MOST SIGNIFICANT CONTRIBUTIONS

I suppose my most significant achievement was the invention of the piezoelectric oscillator. This resulted from the discovery of the reaction of a vibrating piezoelectric crystal upon the driving circuit.

My work on piezoelectric crystals began as a result of the conference on submarine detection organized by R.A.Millikan and held in Washington June 14-16, 1917 under the auspices of the U.S.Navy. I was one of those invited to the conference, and was especially attracted by the report of the French delegates on the attempts that Langevin was making to detect submarines by a piezoelectric method. For some months I had been thinking about submarine detection, and had come to the conclusion that the most promising method was to get an echo from a narrow beam of underwater ultrasonic waves. I was at the point of trying magnetostriction for this purpose when I heard about Langevin's work. The idea of using vibrating quartz appealed to me so strongly that I abandoned the magnetostriction project and began to read up on piezoelectricity.

Until the armistice in November, 1918, I cooperated with groups at the General Electric Research Laboratory and at Columbia University, working mostly on underwater receiving devices that contained Rochelle salt crystals.

In the course of this work I had occasion to measure the dielectric constant of Rochelle salt at different frequencies and different temperatures. Two anomalies were observed: One was in the neighborhood of a resonating frequency (Apr. 24, 1918), including a negative value for the apparent dielectric constant on the high-frequency side of resonance (Aug. 15, 1918); the other was an anomaly at a temperature of about 23°C. To the best of my knowledge the latter was the first record of the Curie point of Rochelle salt, but I did not publish it.

When I came to make similar observations on quartz bars I found the same sort of anomaly in the dielectric constant at resonant frequencies as in the case of Rochelle salt.

The effect was so sharp that it suggested to me the use of quartz bars as frequency standards. I therefore worked out the theory of the piezoelectric resonator and read a paper on it at the New York meeting of the American Physical Society on Feb. 26, 1921 (ref.28). In a conversation immediately after that meeting Dr. H.D.Arnold of the Western Electric Co. raised the question whether a quartz crystal could not be made also to control the frequency of an oscillating circuit. Within a few days I succeeded in solving this problem, though I did not arrive at the circuit that later became commonly employed, which was invented in 1923 by G.W.Pierce.

The first paper on the piezo-oscillator was read at the Washington meeting of the APS April 23, 1921 (ref.29).

Further papers on this subject are refs. 31 to 47, 60, and 62. They include the crystal filter and other piezoelectric devices, the L-cut in Rochelle salt, and the introduction of some terms that are now in common use, such as "X-cut", stabilizer, piezo-oscillator, wave-constant, primary and secondary pyroelectricity, stress- and strain-constants, together with various aspects of the theory.

Progress down to 1946 in discussed in my book "Piezoelectricity", published in 1946; a revised edition will appear in 1962. The bibliographies in this book show how extensively research on vibrating crystals has expanded since 1923.

My patent on the piezoelectric resonator is No.1,540,246, issued April 3, 1923. The patent on the oscillator is No. 2,472,583, issued Oct.30, 1923.

Immediately after the issuance of the first patent an interference was instituted by the Western Electric Co., claiming that the principle of the piezoelectric resonator and oscillator was inherent in a certain figure in AMM. Nicolson's patent No.1,495,429, application date April 10, 1918 (although Nicolson himself had not thought of these devices nor mentioned them in his application).

This is not the place to recount the events that followed. It is enough to refer to F.V.Hunt's book "Electroacoustics", 1954, in which the legal history of the piezoelectric resonator and oscillator is discussed, ending with a judge's opinion that credit for the invention of these devices should go to me and not to Nicolson.

Comments will now be made on other investigations, as indicated by references to my bibliography.

Arc and Glow Discharge. Between 1907 and 1915 I published a number of papers on this subject. It began when I suggested to H.D.Arnold, then a graduate assistant at Wesleyan, that he make a study of the arc between metallic electrodes for his Master's thesis. He soon discovered what he called a "doughnut" at the anode of the iron arc in air. At currents between 1 and 5 amp. the bright spot at the anode (molten iron oxide) moved around rapidly in a minute circular path, while at the same time the arc emitted a whistling sound (13, 24).

This investigation was followed by papers 14, 15, 23, and 26 on various types of glow and arc discharge, the transitions between them, and the discovery of the "glow-arc", in which the discharge fluctuated at high frequency between the two types. This work was done partly with the aid of G.W.Vinal, then a graduate student. Although these papers did not receive much attention at the time, still some of the effects described in them might well be investigated further in the light of modern theory and techniques.

The Self-recording Magnetic Declinograph, refs. 6, 9, 10, 12. This instrument was designed and constructed in response to a desire on the part of the Dep't of Terrestrial Magnetism of the Carnegie Institution for a magnetic storm alarm, to be used in connection with observations of sunspots. The idea was to have an alarm that would ring whenever the Earth's magnetic declination departed by more than an assigned small amount from the normal value. Two such instruments were constructed at Wesleyan, which not only rang an alarm when the declination varied by a small amount from the normal value, taking account of the diurnal variation, but also made a direct recording in ink of the declination. One of these instruments went to Washington, the other to Mt. Wilson. They were not much used, if at all, because in the mean time it was found that the relation between magnetic storms and sunspots was not as close as had been supposed.

Ultrasonics. After the first World War I was not concerned with ultrasonics until shortly after the attack on Pearl Harbor, when I was called to the U.S.Naval and Sound Laboratory in San Diego for a few weeks to aid in the development of Rochelle salt transducers for underwater echo work. In 1945 I cooperated with the Radiation Laboratory in Cambridge, Mass., in developing methods for measuring the output and other characteristics of the quartz transducers used in the radar trainers (ref.49). In this work, in addition to finding a new method for measuring acoustic power (refs. 54, 61), I also developed the progressive-wave method for transducer theory (refs. 52 to 54, 57, 58, 61, 62, 64), and made a study af acoustic streaming, the theory of which was later discussed by C.Eckart and others.

The Bicycle Ergometer. At Wesleyan, Profs. W.O.Atwater and F.G.Benedict used a stationary bicycle with an electromagnetic brake to measure the energy expended by the rider. The braking device had been designed by E.B.Rosa. Their experiments showed empirically that, for the same current in the electromagnet, the work done per revolution was approximately independent of the speed. A certain critic had contended that such a relation violated fundamental theory, and that it must therefore be in error. To answer this criticism I made a study of the theory, and found that when the self inductance of the copper disk is taken into account, theory and experiment are in satisfactory agreement.