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# DESIGN, CONSTRUCTION AND CALIBRATION OF THREE DEVICES TO MEASURE DIRECTLY LIGHTNING PARAMETERS

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ABSTRACT

**This paper describes the design parameters, construction and calibration of three devices: a Differentiating Rogowski Coil, a Integrating Rogowski Coil and a Shunt Resistance to measure directly the following lightning parameters: Peak Current Amplitude, Current Rate of Rise, Stroke Current Impulse Shape and Action Integral. These three devices were installed in a guyed insulated tower of 30 meters.**

**Keywords: Lightning, Measurements of Lightning Parameters**

## *1. INTRODUCTION*

At present most of the information available on the characteristics of lightning flashes is based on studies conducted in temperate and semitropical regions. However, the global circuit contribution is dominated by a superposition of effects from three major zones of convection: Tropical South America, Africa and the Maritime Continent [6].

In the last 10 years we have estimated lightning parameters in Tropical Zone, by means of indirect measurements through the Colombian Lightning Location System [7]. According to last results obtained by Torres and Williams [1],[2],[3], we have seen the necessity of complement the lightning characterization by means of direct lightning measurements. Recently we start a research project named ILLAPA, which has three general goals:

1) To obtain, by means of an instrumented-guyed insulated tower, direct lightning data, in order to compare its results with the data obtained by the Colombian Lightning Location System [7].
2) To compare the lightning data measured directly, in Tropical Zone, with the data measured in other latitudes, in order to demonstrate the hypothesis of latitudinal variation of lightning parameters magnitude.
3) To introduce improvements on the electrical equipment design, located in Tropical Zone, in order to achieve life expectancy increments.

The knowledge of the lightning parameters (peak value, time duration, wave shape, polarity, and subsequent strokes) comes from direct or indirect measurements. In the first case, using instrumented towers, or triggered lightning. In the second case, the estimations of several lightning current parameters can be obtained by means of measurements of lightning electromagnetic fields and/or vertical electric field, considering some empirical relations or theoretical models between the gathered fields and the lightning current.

This paper describes the design parameters, construction and calibration of three devices: a Differentiating Rogowski Coil, an Integrating Rogowski Coil and a Shunt Resistance. The three devices were installed, together with a Current Transformer (CT – Pearson Electronic, Model 1423), in a guyed insulated tower of 30 meters, in order to obtain redundant information of lightning parameters in Tropical Zone.

## *2. DESIGN PARAMETERS*

To obtain a reliable measure of lightning parameters, we choose the following references magnitudes for the devices:

| | | |
|---|---|---|
| Max. | Lightning Peak Current Amplitude | 400 kA. |
| Max. | Lightning Current Rate of Rise | 200 kA/ms. |
| Max. | Action Integral | $2x10^8 A^2$-s. |
| Min. | Bandwidth | 2 MHz. |
| Max. | Voltage output | 200 Volts. |

## *3. ROGOWSKI COILS*

The Rogowski coils generally have been used where other methods are unsuitable. Actually, they are the preferred method of current measurements, because they have more suitable features than current transformers and other iron-cored devices.

In order to measure the Lightning Current Rate of Rise, it was designed and built a Differentiating (DRC) and to measure the Lightning Peak Current Amplitude was designed and built a self-integrating Rogowski coils (IRC), according to [4],[9].

If a time-varying current $I$ threads the coil, its flux $\phi$ induces a voltage in it. The circuit equation for the current driven by this voltage $U$ is:

$$\frac{1}{L}.\frac{d\phi}{dt} = \frac{dI_c}{dt} + \frac{R}{L}.I_c \qquad (1)$$

where:

| | |
|---|---|
| $\phi$ | Magnetic flux linking the windings |
| $I_c$ | Current flowing in the windings of the coil |
| $L$ | Coil self-inductance |
| $R$ | Total coil resistance = $R_{CVR} + Z_s$ |
| $R_{CVR}$ | Current-viewing resistor impedance |
| $Z_s$ | Skin effect resistance |

*4. DIFFERENTIATING ROGOWSKI COIL (DRC)*

The coil may be configured with a very short L/R compared with the pulse-width. For this configuration,

$$\frac{L}{R}.\frac{dI_c}{dt} \langle\langle I_c \qquad (2)$$

in eq. (1) , the output voltage of the coil becomes $R.I_c \cong \frac{d\phi}{dt}$.. This is a differentiating coil since the current in the coil is proportional to $\frac{d\phi}{dt}$.

The advantages of this $\frac{d\phi}{dt}$ monitor are simple construction and high output voltage for a given coil area.

The DRC designed and built for measuring the Lightning Current Rate of Rise is wound along a toroidal core of synthetic material of 1,5 mm minor radio and 5 cm. of major radio. The winding of 20 turns was built with Nikrotal (Ni 80/Cr 20) wire of 0,2mm diameter.

The DRC is mounted on an acrylic support and is contained in an aluminum box, which shields it from undesirable stray fields. The figure 1 shows a schematic diagram of the DRC.

In order to calculate the maximal bandwidth of the DRC, a model, which take into account the mutual inductance, the coil self-capacitance and the coaxial cable, was simulated in the SPICE 7.1. The figure 2 shows the results of the simulation.

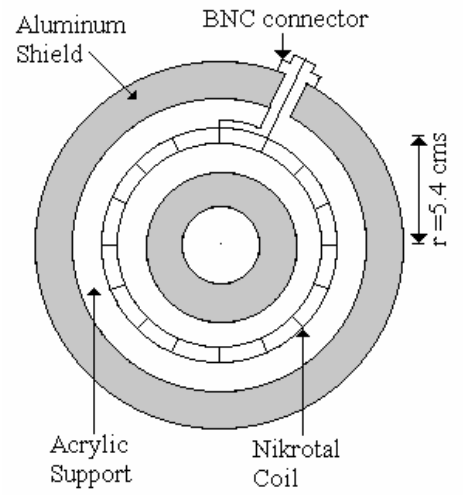


Figure 1. Schematic diagram of the DRC.

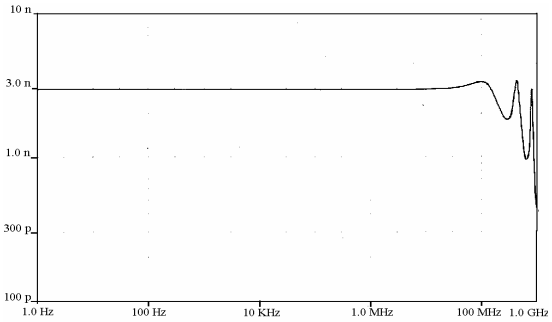


Figure 2. Simulation of Impedance. Vs. Frequency of the DRC

The parameters of the built DRC are:

| | |
|---|---|
| Coil self-inductance (L) | 12 nH |
| Mutual inductance (M) | 0,6 nH |
| Transfer Coefficient (K) | $0{,}6 \times 10^{-9}$ V/A-s$^{-1}$ |

*5. SELF-INTEGRATING ROGOWSKI COIL (IRC)*

The coil may be also configured so that L/R is greater than the pulse-width. In this type of configuration we note from eq. (1) that

$$\frac{L}{R}.\frac{dI_c}{dt} \rangle\rangle I_c \qquad (3)$$

Hence $I_c \cong \frac{\phi}{L}$. This is a self-integrating coil since the current in the coil is proportional to $\phi$ rather than $\frac{d\phi}{dt}$.

The IRC is essentially a toroidal winding of 120 turns connected to a Current-viewing resistor impedance or

tubular resistance ($R_{CVR}$). The winding was built with copper wire of 1mm diameter, wound along a ring rubber shell of 6,5mm minor radio and 11,45cm major radio. The tubular resistance ($R_{CVR}$) was built with Nikrotal of 0,1mm thickness and 7mm external diameter. Due to its good behavior at high frequencies, the IRC was chosen to measure the Lightning Peak Current Amplitude and the Lightning Current Rate of Rise.

The IRC is contained in a metallic box, which shields it from undesirable stray fields. A slit around the inside of the shield prevents shorting of the winding. The figure 3 shows a cross section of the IRC.

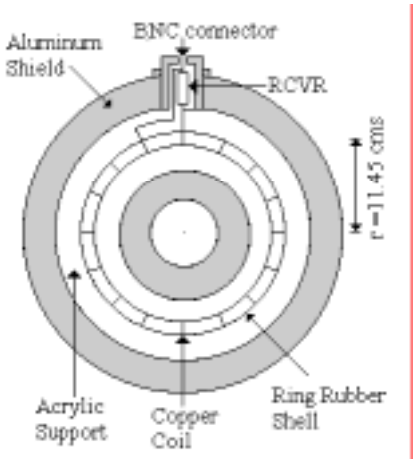


Figure 3. Cross-section of the IRC

In order to calculate the bandwidth lower limit, a model, according to [5], was simulated in the SPICE 7.1. The figure 4 shows the results of the simulation.

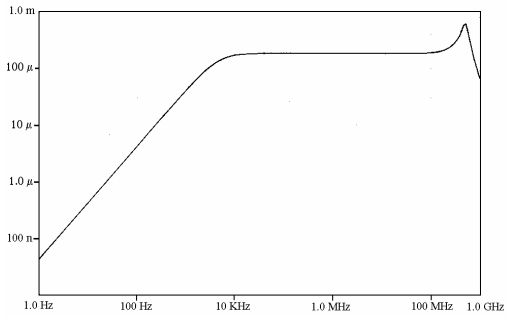


Figure 4_ Simulation of Impedance. Vs. Frequency of the IRC

The parameters of the built IRC are:

| | |
|---|---|
| Coil self-inductance (L) | 4,35 µH |
| Skin effect resistance, to 50kHz. ($Z_S$) | 0,0928 Ω |
| Current-viewing resistor imp. ($R_{CVR}$) | 0,0280 Ω |
| Transfer Coefficient (K) | $1,834x10^{-4}$ V/A |

## 6. SHUNT RESISTANCE

Due to linear performance from high frequencies to DC, the Shunt Resistance (SR) was choose for measuring the following lightning parameters: Lightning Peak Current Amplitude, Lightning Current Rate of Rise, Stroke Current Impulse Shape and Action Integral.

The resistance is essentially a cylinder of Nikrotal, 22,5cm of radio, 19,5cm of longitude and 0,29mm of thickness, welded to two disks of phosphated bronze, 22,5cm of radio and 1cm of thickness. The Nikrotal cylinder is supported by means of refractory concrete, and the outside is covered by means of two mantle of laminated asbestos. The figure 5 shows the schematic diagram of the SR. With this configuration, an action integral of $2.10^8$ $A^2$-s, could raise the temperature of the active part in $350^0$ C.

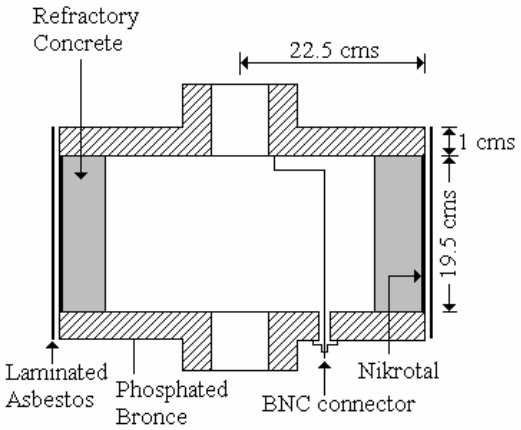


Figure 5. Schematic diagram of the SR

In order to calculate the bandwidth of the SR, a model, according to simplified model [5], was simulated in the SPICE 7.1. The figure 6 shows the results of the SR simulation.

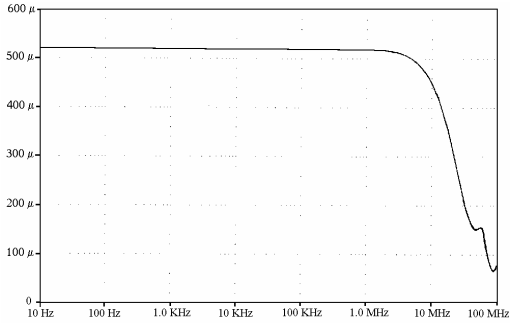


Figure 6. Simulation of Impedance. Vs. Frequency of the SR

The parameters of the built SR are:

Resistance ( R ) $521x10^{-6}$ Ω

| | |
|---|---|
| Bandwidth | 15 MHz. |
| Transfer Coefficient (K) | 521E-6 V/A |

*7. CALIBRATION*

Dues to Rogowski Coils and the shunt resistance are linear, they may be calibrated at any convenient current level and the calibration will be good for all currents including very large ones. The determination of the Transfer Coefficients for each Rogowski coil was made by means of application in laboratory of waves current impulse type 4/10μs, with amplitude variable up to 60 kA. In this case it was take as standard resistance the Shunt resistance of the current impulse generator (Haeffelly), which was calibrated, according to NIST of USA.

The Resistance (R) of the SR was measured by different voltage-current methods with equipment of Accuracy less than 0,5%

8. CONCLUSIONS

- It was designed and built three devices in order to measure directly lightning parameters in Tropical Zone.
- According to the simulation in SPICE 7.1, measurements of L and R and the calibration in laboratory with current impulse waves type 4/10μs, up to 60 kA , the three devices: a Differentiating Rogowski Coil (DRC), a Self-Integrating Rogowski Coil (IRC) and a Shunt Resistance (SR) will measure reliably Lightning Peak Current Amplitude, Lightning Current Rate of Rise, Stroke Current Impulse Shape and Action Integral.
- It is very important to emphasize that the bandwidth of the three devices varies between 10 MHz. for the SR, 100 MHz for the IRC and 100 MHz for the DRC.

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