of the specific inductive capacity of glass at higher frequencies, Fleming immediately concluded that "this is due to the diminished capacity of the Leydens [Leyden jars] with higher frequency."¹⁶⁾

On 11 May, similar observations were made with the variation of the value of d . With $d=2$ and for the fundamental harmonics, the frequency was $0.207 \cdot 10^6$ and the velocity was $165.6 \cdot 10^6$ cm/s. For the first harmonics, these values were $0.623 \cdot 10^6$ and $169.5 \cdot 10^6$ cm/s. Dyke again measured the capacitance of the long coil with a direct-reading Thomson-Elliott galvanometer. Under $d=2$, it was 51.2 m mfd. The mean value of the coil's inductance was $19.9 \cdot 10^6$ cm. From these two, and with $v = 1/(\sqrt{C_h L_h})$, the velocity v turned out to be $198 \cdot 10^6$ cm/s. About a 20% difference existed between this value and that obtained from $v = f\lambda_h$, namely, $166 \cdot 10^6 - 169 \cdot 10^6$ cm/s. Fleming also measured v and λ_h the various harmonics with $d=3$, but the decrease in frequency at higher harmonics was conspicuous.¹⁷⁾

The next day, Fleming measured the same quantities with the earth-wire removed. In this case, the capacitance of the helix being 36 m mfd, the velocity calculated was $235 \cdot 10^6$ cm/s. From the measurement of L and C , he estimated the frequencies at various harmonics, but they were still not $1:3:5:7:9:11$. To reconcile his results with the series of odd harmonics, Fleming assumed that the capacitance of the Leyden Jar falls off by 10% for frequencies higher than $0.82 \cdot 10^6$ Hz. With this assumption, he calculated the values of λ_h that would render v to be $235 \cdot 10^6$ cm/s — a value theoretically determined by $v = 1/(\sqrt{C_h L_h})$. Strangely, the h at fundamental harmonic turned out to be 854 cm, instead of 800 cm. Fleming noticed that this phenomenon was in harmony with the mathematical theory of H. MacDonald, which predicted that the distance from the end of the helix to the last node should be less than $\lambda_h/4$. This implied that, in order to use the Seibt's coil as a wavelength measurer, it had to be made to give a correct value of v at least for harmonics higher than the first one.¹⁸⁾

Though incorrect, Fleming exhibited this instrument as a wavelength measurer at

16) *Laboratory Book*, Vol. I. p.128. For J.J. Thomson's research, see J.J. Thomson, "Specific Inductive Capacity of Dielectrics when acted on by very rapidly alternating Electric Forces," *Proceedings of the Royal Society* 46 (1889), 292-295.

17) *Laboratory Book*, Vol. I. pp.132-135.

18) *Laboratory Book*, Vol. I. pp.136-140. For MacDonald's theory, see H.M. MacDonald, *Electric Waves* (Cambridge Univ. Pr., 1902), pp.111 ff.

the Royal Society *Conversazione* on 13 May, 1904.¹⁹⁾ After that time, Fleming tried every possible way to eliminate the high frequency falling-off phenomenon. First, Fleming constructed several ebonite condensers, whose capacitances were exactly determined by Dyke. He also re-calibrated the variable inductance. On the basis of these two improvements, Fleming, on 28 May, made the same set of experiments with the earth-wire removed. The frequencies were still falling off at the higher harmonics. As Fleming noted, "as in the case of the glass condenser so in the case of the ebonite there is a falling off in the capacity as the frequency increases." Thinking then that the inductance of the main circuit might be too large at higher harmonics, Fleming reduced it until negligible, but the results were the same.²⁰⁾

Though frustrating, this led him to a new way of thinking about the anomaly. He noted that "these experiments with the ebonite condenser make [him] suspicious that the apparent decrease in the capacity may due to some other causes." He calculated the capacity of the ebonite condenser from its dimensions and the value of the dielectric constant of ebonite. This estimation showed that, to satisfy the decrease of frequency, the dielectric constant K of ebonite should fall from 2.7-3.0 at a low frequency to 1.0 at a high frequency like $3 \cdot 10^6$. This was too much, and Fleming concluded that it was "improbable that K falls to unity for a frequency of $3 \cdot 10^6$ [Hz]; hence there is something wrong."²¹⁾

On 1 June, Fleming thus assumed that "the cause of difficulty was not in the condenser but in the [variable] inductance" and replaced the variable inductance with his new "accordion inductance coil." With this, it was easy to change the value of inductance by varying its length like an accordion, but then there was the problem of exact calibration. Fleming predetermined its inductances in the various cases from its dimensions, but he could not make them coincide with those measured by Shields. Fleming then constructed several square inductances, whose values were also predetermined from their dimensions.²²⁾

During 7-9 June, with these square inductances, and with a new neon tube indicator which was prepared by William Ramsay at UCL, Fleming obtained the first positive result. With the earth-wire removed and with $C=0.00062$ mfd, the velocity for the first harmonic, v_1 turned out $235 \cdot 10^6$ cm/s, which was exactly the same that derived from $v=1/(\sqrt{C_h L_h})$. The other results were, however, still disappointing. For the higher harmonics, $v_2=204 \cdot 10^6$ cm/s; $v_3=189 \cdot 10^6$ cm/s; $v_3=183 \cdot 10^6$

19) "The Royal Society *Conversazione*," *Nature* 70(19 May, 1904), 63; [Anonymous], "Electric Wave Measurement," *Knowledge and Scientific News new series* 1(June 1904), 131.

20) *Laboratory Book*, Vol. I, pp. 140-42.

21) *Laboratory Book*, Vol. I, p.143.

22) "June 1 1904," *Laboratory Book*, Vol. I(unpaged); Shields, "Measurements of Inductances of Accordion Spiral Inductances," *Laboratory Book*, Vol. I.

cm/s; $v_3 = 167 \cdot 10^6$ cm/s. The decrease of velocity for the higher harmonics was apparent. He then tried a similar set of experiments with both ends of the Seibt's coil earthed. The trial was successful. The result for the fundamental and the first harmonic proved very satisfactory, and corresponded with theory, but at a frequency higher than 10^6 , the velocity again decreased. "Why the velocity [$f\lambda_h$] decreases for frequencies beyond 10^6 " was very intriguing, because "it cannot be anything to do with the inductance or capacity in main circuit." Fleming finally thought that it might be due to the influence of the helix's capacitance upon the inductance of the earth shunt, but a rough estimation indicated that the influence would be less than 1% of the inductance.²³⁾

Though not entirely successful, Fleming nevertheless found an important condition for practical success: connecting both ends of the coil to earth. At the same time, he began to regard the decrease in frequency as a *fact*. In other words, he inclined to the "view that there is a real decrease in the velocity of the wave along the spiral." The cause of the problem should thus be transferred from the main circuit to the helix. Fleming speculated that this might be due to the conductivity of the helix's wooden core. He then made a simple test. When a vacuum tube was made to glow near the helix, the insertion of an ebonite plate between them did not change the glow, but an insertion of a wooden plate stopped it completely. This showed that wood had enough conductivity to block the radiation, and that the wooden core might increase the capacitance of the helix at higher frequencies, making the velocity actually decrease. The removal of the wooden core was crucial for successful employment of the Seibt coil as a wavelength measurer.²⁴⁾

Fleming's battle with the anomaly in the Seibt coil had nearly come to an end. On 16 June, he made some preliminary experiments with a grounded metallic saddle, which moved along the helix, creating a closed standing wave like a closed pipe organ (see Figure 3). The saddle moved to the place S where the distance SP was equal to λ_h . The next day, on 17 June, Fleming's Laboratory Book first recorded his application of the "Kummeter" derived from "kuma" ($\kappa\upsilon\mu\alpha$), a wave, and "meter" to determine the wavelength of his experimental wireless plant at UCL.²⁵⁾ The same day, he filed a British patent on the Kummeter. The Provisional Specification begins with the following:

23) "Observations made June 7-9", *Laboratory Book*, Vol. I. (unpaged).

24) "I incline to the view", *Laboratory Book*, Vol. I. (unpaged). Such recognition and the subsequent improvement was described in some detail in Fleming, "The Propagation of Electric Waves along Spiral Wires, and on an Apparatus for Measuring the Length of Waves used in Wireless Telegraphy" (read at the British Association at Cambridge in August 1904), *Philosophical Magazine* 8 (Oct. 1904), 417-437, on pp. 431 ff.

25) "June 16. 1904" and "June 17. 1904," in *Laboratory Book*, Vol. I. (unpaged).

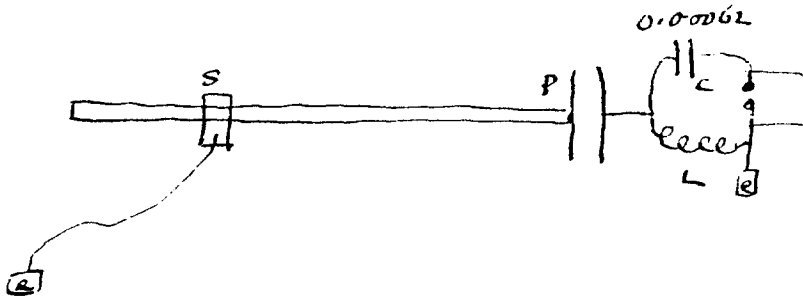


figure 3. Fleming's Kummeter Circuit with an earthed Saddle. *Laboratory Book*, MS UCL Vol. I, (16 June, 1904).

This invention relates to improvements in apparatus for measurements made in connection with space telegraphy by means of electric waves, the said apparatus being for the purpose of measuring the length of the wave employed. According to this invention stationary electric oscillations are set up on a long spiral wire. This spiral wire consisted of a long insulated copper wire which is wound in a single layer in closely adjacent turns on *a rod of ebonite, glass or other highly insulating material*.²⁶⁾ [emphasis added]

A wooden rod was excluded from the core of this long spiral. Fleming soon replaced it with an ebonite core, and obtained a nearly constant value of v at higher harmonics. With this replacement, the Seibt's coil eventually became an accurate and practical wavelength measurer. Certainly, nobody would have noticed the replacement to be a crucial point. It was, however, the most fruitful outcome of Fleming's battle with the Seibt's coil for two months.

IV. Credibility or Marketability?

Fleming filed a patent for his "Kummeter" in his name, not with the Marconi Company, since he was not a scientific advisor to Marconi at that time. He exhibited the exact Kummeter with an ebonite rod at the British Association annual meeting on 24 August, 1904. A detailed working principle and the description of the instrument appeared in the October issue of *Philosophical Magazine*. At the end of November, he wrote Marconi that he had an "instrument with which [he] can measure exactly the wavelength of electric waves up to 1 mile in length."²⁷⁾ Fleming'

26) Fleming, "Improvements in Apparatus Employed for Measuring Wave Lengths in Wireless Telegraphy," British Patent, No. 13,736, (Provisional Specification, 17 June 1904).

s new wavemeter, as well as his thermionic valves, moved Marconi. In the Friday Lecture on 3 March, 1905, Marconi exhibited them. On 26 May, 1905, the Marconi Company re-appointed Fleming as Scientific Advisor for the next three years.²⁸

Around this negotiation, Fleming strengthened his claims on the Kummeter. The crucial problem was that a German company, Gesellschaft für Drahtlose Telegraphie, had already filed a patent for the Dönitz's wave-meter, which measured the wavelength of a closed circuit by inductively coupling the wave-meter to the circuit. It also used the principle of resonance in the circuit with capacitance and inductance, but used the hot-wire ammeter as an indicator of resonance, instead of using vacuum tubes. The details were well known by the *Electrician's* translation and publication of the German article on that subject.²⁹ It was too evident that using the ebonite rod could not be something original that could protect Fleming's invention in the following patent litigation. After critically analyzing the characteristics of the German wavemeter, Fleming found that they changed *either* capacitance *or* inductance to obtain the maximum resonant condition. He therefore filed a patent, on 19 December 1904, for a Kummeter in which the capacitance and inductance were *simultaneously moved*. He then read a paper on this new form of wave-meter at the Royal Society, carefully delineating differences between Dönitz's and his wave-meters. This feature of simultaneous moving later proved to be very effective in his debate with the Gesellschaft für Drahtlose Telegraphie.³⁰

In early 1905, Fleming changed its name from Kummeter to Cymometer derived again from *cyma*, a wave, and "meter," but according to the rule of anglicizing Greek words. He extended its use to the estimation of the coupling coefficient of the

27) Fleming, "The Propagation of Electric Waves along Spiral Wires, and on an Apparatus for Measuring the Length of Waves used in Wireless Telegraphy," *British Association Report* (1904), 474-475. See also Fleming's *Philosophical Magazine* paper cited in note 24. Fleming to Marconi, n.d., (circa 30 Nov. 1904), MCA, Chelmsford.

28) G. Marconi, "Recent Advances in Wireless Telegraphy" (read at the Royal Institution on 3 March 1905), *Proceedings of the Royal Institution* 18(1905), 31-45. Fleming's contract with the Marconi Company remains as "Memorandum of Agreement between the Marconi Company and Fleming" (26 May 1905), MCA, Chelmsford. For details about this reappointment, see Hong, "Forging the Scientist-Engineer," pp. 294-296.

29) It avoided a long helix, which was "not as accurate as present-day requirements demand." See J. Dönitz, "A Wave Meter," *Electrician* 52(1 Jan. 1904), 407-410.

30) Fleming, "Improvements in Instruments for the Measurement of Wave Lengths in Wireless Telegraphy," British Patent, No. 27,683, (Provisional Specification, 19 Dec. 1904); Fleming, "On an Instrument for the Measurement of the Length of Long Electric Waves, and also Small Inductances and Capacities" (read at the Royal Society on 26 Jan. 1905), *Proceedings of the Royal Society* 74(1905), 488-498. For debate between Fleming and the Gesellschaft, see *Electrician* 56 (1905), 324, 360-361, 445, 483.

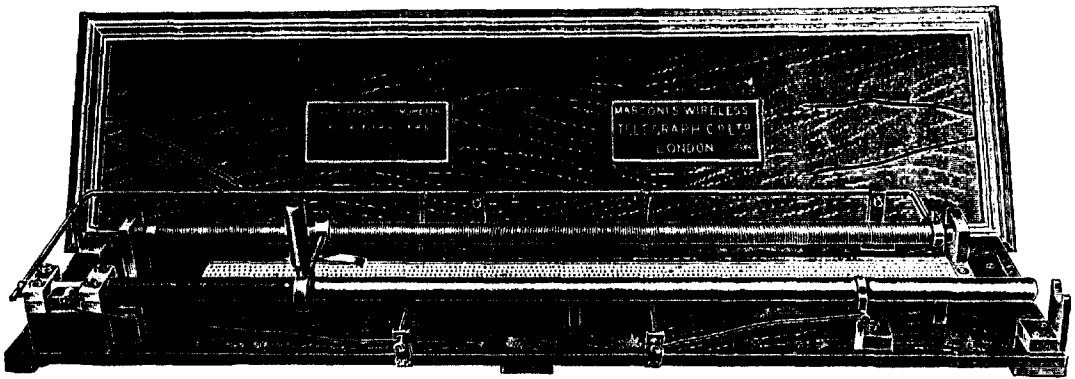


Figure 4. Fleming's Cymometer of the Marconi Company in 1906.

oscillation transformer.³¹ After Fleming's reappointment to the scientific advisor to Marconi, "Fleming's Cymometer of the Marconi Company" (Figure 4) was first demonstrated in October 1905 at the Electrical Exhibition at Olympia, London. By early 1907, the Cymometer was constructed in Fleming's Pender Laboratory and then sent to the Marconi's Company. Fleming constructed cymometers for 5,000, 7,000, 10,000, and 20,000 foot waves according to the Company's request. From 1907, however, the "direct-reading" cymometer was constructed at the Company workshop in Chelmsford under the instruction of Fleming. In 1909, a portable form of cymometer was constructed, which was awarded the grand prize at the Franco-British Exhibition. During 1905-1910, cymometers were exclusively used in Marconi's stations in Britain and in some university laboratories.³²

31) Fleming, "The Application of the Cymometer to the Determination of the Coefficient of Coupling of Oscillation Transformer" (read at the Physical Society on 24 March 1905), *Proceedings of the Physical Society* 19(1905), 603-614.

32) For the Olympia Electrical Exhibition, see [anonymous] "Electrical Exhibition at Olympia," *Electrician* 55(13 Oct. 1905), 1040-1041. For the construction of the cymometers, see Fleming to Marconi, 5 Feb. 1906; Fleming to Marconi, 12 Oct. 1906; Fleming to Marconi, 17 Apr. 1907. MCA Chelmsford. For a direct reading cymometer, see [anonymous] "The Fleming Direct-reading Cymometer and its Applications," *Electrician* 58(11 Jan. 1907), 495-497; (18 Jan. 1907), 536-37, and for a portable cymometer, see [anonymous] "The Fleming Cymometer," *Engineering* (12 Feb. 1909), 211.

Its use was, however, strictly local. Fleming's success in the laboratory did not ensure success in the instrument market, where German wavemeters prevailed. The cymometer had grown from a *long* Seibt coil, and this *length* severely constrained the cymometer's utility as an instrument, since an instrument of 4-6 feet was not customary by any standard. Another reason was its employment of a neon tube as an indicator, which was not suitable for engineers who were already accustomed to "direct-reading" meters with scales. There was no way to overcome these limitations as long as the cymometer used long helix. In the early 1910s, even the Marconi Company turned to the German-style, compact wavemeters. Yet, the cymometer remained a useful instrument in the laboratory, since it vividly exhibited the harmonics of electromagnetic waves and its use to measure the wavelength. Even in 1947, two years after Fleming's death, the physics department at Nottingham University still used it to measure wavelength of electromagnetic waves.³³⁾

V. Conclusion

Both the theory and measurement of high-frequency oscillations were ambiguous at the early stages of wireless telegraphy. The theoretical estimation of capacitance for long antennas, for example, routinely differed even by ten times from experimental measurements. The most difficult obstacle was that one could not tell with confidence whether either theory or measurement was right. Such a discrepancy between theory and practice was reflected in the construction of an exact, practical wavelength measurer. From the beginning the Seibt coil had been a good candidate for the wavemeter. But it had a problem in precision. German scientists and engineers such as Adolf Slaby, Count Arco and G. Seibt had usually exploited the fundamental and the first harmonic and concluded from the results that the coil was not reliable. Fleming encountered the same trouble, but he could solve the inconsistency with the mathematical theory of MacDonald. The fundamental was calibrated with the first harmonic; the calibration then became a guiding standard for higher harmonics. It also led Fleming to the conclusion that, for the coil to be used as a wavelength measurer, he should use the higher harmonics. Fleming carefully followed the method by which the gap between theory and experiment could be minimized. But the most serious anomaly occurred next: the velocity of the waves along the coil, which must remain constant, seemed to decrease as

33) George Seibt, "The Development of the Wavemeter in Wireless Telegraphy," *Electrical World* 56(29 Sep. 1910), 725-728. The last testimony was made by Prof. L.F. Bates, professor of physics at Nottingham University in 1947, in MacGregor-Morris, *Inventor of the Valve* (cit. n. 4), p. 97.

harmonics increased. He first thought of this decrease as virtual. He tried to account for this with the help of J.J. Thomson's physical experiment and theory, but the discrepancy did not disappear even after Fleming replaced, following J.J. Thomson, the glass condenser with the ebonite. There remained then no "higher" theory that could guide him to resolve the anomaly. "Lower" theories, which were immersed and fused in routine laboratory practices, led him afterwards. He devised a new variable inductance to make it easier to calibrate, used a more sensitive indicator, grounded the other end of the helix, and, finally, changed the core of the helix. He had reasons and theories that led him step-by-step to each modification, but they were not well-established mathematical or experimental physical theories, but engineering-style tacit theories epitomized from laboratory practice.³⁴⁾ It was not the instrument itself, but Fleming's active mobilization of theories and practices at different levels of physics and engineering that mediated between science and technology and that resulted in a stable technological artifact.³⁵⁾

34) For a discussion of the tacit theories, see also Jed Z. Buchwald's concept of "unarticulated knowledge," in his "Design for Experimenting," in *World Changes*, pp.175-178.

35) Latour's and Callon's actor-network theory usually emphasizes the active role of the non-human actors, such as instruments and machines, in expanding and stabilizing technoscience networks. See, for example, Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, Mass. : Harvard University Press, 1987) ; Michel Callon and John Law, "On the Construction of Sociotechnical Networks : Content and Context Revisited," *Knowledge and Society: Studies in the Sociology of Science Past and Present* 8(1989), 57-83. Shapin has, however, criticized Latour for not paying much attention to scientists' laboratory practices and thereby exaggerating the role of non-human actors. See Shapin, "Following Scientists Around," *Social Studies of Science* 18(1988), 533-550. My opinion is similar to Shapin in that I regard scientist's laboratory practices as active actors, but differs from him in that I admit creation of the artifactual space in instruments. Also relevant is Hacking's reading of Shapin and Schaffer's *Leviathan and the Air Pump* as the emergence of new laboratory practices (experimental style of scientific reasoning) in Ian Hacking, "Artificial Phenomena" (review of Shapin and Schaffer's *Leviathan and the Air Pump*), *British Journal for the History of Science* 24(1991), 235-241.