



How Spark Transmitters Work

by Hal Kennedy, N4GG

[This article was written in support of “The History of QST, Volume 1 – Technology” published by the ARRL and available at www.arrl.org/shop.]

Pondering spark transmitter operation is, at best, an infrequent occurrence among today’s amateurs. It shouldn’t be however, because in addition to the historical significance of our original methods, virtually all of us own and operate one or more spark rigs today. If you drive a gasoline-powered car - or even if you don’t - you have listened to the ignition noise from one. What is that noise? It is the broad spectrum electromagnetic (EM) wave propagation from a spark gap. Every time a spark plug fires, that electrical impulse excites the ignition wiring in the vehicle – an antenna – which radiates an EM wave; sometimes with considerable power, to considerable distance and over a very broad range of frequencies.

A modern car uses the exact components found in a 1900 spark transmitter; a battery, an induction coil to step up to high voltage (ignition coil), a spark gap (spark plug) and an antenna (ignition wiring). All that’s missing is a telegraph key.

If we grounded the car’s chassis, connected an antenna directly to the ignition coil’s HV output and added a telegraph key in series with the ignition coil primary, we would have a complete 1900 spark gap transmitter along with 21st century “comfort features” like a leather operating seat and a sun roof. What could we do with this lash-up? We could transmit Morse code to a range of about 10 miles, with the emission occupying a huge amount of spectrum, centered on a frequency determined by the L-C resonance of the antenna’s series inductance and parallel capacitance to ground. We would also endure the wrath of the FCC and anyone operating a receiver for miles around. Amateur spark had left the air by 1923 and was outlawed in 1929 for good reason.

A pictorial diagram of a 1900 spark transmitter is shown in Figure 1. The basic components include a battery supply, key, induction coil (HV transformer), spark gap and connections to an antenna and ground. Also shown is an inductor in series with the antenna to provide for small adjustments, and an interrupter to chop the DC battery voltage into a quasi-AC waveform to allow the induction coil to operate as a transformer.

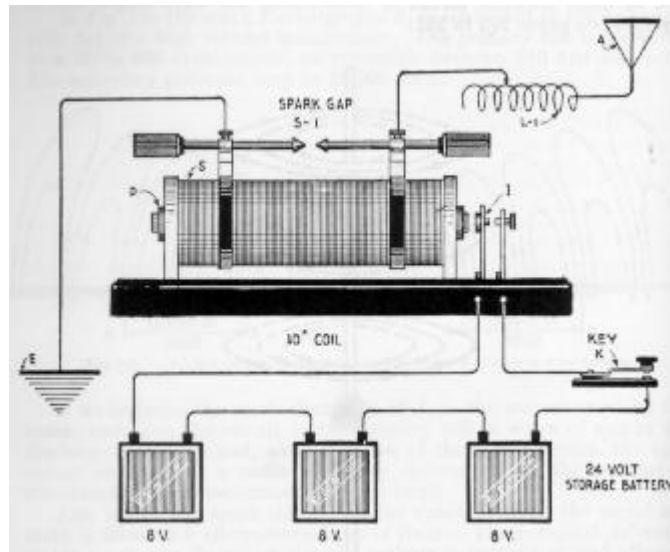


Figure 1. Diagram of a 1900 spark gap transmitter

Basic operation is straightforward. Close the key and the induction coil’s output rises to a sufficient voltage to begin and then maintain an arc across the spark gap. But how does this create an EM wave we can transmit?

The spark gap itself is an electronic switch. When not firing, it is an open circuit. When firing or “arcing over” the air within the gap is ionized into a conducting plasma and the resistance across the gap drops to around two ohms. Gaps require high voltage to begin firing, but require current, not voltage, to maintain firing once started. Spark gap induction coils used limiting mechanisms to continue to deliver small amount of current to the gap, (a $2\ \Omega$ near-short across their secondary) without burning up.

The structure of the ionized discharge across the gap is highly erratic, with constant current fluctuations occurring within plasma. These fluctuations occur rapidly, with a frequency content that covers nearly the entire EM spectrum. In 1887 Heinrich Hertz referred to a spark gap as an “oscillator.” Being connected directly to the antenna, the broad spectrum current fluctuations at the spark gap are radiated by the antenna. Note that with the gap firing, its $2\ \Omega$ resistance completes an RF path from the antenna back to ground, allowing current to flow in the antenna.

Spark gaps in the earliest transmitters fired continuously as long as the key was depressed. This produced an output signal that sounded like a buzz or a “sizzle” in a receiver. This was very inefficient as continuous firing of the gap caused the power in the spark to be limited by the current the induction coil could deliver into the 2 Ω load of the gap – typically 100 mA or less.

In addition to poor efficiency, a 1900 spark rig had other unfortunate characteristics. Opening the gap too wide as well as other disturbances could cause misfiring, placing the 10,000 volts at the secondary of a typical induction coil directly on the antenna. This made for potentially lethal accidents. Also, the antenna radiation resistance in series with ohmic and ground resistance yielded low Q and furthered the broadband nature of the EM radiation. You can hear a car’s ignition noise from below 30 kHz to above 30 MHz, about the same as a 1900 spark rig. Spreading the emitted energy across that much spectrum drastically reduces the output power on any single frequency. These characteristics limited early spark transmission to a range of about 10 miles. The inability to control bandwidth of both transmitters and receivers in 1900 also meant that within a 10 mile radius it only took two transmitters operating at the same time to produce intractable QRM.

However, amateurs are an inventive bunch, and from 1900 to 1915 that was in full evidence. In that era, experimentation was the order of the day, and spark transmitters quickly underwent major improvements based on empirical trial and error.

The first advance was adding a capacitor across the induction coil secondary. The capacitor eliminated continuous arcing at the gap. Instead, the capacitor charged until sufficient voltage was achieved to fire the gap, at which point the gap fired, the capacitor was discharged and the spark extinguished. The energy stored in the capacitor and delivered to the gap was $\frac{1}{2} CV^2$. At 10,000 volts, voltage squared yields a lot of energy! The gap current was no longer determined by the induction coil trying to drive 2 Ω, it was determined by the energy stored in the capacitor. As a result, gap current increased orders of magnitude while the transmitter input power remained unchanged.

The simple addition of the capacitor provided two major improvements. The gap current and corresponding antenna current went up, and the quick discharge of the capacitor removed the 2 Ω resistance from the antenna circuit between firings. This fundamentally altered the excitation of the antenna from being continuously excited by a wide-band low current “oscillator,” to being excited by impulses from a high current gap discharge. When the gap was not firing, the antenna no longer had a 2 Ω connection to ground and was free to ring at its own

natural resonant frequency. The introduction of the HV capacitor across the gap greatly increased output power and narrowed radiated bandwidth. Both improved efficiency. Spark transmitter output had moved from low power, white noise to higher power, narrow band quasi sine waves.

This modification alone pushed spark transmission well beyond 10 miles. It also left both amateurs and “commercial” interests such as those of Marconi with the idea that from here forward more powerful sparks and higher antennas were all that was needed to extend range. This viewpoint persists today and when viewed in the long term is just as incorrect now as it was then. The major performance enhancements in amateur and commercial transmission have been technology driven. Moving from spark to CW and from AM to SSB have had far greater impacts than increased power and higher antennas.

Meanwhile, power and antenna height can’t be discounted. By 1905, the addition of a HV capacitor and an output tuning coil to further reduce bandwidth, together with raising power and antenna height, resulted in the night-time ranges shown in Table 1. Coil length determines the voltage across the capacitor at the gap. There were no regulations – you could run as much power as you could generate.

Table 1. 1905 spark transmitter performance as a function of power and antenna height.

Coil Length (inches)	Antenna Height (feet)	Distance (miles)
1"	40	.25-.5
2"	50	5-10
4"	75	10-20
6"	100	15-30
10"	150	50-75
15"	180	75-100

[Source: 200 Meters and Down, ARRL]

A pictorial diagram of a typical spark transmitter from 1905 is shown in Figure 2. The addition of the output coil provided crude selection of operating frequency, reduced bandwidth, and removed up to 10,000 volts from the antenna. The tuning coil was the earliest instantiation of what we today call an “antenna tuner.” It was the first device to roughly match the impedance of the antenna to that of the transmitter, although it was not understood as such until years later. The coil further increased antenna current – another step forward.

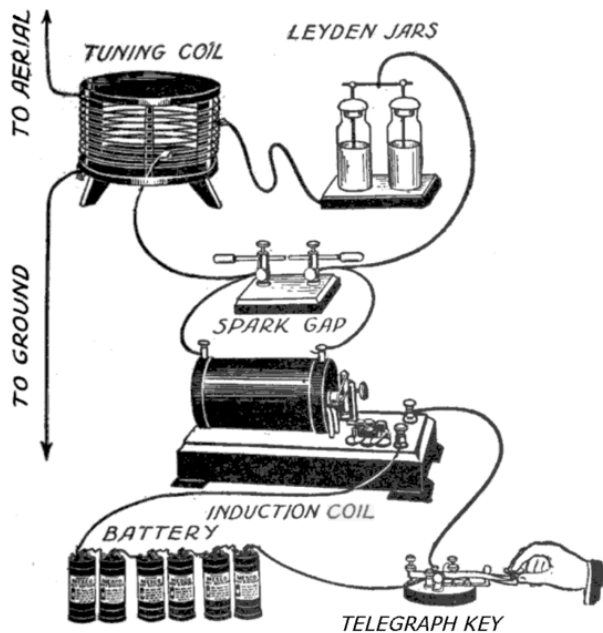


Figure 2. Pictorial diagram of a 1905 spark gap transmitter with HV capacitor (Leyden Jars) and output tuning coil.

The last major technical advances were the introduction of rotary gaps, both non-synchronous and synchronous types, and air-coupled output transformers, known at that time as “oscillation transformers.” These improvements appeared on the air between 1910 and 1915 and greatly extended range again. It’s worth noting that even from 1900-1915, range was being extended more through technical improvements than through increasing power and antenna height.

The schematic of a 1915 spark transmitter is shown in Figure 3.

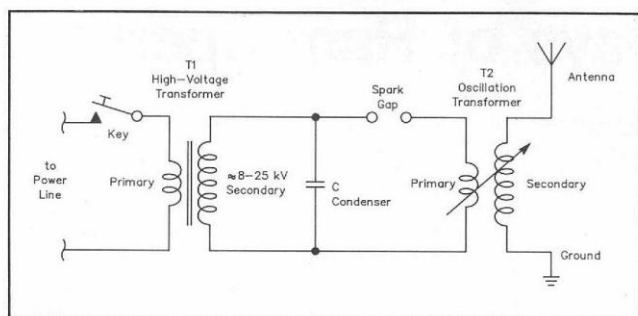


Figure 3. Schematic diagram of a 1915 spark gap transmitter with air coupled output transformer. The fixed gap in this schematic is replaced by a rotary gap symbol for the transmitter under discussion.

The introduction of the rotary gap had as much or more impact on the performance of spark transmitters as adding the HV capacitor did in 1905. A rotary gap consists of a rotating disk containing a series of electrodes that spin through the plane of a fixed gap, allowing gap firing only when the electrodes on the rotating disk align with the electrodes of the fixed gap. This permits precise timing of the firing and precise setting of the spark rate. Gone were the “sizzle” of a fixed gap, replaced by the tone of a gap firing at anywhere from 120 to as many as 1,000 times per second. Anyone who has copied CW knows a 400 to 600 Hz tone is pleasing to listen to and a lot easier to pick out of background noise than a sizzling sound. A commercial rotary gap available to amateurs is shown in Figure 4.



Figure 4. A commercially available rotary gap, circa 1915.

The earliest rotary gaps were rotated by AC series motors and were not synchronous with the AC power source (battery supplies had been replaced by electrical service by this time). As a result, electrodes would sometimes rotate into firing position when the secondary voltage was at a peak, producing a strong spark, but at other times at a voltage null and the gap would not fire at all. The “tone” of the spark rig’s output was ragged as a result; caused by occasional misfiring of the gap.

Line-synchronous motors eventually replaced non-synchronous motors, allowing gap firing at precise points in the AC waveform powering the transmitter. Firing at the peaks in the AC waveform maximized power, and the growl of misfires superimposed on the tone of a non-synchronous spark rig was eliminated. Air coupled output transformers further reduced bandwidth by raising Q and decoupling the secondary circuit (antenna and output transformer secondary) from the primary circuit (output coil primary together with the induction coil and HV capacitor). Spark transmission

was becoming “clean.” Old timers began waxing nostalgic for the sound of a growler or a sizzler. Blatterman’s article “Operation of a Non-Synchronous Rotary Gap” in Nov 1916 *QST* gives a detailed explanation of how rotary gaps work.

Figure 5 shows a synchronous rotary gap built by N4GG, firing at 2,000 amps. Only the 2 Ω resistance of the firing gap, the equivalent series resistance of the capacitor and stray inductance limit the gap current. Rotary gaps running at 2,000 amps and higher were loud, bright, created copious amounts of ozone and ultraviolet light, and were very dangerous. They were also exciting and as such a recipe for disaster.



Figure 5. N4GG’s synchronous rotary gap firing at 2,000 amps

Harry Hyder, W7IV, while taking a nostalgic trip backward from solid state to vacuum tubes to spark, wrote in March, 1992 *QST*:

“REAL radios glow in the dark. The REALEST real radios Whined, Roared and Hurlled Blue Lightning.”