The Sounds of a Spark Transmitter: Telegraphy and Telephony

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The first wireless transmissions (1888-1905) employed spark technology. Marconi systems were based on spark technology. Fessenden recognised that continuous wave transmission was required for speech, and he felt that he could transmit and receive Morse code better by the continuous wave method than with spark apparatus as Marconi was using. Fessenden was right, but "King Spark" was slow to die.

As CW systems were developed (1906-1912), Marconi sought to use his spark technology to achieve a semi-continuous timed spark that would approximate CW. Eventually the Marconi spark transmitter was replaced by the Fessenden/Alexanderson HF alternator, which in turn was replaced by vacuum tube transmitters. The three element vacuum tube was well known by 1915 to be capable of regeneration and oscillation. It could therefore generate CW. World War I spurred transmitter-tube development. The rise of CW followed in post war years. By 1924 spark was forbidden on the new 80, 40, 20 and 5-metre amateur bands. But spark was still used on the lower bands, and for another decade or more in the maritime service as a back-up for distress messages on the international distress frequency of 500 kHz (600 metres) right up to the beginning of the WW2. Had it not been for the war, spark would have been completely phased out in the maritime service except for emergency (lifeboat) purposes by the end of 1939.

The distinctive sound of spark is not easily forgotten, yet I suppose the vast majority of modern radio scientists and operators have no knowledge of how the spark transmitters used from about 1900 to about 1925 sounded, when received on the simple crystal receivers of the day. Or what the first crude attempts of Fessenden to transmit voice on a spark transmitter might have sounded like.

So we constructed a 5 MHz spark transmitter using a high performance automotive ignition coil for the induction coil, and circuitry to simulate a Braun type spark transmitter stimulating a 5 MHz quarter wave monopole antenna.

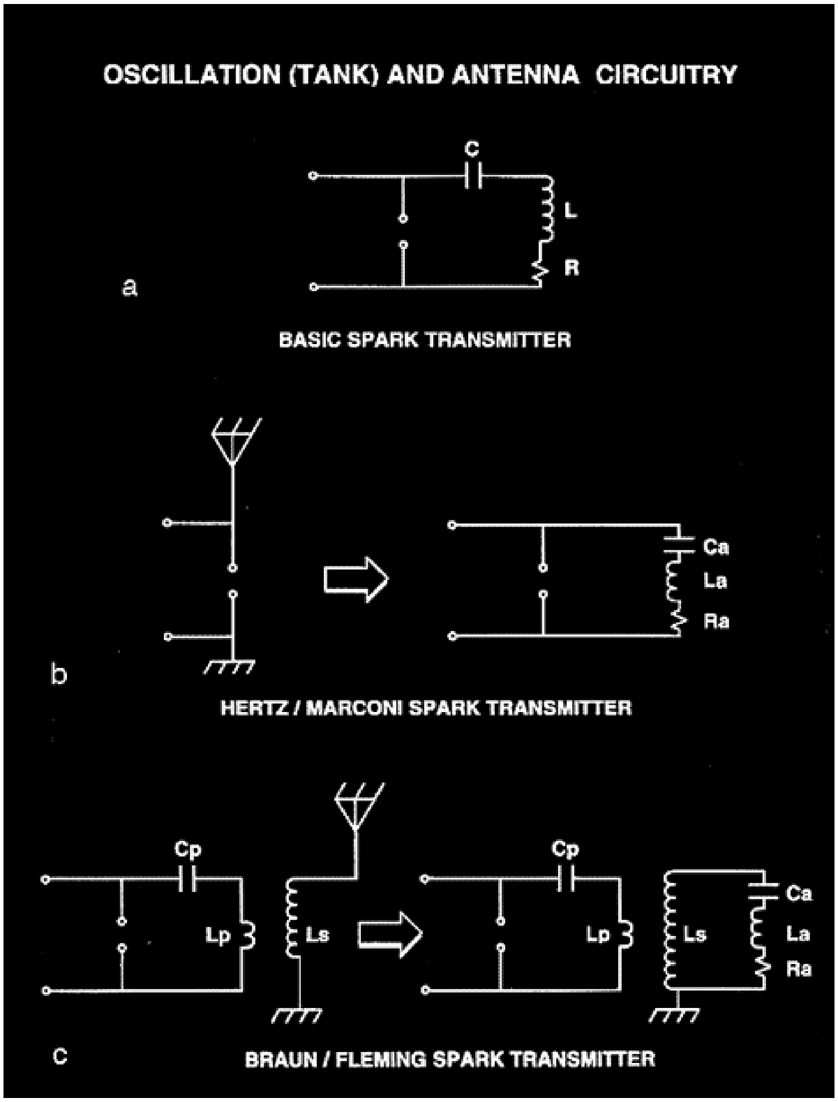


Fig 1 Sketches illustrating actual and equivalent circuits for spark transmitters.

Spark Transmitters

In its simplest form a spark transmitter consists of a spark gap connected across an oscillatory circuit consisting of a capacitor and an inductor in series. The capacitor C (see Fig 1a) is charged to a high voltage by an induction coil (not shown). When the potential across it was sufficiently high to break down the insulation of air in the gap, a spark then passed. Since this spark has a comparatively low resistance (an ohm or two), the spark discharge was equivalent to the closing of an L-C-R circuit. The condenser then discharged through the conducting spark, and the discharge took the form of a damped oscillation, at a frequency determined by the resonant frequency of the spark transmitter.

Hertz in 1888 placed the spark gap across the terminals of the antenna, and so the frequency transmitted was determined by the self resonant frequency of the antenna system (an end loaded dipole). Marconi, following the work of Popov, used an end fed wire aerial (a monopole). The damped wave had a very short duration, since as soon as the spark ceased, the oscillation ceased, since the connection for current flow between the antenna terminals (or connection to ground in the case of a monopole antenna) was by way of the spark.

The not wanted gap across the antenna terminals was eliminated by Braun, who in 1898 patented a circuit in which the spark gap was in a separate primary circuit in series with an appropriate coil and condenser. The RF energy flowing in the inductor was inductively coupled to an antenna, which was tuned to the same frequency of the spark transmitter (Fig 1c). The induced oscillation in the antenna circuit was also a damped wave, but the period of oscillation was considerably longer than the oscillation period in the primary, since when the spark ceased, the antenna circuit could continue to oscillate on a frequency determined by the antenna system resonant frequency.

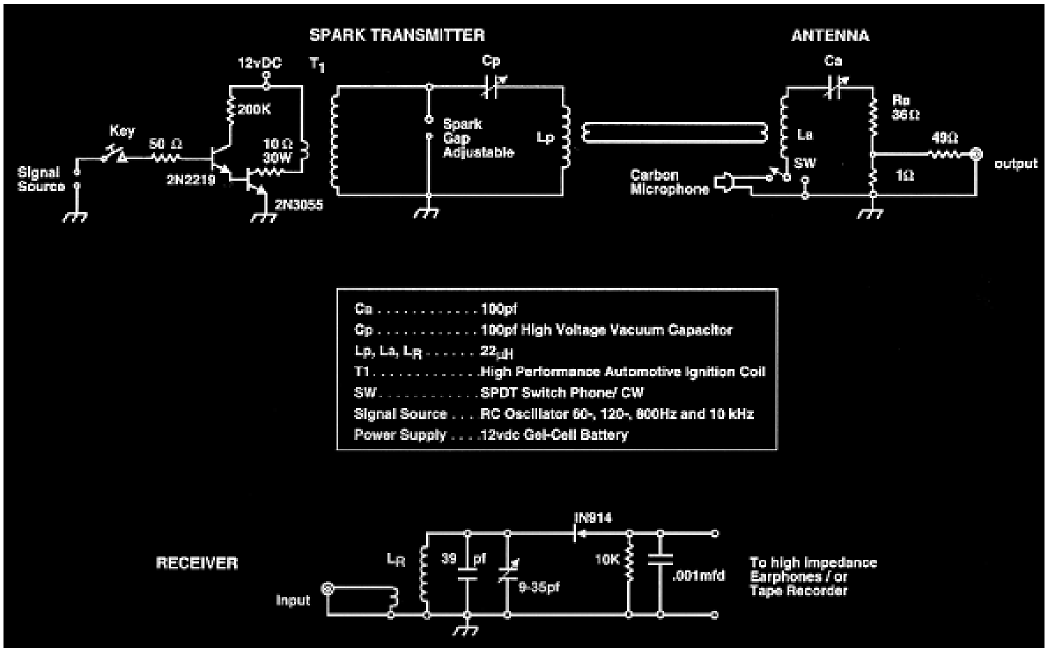


Fig 2: A 5 MHz spark transmitter and crystal receiver used to make recordings "Sounds of a Spark Transmitter" for telegraphy and telephony.

Our spark transmitter was like the Braun transmitter, excepting that the secondary winding wound over the primary (see Fig 2) was not directly connected to the antenna, but link coupled through a short length of transmission line to an equivalent circuit for the antenna system.

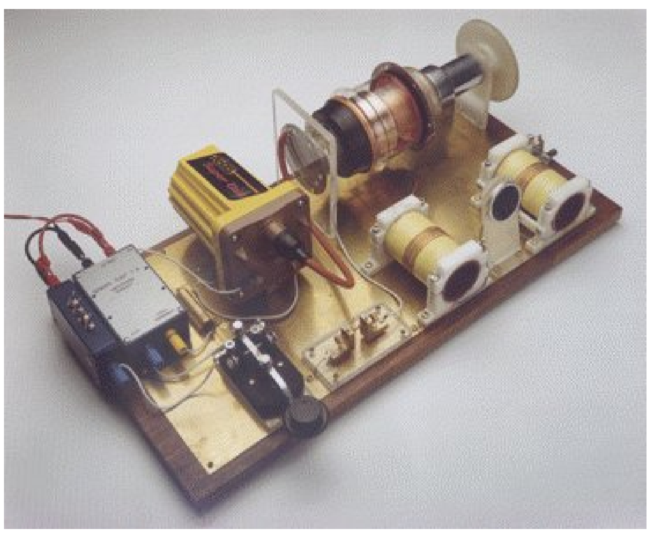


Photo 1: A Laboratory version of a Braun-type spark transmitter.
Janice Lang / Communications Research Centre ©

Design Notes

The lumped-constant equivalent circuit of an antenna input impedance, for a small band of frequencies near to the resonant frequency of the antenna, can be represented approximately by a series Ra, La, Ca circuit, see Fig 2, where

$$Q = \frac{2\pi f L_a}{R_a} = \frac{1}{2\pi f C_a R_a}$$

[1]

For a quarter wave monopole Ra = 36 ohms, and Q depends on the "thickness" of the antenna. Suppose, for our 5 MHz antenna, the bandwidth is 250 kHz. Hence Q = 20, La = 22.9 microhenries, and Ca = 44 pF.

The power input to the a spark transmitter is

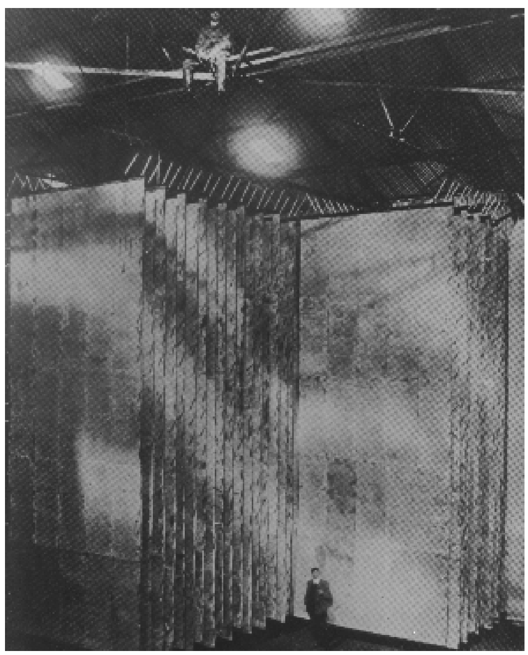
$$P_{input} = \frac{CE^2}{2} \times (\text{spark rate})$$

[2]

providing that the charging rate is sufficiently rapid that the capacitor is fully charged prior to each spark discharge.

For our spark transmitter Cp = Ca [*] and Lp = La

[* Spark transmitters of the day employed very high capacitance condensers, to resonate with a 1- or 2-turn inductor, in order to achieve high transmitter powers (see for example Photo 2 below).]



Marconi's Clifton, Ireland condenser under construction
after Guglielmo Marconi*, published by the Marconi Company Ltd, 1984.*

Hence for E = 25 kV, Cp = 44 pF, the power input for a spark rate of 750 sparks/sec, Pinput = 10 watts. At 60 sparks/second, Pinput = 0.8 watts.

Efficiencies for early spark transmitters were probably 60 percent or greater, but we did not attempt to validate this simple power approximation. Power was not a requirement for the experiment. The output of our spark transmitter attenuated by 120-130 dB was coupled directly to our receiver. The receiver was a simple tuned circuit, a detector, admittedly a modern silicon diode, and earphones, actually a tape recorder. High impedance earphones are hard to come by these days, as is a carbon microphone for the transmitter. We used the carbon microphone from an old telephone hand set.

The switching circuit for the spark transmitter was a mechanical interrupter, a relay operated off the 60 Hz mains; or a square wave signal generator, employing a NE 555 IC.

The spark transmitter was operated off a 12 volt lead acid battery, which has a low internal resistance. The instantaneous current is high, and a laboratory voltage regulated power supply will not cope. Besides this, one wants to be as decoupled as possible from the mains, which is used to power the tape recorder, and measurement instrumentation.

Performance

To make recordings of the signal received we had to relearn how to set up and 'tune' a spark transmitter. The primary and secondary circuits, the 'tank' and 'antenna' circuits, must not be overcoupled, since this results in a double peaked extremely broad amplitude-frequency response.

The antenna circuit was loosely coupled to a receiver, consisting of a tuned circuit, a diode detector and earphones -- in our case the audio amplifier of our tape recorder.

The first recording is for a spark transmitter using a mechanical interrupter, operating a 60 breaks/second. Listen, you will hear the ragged sound of a train of sparks, and the irregular make and break of the mechanical interrupter.

For those of you that do not know the Morse code, the transmission was: CQ, ("seek you") calling any station or calling all stations, from PN. PN was the call sign used by the Marconi station at Poldhu, Cornwall.

Now let us listen to our same spark transmitter, where the interrupter was a 125 Hz audio signal generator and a solid state switch, simulating a 125 Hz AC generator.

Finally, let us hear what a synchronous spark transmitter might have sounded like. The spark rate was 750 sparks/second, which could have been derived using a 3-phase AC generator, and the rotary spark gaps arranged to fire on both positive and negative peaks of the 3-phase waveform. Listen, you might be surprised. The station's call sign is BO, the call sign of Fessenden's Brant Rock (MA) transmitter. [The full message is "CQ DE BO"]

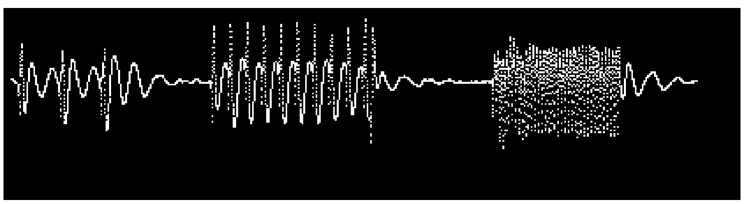
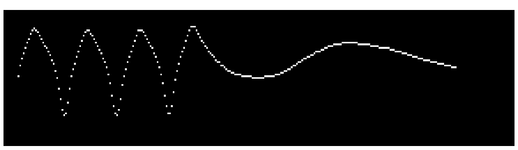


Fig 3 above shows the sound wave form of the "E" (a single "dit") of "DE" (= "from") in the message presented in the three samples above. The third (750 sparks/second) is repeated in Fig 4 below made with expanded time scale.



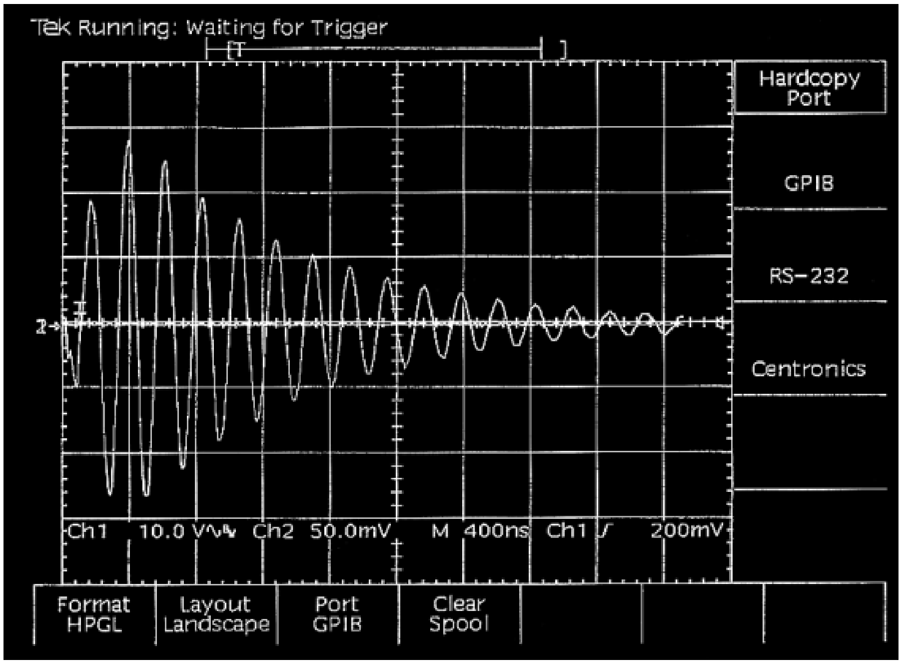


Fig 5: Damped wave as recorded with our 5 MHz spark transmitter.

A spark transmitter emits a series of damped waves, the period of which is the spark rate. Certainly our spark transmitter behaved as expected for a well adjusted Braun type spark transmitter, see Fig 5. An overcoupled Braun circuit would have shown evidence for a two frequency amplitude-time response. The peak response occurs within 1-cycle of the radio frequency, and dies away after about 14-cycles. The spark transmitter was carefully 'tuned' to achieve this response -- it is very easy to observe a noisy trace.

The output power spectrum for our spark transmitter is indeed very broad, megahertz wide (see Fig 6).

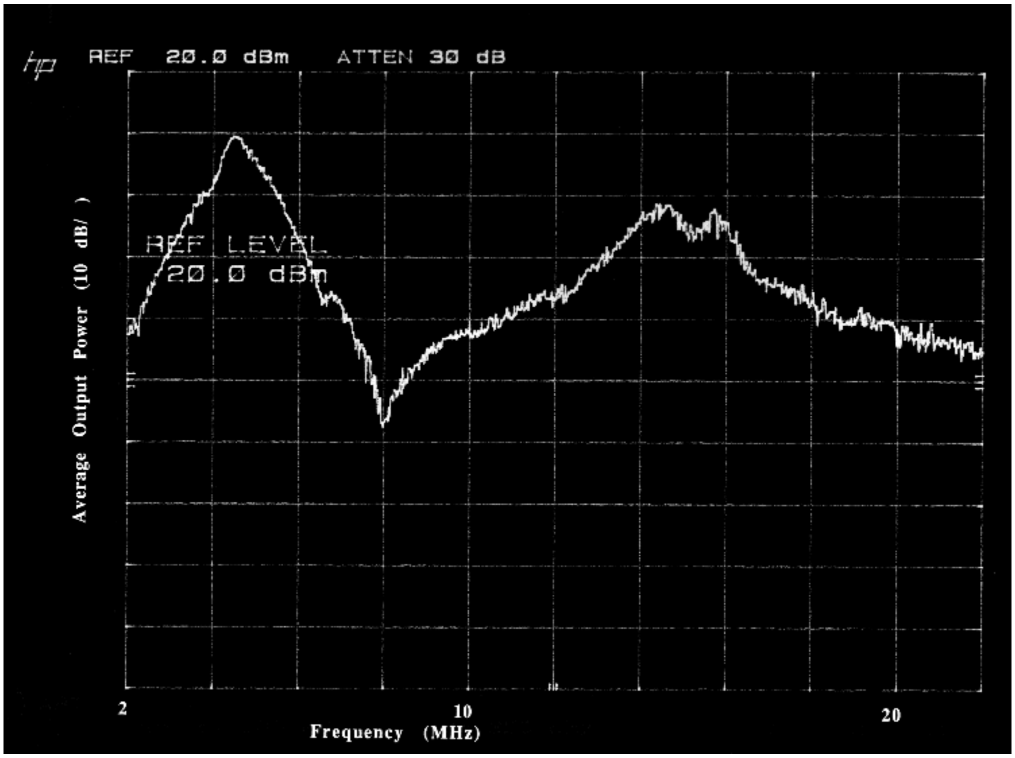


Fig 6: Relative power output of the author's 5 MHz spark transmitter.

Somewhat surprising is the magnitude of what at first sight appeared to be, say, a 'third harmonic' of the fundamental oscillation frequency. This response would be expected for a real thin wire quarter wave antenna, since it would be sharply resonant at three, five, seven, etc. times the fundamental resonant frequency. But for our simulated antenna, the 'third harmonic' should not be accentuated. So we measured the CW signal amplitude frequency response of our spark system. The response was like that traced out by the spectrum analyser when the generator was a spark not a swept frequency signal generator.

As noted above, the 'transmitter' and 'antenna' circuits were link coupled. Initially 6 turns were used (which can be seen in Photo 1). The circuit was overcoupled. We reduced the number of turns to 2. Both inductors were on the same chassis, and the leads to the primary circuit long, running from the induction coil, to the high voltage capacitor (a vacuum capacitor), to the spark gap.

For our spark transmitter some other form of coupling was responsible for the secondary peak -- the frequency of which depended on the coupling (number of turns for the coupling coil), and the phasing. Reversing the connections to the coupling coil eliminated the sharp minimum near 8 MHz (see Fig 6).

The spark should take place between polished hemisphere shaped electrodes, not between pointed electrodes. And, the widest gap possible consistent with regular sparking when the key is held down must be used, since otherwise the signal becomes all 'mushy'. In effect we 'optimised' our transmitter by gradually adjusting the gap for the best received sound, before making a recording at a particular spark rate. Hence the sounds you hear are undoubtedly the best (ie quality of sound) that could have been heard. In fact in our view the transmission quality is remarkably good considering the broad response of the transmitter, and considering the source was initiated by a spark discharge.

Listen to this sample employing the same spark rate (750 sparks/second) as we narrow the width of the gap.

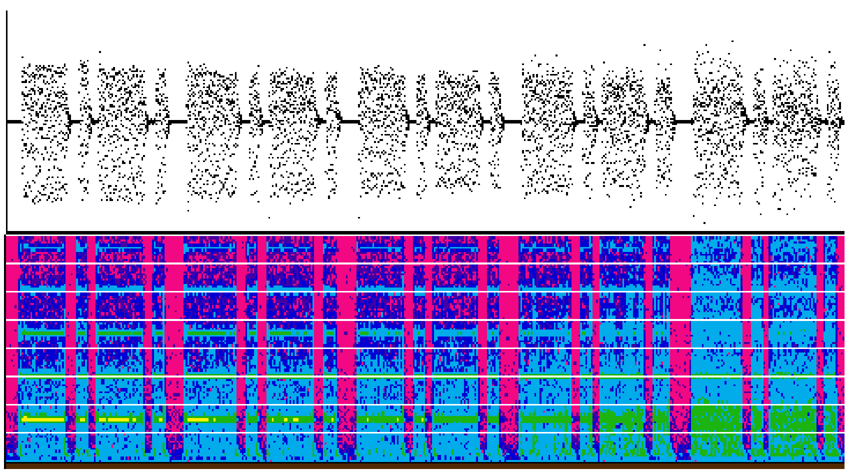


Fig 7 The spectrogram (lower panel) of these five segments (each one is letter "C") of decreasing gap width show the increasing noise amplitude and frequency extent. The horizontal white lines are frequency markers (500, 1000, ... 4000 Hz). In time domain (upper panel) the resolution is not sufficient to show the waveform but the increasing raggedness is clear.

The signal of our spark transmitter sounds terrible on a narrow band receiver, but the receiver used for spark reception was broadly tuned, and the recovered audio can be remarkably good. Because of the wide variety of spark rates, gap speeds for synchronous and non-synchronous rotary gaps, electrode shape and spacing, operating voltage, and tuning, every spark station had its own characteristic sound. This was an advantage when there were a number of stations on the air operating at near the same wavelength. Wireless telegraphy would have been more difficult if all signals had sounded the same. Thus if two or more spark transmitters were operating at the same time, each receiver was likely to get all of them. Receiver operators therefore learned to distinguish wanted signals from unwanted ones by the characteristic sound (frequency, attack, harmonic content, etc) of the wanted signal using the "cocktail party effect" whereby one can listen to one conversation ignoring other simultaneous and maybe even louder ones.

Spark Telephony

For telephony Fessenden's first attempts to transmit voice employed a spark transmitter operating at something like 10,000 sparks/second. To 'modulate' his transmitter he inserted a carbon microphone in series with the antenna lead -- as we have done (see Fig 2). He experienced great difficulty in achieving intelligible sound. We can attest to this. We started out with an automotive induction coil from a junk box, which was not very good, even for a low spark rate. We bought a standard automotive induction coil, which was useless for a spark rate of 10,000 sparks/second. Finally we bought an expensive automotive induction coil for high performance automobiles. Even so the spark gap width was very critical for a spark rate of 10,000 sparks/second.

To conclude, let us hear how this telephony transmission employing spark might have sounded like.

On the 23 December 1900, Fessenden, after many unsuccessful tries, transmitted words without wires. The speech you hear is the voice of the author, using the transmitter as described above (the best transmission out of several recorded), but the words are those used by Fessenden the inventor.

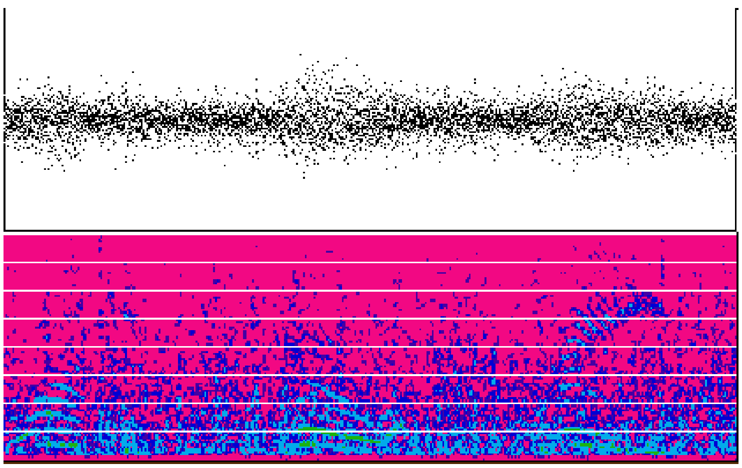


Fig 8: The power spectrogram (frequency range as above) of "Fessenden" saying "one, two, three" shows the voiced words clearly despite the spark noise.

Mr. Thiessen telegraphed back immediately. It was indeed snowing where he was. After all Mr Thiessen and Professor Fessenden were only 1 mile apart. But not withstanding, the short distance, and the poor quality of the transmission, this date heralded the beginning of radio telephony.

Addendum to:
Sounds of a Spark Gap Transmitter 1

To send messages in Morse code using a Spark Gap transmitter it is necessary to employ a moderately high spark rate, high compared with the speed in sending the Morse letters, and high enough to produce a musical tone in the ears of the listener, clearly distinguishable from interference and atmospheric noise.

Marconi compromised himself by using his curious 2-stage spark transmitter at Poldu for his first transatlantic experiment in December 1901. At best he could realize only a low spark rate, estimated to be 10 sparks/second or less [note:2].

Listen, using our Laboratory spark transmitter, and a simple receiver (a tuned circuit, a detector and ear phones/or a tape recorder) I send several sequences of three slowly spaced dots, the letter 'S', followed by a brief period of key down, for three spark rates: 7, 120 and 800 sparks/sec.

During December 2001 the media remembered Marconi's first transatlantic experiment on 12 December 1901. Radio broadcasters retold the story about the Marconi sender sending the letter "S" --- and in the background behind the words accompanying these radio/TV broadcasts we hear buzz-buzz-buzz --- the famous letter S.

But with the low spark rate Marconi used, he would not hear buzz-buzz-buzz; he would hear click-click-click, a signal which is indistinguishable from atmospherics/or particularly electrostatic aerial discharges (whether he had a detector that was working or not). History has told us that he had a very unreliable detector.

Remember Marconi was using a kite supported long wire aerial, bobbing in the wind in a coastal environment (prone to precipitation static). You do not need a detector to hear sounds. Electromagnetic signals in the audio frequency range are picked up by the wire aerial and can be heard using only a pair of earphones (no detector). There were no interfering signals, there was no power line noise, just the natural ELF/VLF atmospheric noise background --- swooshes, aurorally associated hiss, clicks, which usually come in groups (precipitation static), and whistlers.

Marconi did not attempt to send a message, or even a simple word, only the letter S. He chose to send "dots", because (so history tells us) the ac alternator supply for his spark transmitter could not provide the required power to hold the key down for a "dash".

Whatever, I would like to demonstrate the impossibility to send words (even if he wanted to) by the Morse code using the low spark rate Marconi used in December 1901, and February 1902: Listen , I will try to send the word Marconi, in slow Morse code, first at 7 sparks/second, and then at the higher spark rates of 120 and 800 sparks/sec.

With the low spark rate it is impossible to recognize Morse letters, since all we can hear is clicks: 1 or 2-clicks for a dot, depending on how long one holds the key down, even briefly for a dot; and 2- 3 or more-clicks clicks for a dash, depending on how long the key is held down.

During Marconi's follow on experiments in February 1902 on the SS Philadelphia (using a tuned aerial on the ship supported by 45m masts), Marconi (so history tells us) "silenced the skeptics by producing visible proof of his successful reception of signals (to distances of about 1120 km by day, 2500 km at night) --- the simple 'S' motivated the Morse inker for all to see, **the first readable transatlantic messages, as distinct from signals were recorded**" (words published words by the Marconi Company in a booklet edited by Pam Renolds, entitled "**Guglielmo Marconi", 1984**).

But, more recently, R.W. Simons, in a paper published in the **GEC Review, Vol. 11, No. 1, 1996**, page 51, describing this signed tape "**for all to see**", has written: "----**I am intrigued that the certified tapes of messages that we (the Marconi Company Museum) have, do not contain any recognizable plain language, or code, unlike the earlier (short distance) records of experiments ---**".

Clearly there is controversy regarding early claims by Marconi that signals were received in December 1901 [2]. And, in February 1902 Marconi was having problems with recording the letter 'S', at locations where he said signals could be heard aurorally.

John S. (Jack) Belrose, PhD (Cantab), VE2CV
December 2001

1. Belrose, J.S., "The Sounds of a Spark Transmitter", 22 December 1994 [Online]. Available www.hammondmusiumofradio.org/spark.html

2. Belrose, J.S., "A radioscientist's reaction to Marconi's first transatlantic experiment - revisited", Conference Digest, IEEE AP-S Symposium, Boston, MA, July 8-13, 2001, Volume 1, pp. 22-25.
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3. Belrose, J.S., "Reginald Aubrey Fessenden and the Birth of Wireless Telephony", IEEE Antennas and Propagation Magazine, Vol. 44, No. 2, April 2002, pp. 38-47. Available www.radiocom.net/Fessenden

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Additional material and illustrations by the Editor.

Comments and discussion by electronic mail are welcome.
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webmaster note:
Peter Dowden of Dunedin, NZ, set up the original web page. Richard Dowden constructed the waveforms and spectrograms from sound tapes provided by the author Jack Belrose VE2CV.

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