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The Remote Control and Beyond: The Legacy of Robert Adler

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Robert Adler, best known as the co-inventor of the television remote control, died in February at the age of 93. He had been active, as a consultant in ultrasonics, well beyond the age of 90. Indeed, the last of his approximately 180 U.S. patents is dated February 1, 2007—two weeks before his death.

Adler was born in Vienna in 1913 and received a doctorate in physics from the University of Vienna in 1937. Not long afterward he fled Vienna for the United States, to escape Nazi persecution. In the U.S. he took a position at Zenith Corporation, where he would continue to work for 60 years.

Adler's TV remote control systems had predecessors. In 1950 engineers at the Zenith Radio Corporation (later renamed Zenith Electronics Corporation) resorted to cumbersome wires to produce a system known as "Lazy Bones." In 1955 Zenith engineer Eugene Polley proposed a photocellular device without wire, the "Flashmatic." But both systems had problems: A wire running across a living room was not safe, and photocells were too sensitive to sunlight.

It was in this setting that Adler, then working at Zenith headquarters in Chicago, had the idea of using ultrasonic waves to control a television. This marked the birth of a truly convenient and reliable remote control system. Designed in 1955, the device went into production in 1956. Details can be found in [2].

Most current remote control devices are operated by infrared signals; Adler's invention dominated the market for more than 25 years, however, and for this reason he is often called "the father of the TV remote control." Less well known is that Adler also did early work on certain highly nonlinear oscillating circuits, which led eventually to the well-known Kuramoto model of synchronization.

Near the end of 2003, in private correspondence with one of us (R.S.), Adler wrote that in the 1940s, he and others at Zenith were interested in reducing the number of vacuum tubes in an FM radio. The possibility that a locked oscillator might offer a solution inspired his 1946 paper, "A Study of Locking Phenomena in Oscillators" [3]. He did not continue to explore this topic, turning his attention instead to special-purpose vacuum tubes, low-noise amplifiers, and ultrasonic devices. But in October 1973, a quarter of a century after the appearance of the paper, Anthony Siegman of Stanford arranged for its republication in the *Proceedings of the IEEE* [3]. As Siegman explained to Adler, a large part of the scientific content of the paper could be applied directly to locked lasers, a subject of great interest at that time.

Adler's pioneering work concerned a single nonlinear phase oscillator; later, the idea was also exploited and generalized [9] to describe a number of similar, coupled oscillators. Even today, some authors refer to "Adler-type equations" in connection with certain models; see [6]. The coupling can be of various types—global or nearest-neighbor, for example; the former essentially represents the Kuramoto model; see [4,5]. The Kuramoto model, which dates to 1975, describes the dynamical transition of large populations of coupled elementary oscillators from incoherence to a synchronized state. Such behavior seems to be ubiquitous, arising in nature as well as within a number of technological applications. Indeed, the widely ranging phenomena in which it is seen include flashing fireflies, chirping crickets, menstrual cycles, pancreatic beta cells, heart pacemaker cells, arrays of Josephson junctions and lasers, applauding crowds, neutrinos, ... We refer readers to [7], an excellent technical monograph on synchronization; [1], a recent survey more specifically confined to the Kuramoto model and its generalizations; and [8], a beautiful expository book addressed to a broad nontechnical audience.

A closer look at the 1946 paper [3] shows that Adler derived a nonlinear differential equation satisfied by the oscillator phase α as a function of time t to describe locking phenomena:

$$\frac{d\alpha}{dt} = \Delta\omega_0 - \frac{E_1}{E}\frac{\omega_0}{2Q}\sin\alpha. \tag{1}$$

Here $\Delta\omega_0 = \omega_0 - \omega_1$ is the "undisturbed" beat frequency, with ω_0 being the free-running frequency of the oscillator, ω_1 the frequency and E_1 the voltage of the impressed signal, and E the voltage induced in the grid coil; Q denotes the figure of merit of plate load (when Adler did this work, the circuit would have contained a vacuum tube).

Adler also recognized that equation (1) could serve as a model describing the motion of a pendulum suspended in a viscous fluid inside a rotating container; see [3].

In his famous 1975 paper, Y. Kuramoto proposed a model for self-synchronization occurring (and observed) within a large population of coupled nonlinear oscillators [4]. The model is given by the set of equations

$$\frac{d\theta_i}{dt} = \omega_i + \frac{K}{N}\sum_{j=1}^{N}\sin\left(\theta_j - \theta_i\right) + \xi_i(t), \tag{2}$$

where θ_i is the phase of the ith oscillator and ω_i its natural frequency (picked up from the support of a given frequency distribution), and K represents the strength of the nonlinearity. The terms $\xi(t)$, $i = 1, 2, \ldots, N$, denote Gaussian random noise processes. A number of features concerning the dynamical behavior of the population, such as bifurcations and stability of the various possible states, transition to incoherence, and bistability can be detected and examined in such models [1].

In [9], finally, quasi-optical oscillator arrays were considered a promising technological solution, capable of overcoming inherent power limitations of solid-state devices working at millimeter-scale wave frequencies. A sufficient power level, in fact, can be reached with a sufficiently large number of oscillators, provided that the oscillators work in synchrony at a common frequency and maintain a certain phase relation in the steady state.

In general, an oscillator is characterized by both phase and amplitude dynamics; in some cases, in some approximations, the dynamics of the phase function alone may suffice. It was found that such a quantity, the phase θ, obeys an "Adler-type" equation, similar to (1),

$$\frac{d\theta}{dt} = \omega_0 + \frac{\omega_0}{2Q}\frac{A_{\text{inj}}}{A}\sin\left(\theta_{\text{inj}} - \theta\right), \tag{3}$$

where A_{inj} and θ_{inj} are the amplitude and phase (in general time-dependent) of the injected signal, and $A = A(t)$ is the amplitude of the oscillator of phase $\theta(t)$, which is assumed to be known; see [9].

For a loosely coupled ensemble of N oscillators of the same type, an approximate model can be derived, in the form of a system,

$$\begin{aligned} \frac{d\theta_i}{dt} &= \omega_i - \frac{\omega_1}{2Q} \\ &\sum_{j=1}^{N} \varepsilon_{ij}\frac{\alpha_j}{\alpha}\sin\left(\Psi_{ij} + \theta_i - \theta_j\right), \end{aligned} \tag{4}$$

for $i = 1, 2, \ldots, N$. Here, the meaning of the quantities α_j and Ψ_{ij} is similar to that of A_{inj} and θ_{inj} in (3), and the ε_{ij} represent the amplitudes of coupling coefficients. Again, the amplitudes of such an ensemble of oscillators are assumed to be known, and equation (4) can be viewed as a generalization of (3) and, hence, of Adler's equation.

The model for coupled oscillators described by (4) is rather general, in that the type of interaction among the members of the population has not been yet specified. In many instances, including those investigated in [9], it seems natural that every oscillator should be affected mainly by a few close neighbors, perhaps only by the two adjacent to it. In this case the ensuing model is said to be characterized by "nearest-neighbor coupling." In another important case, however, each oscillator is affected by all the others, possibly in such a way that all the oscillators feel the same effect. In this case, which arises, for example, when an array of oscillators is placed in a Fabry–Perot cavity, the oscillators are described as showing "global" or "all-to-all" coupling. It is the latter that coincides with the classic Kuramoto model in (2).

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