PUPIN COILS AND PUPINIZATION OF THE TELEPHONE LINES

Marija Bošnjak

Faculty of Education, Sombor, University of Novi Sad

Mihajlo Pupin and the transfer of sound over long distances

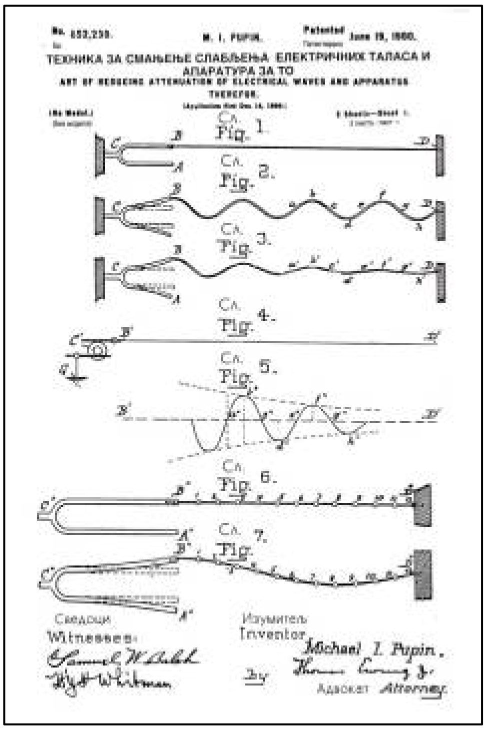
In the early summer of the year of 1894 Mihajlo Pupin (Figure 1) and his wife Sara resided in a small hotel on Lake Vanense in Switzerland. A former pastor from Idvor in Banat in Serbia, and now a professor of mathematical physics at the Department of Electrical Engineering at Columbia University, was preparing his lectures on the mathematical theory of sound. Occupied by a hypothetical problem: How will tight end of a rope with no weight flicker, loaded with evenly distributed weight of low-mass? La Grange was the one that found a nice solution to this problem from the famous eighteenth century, which helped him to examine the flickering strings on a violin. Pupin went a step further and asked himself: How would a rope that has weight flicker, so that it, like small weights on it flicker through the matter that, due to the friction, resists the flickering? He guessed the solution, and these premonitions were the product of his boyish experiences from Idvor pastures, which involved signaling through the transmission of sound through the ground. He enjoyed the thought that he was able to add something important to the solution of this historical problem that preoccupied famous La Grange. One day while climbing the gorge Furka, Pupin began to think as follows: Given that the movement of electricity through a wire encounters a resistance force, similar to those that occurs at flickering of a taut wire, general solutions obtained for the wire could be implemented on the movement of electricity. At once he was fully aware that he is on a beginning of a very significant finding.

Figure 1. Mihailo Pupin

Figure 2. Pupin coil

In the next year Pupin conducted some preliminary research, but at the end of 1895 his attention, and most physicists, drew the invention of X-rays, and he continued to address the movement of electricity in the following year.

In the year of 1855 Professor at Glasgow University William Thomson (later Lord Kelvin) was dealing with the transfer of electrical movement through the long wires and found a solution for transmitting electrical signals through submarine cables. Three years later, a professor at the Berlin University, Kirchhoff, found a solution for a telegraph transmission of characters through the land, with wires connected to the pillars. The discovery of the phone in 1876 brought up the logical question, on the transfer of telephone conversations at a distance. The first studies on this subject were done by Vasi and Heaviside who found that the telephone applies the same rules as well as telegraphy, the losses in the transmission of electricity are the lower the greater the inductance of the conductor is. If increasing the inductance increases the ability of the conductors for the transmission of electricity, it is clear that the setting of the coil of wires along the telephone lines contributes to the transfer of telephone conversations at a distance. Many experimented with coils of wire, but without success, finally Mihajlo Pupin succeeded, but as he said, it worked because he did not rely on luck; he instead had in mind the mathematical solution of La Granges problem. The solution indicates that for all the oscillatory movement of electricity that we want to convey we need to set up several induction coils at one wavelength. In practice this means that for the transfer of telephone calls we must put one coil for every four or five miles on pillars and concerning underground cables one coil for every mile or two (Figure 2).



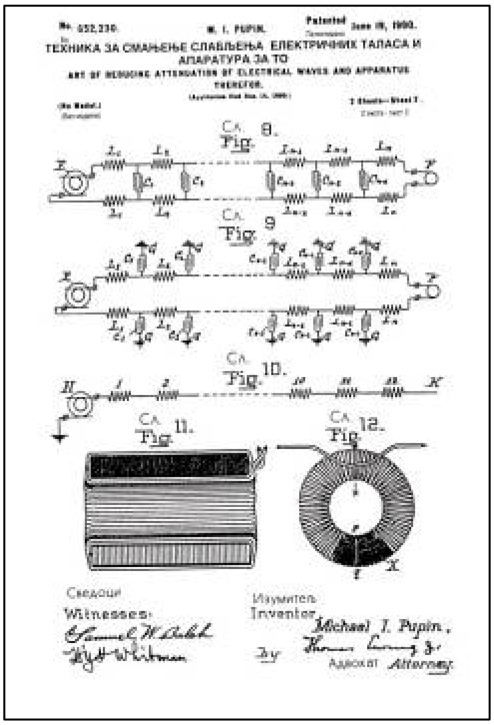


Figure 3: Pupin’s patent application

The first part of his research Mihajlo Pupin presented at the American Institute, of electrical engineers in March of 1899. In October of that year a friend of Mihajlo warns him that he should make a patent application, because if he is on the trail of a new invention, then it is definitely noticed by others as well and other scientists are already at the door of the Patent Office (Figure 3). This advice was beneficial because even this time there was a small wrangling over patent rights, but not nearly as unpleasant as it was with the first Pupin's patent of electrical tuning. One year after application of this patent American Telegraph and Telephone Company bought the patent rights without asking for the price. So that is when various legends about this invention of Pupin and fabulous amount that was paid for it started. Fame and publicity that he earned helped him to sell its earlier patents for electrical tuning and a correction in wireless telegraphy, who have found practical applications in radio. Mihajlo Pupin often used to mention the 14th July 1884, as his lucky day, because at that time in Berlin he found that old antique shop and in it La Grange’s book. When once asked by Idvor farmer how he managed to deal with all of his inventions he answered: "The modest Idvor farmers and famous La Grange from Paris taught me this art!"

HELLO, CAN WE HEAR EACH OTHER?

With two plastic cups pierced on the bottom and a rope students make a “real phone”. First they have to check if the sound can be transferred if the rope is relaxed, and then they should come to the conclusion that it is necessary to tighten the rope. Through conversations, based on the text from Pupin autobiography, where it is stated that the sound is oscillation of air (or in general any matter), they conclude that their speech is transmitted by oscillation of tight rope (Figure 4). Further they can continue to experiment with different lengths of the rope. As the rope is longer or the distance between them grows the effect of transmitting sound at a distance is more obvious.

Figure 4. "Phone" from plastic cups and rope

Figure 5. Underground signalling

Students already know that sound is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas and reaches the human ear. Matter in the medium is periodically displaced by a sound wave, and thus oscillates. With two metal knives (not sharp, for the safety of students), students can check through which medium the sound transfers better and faster. If they flash a knife in the air, the sound will not be heard. If they insert a knife into the ground and flash the handle, they will not hear the sound also, but if they lean their ear to the ground they can hear the sound (Figure 5). So the sound is better transmitted through the ground than through the air. Furthermore, if between the transmitter (flashing knife stuck into the earth) and receiver (student with his ear leaned to the ground) is a hard land (lawn) the sound will transmit better than if between them is loose soil (or sand). Through experimenting, students should independently come to the conclusion, that denser the medium is, the sound will move faster and easier through it.

Pupin used for many of his discoveries the analogy between the mechanical (primarily sound) and electrical phenomena because mechanical phenomena can be sensed and much easier to understand. That was the case with his discovery of perhaps the most important techniques for reducing attenuation of electrical waves from 1899 which allowed the voice transmission to far longer distances than before. The weakening of the electrical wave propagation in the electric power lines represented an insurmountable obstacle to the achievement of telephone traffic over long distances. Pupin came to the bright idea that this problem can be rectified by planting the inductive coil within strictly defined distances along the lines. These inductors are called Pupin coils, and a process of engaging in line is called “pupinization”. This patent brought him worldwide fame, thanks to his inventions intercity and international telephone traffic operates today. Pupin coils allow the transmission of radio programs by wire systems. He came to the idea by the analogy to the fact that sound waves are better transmitted along a stretched string loaded with equal masses uniformly distributed along its length, than without them. Pupin in his autobiography explains this:

> *In order to illustrate this by a mechanical analogy, we can say that a light silk cord stretched between two fixed points and carrying at equidistant points heavy bird-shot will act like a heavy uniform cord for all vibratory motions the wave-length of which embraces several intervals separating the bird-shot, and will transmit these motions much more efficiently from one end of the cord to the other than if the bird-shot was not there.*
>
> (Pupin, M. (1924): From Immigrant to Inventor)

The analogy between mechanical and electrical oscillations which served Pupin, can serve as a help for explaining to the students more closely the finding of "Pupin coils" and meaning of "pupinization" electrical lines, and help them to understand the significance of this discovery for the transmission of voice at great distances.

Students study the acoustic oscillations by monochord and weights of low mass (Figure 6). Along the taut wire of monochord which has a length of 60 cm students move the bridge that can be fixed and that is how they change the length of the wire, and thus the pitch. Firstly they set the bridge to a distance of 15 cm from the left end of the monochord then they flash the wire and notice the wire pitch. Then move the bridge at the doubled distance (30 cm), detect the pitch and conclude that it is lower. Ask them the question at what length they can achieve a tone identical to that on the wire length of 15 cm. They independently come to the conclusion that it can be done if they post a weight at the middle of the wire which has a length of 30 cm. Then, the bridge moves to a distance of 45 cm. Now along the wires it is needed to set up two weights at evenly distances to get the same tone of the initial tone. Finally the bridge is moved to the right end resulting in a string of length of 60 cm, and to obtain an identical tone three weights should be set at a steady range.

Figure 6. Transfer of sound over long distances - monochord

The described experiment is only an association to the famous discovery of Pupin, but it helps students to recognize the problem of pitch changes with increasing wire length (distance). The solution in the form of evenly distributed weights, associates students with the induction coils evenly spaced (Pupin coils) along the telephone lines, which eliminated the reduction of intensity and distortion of speech that is transmitted.

Mihajlo Pupin

"From immigrant to inventor" (1924)

During those school days in Pančevo I spent my summer vacation in my native village. Idvor, just like the rest of Banat, lives principally from agriculture, and during harvest-time it is as busy as a beehive. Old and young, man and beast, concentrate all their efforts upon the harvest operations. But nobody is busier than the Serbian ox. He is the most loyal and effective servant of the Serb peasant everywhere, and particularly in Banat. He does all the ploughing in the spring, and he hauls the seasoned grain from the distant fertile fields to the threshing-grounds in the village when the harvesting season is on. The commencement of the threshing operations marks the end of the strenuous efforts of the good old ox; its summer vacation begins, and it is sent to pasture-lands to feed and to rest and to prepare itself for autumn hauling of the yellow corn and for the autumn ploughing of the fields. The village boys who are not big enough to render much help on the threshing-grounds are assigned to the task of watching over the grazing oxen during their summer vacation. The school vacation of the boys coincided with the vacation of the good old ox. I spent several summers in that interesting occupation. These were my only summer schools, and they were the most interesting schools that I ever attended.

The oxen of the village were divided into herds of about fifty head, and each herd was guarded by a squad of some twelve boys from families owning the oxen in the herd. Each squad was under the command of a young man who was an experienced herdsman. To watch a herd of fifty oxen was not an easy task. In daytime the job was easy, because the heat of the summer sun and the torments of the ever-busy flies made the oxen hug the shade of the trees, where they rested awaiting the cooler hours of the day. At night, however, the task was much more difficult. […]

To prevent the herd from straying into the corn-fields at night was a great task, for the performance of which the boys had to be trained in daytime by their experienced leader. It goes without saying that each day we boys first worked off our superfluous energy in wrestling, swimming, hockey, and other strenuous games, and then settled down to the training in the arts of a herdsman which we had to practice at night.

One of these arts was signaling through the ground. Each boy had a knife with a long wooden handle. This knife was stuck deep into the ground. A sound was made by striking against the wooden handle, and the boys, lying down and pressing their ears close to the ground, had to estimate the direction and the distance of the origin of sound. Practice made us quite expert in this form of signaling. We knew at that time that the sound travelled through the ground far better than through the air, and that a hard and solid ground transmitted sound much better than the ploughed-up ground. We knew, therefore, that the sound produced this way near the edge of the pasture-land could not be heard in the soft ground of the corn-fields stretching along the edge. A cattle-thief, hidden at night in the corn-fields, could not hear our ground signals and could not locate us. Kos, the Slovenian, my teacher and interpreter of physical phenomena, could not explain this, and I doubt very much whether the average physicist of Europe at that time could have explained it. It is the basis of a discovery which I made about twenty-five years after my novel experiences in that herdsmen's summer school in Idvor. […]

Sound and light being associated in my young mind of fifty years ago with divine operations by means of which man communicates with man, beast with beast, stars with stars, and man with his Creator, it is obvious that I meditated much about the nature of sound and of light. I still believe that these modes of communication are the fundamental operations in the physical universe and I am still meditating about their nature. My teachers in Pančevo rendered some assistance in solving many of the puzzles which I met in the course of these meditations. Kos, my Slovenian teacher, who was the first to tell me the story of Franklin and his kite, was a great help. He soon convinced me that sound was a vibration of bodies. This explanation agreed with the Serbian figure of speech which says:

"My heart quivers like the melodious string under the guslar's bow."

I also felt the quivering air whenever during my term of service as guardian of the oxen I tried my skill at the Serbian flute. Few things excited my interest more than the operations of the Serbian bagpiper as he forced the air from his sheepskin bellows and made it sing by regulating its passage through the pipes. The operations which the bagpiper called adjustment and tuning of the bagpipes commanded my closest attention. I never dreamed then that a score of years later I should do a similar operation with an electrical circuit. I called it *electrical tuning*, a term which has been generally adopted in wireless telegraphy. But nobody knows that the operation, as well as the name were first suggested to me by the Serbian bagpiper, some twenty years before I made the invention in 1892.