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ULTRAFAST AUTONOMOUS DETECTION AND SCANNING SYSTEM BASED ON OPTOELECTRONIC PULSE SWITCHING

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Abstract—A novel method allowing the ultrafast scanning of an area thanks to an Ultra Wide Band (UWB) antenna array is proposed in this paper. This method is based on the use of asynchronous optical pulses trains with different repetition rates obtained in amplified regenerative cavities. By means of optoelectronic switching, providing short powerful electrical pulses trains to an UWB antenna array, it is possible to spatially scan a large area in less than 1 ms. The paper presents the principle of the transient beam steering and its potentialities to realize an ultrafast detection system.

1. INTRODUCTION

Ultra Wide Band (UWB) antenna arrays offer the possibility to generate a large band signal in a sharp direction, which can drastically improve the detection sensitivity. With a configuration including as many antennas as generators, an UWB array presents the advantage of increasing the radiation power on one hand and offering the agility to the array on other hand [1]. Indeed, the application of time delays between the feeding pulses of the antennas permits to steer the radiated fields in each wanted direction and to realize a coherent sum of each initial power. However, a major difficulty with such a

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configuration is the minimization of the radiation source jitters, to obtain the better synchronization as possible. A solution consists in using pulsed optoelectronic devices, operating in linear switching regime, which permits to bypass this difficulty and to obtain ultra-short electrical waveforms with small temporal jitters (2 ps typically) [2]. In that linear switching regime each incident photon is converted in an electron-hole pair inside the semi-conductor. Then its resistivity is linearly decreased with respect to the received optical energy amount which guaranties a perfect synchronization between the optical pump command and the electrical released output pulse [3, 4].

Many applications such as transient radar cross section (RCS) measurements [5], UWB synthetic aperture radar (SAR) [6], and high power UWB radiation source [7] have been developed using antenna arrays. Unfortunately, the phase difference between each basic element is governed by optical delay lines that exploit mechanical displacement of mirrors.

Then, a long and complex process is used to set all the temporal parameters that control the direction of emission of the array and the coherent coupling between antennas.

Thanks to the association of an optoelectronic device and an UWB array, the method presented in this paper deals with an automatic and rapid beam steering, azimuth by azimuth, with a defined step. The principle of the transient beam steering, based on the use of series of pulses having different repetition frequencies, and its application to the autonomous scan of an area is presented in Section 2. Then, the implementation is detailed in Section 3.

2. TRANSIENT BEAM STEERING

2.1. Principle of the Transient Beam Steering

With a "N generators/N antennas" architecture, the aimed direction of emission depends on the delays applied between the electrical pulses feeding the antennas array. Indeed, a perfect synchronization of all sources leads the emission of pulses in front of the array, at the 0° azimuth, while a t_1 delay between two adjacent sources involves an emission at the azimuth θ_1:

$$\theta_1 = \arcsin\left(\frac{t_1 \times c}{d}\right) \quad (1)$$

where:

- θ_1 is the azimuth corresponding to the aimed direction.
- t_1 is the time delay between two adjacent sources (in s).

- c is the light velocity in vacuum (in m/s).
- d is the distance between the input ports of two adjacent antennas.

Commonly, the transient electric field radiated by an UWB antenna array is presented as function of time and angle [8]. Thus, Fig. 1 presents an example of perfect synchronization of five sources, giving rise to a single shot at the azimuth 0°. By introducing a delay (t_1) between the pulses feeding two adjacent sources the resulting electric field is steered at the azimuth $\theta_1 = 20°$. In this paper, the antenna used in the experiment of the autonomous scan is the *Shark* antenna, described in references [9, 10]. It works over a very wide frequency band (higher than a decade) with a sectorial radiation pattern in the horizontal plane.

The considered array, composed of five *Shark* antennas in the horizontal plane, is shown on Fig. 1. The distance between two adjacent input ports is 80 mm and the temporal delay t_1 (91 ps) between two pulses feeding two adjacent sources allows an orientation of the energy propagation direction of 20°.

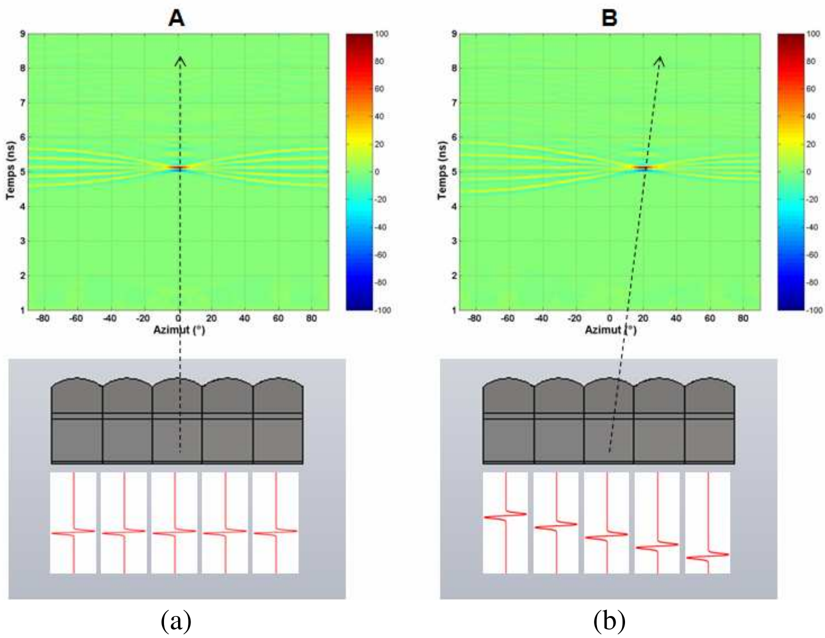

Figure 1. Perfect synchronization of all sources, (a) involving a single shot at the 0° azimuth and application of a delay t_1 between two adjacent sources, (b) involving a single shot at the 20° azimuth.

2.2. Application to the Autonomous Scan of an Area

With the generation of series of pulses, the autonomous scanning system is based on the capacity of the optoelectronic device to modify the delay t_1 between two electrical pulses feeding two adjacent antennas.

Each generated pulse exhibits a monocycle pulse shape (Fig. 2) covering the bandwidth [800 MHz–8 GHz]. This pulse has been chosen

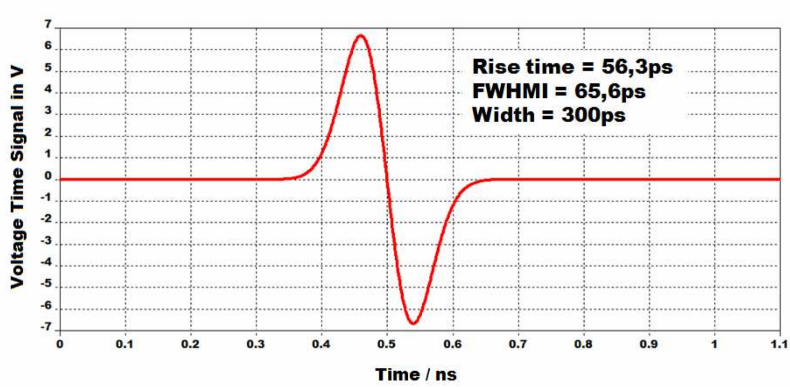

Figure 2. Example of a monocycle pulse shape (duration of 300 ps).

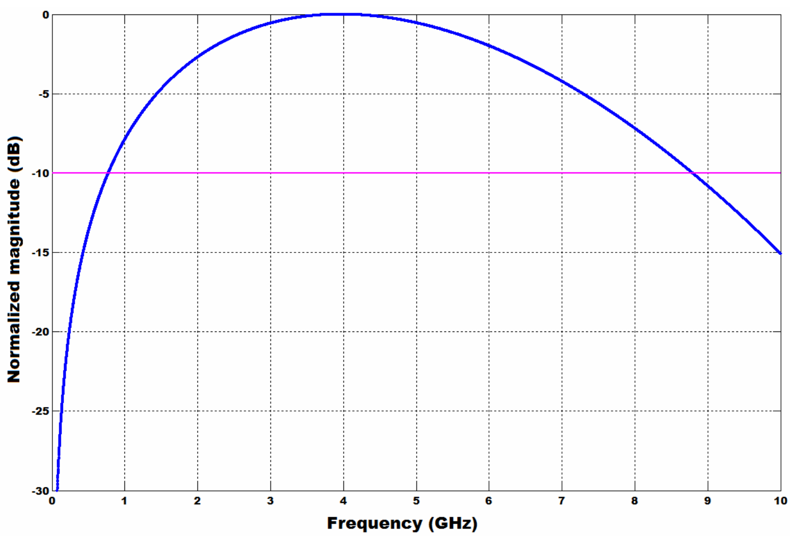

Figure 3. Spectrum of a monocycle pulse, covering a decade of band.

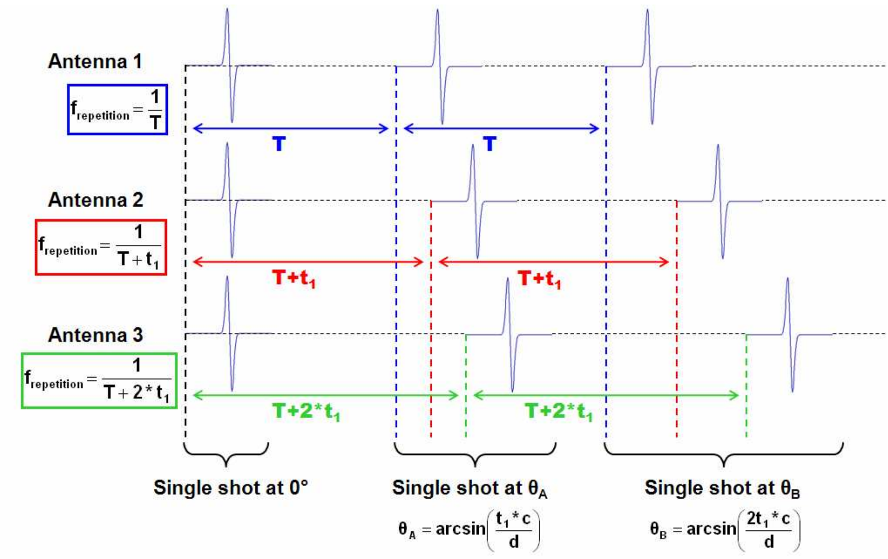

Figure 4. Series of pulses having different repetition frequencies.

because of its low amount of low frequencies that drastically reduce the coupling between antennas (Fig. 3).

The used electrical device allowing electrical pulse generation is based on the frozen wave generator [11–14]. It is composed of two high voltage silicon rectifier diodes separated by an electrical propagation line. The synchronous lightening of the two semi-conductors leads to bipolar pulse generation.

Figure 4 shows that each antenna of the array is fed with a pulse train with a given repetition rate, defined by the following expression:

$$F_i = \frac{1}{T + i * t_1} \quad (\text{For} \quad i = 0 \quad \text{to} \quad N - 1) \tag{2}$$

where:

- F_i is the repetition rate of the pulse train feeding the antenna number $i + 1$.
- T is the period of reference of the series of pulses (in s).
- t_1 is the time delay between two adjacent sources (in s).

At the beginning, the first pulse of each train is generated at a same time t_0. In this case, the coherent sum of all the contributions is realized in front of the array, at the azimuth 0°. The second radiated shot of the system is induced by all the second pulses of each train.

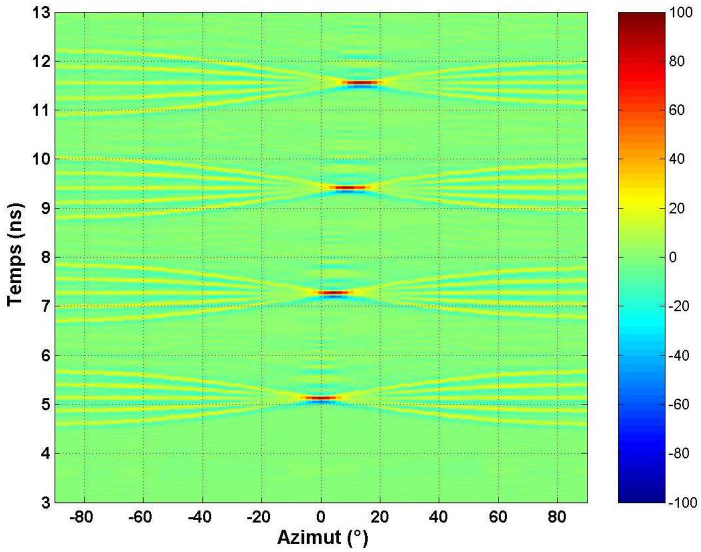

Figure 5. Example of a scanning involved by the system.

They are generated with a delay t_1, $2t_1$, $3t_1$, and $4t_1$, respectively for the second, the third, the fourth, and the fifth antenna. In these conditions, the direction of emission is shifted from a given angle fixed by the time delay t_1. In a same way, the third pulses of each train are then delayed with a higher value, corresponding to a third direction of emission.

Based on this principle, Fig. 5 shows the calculated transient electric field as function of time and angles for the four first shots. The array is composed of 5 *Shark* antennas, the time delay t_1 is 23 ps and the distance between the feeding ports of two adjacent antennas is 80 mm. In this case, four directions have been scanned with an angular step of 5 degrees ($\theta_A = 5°$). The time difference between two successive shots is controlled by the period T ($T > 2$ ns in this case).

Such a method permits to realize a coherent sum of several fields in different directions in a very short time. Indeed, with a pulse duration lower than 1 ns and a period T of a few nanoseconds, an area extended from $-55°$ to $+55°$ with a 5° step can be scanned in less than 1ms. Additionally, a short angular sector can be more precisely scanned in using a smaller angular step with more pulses.

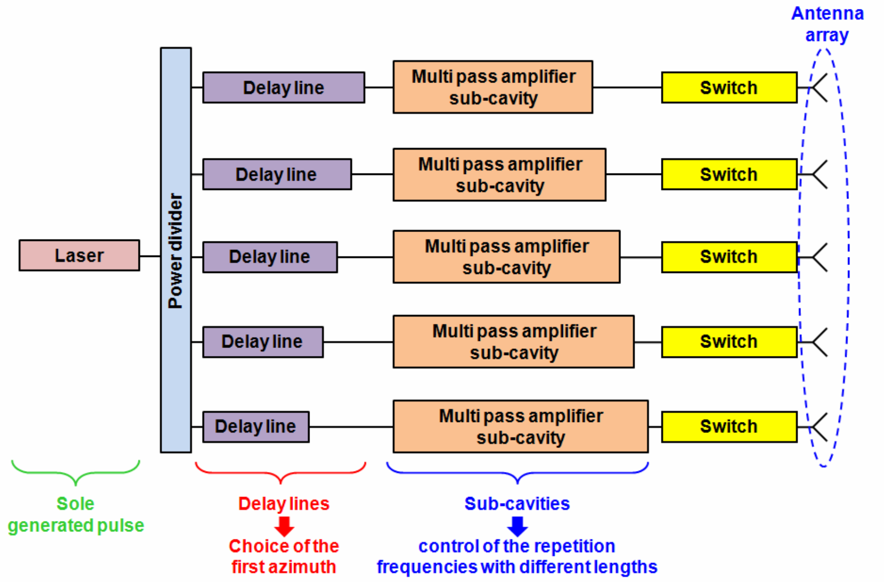

Figure 6. Implementation of the autonomous scan with different sub-cavities.

3. IMPLEMENTATION

Figure 6 presents the implementation of the optoelectronic device making possible the autonomous scan presented in Section 2. It is composed of four main parts:

- The initial optical pulse generation.
- Delay lines, controlling the first azimuth of emission of the antenna array.
- Sub-cavities, with different lengths, allowing the generation of asynchronous pulses trains.
- Optoelectronic switches, which are able to produce picosecond bipolar pulses.

The optical pulse produced by the laser source is divided in five sub-pulses with equal energy. With the use of delay lines, positioned before multipass amplifiers, the orientation of the first shot of the antenna array can be controlled. In our case it corresponds to the azimuth 0° (see Fig. 5). The change of the emission direction is driven by the sub-cavity length introducing a given time delay between the electrical pulses. Fig. 7 shows an example of the sub-cavity constitution, including an optical amplifier, an acousto-optic

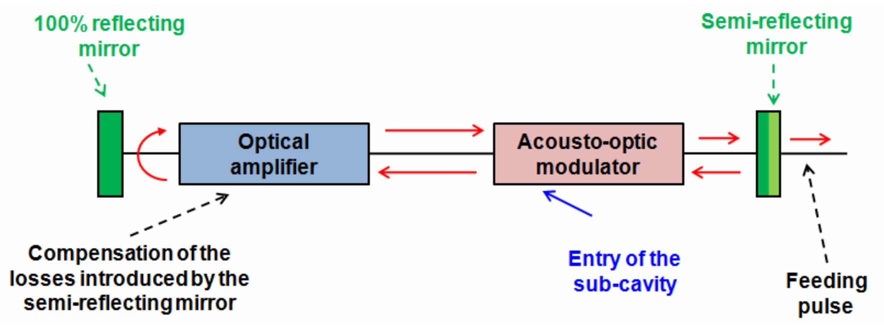

Figure 7. Multipass amplifier constitution.

modulator (AOM), and a semi-reflecting mirror, which delivers the useful power to the optoelectronic switch generating bipolar signals. The concept of these amplified delay lines is illustrated in [15, 16].

In a first step, a part of the initial pulse is introduced in the sub-cavity by means of the AOM placed in the "on" position. Then, the optical pulse is oscillating in the cavity where the AOM is switched in the "off" position. The optical pulse is successively depleted and amplified respectively by the reflection on the end cavity coupler and by propagating in the amplifier.

At the end, due to the semi-reflecting mirror, the initial optical pulse is transformed in a pulse train by recirculation in the multipass cavity. In order to obtain pulses with stable output peak power, the intracavity gain over one round trip in the sub-cavity have to remain below the unity.

The concept of the proposed sub-cavity was already experimentally demonstrated and largely published [15–17]. 1200 replica of an initial input picosecond pulse have already been obtained with peak power variation lower than 3% between two consecutive pulses [17].

Finally, thanks to the emission of a single optical pulse and its replication in several multipass amplifiers, it is possible to feed an antenna array with asynchronous electrical pulses trains.

Receiving system and detection algorithms have recently been developed to achieve imaging radar including this scanning system [18].

4. CONCLUSION

The original method presented in this paper is suitable for automatically scanning an area in a very short range of time (less than 1 ms) thanks to several shots in different directions. The principle of this method, which is very interesting for Radar applications, is based on the generation of asynchronous electrical pulses trains. The optical processing permits to easily manage the time delays between the pulses trains feeding the antennas. Additionally, the use of switching devices operating in linear regime guarantees the jitter minimisation between all electrical pulses.

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