Chapter 2
UWB Signals and Systems

Abstract this chapter introduces UWB signals and systems. The utilization of UWB systems, in the last one hundred years, is described in a brief history of UWB signals and systems. This chapter shows some examples of UWB signals and characterizes the time domain and frequency domain properties of these signals. It is shown, that baseband UWB signals can be easily generated using circuits built in a CMOS technology. The chapter ends with a study of the interaction between UWB signals and the antennas used to transmit and receive them. In this analysis, a methodology that allows to calculate the shape of the received UWB signal in an antenna link is developed. Using this methodology, it is show that the optimal input impedance of an UWB receiver is not necessarily the same as the optimal input impedance for a narrow band signal. There is also an analysis about the best type of antenna for UWB signals and how each type of antenna affected the PSD of the radiated signal.

2.1 A Brief History of UWB Systems and their Applications

The first intentional emission of electromagnetic radiation was based in the generation of electrical signals with short duration [1]. In his pioneering experiments, Heinrich Hertz [2] invented a RF oscillator consisting of a resonant circuit (a balanced half wave length dipole, capacitively loaded by large metal spheres) and a fast acting switch (a spark gap in the center of the dipole). This arrangement was operated by applying a high voltage DC pulse to the dipole, this high voltage DC pulse was generated by the secondary of a transformer where a large DC current ($i_1$) was interrupted in the primary. A simplified representation of this circuit is shown in Fig. 2.1.

![Fig. 2.1 Simplified representations of the Hertz RF generator and receiver](image)

The capacitance of the dipole is charged by the high voltage pulse until the voltage across the spark gap \( (v_{SG}) \) is enough to cause a spark. The spark arc has a low resistance that effectively connects the two parts of the dipole causing a large abrupt current \( (i_2) \) to flow between the two charged spheres. This current causes a magnetic field that reaches its maximum value when the electrical field between the two spheres is zero. As the magnetic field collapses, the electrical field increases (with an opposite polarity as before) because the current continues to flow charging the spheres, when the current reaches zero, the energy is once again stored in the electrical field and the cycle will repeat itself. The charge will thus flow back and forth between the spheres, as the energy alternates between the magnetic and the electrical field, except that approximately 15% of the energy is radiated as RF energy in each half cycle. The dipole produces about five half-cycles of RF energy for each high voltage pulse applied. The typical output wave of this oscillator is a short duration damped sine-wave and the resulting RF frequency spectrum is very wide.

In his experiments Hertz used his oscillator apparatus to generate electromagnetic waves with frequencies\(^1\) of 50 MHz, 100 MHz and 430 MHZ; he used such high frequencies in order to obtain a wave-length with an acceptable small value, necessary to run his experiments inside his laboratory. He detected the electromagnetic waves using a very small spark gap connected to a resonant circuit consisting of a loop with half wave-length (as shown in Fig. 2.1). A small spark would indicate the presence of an electromagnetic field; this setup is not very sensitive and requires almost complete darkness to detect the small spark. Nevertheless, he was able to measure the wave length by determining the position of the peaks and nulls of the radiated RF signal.

Latter Marconi used and perfected Hertz experiments in order to obtain a wireless telegraphy system. His systems used variable capacitors to provide tuning to both receivers and transmitters, in order to select different frequencies of operation \[^3\]. The transmitters were still based in spark plugs and therefore a considerate amount of RF energy was spread outside the band of interest, resulting in inefficient operation. The receivers were based on coherer tubes, a glass tube filled with metallic powder, whose resistance would drop approximately an order of magnitude when submitted to an electrical discharge. The sensitivity of this detector is very low. These systems were suited for communication using only Morse code.

To compensate the large inefficiencies of the transmitters and of the receivers, the transmitters needed to radiate a large amount of power (over 10 kW). The result was, as the number of spark plug transmitters increased, the interference between them prevented clear communication between a given transmitter and a given receiver. This led to the invention and development of continuous wave oscillators, where the output signal is a continuous sine wave with a desired frequency value, resulting in a reduction of the power transmitted outside the desired frequency band and therefore a reduction in the interference between different transmitters.

\(^1\) This is the fundamental frequency of the damped sine-wave pulse which is very rich in harmonics.