COMPACT HIGH-VOLTAGE PICOSECOND GENERATOR USED AS PULSAR TRANSIENT RADAR SOURCE

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Abstract

This article relates to the development of a fast compact pulse generator used as the generation system of an ultra wideband radar device called PULSAR for the French Technical Centre for Armament Electronics (CELAR) [1].

The design, the fabrication and the experimental results of a short pulse generation system are presented in this paper. This system, developed by the LGE (Laboratoire de Génie Electrique), deals with the association of a pulsed source to a coaxial generator in order to realise a peaking circuit. This generation system is able to generate pulses with 25kV amplitude and 70ps rise-time through a 50Ω impedance.

It is associated to a radiating structure. So, the IRCOM (Research Institute of Microwave and Optical Communications) has developed a new radiation device (antenna and balun made by Europulse company Cressensac, Lot, France). The antenna, called Dragonfly antenna [2], is able to support high peak voltage (25kV) and has a very large bandwidth (300MHz to 3GHz) as well as a high gain along the axis (up to 12 dB).

Main results concerning the new generator associated to the antenna are presented in this paper.

I- INTRODUCTION

The demand for switch closure on sub-nanosecond time scales has arisen in a range of applications including high power microwave or pulse laser drivers. That is why ultra-wide band (UWB) microwave sources and antennas are of interest for an application such as transient radar. One of the most promising missions of such potential radar is the detection of buried and surface land mine targets. In order to detect foliage and ground concealed targets, a UWB short pulse radar seems to be of the emerging solution. The PULSAR radar (figure 1) is dedicated to pulse measurements on outdoor targets and low frequency clutter.

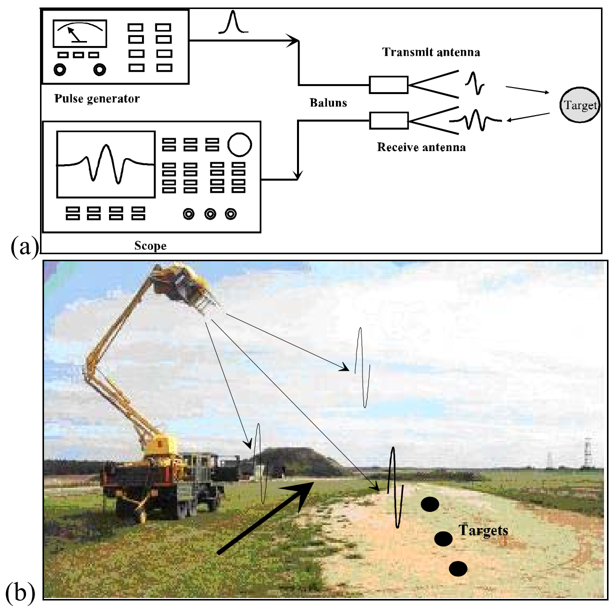


Figure 1. The UWB synthetic aperture Radar PULSAR
(a) Schematic representation (b) Photography

An extremely short pulse generated by a source is transmitted through a transmit antenna, interacts with dense media and objects ahead, and radar returns are captured with a receive antenna and sampled. To enhance discrimination between targets and clutter, the excitation should be as wide band as possible. However it is also essential to operate at frequencies for which adequate soil and foliage penetration can be effected. The device must transmit and receive waveforms with usable bandwidth from 300MHz to 3GHz.

The usable range of UWB radar is ultimately dependent upon the peak power of the transmitted pulse and the pulse repetition rate, which define the total energy transmitted in a given period, while the range resolution is dependent upon the rise-time and duration of the transmitted pulse. That is why a fast rise-time is needed to detect objects with small size: the discretisation is improved as the bandwith is increased. So a UWB coaxial pulse generator is used for the peaking function. The object is to pulse sharpen the output of a first device in order to generate a very fast repetitive voltage pulse. For this function, the technology concerning a high pressure gas switch in the coaxial generator is largely used [3] because the gas quickly regains its dielectric strength after the discharge and the dielectric withstand of gas allows very interesting voltage levels. This technology can be easily designed for the sub-nanosecond time scales, and the ratio between the parasitic inductance generator and the geometry impedance can be reduced enough to generate sub-nanosecond rise-times.

II- HIGH VOLTAGE PICOSECOND PULSE GENERATOR

The complete generator can be suitable for UWB radar applications provided that the output pulses reproducibility obtained is good (±5% or less). The coaxial generator needs a pulsed source to improve this main characteristic (figure 2). The aim is to lead to the breakdown of the high pressure gas switch during the rise of the pulsed source voltage output. In these conditions, the time allowing to find an initiatory electron is very short (<100ns) and the stability and the reproducibility of the output pulses are improved. In this case, the breakdown of the coaxial generator gap will occur at the same voltage level and the output voltage amplitude is always similar. This source must generate pulses with fast rise-time and amplitude twice higher than the coaxial generator one.

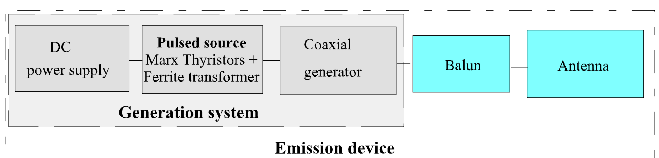


Figure 2. Basic structure of the pulsed power generation system

A- The pulsed source (Marx generator and ferrite transformer)

The pulsed source associates three power modules :
- a 1kV DC power is used to supply a Marx generator;
- a ten-stage Marx generator using thyristor switch can generate pulses of about 10kV;
- a pulse transformer using the magnetic properties of ferrite cores allows to amplify the 10kV pulse to reach 60kV.

Usually, a Marx generator forms the first section of the energy storage system in most experimental set-ups. For the switching function, thyristors were chosen. They offer a perfect discharge allowing high repetition rate with weak jitter, considerable output voltage and fast rise-time sufficient for our application. One thyristor 30TPS16 from IRF is used by stage.

First experiments have shown that to obtain a good yield between the output of the Marx generator and the pulse transformer, an energy value of 110mJ is required at 7kV. That is why we designed and built a generator containing 2 parallel Marx circuits, to limit the current value on each thyristor. To reach the energy value required, each Marx circuit is made of 10 stages loaded at 1kV with 22nF capacitors per stage (the equivalent output capacitor is 4,4nF).

Therefore the input capacitor is 44nF. The schedule of conditions requiring a 500Hz behavior, the generator's DC supply must therefore supply a 400mA current, 1kV source. However this high value current value leads to thermal dissipation problems in the Marx resistors. As a result, all the resistors of a standard Marx generator were replaced by diodes. In these conditions, the Marx generator only work if it is connected to its output impedance, i.e. the pulse transformer. A pulse transformer using the magnetic properties of ferrite cores is used to reach 60kV. The tests and description concerning this pulse transformer can be observed in [4].

Finally, the main characteristics of the pulsed source are summarized in the following table:

Input Transformer Voltage	7kV
Output Transformer Voltage	60kV
Transformation Ratio	8.6
Rise-time (10%-90%)	250ns
Width (50%)	500ns
Repetition Rate	500Hz

B- Design of the coaxial generator

To achieve energy compression (to enhance the pulse power by decreasing its duration) as well as to shorten the rise-time, the energy from the pulsed source (Marx generator associated with pulse transformer) is fed into a coaxial pulse forming line. This generator (figure 3) is made of a 50Ω coaxial pulse forming line charged by the pulsed source through a resistor, a high pressure gas switch and a transmission line impedance adapter equal to its characteristic impedance. The high-pressure gas switch is then switched on and a pulse is generated due to the boundary conditions ($Z_{in} \rightarrow \infty$ and $Z_{out}=50\Omega$). Theoretically, under these conditions, high-voltage square pulses are produced with an amplitude equal to half of the charging voltage value. The duration of the output pulse is equal to twice the one-way wave transit time in the pulse forming line. The fast pulse generated is observed at the end of the output line.

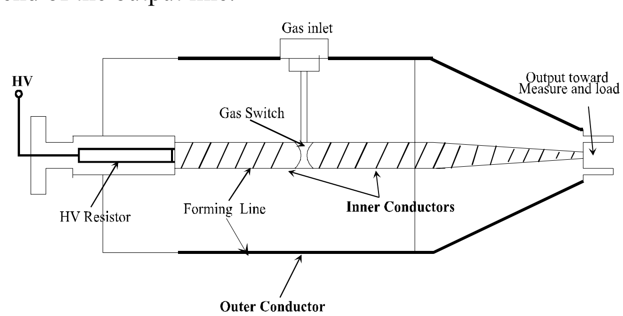


Figure 3. Schematic representation of the coaxial generator using a high pressure gas switch

The main advantage of this system is to allow the setting of various parameters such as the amplitude, the rise-time or the width of pulses. The pulse width is dependent on the length of the forming line (figure 3). Different additional forming lines lead to width pulses contained between 600 ps and 1.5 ns.

Also, the pulse waveform is closely linked to the properties of the switch, and particularly to the gap length, the pressure and the nature of the gas used in the switch filling.

The switching element is the major component of any power conditioning system and ultra-fast closing capability. Our technology uses high pressure gas switch in a transmission line structure to produce a powerful UWB pulse. A technical problem concerns the production of the mechanical design. The switch must be able to withstand voltage pulses of 60kV, pressures up to 50bar with no gas leakage and heat from the repetitive spark channel. It is constituted by two brass electrodes terminated with hemispheres made of tungsten.

The switch works on spark discharge. When the gas gap is overvolted, it breaks down and launches a wave between the inner and the outer conductor toward the output end. The dependence on the rise-time with the molecular weight of the filling gas and the electric field into the switch has been shown [3]. That is why hydrogen gas gives the fastest breakdown since it has the lowest density. So, an improvement in recovery time can typically be achieved using hydrogen gas over other atomic gases. The rate of repetitive operation is dependent upon the ability of the HV pulsed source to charge the pulse forming line after each discharge. It appears that a 500Hz pulse repetition frequency can be reached. In this case, the pulse repetition frequency is not limited by the recovery time of the gas due to the weak energy of each pulse but by the ability of the pulsed source to load the pulse forming line after each discharge.

C- Performance of the complete device

The pulsed source is used near the top of its possibilities. The pulses generated by this source have 60kV amplitude, 250ns rise-time and the pulse repetition frequency is adjusted to 500Hz.

The filling gas is hydrogen to optimise the rise-time and the recovery time. Only the pressure of the gas and the gap spacing of the high pressure gas switch varied.

The experimental investigations described here were performed on gap spacings of 0.2mm to 0.7mm with the gas pressure being varied between 15bar and 50bar.

The amplitude of the output impulse voltage can be adjusted from 3kV to 26kV into a 50Ω impedance. This first test aims at determining associations pressure - gap spacing which allow to vary the pulse amplitude in hydrogen. These results are presented on figure 4.

A linear variation of the pulse amplitude with the product gas pressure time gap spacings is observed in accordance with the right-hand portion of the Paschen curve. So this linear variation seems to consolidate the fact that very fast gas breakdown occurs with classical streamer propagation mechanism leading to breakdown at high pressure.

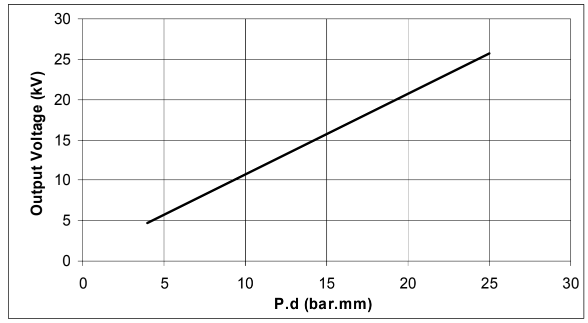


Figure 4. Output voltage versus pressure × gap spacing

The rise-time of a gas switch is found to be strongly dependent on the electric field value (figure 5). Typically, the highest pressure with the shortest gap spacing produces the fastest output rise-times. The rise-time can be controlled continuously by varying the pressure of hydrogen in the switch. Initially it decreases rapidly with increasing applied electric field, then slowly when it saturates at 70ps. A minimum measured rise-time of 70ps (figure 6) can be obtained thanks to an improvement of the geometry configuration. The rise-time of 70ps is measured with a sampling scope 6GHz bandwidth : the real rise-time is certainly faster because the measurement system leads to an over-evaluation of the rise-time.

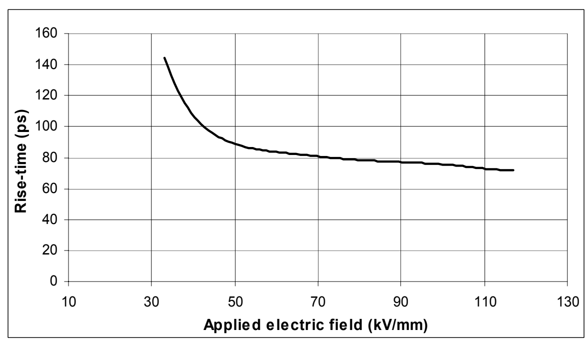


Figure 5. Rise-time of the output pulses versus electric field in the switch

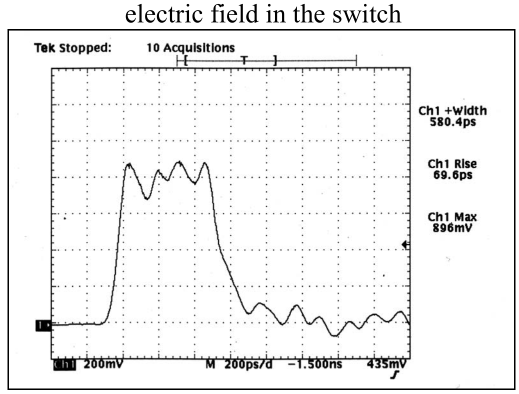


Figure 6. Output pulse shape of the coaxial generator (P=55bar, d=0.45mm, τ=68ps, V_{OUT}=26kV)

III- PULSE GENERATOR - RADIATING STRUCTURE ASSOCIATION

The complete generator in association with the Dragonfly antenna and balun was characterised in an anechoïc chamber (figure 6).

The dragonfly antenna, is made up of four metallic flared plates with a 50Ω input impedance. The input antenna is a symmetrical double-strip transmission line. To build the radiation part of the new antenna, each input strip is divided in two flared plates. The balun ensures the transition between a 50Ω coaxial cable and the 50Ω input impedance fixed by the input planar configuration.

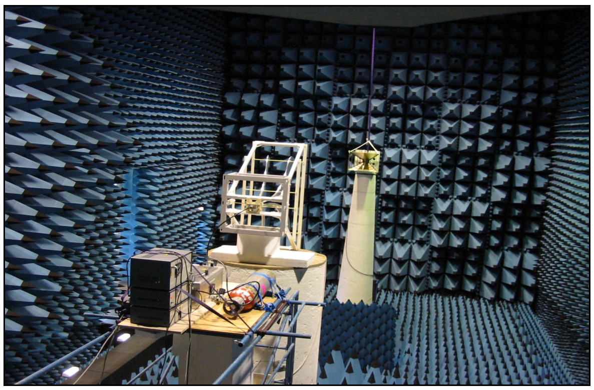
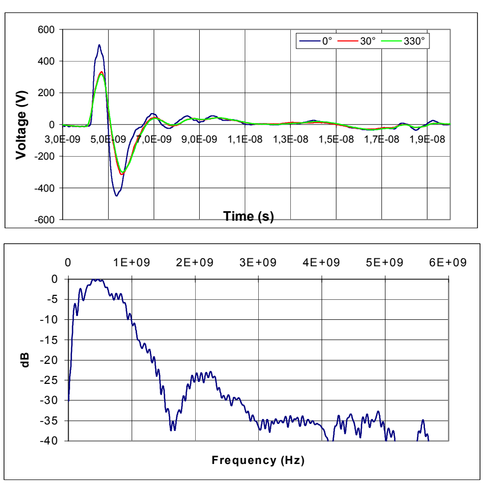


Figure 6. Characterisation test in an anechoïc chamber

On figure 7, the measured signal is presented for two dragonfly antennas facing each other at 10.5 meters (three angles). One of the antenna, connected to the LGE pulse generator, is used as transmitter. The pulse issued from the pulse generator presents the following characteristics : output voltage 23kV and rise-time of 80ps. The receiving antenna is connected to a digital sampling Tektronix sequential acquisition oscilloscope TDS820 (6GHz bandwidth). The Fourier transform of the measured pulse (figure 7-b) exhibits a bandwidth from 400 MHz to 1.4GHz of -20dB below the maximum.



(a)

(b)

Figure 7. Measured signal at the receive antenna for antennas positioned facing each other (a) transient response (b) Fourier transform of the transient response

The radiation patterns H plane at 500MHz frequency is shown as example in figures 8. Note that the main lobe is narrower in the H plane than in the E plane and becomes narrower with the frequency increase.

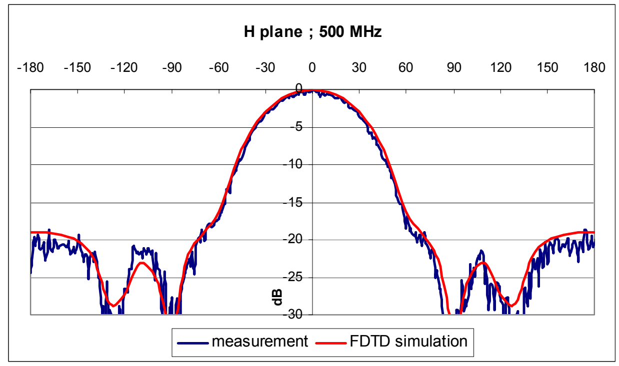


Figure 8. Radiation patterns in H plane (500MHz); transient measurement compared to FDTD method

IV- CONCLUSION

The pulse generator and the UWB antennas will be associated on PULSAR system. With the high bandwidth and the high field level, we expect to improve the radar resolution for buried mine detection. The pulse generator offers the possibility to parametrize the pulse shape specially the width and the rise-time. The influence of these parameters on the image quality will be studied.

V- REFERENCES

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