Microwave field influence on the EMI 9656B photomultiplier tubes and NaI(Tl) crystal scintillator

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We tested the influence of microwave field on a cosmic ray detector which consist of a photomultiplier tube (PMT) type EMI 9656B and a NaI(Tl) crystal scintillator. We investigated the PMT output signal when the PMT is optically coupled with NaI(Tl) crystal scintillator and when the PMT is separate of NaI(Tl) crystal scintillator. We found that the PMT generates output signal to PMT anode when is exposed to a microwave field. When the PMT is optically coupled with NaI(Tl) crystal scintillator the PMT anode amplitude increases. As microwave source we used a commercial magnetron, which emits 2.45 GHz frequency with 800W microwave power and a cylindrical waveguide having TM_{011} propagation mode.

1. Introduction

The photomultiplier tubes (PMT) are among the most widely used types of transducers for detecting ultraviolet, visible and near-infrared ranges radiation. For applications of detection of the ionizing radiation a PMT optically coupled with a scintillator is used. Currently NaI(Tl) crystal scintillator is used in many fields for detecting x-ray and gamma-ray.

Is well known that the output signal of the PMT is very sensitive to the external magnetic field [1, 2, 3, 4]. Studies about interference of electromagnetic field on the medical devices like SPEC gamma camera during scanning process showed a mobile phone would be an electromagnetic field source disturbing normal function of gamma camera [5]. The electromagnetic fields would influence the PMT output signal because the electromagnetic field generates electric charges on the surfaces of metals. Since all PMT components (dynodes, focusing electrode, PMT anode) are made from metallic conductors in this work we are looking to see if the microwave field could by influence the signal output of the PMT anode. Presently it is known that metallic powders are heated by microwave field. In metallic powder the microwave absorption mechanism is characterized only by ohmic loss [6, 7]. Also the metallic wires can be vaporized and ionized by a microwave field [11, 12, 13, 14, 16]. In this work is investigated influence of the non-ionizing radiation like microwaves on a cosmic ray detector which consist of a EMI 9656B PMT and a NaI(Tl) crystal scintillator. We tested when the PMT is optically coupled with NaI(Tl) crystal scintillator and when the PMT is separate of NaI(Tl) crystal scintillator. To separate the PMT of NaI(Tl) crystal scintillator we removed the scintillator from PMT housing. The EMI 9656B PMT has a 50 mm diameter with spectral coverage of about 300 nm – 650 nm. The maximum sensitivity of EMI 9656B PMT is located at about 400 nm. The NaI(Tl)

crystal scintillator is the most widely used scintillator material in many applications to detect ionizing radiation like X ray, gamma radiation, cosmic rays. The scintillation emission spectrum of NaI(Tl) have the spectral coverage of about 350 nm – 600 nm with 415 nm maximum wavelength emission.

2. Experimental chain calibration

To see how the cosmic radiation detector interacts with the microwave field, first we obtained the cosmic ray detector response to cosmic radiation and then we characterized the microwave waveform from microwave generator. Cosmic rays are protons and atomic nuclei that travel through space at speeds close to that of light and have the highest energies observed in nature.

2.1. Calibration of the cosmic detector

Scintillator detectors with PMT tube are among the most important detectors used for many cosmic ray and high energy physics experiments. A cosmic rays detector consists of a PMT tube optically coupled with a NaI(Tl) scintillator and an amplifier electronic module (Fig. 1). When the cosmic ray interacts with NaI(Tl) crystal scintillator, the crystal scintillator converts the energy lost by ionizing radiation into pulses of light.
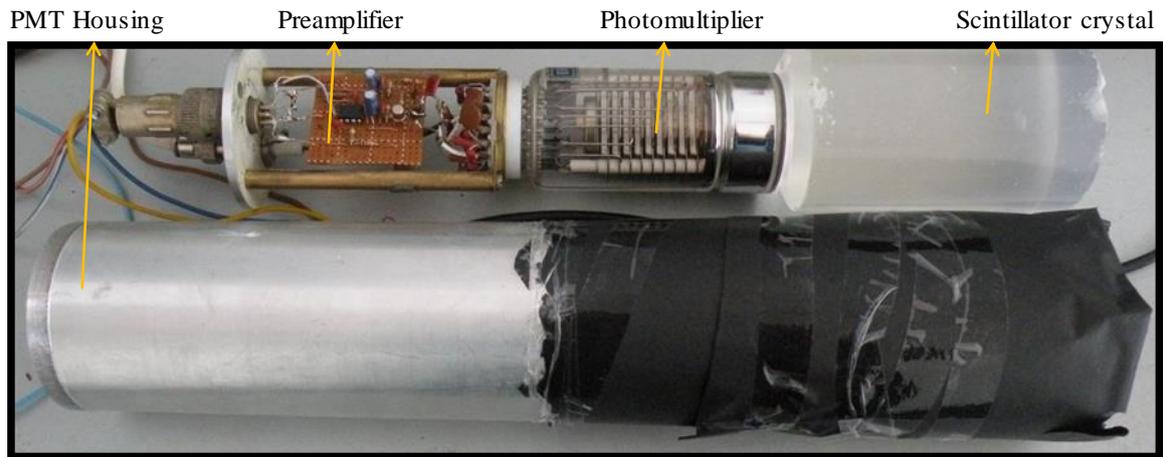
PMT Housing   Preamplifier   Photomultiplier   Scintillator crystal

Fig. 1. Image of typical cosmic rays detector

Pulses of light emitted by scintillating material are detected by PMT and converted in electrical signal (Fig. 2). The signal output of the PMT anode is amplified by the amplifier electronic module (charge sensitive preamplifier) (Fig. 3).
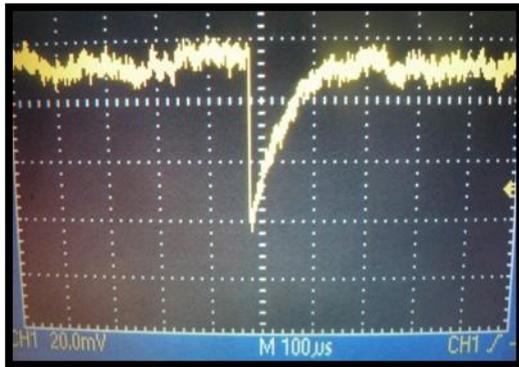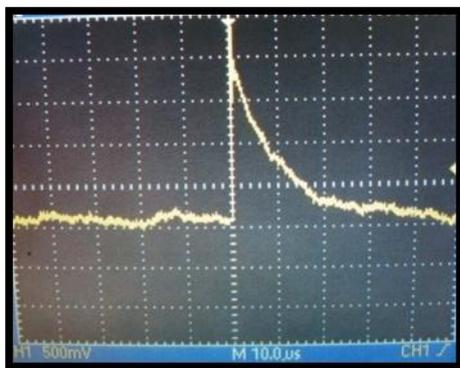

Fig. 2. Pulse shape of output PMT anode

Fig. 3. Pulse shape of preamplifier

2.2. Calibration of the microwave generator

The microwave generator contain a commercially available magnetron type 2M214 which generates a microwave field at 2.45 GHz frequency and 800W microwave power with 50 Hz repetition rate, a power supply and a TM_{011} air–filled cylindrical waveguide Fig. 4.
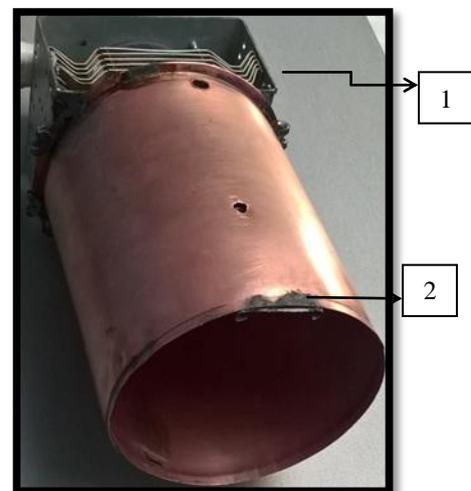

Fig. 4. Image of microwave generator: a) magnetron; b) cylindrical waveguide

In cylindrical waveguide having TM_{011} propagation mode the microwaves electric field propagates along the axis of the cylindrical waveguide as sketch in Fig. 5.
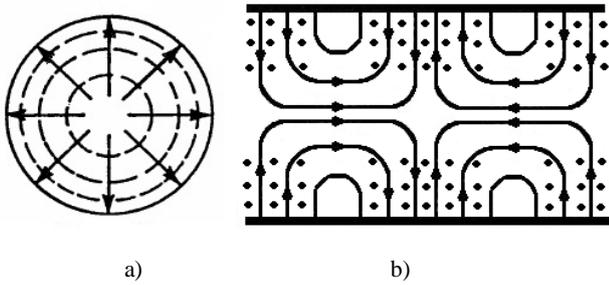
a)   b)

Fig. 5. Field distribution of TM_{01} mode in the cylindrical waveguide: a) Cross-Sectional view; b) Longitudinal view E- full lines; H- dashed lines

In order to obtain the dimensions of the cylindrical waveguide we used equation (1) for 10 cm long metallic tube with a diameter of 10.5 cm:

$$(f_r)^{TM}_{mnl} = \left(\frac{1}{2 \cdot \pi \cdot \sqrt{\mu \cdot \varepsilon}} \right) \cdot \sqrt{\left(\frac{p_{01}}{a} \right)^2 + \left(\frac{l \cdot \pi}{h} \right)^2} \quad (1)$$

where:

a - radius of the cylindrical waveguide (m); h - height of the cylindrical waveguide (m);

l - longitudinal mode of the cavity; μ - permeability of the medium within cavity (H/m);

ε - permittivity of the medium within cavity (F/m); p_{01} - first zero of the Bessel function, (equal to approx. 2.405); f_r – the resonant frequency of the waveguide.

The indices *nml* of the *TM* mode propagation is referred to the number of half wavelength variations in the radial, axial and longitudinal directions The microwave power in the cylindrical waveguide is given of Poyting equation (2) [15].

$$\vec{P} = \vec{E} \times \vec{H} = \frac{|E|^2}{\eta} \quad (2)$$

where:

η is the impedance of medium, for air η= 377Ω; E is the electric field; H is the magnetic field.

To calibrate the microwave generator within the cylindrical waveguide we placed an inductor able to measure the microwave field waveform. In Fig. 6 are shown the oscillograms recorded by oscilloscope that are the supply voltage waveform of the magnetron and the microwave field waveform within the cylindrical waveguide. On the channel 1 of the oscilloscope is measured the voltage applied on magnetron (Yellow oscillogram) and on the channel 2 (Blue oscillogram) the voltage waveform from the inductor.

Fig. 6. Yellow oscillogram- supply voltage waveform of the magnetron. Blue oscillogram- the microwave field waveform inside of the cylindrical waveguide

3. Experimental setup

In order to investigate the influence of the microwave field on a PMT optically coupled with NaI(Tl) crystal scintillator and when the PMT is separate of NaI(Tl) crystal scintillator we exposed the cosmic ray detector to 2,45 GHz electromagnetic radiation. The PMT was biased to -950V. The wavelength of microwave field emitted by magnetron is about 12.2 cm. NaI(Tl) crystal scintillator has a 6.7 cm diameter and 12 cm length. The cosmic rays detector is located at distance of 122.2 cm from magnetron antenna which corresponds about ten successive microwave wavelengths (Fig. 7).
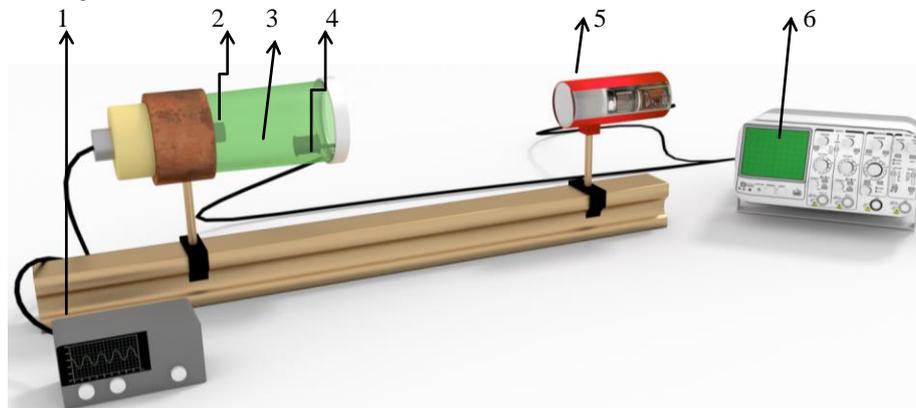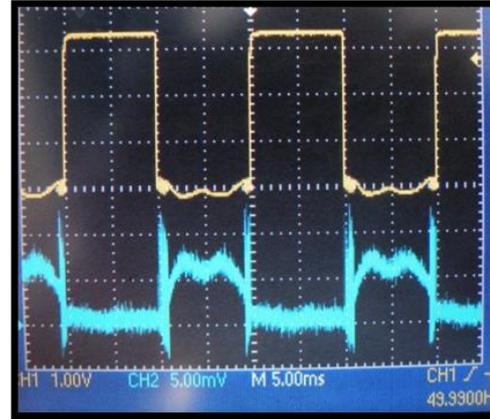

Fig. 7. Sketch of the experimental setup: 1-microwave generator power supply; 2- magnetron antenna; 3- cylindrical waveguide; 4-inductor; 5-cosmic rays detector; 6- oscilloscope

According to formula (3) in free space the electromagnetic field is attenuated.

$$\alpha = \sqrt{\pi \cdot f \cdot \mu \cdot \sigma} \qquad (3)$$

where: α – attenuation factor; f – electromagnetic field frequency; µ – permeability of free space; σ – conductivity of free space.

The distance between the microwave source and cosmic ray detector was selected to avoid damaging the PMT cosmic ray detector due to a high microwave power.

4. Experimental results

4.1. Influence of microwave field on cosmic ray detector when the PMT is optically coupled with NaI(Tl) crystal scintillator

When the microwave field is applied on the cosmic rays detector (PMT optically coupled with NaI(Tl) crystal scintillator and charge sensitive preamplifier), the microwave electric field generates electric charges on PMT components.

The cosmic rays detector will record a signal only if the scintillator and PMT window are incident on antinode of microwave wavelength. When the cosmic rays detector is rotated with 90 degree with respect to microwave generator the signal of the cosmic rays detector decreased. In Fig. 8 is showed the signal output of the PMT anode when the cosmic rays detector is find to 0 degree with respect to microwave generator.
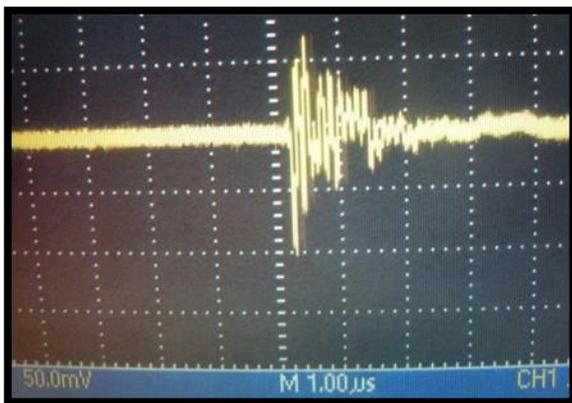

Fig. 8. PMT output signal with scintillator at 0^0

In Fig. 9 is showed the signal output of charge sensitive preamplifier to 0 degree with respect to microwave generator and in Fig. 10 is showed the signal output of charge sensitive preamplifier to 90 degree with respect to microwave generator.
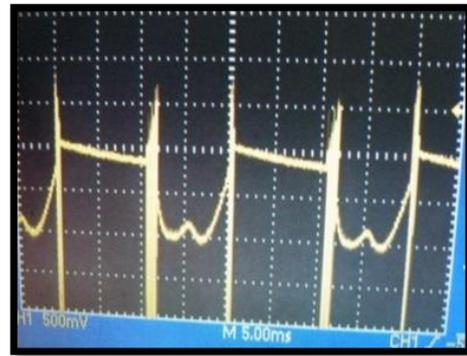

Fig. 9. The signal output of charge sensitive preamplifier with scintillator to 0^0
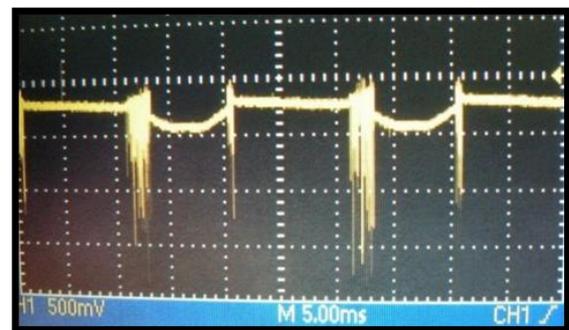

Fig. 10. The signal output of charge sensitive preamplifier with scintillator to 90^0

4.2. Influence of microwave field on cosmic ray detector when the PMT is separate of NaI(Tl) crystal scintillator

When the NaI(Tl) crystal scintillator is removed from PMT housing and is applied a microwave field on cosmic ray detector the signal from PMT anode decreased.

In Fig. 11 is showed the signal output of charge sensitive preamplifier to 0 degree with respect to microwave generator and in Fig. 12 is showed the signal output of charge sensitive preamplifier to 90 degree with respect to microwave generator.
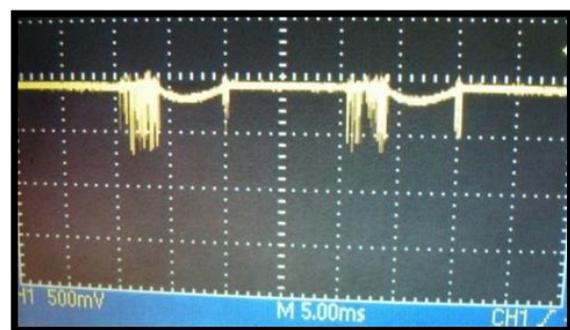

Fig. 11. The signal output of charge sensitive preamplifier without scintillator and positioned at 0^0
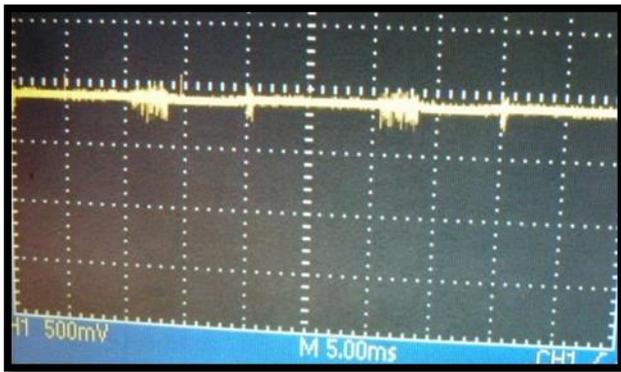
Fig. 12. The signal output of charge sensitive preamplifier without scintillator and positioned at 90^0

5. Discussion

To investigate the behavior of the scintillator in interaction with the microwave field we introduced a black paper between the crystal scintillator and PMT. When the microwave field was applied on cosmic ray detector, the PMT anode output had a large amplitude signal as that shown in Fig. 9.

We concluded that the crystal scintillator does not emit pulses of light in interaction with the microwave field. In configuration PMT coupled with crystal scintillator the PMT housing acts as a waveguide filled with dielectric material.

The PMT housing waveguide with dielectric material (NaI(Tl) crystal scintillator) is resonating on microwave field frequency of microwave generator focusing the microwave energy on PMT.

When the PMT housing is close to both end and is exposed to microwave field the PMT anode does not record signals. The PMT housing is made of aluminum and acts like electromagnetic shielding to block the microwave field to protect PMT and amplifier electronic module.

Is known from Maxwell equation that the metals are generating electric current when is exposed to electromagnetic radiation.

In TM_{011} cylindrical waveguide the microwaves electric field propagates along the axis of the cylindrical waveguide. The PMT components (dynodes, focusing electrode, PMT anode) are made from metallic conductors.

The microwave electric field generates electric charges on the surfaces of metals. The relationship between microwave electric field and current density (conduction and displacement current) is: $\vec{J} = (\sigma + j\omega\varepsilon)\vec{E}$ (4).

According to equation (2) the microwave electric field depends of microwave power. So when the microwave power is changed the current density from PMT components will also be changed.

6. Conclusions

- When a PMT is exposed to a microwave field, the microwave electric field will disturb normal functionality of the PMT.
- The crystal scintillator does not emit pulses of light in interaction with the microwave field.
- The PMT housing act as a waveguide filled with crystal scintillator and is resonating at microwave field frequency of microwave generator focusing the microwave energy on PMT.

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