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A Historical Review of Continuous Wave Radio Frequency Power Generators

Overview

The many disadvantages of the spark transmitters that were the original means of radio communication eventually led to the development of better methods for generating a radio frequency signal. Herculean-type arc transmitter ably presented in Henry Bradford's recent award winning article on the Marconi transatlantic site in Nova Scotia (1) was one historically significant means of developing large amounts of r.f. power in the long-wave spectrum. This article will briefly review some others. These were the Poulsen Arc transmitter, Alexanderson and Goldschmidt HF generators, and the static frequency changers.¹ Hopefully, one or more readers will be enticed to contribute detailed articles on each of these devices.

Introduction

At the start of the twentieth century, wireless communication lost its curiosity status and became a practical means of spanning large distances. "King Spark" ruled the realm. But all too frequently, the spark signals filled the airwaves with a muddle of almost unintelligible overlapping messages! The interference was due to a number of major factors:

1. There was little or no regulation of the airwaves or assignment of priorities. Radio services transmitted whenever they wished and in any part of the radio frequency spectrum they desired.

2. A transmitter "horse power competition" evolved. Those who could afford the more powerful transmitters built them in order to improve their chances of being heard.

3. The very wide bandwidth of the spark transmission² resulted in lower transmitter

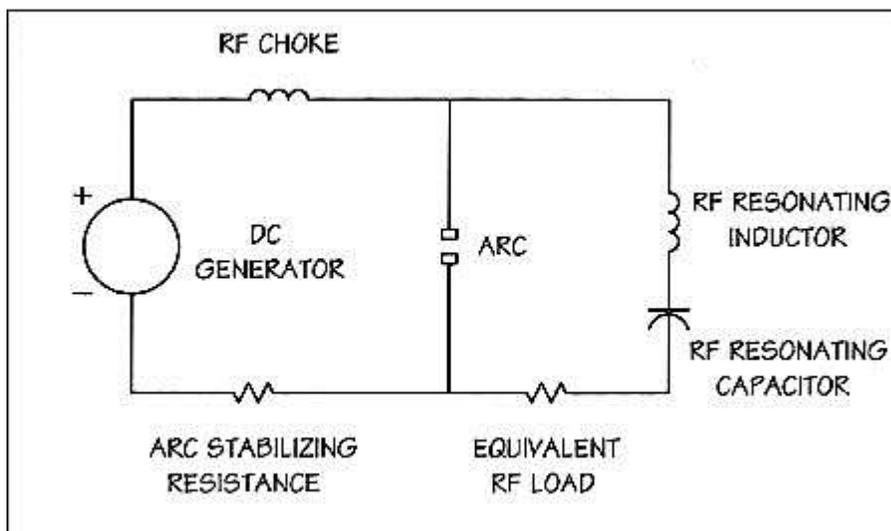


Figure 1. Basic Poulsen arc system.

efficiency and communications effectiveness, while splattering the r.f. spectrum with interference.

4. The selectivity of the receiving devices was "wide as a barn door."

Competing proposals for correcting the situation came from government, academia and other scientifically-oriented establishments. Rules and regulations were promulgated on a national and international level. Needless to say, the *Titanic* disaster greatly accelerated certain types of legislative actions. On the technical front, competing methods to generate high r.f. power levels were under development and implementation. These new devices offered the promise of high power with minimum occupied bandwidth.

We must not forget other important early 20th Century factors that influenced the design of radio transmitters:

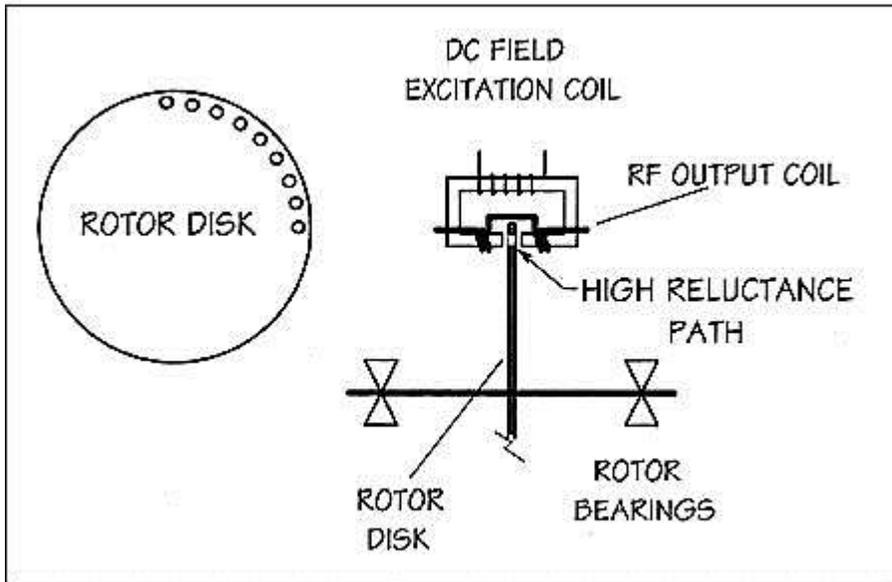


Figure 2. Basic Alexanderson h.f. alternator.

1. Receiver sensitivity was poor. Thus the need for high power transmitters.

2. Antenna efficiency at long waves was low; another reason to develop high-powered transmitters.

3. The radio community had little or no use for frequencies above 500 kHz. The role

of solar activity and the ionosphere on radio communication had yet to be understood. VLF and the lower LF frequency range seemed to propagate 24 hours a day.

4. The three-element vacuum tube just started to make a feeble showing. We had to wait until World War I to see the development of vacuum tubes having power capability adequate to be used in the design of low to moderate power transmitting sets.

We will briefly explore the more significant devices that were developed for generating high-power radio frequencies to replace spark. These were generally developed by personnel and companies already actively engaged in the commercial and residential electrification of our country.

The Devices

1. The Poulsen Arc Converter. Basically, this generator can be likened to a continuous-duty-rated electric arc welder with a tuned circuit connected across the arc. Figure 1 gives a typical schematic of such a transmitter. The "negative resistance" characteristics of an electric arc converts direct current to radio frequency. The arc takes place between a carbon and a copper electrode encased in a closed hydrogen rich atmosphere. The electrodes are cooled by water. A magnetic field is presented at right angles to the arc. This field helps to stabilize the arc and improve overall conversion efficiency. In today's world we still find oscillators based on negative resistance devices; the tunnel diode is one of them.

2. The Alexanderson HF Alternator. The concept of this device is relatively simple. Vary the flux within the air gap of an electromagnet. This induces a voltage in the electromagnet's winding according to the relationship

$$E=d\phi/dt,$$

where E is the induced voltage, and $d\phi/dt$ is the rate of magnetic flux change with time.

In the Alexanderson alternator (Fig. 2), the electromagnet is a stationary laminated steel structure with two windings. One winding biases the electromagnet; the other is the "r.f. pickup"

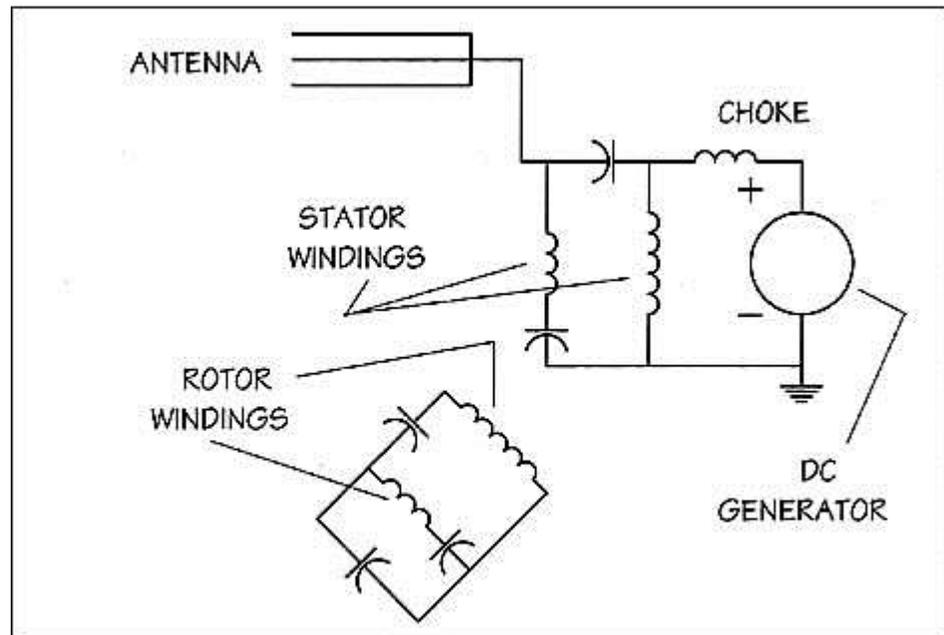


Figure 3. Basic Goldschmidt alternator.

winding. The rotor is a laminated steel disk with "windows" cut into the disk near the disk's rim. The rotor has no windings. In the "windows" are materials having a high magnetic reluctance, such as brass.³ The windows are filled primarily to reduce wind drag and quiet the siren effect. Typical rotor speeds are in the order of 10 to 20 thousand r.p.m. The alternator's armature was driven by a step-up gearbox to produce this high speed.

3. The Goldschmidt, or Reflection-Type (Frequency Changing) Alternator. The first concept to understand is two currents are produced in a coil rotated at synchronous speed within a volume swept by an alternating magnetic field (Fig. 3). In order not to get bogged

down in motor theory, take the following on good faith: one current is zero, while the other current is in the opposite direction, and double the frequency, of that in the rotating field. If we feed this current back into the machine, we generate two more currents, one at synchronous speed, the second at three times the synchronous speed. Table 1 gives an example of the frequency multiplying effect that can be realized for two possible Goldschmidt Alternator configurations.

Notice the "tuned circuits" of the armature and stator windings. The tuned circuits enhance the development of the desired harmonic currents. The process of feeding back the armature current allowed for the development of r.f. currents at armature speeds in the order of 3600 RPM. Quite reasonable compared to the significantly higher Alexanderson Alternator's armature speed.

4. Static Frequency Changers, aka the Joly/Valouri and Taylor Systems. These passive devices operate on the principle that an appropriately designed laminated iron core can produce an asymmetrical flux variation within a saturated core. Since the saturated core reactor (inductor) is non-linear, the net result (without belaboring the theory) is that the circuit's drive current produces strong harmonic components. Obviously, an r.f. input is required. This can be provided by a Poulsen Arc Converter, or an Alexanderson or Goldschmidt Alternator. Figure 4 illustrates the Joly/Valouri type of passive frequency doubler. A discussion on the Taylor tripler can be found starting on page 743 of reference 3. It is interesting to note that in modern times, passive non-linear devices continue to be used to multiply frequency at low to moderate r.f. power levels. For example, the VHF to UHF,

and the UHF to microwave varactor diode frequency multipliers⁴.

EXAMPLES OF THE FREQUENCY MULTIPLYING EFFECT IN 3-STAGE GOLDSCHMIDT ALTERNATORS OF DIFFERENT CONFIGURATIONS ³		
Stator Excitation Frequency	Stator Frequencies Produced	Rotor Frequencies Produced
N	N	2N and 0
	3N and N	4N and 2N
		5N and 3N
0 (i.e., DC)	0	N
	2N and 0	3N and N
		4N and 2N

where N is the frequency of the alternating field current

Table 1

Characteristics of the R.F. Power Generators

The r.f. power generators described above

were available in power ranges from a few kilowatts to a half-megawatt or more. Only the Poulsen Arc converter and passive frequency multiplier were suitable for portable and maritime use. The two alternator designs had to be precision machined to close tolerances in

order to achieve decent efficiency and high power output. The gyroscopic and centrifugal effects caused by the high rotor speeds would tear these machines apart if used on shipboard.

CW was the typical modulation scheme used. It was not uncommon to send 100+ WPM CW from pre-made punched paper tapes. The received signal would be recorded, then played back at a lower speed for transcription.

Since the arc equipment took a little coaxing to get it started and operating in a stable fashion, normal "on-off" CW keying could not be used. Instead, a form of frequency shift keying was employed. The arc was left operating continuously and a portion of the tuned circuit's was shorted out when the key closed. Therefore, the "mark" (key closed) was sent at one frequency; the "space" (key open) at another frequency.

If these frequencies were far enough apart, and the receiving station receiver had adequate selectivity, the receiving station would hear standard CW when tuned to the "mark" frequency. The tone was a little on the rough side. The arc generator's frequency multiplier and antenna tuning had to be selective enough to suppress the high harmonic output of the arc converter.

Modulation of the two alternator designs was done primarily by diverting the alternator's output power, or by detuning an impedance matching circuit at the alternator's output. Amplitude modulation could be realized by varying the alternator's stator field current at the audio rate. Precise armature speed control was required to maintain a constant frequency output.

The arc converter and Goldschmidt Alternator were most successful when made to operate in the frequency range of a few kilohertz to a few tens of kilohertz. The passive frequency converter was relied upon to bring the output frequency up to "practical" transmission frequencies, i.e. 16 to 200 kHz.

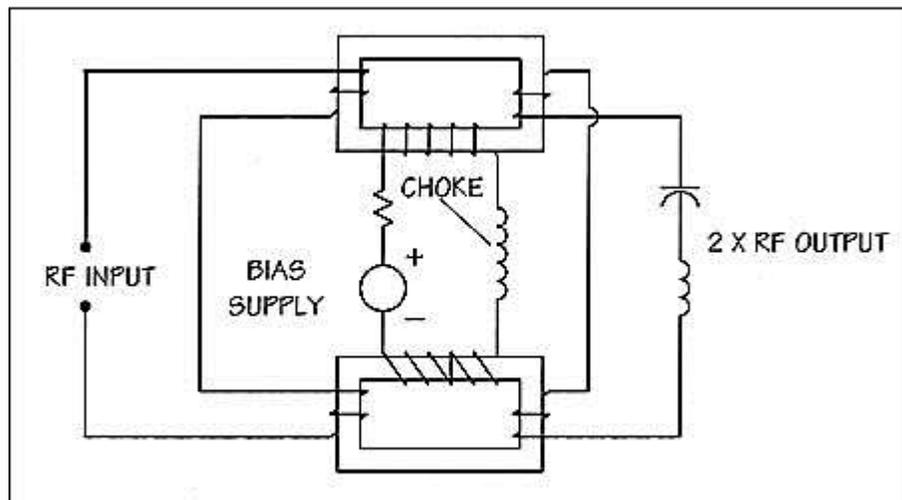


Figure 4. Times two frequency multiplier.

Designing the Alexanderson Alternator for the lower frequencies was also helpful; it

lowered the rotor speed and lightened the design and manufacturing tolerances. However, 200-kHz Alexanderson machines of moderate power were manufactured and used with some success. No doubt the electrical designers had to balance the losses in the r.f. generators and frequency converters against the higher radiation efficiency achievable from antenna systems designed for the shorter wavelengths.

Conclusion

By the start of the 1930's, the vacuum tube had taken over as the undisputed king of r.f. power generation for both long and short waves. A few US Navy and foreign government long-distance VLF and LF mechanical generators did survive to the end of World War II. The interested reader may wish to search the Internet using "Goldschmidt" or "Alexanderson" as key words. A historical preservation society in Sweden has probably the only surviving operational HF alternator. This 17.2 kHz machine comes alive for special occasions. It is infrequently heard in N. America. Use SAQ or Grimeton as your browser's search criteria for the Swedish Alexanderson Alternator website. Scroll down and click on the English language link. The Long Wave Club of America web site, <http://www.lwca.org>, also features articles and Internet links on low frequency generators.

NOTES

1. The development of high-power vacuum tubes during and immediately following World War I will not be considered. Without a doubt, the vacuum tube instigated the rapid demise of all prior forms of r.f. power generation. Also not discussed in this article is the "multiple disc dischargers" spark transmitter, which created a more continuous wave emission from a rotary disc spark transmitter. See reference (2).
2. "Occupied bandwidth" is a modern term quantitatively describing the bandwidth of a transmitter's radiated signal at points 23 dB down from the mean signal power. For example, with a well-designed AM transmitter, the occupied bandwidth is approximately twice the maximum modulation frequency. In a modern transmitter design, the CW signal without an adequate key click filter can have an occupied bandwidth of be tens of kHz under good propagation conditions. For a spark transmitter, the effective bandwidth is literally hundreds of kilohertz! See reference 5 for a more thorough discussion of occupied bandwidth.
3. Reluctance is the "resistance" to the passage of magnetic flux, usually designated as a script "R." Permeability, designated as a lower-case Greek mu, is the ratio of the number of lines of (magnetic) flux that exist in the material (a magnet's core) as compared to a vacuum (core). See Dawes, Chester, A., *A Course In Electrical Engineering*, McGraw-Hill Book Company, Inc., NY, 1937, volume 1, 3rd edition, page 250.

REFERENCES

- (1) AWA Conference Recognition Awards, *The OTB*, vol 42, #4, November 2001, page 19.
- (2) Bucher, Elmer, *Practical Wireless Telegraphy*, The Wireless Press, NY, May 1918,

section 219, pages 274-276.

(3) Morecroft, J. H., *Principles Of Radio Communications*, John Wiley & Sons, Inc., NY, NY, 3rd Edition, 1933, Page 735.

(4) Amateur Radio Relay League, *The Radio Amateur's Handbook*, Newington, CT, 1981 edition, pages 4-11 through 4-13 (and other editions of that period).

(5) Amateur Radio Relay League, *The Radio Amateur's Handbook*, Newington, CT, 1992 edition, Chapter 9 (and other editions of that period).

Schematic Sources

Morecroft, J.H., *Principles Of Radio Communications*, John Wiley & Sons, Inc., NY, NY, 2nd Edition, Chapter VII, Figures 4, 20 and 24: Poulsen Arc, Goldschmidt Alternator, Joly/Valouri Frequency Doubler, respectively.