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Microwave Transmission of Pressure Sensor Signal Through Explosive Fireballs

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***Abstract*—In this paper, we use microwaves for wirelessly transmitting the pressure signal delivered by sensors placed inside high explosive fireballs. It is demonstrated that the modulation of a microwave carrier frequency by pressure signal may be transmitted through fireballs without significant distortion, spectral filtering and attenuation of pressure signal. For experimental validation purpose, we show that the proposed wireless measurement of the pressure variation inside fireballs is in very good agreement with that obtained from a wired transmission, even if aluminized explosives create fireballs.**

***Keywords*— Microwave transmission through fireball – Pressure sensors – High explosives – Blast pressure measurement**

I. Introduction

Nowadays, the measurement of blast pressure generated by a controlled high explosive detonation requires long cables between pressure sensors and the acquisition unit (see, e.g., [1]). For safety reasons, few tens meters separate usually this unit from explosive charges. However, the long-term functionality of connectors and long cables used in these wired systems is not guaranteed, due to harsh experimental conditions, such as, high temperatures and strong vibrations. Wireless systems could be an advantageous alternative for transmitting sensor signals to the acquisition unit [2, 3]. However, the transmission of electromagnetic waves through high explosive (HE) fireballs may involve undesirable –but poorly documented– signal distortion, filtering and/or attenuation (see, e.g., [4, 5] for the study of electromagnetic wave propagation through fires). If the center of quasi-spherical HE fireballs is modeled by a plasma with electron density of about $10^{17}\ cm^{-3}$ [6], the plasma cutoff frequency is of few terahertz and, as the distance from the fireball center increases, this density (and accordingly, the plasma cutoff frequency) sharply decreases. Consequently, electromagnetic waves may be used for transmitting the signal delivered from sensors located inside a fireball, but far enough from the fireball center.

In this paper, we demonstrate that pressure sensor signal used for frequency-modulating a microwave carrier frequency of 4 GHz or 5 GHz can be transmitted through the HE fireball without distortion, spectral filtering and attenuation.

II. Wireless System Architecture for Microwave Transmission Through Explosive Fireballs

In this study, the wireless transmission through HE fireball of pressure sensor signal is based on the analog Frequency Modulation (FM) of a microwave carrier frequency [2]. In the transmission (Tx) unit, the HMC 358 Voltage Controlled Oscillator (VCO) is used to convert the signal variations at the output of the piezoelectric PCB 113A34 sensor into a frequency deviation of the microwave carrier frequency of 4 GHz or 5 GHz. The resulting analog FM signal is radiated by a half-wave dipole in the HE fireball. The transmitted power of the Tx-unit is of 4 dBm. The radiated FM microwave signal reaches the receiving horn antenna (16 dBi of gain) of the acquisition unit (Rx-unit). The received signal is next amplified, low-pass filtered for suppressing aliasing spectrum effect and sampled by using the digital oscilloscope Keysight DSOV164A. The variation of the instantaneous microwave frequency embedded in the received FM signal is then derived from Fast Fourier Transform. This variation allows estimating the pressure variations inside the fireball by post-processing from the knowledge of the VCO characteristics and sensitivity of the sensor. The Tx-unit and Rx-unit of the wireless setup used for the experiment are shown in Figure 1.

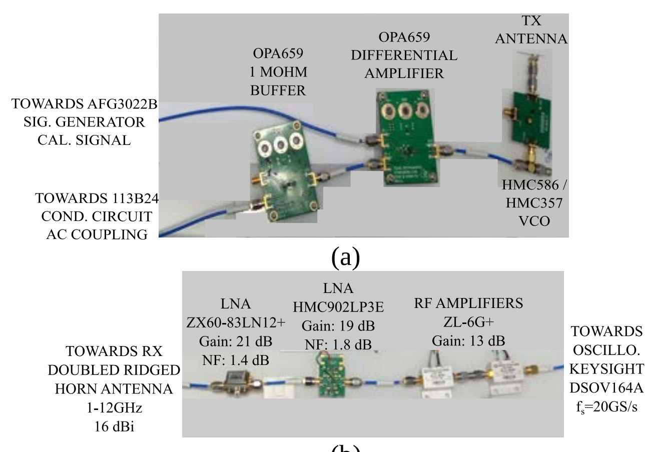

Fig. 1: Scattered views of (a) the Tx-unit and (b) Rx-unit (b) used for investigating the transmission through HE fireballs of a microwave carrier frequency of 4 GHz or 5 GHz frequency-modulated by the pressure sensor signal.

The wireless setup is installed on a platform used for studying structure vulnerability and explosive detonation (see Figure 2). PCB 113A34 piezoelectric pressure sensors in side-on configuration are deployed around a spherical HE charge. For comparison purpose, both the wireless and wired transmission of pressure signal delivered by two sensors located at equal distance of 0.5 m from the charge. To prevent from interaction with the shockwave generated by the explosion, the VCO and Tx-antenna are placed at 0.8 m from the charge. Moreover, in order to protect the electronic devices and half-wave dipole antenna of the Tx-unit from eventual damage caused by ionized gases and/or high temperatures, a robust dielectric Acrylonitrile Butadiene Styrene (ABS) package (transparent to microwaves) has been used. Each detonation experiment is recorded using ultra-fast cameras in order to estimate, in particular, the time at which the sensors are inside the fireball.

Fig 2 Plateform used here for investigating the transmission through HE fireballs of two microwave FM carrier frequencies of 4 Ghz and 5 Ghz. The HE charge (1) is placed at 0.5 m from the pressure sensor (3). The VCO and the half-wave dipole antenna are protected by a dielectric package (2) and are located at 0.8 m from the center of the charge. The horn Rx-antenna (4) is placed at 20 m from the Tx-unit and the HE charge (5).

III. Experimental Results and Discussion

Figure 3 displays the variation of pressure signal measured during a controlled ignition of aluminized TriNiTrotoluene (TNT) explosive of 2 kg. This signal has been derived in the Rx-unit from the digital demodulation of the received microwave carrier frequency of 4 GHz or 5 GHz, which was modulated in the Tx-unit by the pressure signal delivered by sensors. For comparison purpose, the measurement results obtained from the wired transmission of the based-band sensor signal is also reported in Figure 3. The proposed wireless measurement of the pressure variation inside fireballs is in very good agreement with that obtained from a wired transmission. As expected, at the shock wave front, the pressure reaches quasi-instantaneously a pressure peak and then, it decays back to ambient pressure (After this phase, the pressure may be lower than the ambient pressure during the so-called *negative phase*). To determine the pressure peak (and accordingly, the TNT equivalent of the explosive charge), the post-processing of Figure 3 can be performed (see, e.g., as described in [6]). From the analysis of images provided by the ultra-fast cameras, it can be concluded that the VCO device is immerged in the fireball about 200 µs after the shockwave front arrival on the sensor located at distance of 0.5 m from the explosive charge. Some spikes are detected in the measured pressure derived from the microwave transmission through the fireball, which are probably due to the interaction of fireball with VCO connecters that are not protected by the ABS package. As the microwave transmission is achieved here through the fireball at 4 GHz, the electron density is estimated to be lower than $10^{11}\ cm^{-3}$ at 0.8 m from the center of the (aluminized or non-aluminized) explosive charges. It can be also concluded that the VCO device seems to not suffer from the harsh conditions imposed by HE fireballs and, good functionality is found to be ensured during at least 1 ms when the device is inside the fireball.

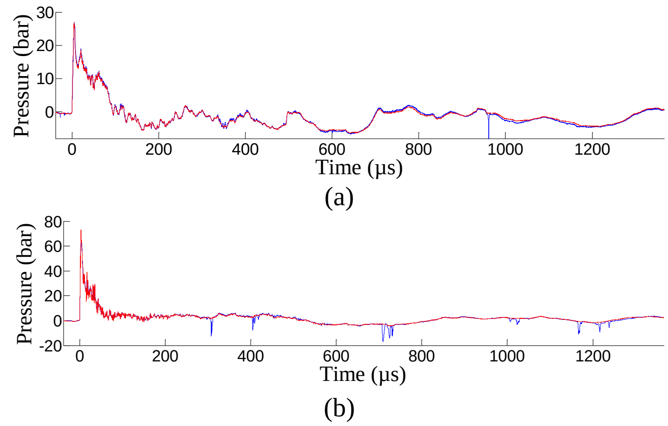

Fig 3 Pressure signal (in blue) measured during the controlled ignition of : (a) a non-aluminized HMX-Viton explosive of 600 g and derived from the transmission through the fireball of the frequency-modulated microwave carrier frequency of 4 GHz; and (b) an aluminized TNT explosive of 2 kg and derived from the transmission through the fireball of the frequency-modulated microwave carrier frequency of 5 GHz (in blue). In Fig. 3(a) and Fig. 3(b), the red curve displays the variation of the signal measured from the wired transmission of the base-band pressure sensor signal.

IV. Conclusion

We demonstrated in this paper that pressure sensor signal used for frequency modulating a microwave carrier frequency of 4 GHz or 5 GHz can be transmitted through the HE fireball. Ongoing works are focused on the long-range microwave transmission of ultrafast pressure signal during very high explosive detonations.

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