Kamil FILIK, Grzegorz MASŁOWSKI, Grzegorz KARNAS, Paweł SZCZUPAK, Lesław KARPIŃSKI, Robert ZIEMBA, Stanisław WYDERKA

Rzeszow University of Technology

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Applications of impulse current and voltage generators dedicated to lightning tests of avionics

***Abstract**. The paper describes selected studies in the field of lightning and their effects carried out over the years at the Rzeszow University of Technology, which used modular impulse generators MIG0618SS and MIG0600MS. This apparatus dedicated to testing of avionics to induced lightning transients in accordance with DO-160 standard has also proved useful for other applications. The analysis of the previous research was done in terms of the applied solutions of test experimental setups and the parameters and configurations of the impulse generators.*

***Streszczenie.** Artykuł przedstawia wybrane badania w obszarze oddziaływań wyładowań atmosferycznych, w których wykorzystano modułowe generatory udarów prądowych i napięciowych, służące do prób odporności awioniki na wtórne efekty wyładowań atmosferycznych. Skupiono się głównie na przedstawieniu dotychczasowych badań pod kątem zastosowanych rozwiązań konfiguracyjnych oraz zadanych parametrów udarów. (**Wybrane badania w obszarze ochrony odgromowej i przepięciowej z wykorzystaniem generatorów udarów piorunowych przeznaczonych do badań awioniki**).*

Keywords: lightning, lightning effects, experimental studies, modular impulse generator.
Słowa kluczowe: wyładowania atmosferyczne, oddziaływania piorunowe, badania eksperymentalne, generator udarów piorunowych.

Introduction

Generators of voltage and current transients are used for many years in experimental research related to the phenomenon of lightning [1,2]. They can be used to reproduce direct and indirect effects of lightning, which are observed in terrestrial objects and those above the surface of the earth. One of such studies is based on simulating an indirect impact of lightning discharge using a dedicated set of generators. This type of apparatus is used in the Laboratory of Lightning Test of Avionics at the Rzeszow University of Technology (RUT). It turns out that thanks to its construction and properties it is also suitable for other applications in the lightning research. In addition to analyzing overvoltages in the onboard systems of aircraft [3], other examples of application of modular impulse generators will be provided below.

Modular impulse generators

The MIG0618SS and MIG0600MS modular impulse generators are designed to carry out tests of avionics susceptibility to lightning induced transients [4,5]. Discharge modules are the basic units of these generators (see Fig. 1 and Fig. 2b). They can be configured in series or parallel to offer an optimum solution. One module includes high voltage capacitor, power-electronic switches, the trigger and polarity reversal circuits and a part of the impulse shaping circuit. Depending on the selected shape, level and number of generated strokes the number of modules and impulse forming networks changes as shown for example in Fig. 1. Single stroke idealized waveforms from MIG0618SS are used for damage assessment tests on equipment, whereas multiple strokes from MIG0600MS are applied for EMC tests on avionics. Fig. 2a shows a view of these generators situated on the test stand. Three different shapes of current or voltage: 6.4/70 μs, 40/120 μs and 50/500 μs can be coupled in three ways to the tested system by direct injection to selected pins, by injection between equipment under test (EUT) chassis and main ground plane or by induction in cable bundles. In this way, the output impedance of generator is determined.

Both generators have similar construction. The most important elements (among others control panel, HV operation panel, voltage and current measurement CRO outputs) are located on the front panel. The control of MIGs is carried out by a microprocessor with remote control option. All this ensures high reliability, generation of reproducible lightning transients and simple of operation.

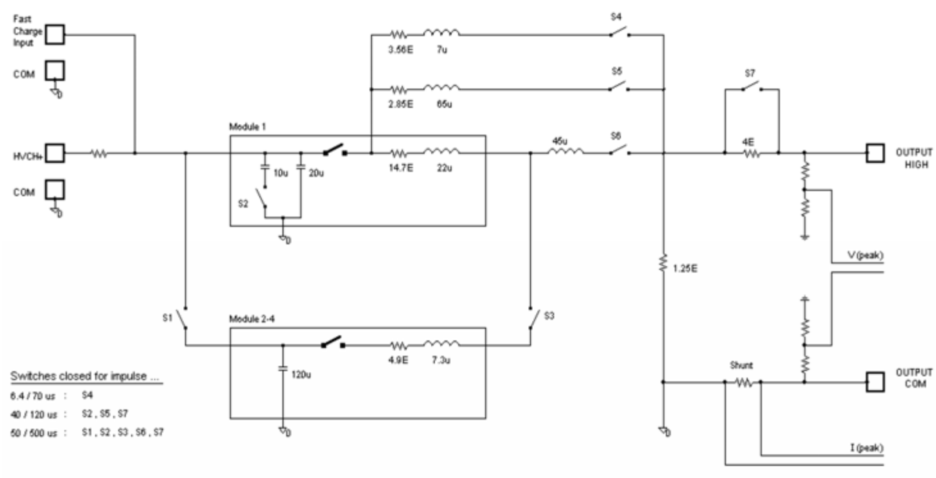


Fig.1. Simplified block diagram of high voltage part of MIG0600MS generator [5].

a) b)

Fig.2. a) Generators: MIG0618SS (on the left) and MIG0600MS (on the right); b) High voltage module of MIG generator.

Examination of windings surge impedances of distribution transformer

The frequency characteristics of input impedance of supplying MV/LV transformer were determined in order to estimate the risk of overvoltage hazard in case of lightning discharge. It was described in more detail in [6]. Precise results for wide frequency range were obtained using measuring system with LCR meter. An alternative method was to use modular impulse generator MIG0618SS, the output of which was directly connected to selected winding terminals of the transformer (see Fig. 3). Tests were performed for different shapes and levels of generated strokes. Voltage and current in the tested circuit were measured simultaneously in time domain.

The results for one of the measurement variants are shown in Fig. 4. The output impedance of MIG0618SS generator was 5 Ω. The applied voltage surge had the 6.4/70 μs shape (6.4 μs from zero to top value and 70 μs from the top to its half value) and the level equal 1 kV for open circuit condition. The magnitude and phase of transformer surge impedance measured between L1 and L2 phase terminals at the low voltage side were calculated on the basis of recorded voltage and current signals. Terminals at high voltage side were shorted together to the ground.

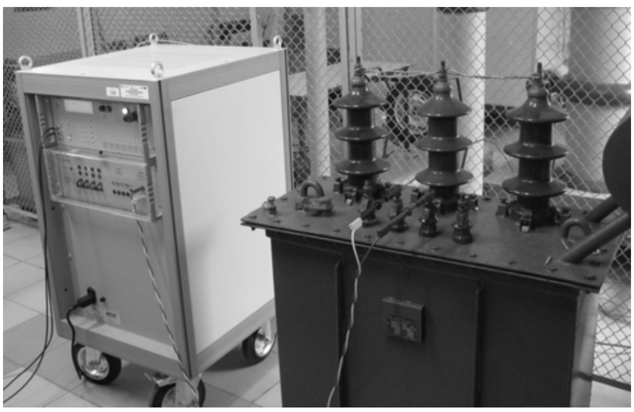


Fig.3. View of 3-phase 15 kV/0.4 kV distribution transformer and connected MIG0618SS surge generator.

a)

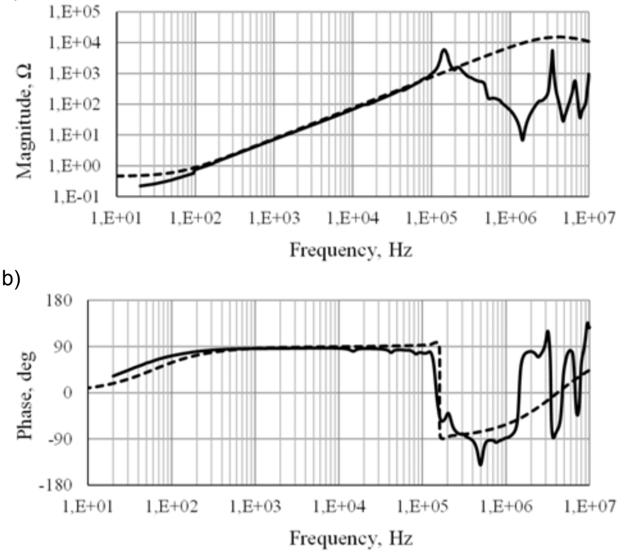


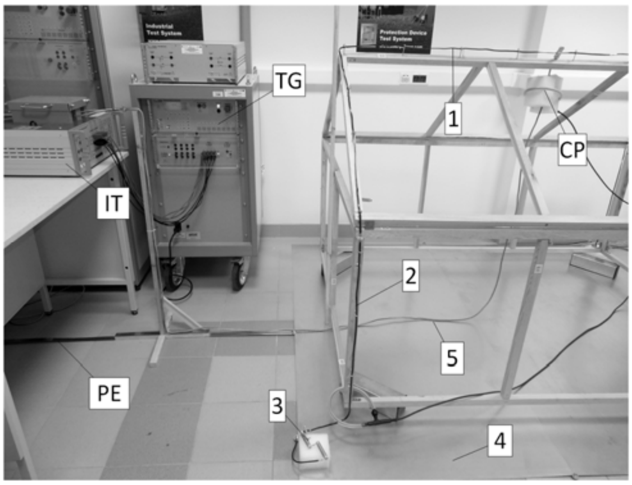
Fig.4. Frequency characteristics of input impedance of supplying transformer, measured with LCR meter (solid line) and surge generator (dashed line) between phase terminals of LV side, HV terminals were shorted: magnitude value (a) and phase (b) of LV windings.

The characteristics obtained in the range up to 100 kHz with the use of surge generator are quite close to those measured with the LCR meter. This frequency range depends on the maximum value and the shape of used strokes. In some cases this will be sufficient. An important advantage of such a solution is the significant time savings needed to achieve the result compared to the LCR bridge measurement.

Simulation of current distribution in the laboratory model of lightning protection system

Lightning strike into a building equipped with lightning protection system (LPS) causes the current to flow in the components of this installation and unfortunately also in the connected power and media installations. Experimental and computer-based research of lightning current distribution in the LPS and in the electrical installation were conducted by several research centers in the world [7]. During the many years of research conducted at the RUT, the tested object has been exposed to the lightning currents simulated by current surge generators. On the basis of the full scale test system at the test site in Huta Poręby, Poland, a laboratory model in a scale of 1:5 was prepared to assess its suitability for studies of impulse current distribution. The examined object was presented in detail in [8]. The results of lightning current distribution in the laboratory model and the comparison with the research results obtained at the open air test sites in Florida and Poland were also presented. The previously described MIG0618SS generator has been used during laboratory experiments. The publication [8] does not show all configuration of the measurement setup. Tested system was a wired model of LPS attached to a wooden frame of building object. System was grounded by terminating to the metal ground plane with use of power resistors (see Fig. 5a). Current impulses were coupled to the LPS model in the middle of horizontal conductor (1) at the top of the system. Two methods of coupling the generated surges to the object were applied. There was both a direct connection of generator (TG) output with injection points (between ground plane and center of horizontal conductor) and with the use of injection transformer (IT), where its secondary circuit was connected to the same injection points in the LPS. An important aspect was the route of the impulse leading conductor (5). This has affected the inductance reducing the injected current. Two paths have been selected. Routing the injection conductor to injection point from the bottom, as long as possible close to the ground and grounded return bar, as in Fig. 5a, results in a smaller loop area. Fig. 5b shows the case of routing the injection wire from the top. Fig. 6 shows the current waveforms at injection point. They are recorded for maximum obtained levels of generated transients for different configurations taking into account the route of the impulse leading conductor, the coupling method, the output impedance of generator and the selected impulse shaping circuit. The applied shapes 6.4/70 µs and 40/120 µs of generated voltage or current have such values only for open circuit or short circuit condition. Table I describes different variants of the test setup for which the injected currents are as shown in Fig 6. The resulting impedance of the wires and the examined object changed the rise and fall time of current observed at the injection point.

a)



b)

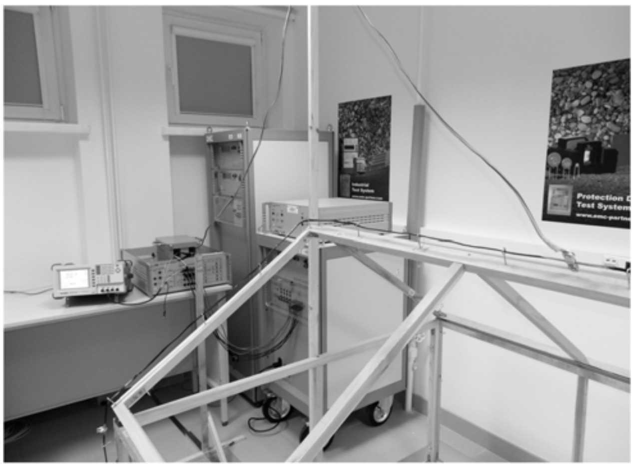


Fig.5. The measurement system. a) injection conductor connected from the bottom: 1 – horizontal conductor, 2 – down conductor, 3 – power resistor, 4 – metal ground plane connected to PE terminal, 5 – impulse current leading conductor, TG – surge generator MIG0618SS, IT – injection transformer, CP – current probe. b) injection conductor connected from the top.

It also affected the maximum value of current. In order to achieve higher maximum values of input current, the method of direct connection of the test object with the MIG generator should be selected (variants B and D). In turn, to obtain relatively short rise times, it is worthwhile to coupling the surge through the injection transformer (variants A and C). By comparing waveforms for case C and E, the negative effect of loop inductance can be observed.

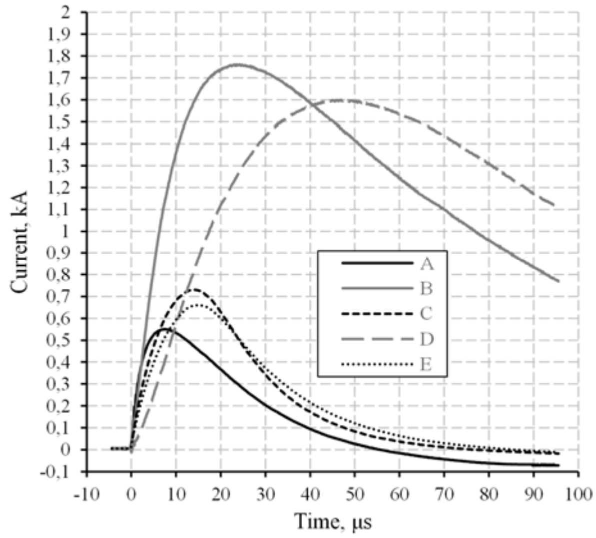


Fig.6. Comparison of current waveforms at injection point for different variants of the test setup.

Table 1. Variants of the test setup

Variant	Routing of Injection Wire	Waveform[a]	Coupling Method
A	Bottom	6.4/70 µs	Cable Induction
B			Direct Injection
C		40/120 µs	Cable Induction
D			Direct Injection
E	Top		Cable Induction

Calibration of electric field antenna

Another example of lightning-related research with using the MIG surge generator was the calibration of fast electric field antenna. This procedure was described in [9]. In order to determine the static gain coefficient of the electric field sensors it was placed in a known electric field. The electric field was produced between two aluminium 4 m2 plates by applying the surge voltage from the MIG0618SS generator (see Fig. 7). The capacitor plates attached to wooden structure were horizontally arranged and spaced 1 m apart. The antenna was set in the middle of the bottom plate.

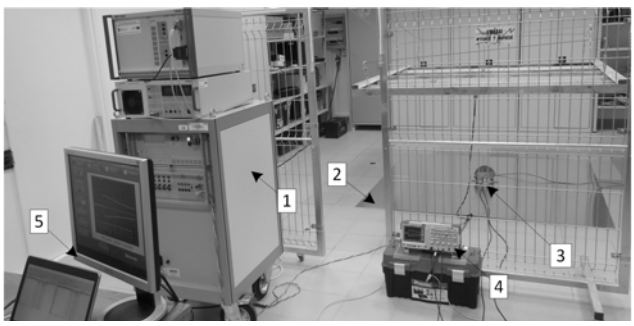
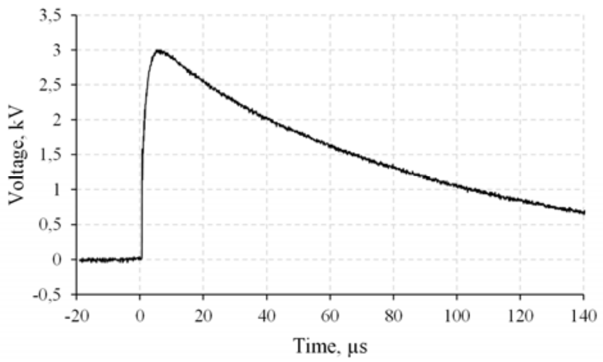


Fig.7. The antenna calibration setup: 1 – modular impulse generator, 2 – flat 4 m2 metal plate, 3 – ELF-MF antenna, 4 – oscilloscope, 5 – system control.

It was connected both to the power supply and to the oscilloscope by dedicated wires. To produce an electric field the voltage waveform WF4 6.4/70 µs was selected, because its rise and fall time is similar to the signals recorded by the calibrated sensor during storms. The peak value of the voltage surge was changed up to 3 kilo volts.

Measurements were made for different antenna configurations. Signal was recorded on the all of four output circuits of the equipment under test. The influence of both, the length of the signal coaxial cables from the antenna to the oscilloscope and the method of terminating the ends of this lines, was investigated. Fig. 8a shows the record of forcing signal while Fig. 8b presents recorded signal of antenna response. This is an example of registration for one of the measurement setup. The voltage transient applied to the plates of capacitor had the peak value of 3 kV and the shape almost exactly 6.4/70 μs. The signal from one of the antenna outputs shown in Fig. 8b was recorded at the end of the 10 m long coaxial cable connecting the device with the oscilloscope. The signal line was terminated at the end on the side of oscilloscope with 50 Ω resistor. The output signal of the antenna reflects very well the nature of the voltage changes between the capacitor plates. The changes on the rising slope in the form of oscillation are noticeable. They could have been caused by electrical field disturbances that coupled to the signal line. The static gain coefficient obtained for this described configuration equals 2.906 V/kV/m.

a)



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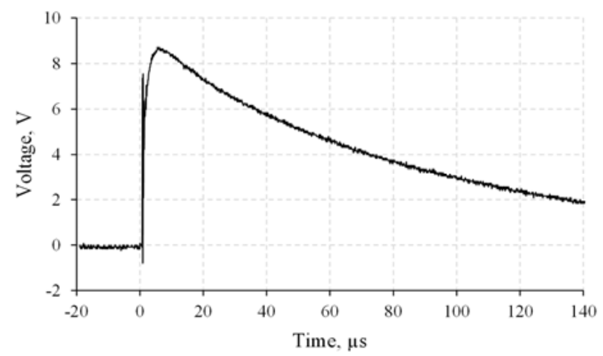

Fig.7. The voltage signals recorded during the test of antenna for one of configuration variant. a) surge voltage transient from MIG0618 generator. b) voltage waveform from one of antenna outputs at the end of 10 meter terminated coaxial cable.

The MIG0618SS generator proved to be very useful in the entire calibration process of all the antennae working in the Lightning Research Station at the RUT, because the same tests with the same levels and shapes of injected voltages could be performed for each device separately. The advantage of the generator was the reproducibility and quality of the generated waveforms.

Conclusion

The modular impulse generators were presented, which were used for lightning research at the Rzeszow University of Technology. They are dedicated to indirect lightning tests of avionics. Due to its properties, this apparatus was able to successfully carry out research of a different nature. Examples of such use were shown, focusing mainly on the parameters and configuration of generators in test setups. Thanks to the knowledge of the behavior of surge generators in specific applications, we can find an application for them in future research. It is planned to measure the frequency characteristics of the impedance of vertical grounding rods in the LPS of the test house located at the open air test site in the village of Huta Poręby near Rzeszów.

***Authors**: mgr inż. Kamil Filik; dr hab. inż. Grzegorz Masłowski, prof. PRz; mgr inż. Grzegorz Karnas; mgr inż. Paweł Szczupak; dr hab. inż. Lesław Karpiński, prof. PRz; dr inż. Robert Ziemba; dr hab. inż. Stanisław Wyderka, prof. PRz; Politechnika Rzeszowska, Wydział Elektrotechniki i Informatyki, Katedra Elektrotechniki i Podstaw Informatyki, ul. W. Pola 2, 35-959 Rzeszów, E-mail: kfilik@prz.edu.pl.*

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