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Renewal of Middle Wave Transmitters in Slovak Republic*

R. Hartansky, Ing., PhD, Professor, Institute of Electrical Engineering, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, Slovakia
J. Hallon, Ing., PhD, Research worker, Institute of Electrical Engineering, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, Slovakia
J. Krchnak, Ing., PhD Student, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, Slovakia
M. Dzuris, BSc, Research worker, MWTC, ltd., Trencianska Tepla, Slovakia

This paper deals with the replacement of middle wave transmitters in Slovak Republic. The original transmitters were based on class C vacuum tube fundamentals and were produced by the Czechoslovakian group company Tesla. Class C transmitters were transmitting reliably to this day, however, the lifespan of these transmitters was nearing its end, moreover the need for a better quality analog modulated signal has pushed for its replacement and therefore they were replaced by modern, highly efficient class D transmitters, while utilizing the original infrastructure consisting of antennas and power inputs. Due to differences in characteristic parameters, however minor, this caused some significant problems, with impedance matching. To resolve these problems, it was necessary to implement a newly designed IMU (Impedance Matching Unit), while also securing a lightning strike protection. This paper has proposed a possibility of lightning surge protection of middle wave transmitters. The original protection implemented with the installations of class C transmitters was consisted only of multiple spark gaps. This kind of protection may prove inefficient using new class D transmitters. The device described in this paper has been designed and successfully implemented on a middle wave transmitter in Čižatice. This transmitter is transmitting with 5 kW power on the antenna with the carrier frequency of 702 kHz. Since the implementation of our device, the transmitter reports no failures and continues to transmit safely.

Keywords: middle wave transmitters, antennas, impedance matching, lightning strike protection.

Introduction

Technology of medium frequency transmitters reached its peak in 80s of past century, therefore is considered outdated, which led to gradual decommissioning of said transmitters along with disassembling of existing infrastructures consisted of antennas and radiators. The radio broadcasts were shifted to VHF and started using frequency modulation. Frequency modulated broadcasting, however, isn't sufficiently effective for broadcasting in a sparsely inhabited areas in Slovak republic, or in neighboring countries inhabited by Slovak minorities. Taking this fact into consideration, it was decided three middle wave transmitters using Amplitude Modulation (AM) will remain in service. These transmitters are *Nitra – Jarok* with 25 kW power on antenna, *Čižatice* with 5 kW power on antenna and *Uzovská Panica* with 15 kW power on antenna. Technology of AM radio broadcasting utilized vacuumtube-based transmitters produced byfy *TESLA*, overhead transmission line with characteristic impedance of 250 Ohm and isolated monopoles with height of 60 – 130 m. This conception had few major problems as following :

– *Transmitter aging*: high failure rate of active and passive components and weathering of wire shielding.

– *Low transmitter efficiency*.

– Operating frequency had been tuned many times; therefore, antenna length had not been ideal anymore since monopole antennas had been constructed for different operating frequencies.

– IMUs were working at their limits or even outside of their designed possibilities.

– Original workers and engineers were gradually enteringretirement;therefore, maintenance had become expensive and ineffective.

Based on these reasonings fy. *TOWERCOM. a.s.*, - provider of terrestrial broadcasting in SVK, proceeded to replace and renovate the outdated systems and MF transmitters.

Problem evaluation

The main task is to ensure a reliable and low maintenance (no maintenance) operation of middle

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wave system with new – updated transmitter. The challenges which we need to tackle are many, for example: to ensure a sufficient cooling system, sufficient and proper grounding, transmitter shielding make sure the VSWR (*Voltage Standing Wave Ration*) resulting from load connection to the transmitter is nearing the value of 1 etc. The issue we will try to solve and explain in this article is light surge discharge protection.

The antenna used as a radiator for middle wave transmitter is an electric monopole situated above ground, isolated by porcelain grounding switch and a rod grounding system. On Fig. 1, *a*) we can see a radiator form *Čižatice*, on Fig. 1, *b*) we can see a porcelain isolator, discharge and grounding system. The shape and location of the radiator is from lightning strike protection point of view very dangerous. Multiple discharge spark gaps are situated on the antenna to lower the danger posed directly to the transmitter. Every anchoring cable contains one spark gap as well as the base of the antenna see Fig 1, *b*). This lighting surge protection however was designed for a overhead transmission line and vacuum tube - based transmitter. With this kind of connection, there was an assumption, that the lightning generated surge voltage would dissipate with every pylon crossed [1]. Since in Čižatice site the 50 Ohm coaxial cable is used, instead of overhead transmission line, this effect is not achievable.

a *b*

Fig. 1. Electric monopole as an radiator with an adjacent antenna house (*a*); spark gap as a heavy surge protection installed at the base of the antenna (*b*)

Residual impulse can enter a coaxial line as a result of lightning strike. Impulse can then be transferred to the new transmitter (via coaxial line) and cause severe damage. It is of utmost importance, that the impulse entering transmitter carries only a fraction of energy created by a lightning strike. Based on the mentioned assumption it is necessary to ensure overvoltage dissipation before the input to coaxial line.

The approximate schematic of the topology of the real connection of system for MF broadcasting in Čižatice is shown in Fig. 2. Surge voltage generated by lightning strike will propagate via antenna towards the ground. Most of the energy of the impulse will dissipate through spark gapson anchoring lines and on the base of the antenna [2]. The residual energy will enter antenna house. There the impulse can damage capacitors in IMU, and then will enter the coaxial line leading to the new transmitter NAUTEL NX 5. Based on the information presented earlier, the ideal place to place the additional surge protection appears to be inside the antenna house, in parallel combination with IMU capacitors. The massive inductor inside the antenna house will fulfill two functions. It will serve as a essential component of IMU, and it will serve as a delaying circuit for the Gas Discharge Tube (GDT) (energy generated by lightning strike will affect the GDT only after the dissipation on spark gaps has occurred).Therefore, the GDT will be stressed only by a fraction of initial energy of atmospheric discharge. GDT has been chosen based on research conducted evaluation of available possibilities also studied by other researchers [3-5].

GDT as a part of middle wave transmitters

As was mentioned in previous section, the GDT will be connected in parallel combination to IMU capacitors as well as to coaxial line [6-8].

Transmitter supplies power of 5 kW onto the antenna input. With this information, it is possible to calculate *RMS* voltage value on GDT:

$$U = \sqrt{PZ_0} = 500\ \mathrm{V}_{RMS}. \quad (1)$$

P is active power of the transmitter and Z_0 is characteristic impedance of the coaxial line. We also must take into consideration the amplitude modulation of transmitted signal. The modulation depth (modulation index m = 80 = 100 %) raises the maximum voltage value the GDT is stressed by [9, 10]:

$$U_P = \sqrt{2}U\left(1+m\right) = 1414\ \mathrm{V}. \quad (2)$$

Based on equation (2), the GDT CITEL BE 800 has been chosen. Properties of this GDT are shown in Table.

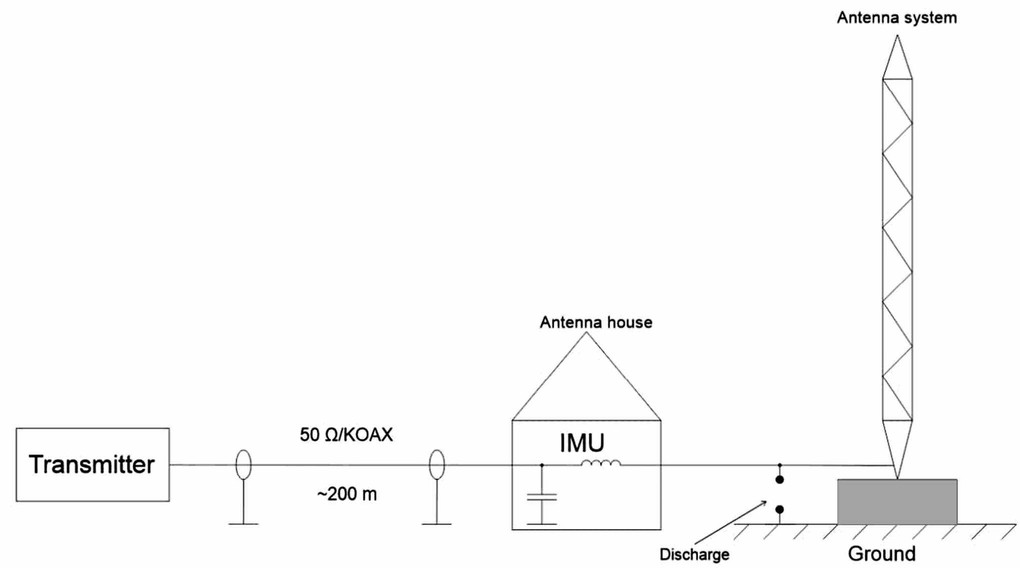


Fig. 2. Approximate schematic of antenna system in Čižatice

BE 800 GDT parameters [4]

Parameter	Value
DC sparkover voltage (100V/s)	≥ 650 V
Maximum impulse sparkover voltage (1 kV/μs)	< 1500 V
Nominal discharge current	100 kA
Max. capacitance	< 7 pF
DC Holdover voltage	800 V

Despite GDT BE 800 being the best suited for use in MF band, as stated in documentation and by manufacturer, this device doesn't meet the requirements defined in equations (1) and (2). It was necessary to perform measurements using GDT BE 800 and find a suitable connection, which doesn't influence signal path of transmitter chain and still fulfilled its function as a surge protection [11, 12].

GDT measurement

The GDT had to be stressed by high voltage with frequency equal to the carrier frequency of the AM transmitter. The transmitter in question is transmitting in 702 kHz. Limits at which the GDT started opening were determined by measuring the voltage on GDT in time domain. This information is very important, however is missing in technical documentation. To achieve high voltage values the amplifier *AG series Amplifier 10 kHz – 20 MHz* was used. As a signal generator the *ROHDE&SCHWARZ SMC100A 9 kHz – 32 GHz* has been utilized. Even with mentioned amplifier, the necessary voltage has not been achieved. To resolve this issue, the current probe *ETS LINDGREN .95236-1* was utilized as a transformer with the ratio of the threads two creating a primary coil and 6 thread creating a secondary coil. Voltage course had been monitored with the help of scope *Tektronix TDS 3032B* using high voltage probe. To prevent amplifier supplying voltage into open load circuit, the secondary coil has been loaded by two 22 kOhm resistors [13, 14].

The GDT is connected in parallel combination to 22 kOhm resistors. The voltage on signal generator is set on frequency 702 kHz and the amplitude is gradually being raised. In Fig. 4, *a* is displayed a voltage stressing GDT at 1.3 kV_{pp} (443 V_{RMS}), we can see, the GDT is not opened yet. Voltage on an already opened GDT is displayed in Fig. 4, *b*). The GDT has opened around voltage 446 V_{RMS}, voltage as a result dropped to a value of 166 V_{RMS}. Based on a displayed voltage function in Fig. 4, *a* and 4, *b*, we can tell, one GDT is not suitable for use as a discharge protection. Since the GDT has been stressed by AC voltage, it is impossible to rely on limiting values described in technical documentation. In Table AC holdover voltage is stated to be significantly lower than DC holdover voltage [15, 16].

To raise the overall holdover voltage, two (Fig. 5, *a*) and later three (Fig. 5, *b*) GDTs has been connected in a series connection.

Measurement of two and three series GDTs had to be measured by differential method using two high voltage probes with attenuation ratio x100 as is shown in Fig. 6, due to occurrence of capacitive bonds among references.

By using two and more series connected GDTs, undesirable results have been eliminated. Measurement of two series connected GDTs started to open at a voltage value > 2006 V_{pp} (709 V_{RMS}). By connecting three GDTs creation of conductive channel occurred at voltage value > 2470 V_{pp} (836 V_{RMS}). In this case, peak-to-peak value does not match RMS value, due to occurrence of non-linear properties of measuring chain [17-20].

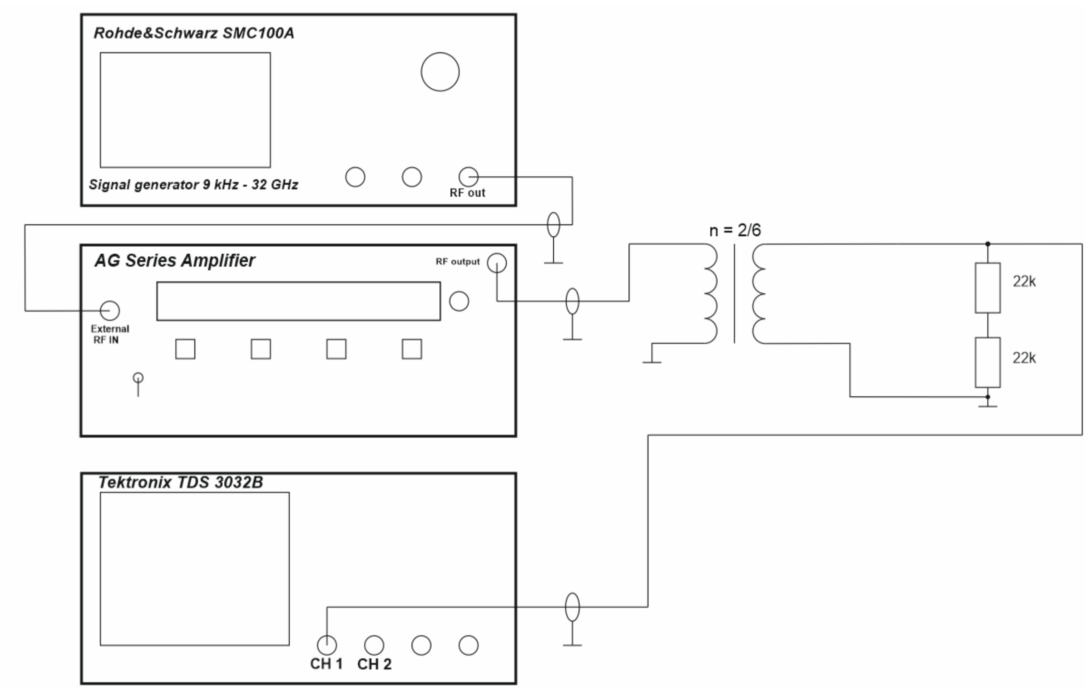
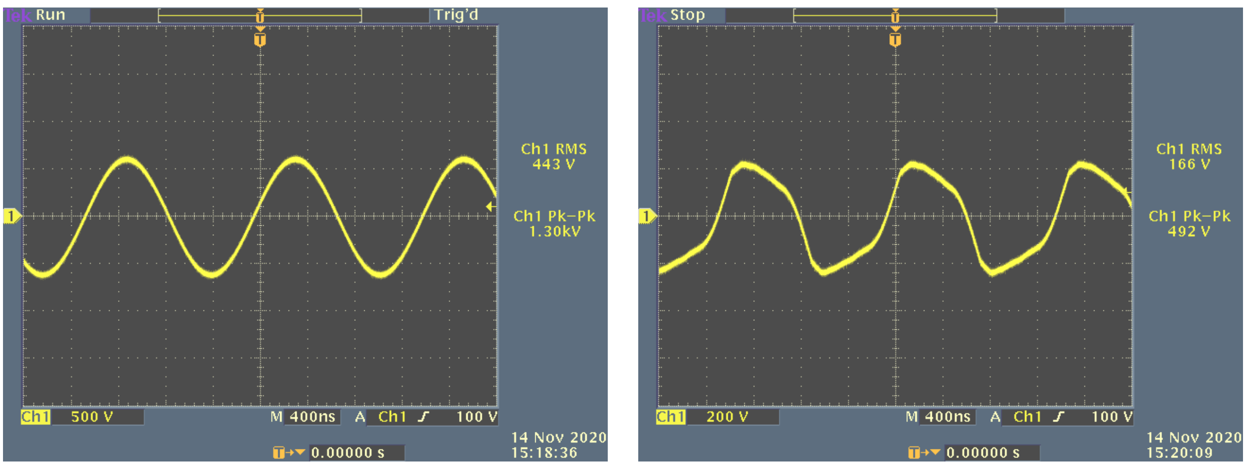


Fig. 3. Block diagram of measurement station



a *b*

Fig. 4. Function of voltage on GDT in time domain:
a - voltage on one GDT; *b* - voltage on one GDT after the opening and subsequent creation of conductive channel

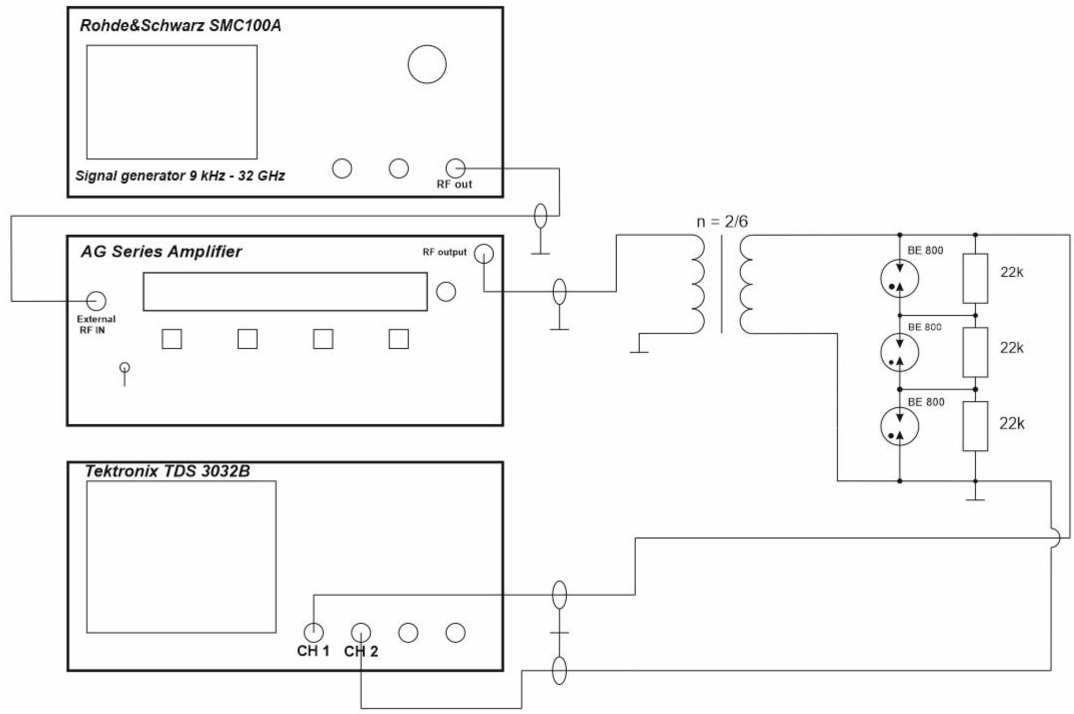
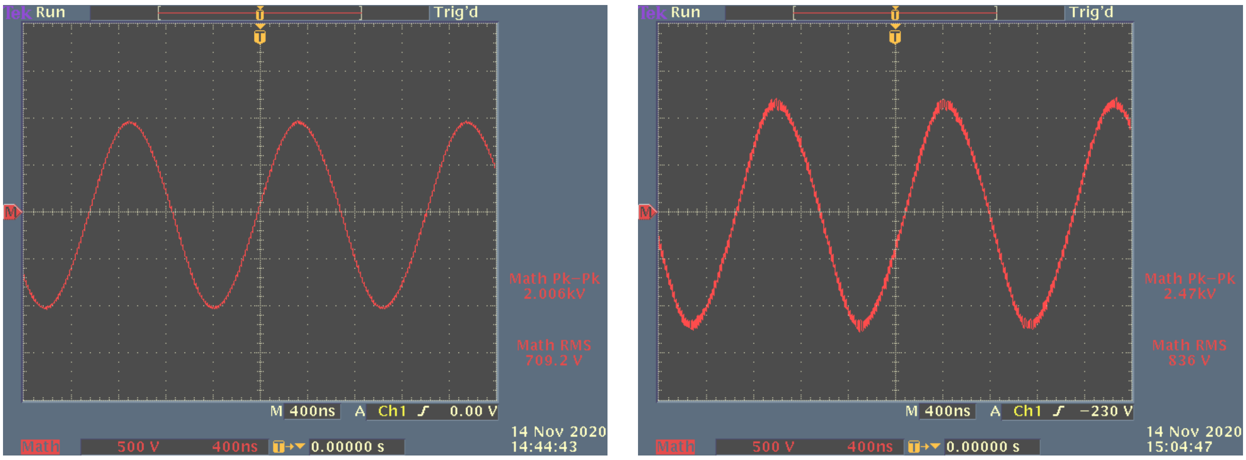


Fig. 5. Block diagram of measurement station with 3 series connected GDTs



a *b*

Fig. 6. Function of voltage on series connected GDTs: *a* - two series connected GDTs; *b* - three series connected GDTs

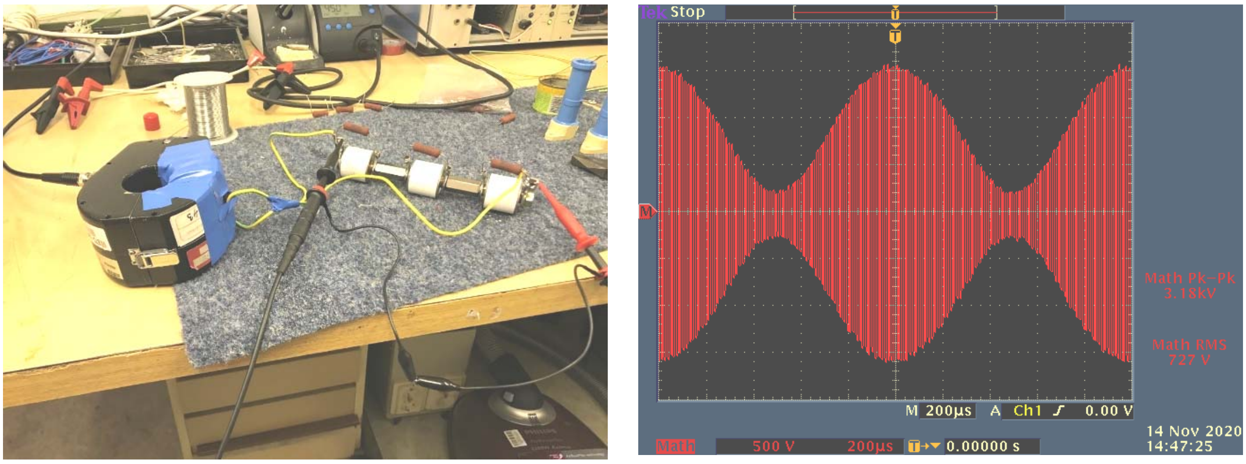
It may appear that even three series connected GDTs does not meet the requirements defined in equation (2). It was necessary to perform a measurement of holdover voltage of three series connected GDTs. In this case GDTs will be stressed by amplitude modulated signal. Differential method will be applied, while the voltage will be symmetrically divided in between three GDTs, which is achieved by three resistors in parallel combination to respective GDTs as shown on Fig. 5, they together form a resistive divider.

In Fig. 7, *a*, we can see a picture of measuring workplace, and in Fig. 7, *b* is displayed a print screen of the oscilloscope display. Generated signal was on frequency 702 kHz with amplitude modulated signal on frequency 1 kHz with modulation depth of 80 %. From measurements we can see that the value of peak-to-peak voltage is U_{pp} = 3180 V, and the effective value of modulated signal is equal to 727 V. Only at values > 3180 V GDTs begin to conduct a channel. Based on the findings we can say that three series connected GDTs are suitable for application on middle wave antenna system Čižatic - Slovakia.

Solution implementation

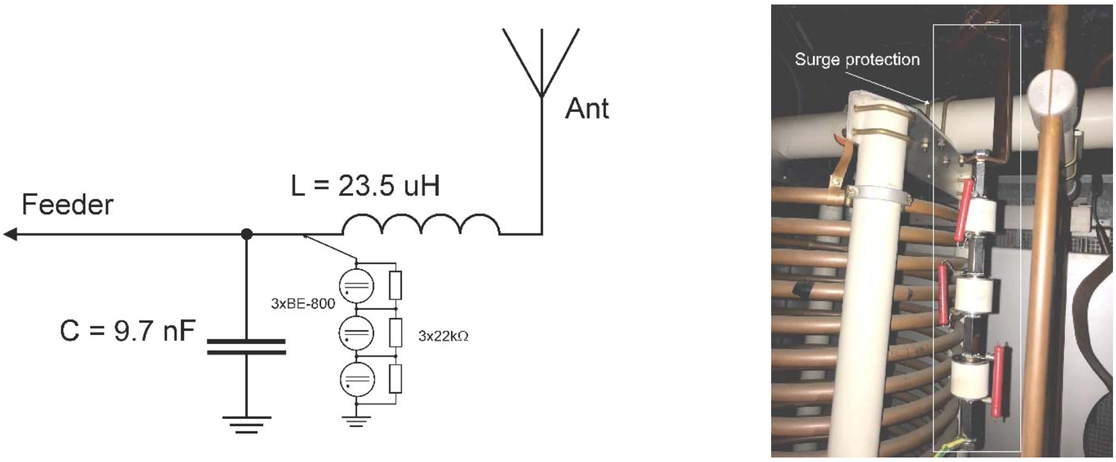
Antenna surge protection device was installed in antenna house, according to schematic in Fig. 8, *a*. Connection was realized consisting of three GDTs

BE 800 in series combination, with each being in parallel combination with 50 MOhm resistor respectively, with one end connected to the copper hook which is hooked on a copper pipe which is an extension of coaxial line connected to series inductance of IMU. Therefore, GDTs are in parallel to the inductor and coaxial line, behind the inductor form antenna point of view. This connection appears advantageous as stated in previous sections, because the inductor causes the delay of surge overvoltage, in the moment of lightning strike, which results in most of the overvoltage dissipating on outside surge protection (spark gaps) shown in Fig. 1 and 2. As a result the GDTs themselves are not stressed by the full energy of the lightning blast. Capacitors have even higher value of nominal voltage (5 kV), which is greater than the maximum holdover voltage of series connected GDTs.



a *b*

Fig. 7. Stressing GDT with AM signal: *a* - veasuring workplace; *b* - modulated signal



a *b*

Fig. 8. Implementation in Antenna house: *a* - IMU with implemented GDTs; *b* - Picture of GDTs in antenna house

With the surge protection disconnected, by the inductance tuning of IMU inductor, the impedance at the input of coaxial line – transmitter connector was tuned to value of 50 Ohm + j 0.5 Ohm. Measuring device used for impedance measurement was HIOKI 3532-50 LCR HiTESTER. After the implementation of GDTs, the impedance remained unchanged.

After the connection of coaxial line - feeder, to the transmitter, VSWR was being measured with GDTs connected and disconnected, as well as at half power and full power. At all four stages, GDTs had no measurable impact on the resulting VSWR whatsoever.

Conclusion

This article has proven a possibility of lightning surge protection of middle wave transmitters. Device described in this article has been designed and successfully implemented on middle wave transmitter in Čižatice. This transmitter is transmitting with 5 kW power on antenna with carrier frequency of

702 kHz. Since the implementation of our device, the transmitter reports no failures and continues to transmit safely.

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Обновление средневолновых передатчиков в Словацкой Республике

Р. Гартянски, кандидат технических наук, профессор, Институт электротехники, факультет электротехники и информационных технологий, Словацкий технологический университет, Братислава, Словакия
Й. Халлон, кандидат технических наук, научный сотрудник, Институт электротехники, факультет электротехники и информационных технологий, Словацкий технологический университет, Братислава, Словакия
Я. Крхнак, аспирант, Институт электротехники, факультет электротехники и информационных технологий, Словацкий технологический университет, Братислава, Словакия
М. Дзуриш, бакалавр, научный сотрудник, акционерное общество MWTC, Тренчинска Тепла, Словакия

Рассматривается замена средневолновых передатчиков в Словацкой Республике. Оригинальные передатчики были основаны на вакуумных лампах класса С и производились чехословацкой компанией Tesla. Передатчики класса С надежно работали до настоящего времени, однако срок службы этих передатчиков приближался к концу. Более того, потребность в повышении качества аналогового модулированного сигнала вела к его замене. Вышеупомянутые передатчики были заменены на современные высокоэффективные передатчики класса D, при этом использовалась оригинальная инфраструктура, состоящая из антенн и линии передачи. Поскольку требования передатчиков отличались (хотя и незначительно), это вызвало некоторые серьезные проблемы, связанные с согласованием импеданса на стороне антенной системы. Чтобы решить эти проблемы, необходимо было внедрить новую конструкцию устройства согласования импеданса IMU (Itpedance Matching Unit), одновременно обеспечив защиту от удара молнии. В данной статье доказана возможность защиты от грозовых перенапряжений средневолновых передатчиков. Первоначальная защита против перенапряжения (удар молнии в антенную систему), реализованная в передатчиках класса С, состояла только из одного (нескольких) искровых разрядников. Такая защита может оказаться неэффективной при использовании новых передатчиков класса D. Устройство, описанное в данной статье, было разработано и успешно внедрено на средневолновом передатчике в Чижатицах. Данный передатчик передает мощность 5 кВт на антенну с несущей частотой 702 кГц. После внедрения устройства передатчик стабильно работает без сбоев и безопасно.

Ключевые слова: средневолновые передатчики, антенны, согласование импеданса, защита от удара молнии.

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