Lightning protecting materials used on Radar System

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ABSTRACT

Because of the extensive use in modern systems of very sensitive electronic components, lightning strikes does not represent only a threat, but something that cannot be neglected anymore and safety hazards caused by direct and indirect lightning to the aircraft or naval industry. Everyday new materials appear that “can” protect against lightning. For a new product, the levels of protection against lightning are determined during the design stage. In the case of existing equipments, the situation gets more complicated. The formulation of the military standard MIL-STD-464A Severe Strike confirms this need. The peak currents of the discharges are between 50 and 200 kA, for the A pulse, 2 kA for the B pulse and 200 to 800 Amps for the C pulse.

Experiments have been carried out using a test setup that could duplicate the three discharge components.

INTRODUCTION

Our everyday life depends more and more on very sensitive electronics. The effects of lightning strikes represent a danger for these components. The new generations of products are designed to stand various levels of threads. The MIL STD 464A and the CEI - IEC 62305 Standard give precise limitations about the levels of damage a structure is allowed_to suffer after a direct or an indirect strike.

After using the Rolling Sphere Method to find all the weak spots missed in the design phase and then make the proper corrections in order to test the results of the RSM (The Rolling Sphere Method is a geometrical construction method for the placement of air terminal systems), our intention is to use a setup that is able to recreate the lightning’s effects in laboratory. These tests will focus, on the behavior of a RADAR Antenna. That in some cases, is the tallest structure on a ship, see Fig 1.

Fig. 1 – Aircraft Carriers for the Royal Navy - HMS QUEEN ELIZABETH

The long-range radars (LRR) that equip the last generation of airplane carriers are at the highest position on these ships, and thus, represent targets for lightning.

Fig. 2 – LRR on top of the deck

The design of the LRR includes several lightning protection features such as lightning rods. The protected area and the maximum currents in the structure of the LRR are obtained using the Rolling Sphere Model.

Fig. 3 – LRR SMART - L

LIGHTNING WAVE SHAPES

Additional analysis using the actual current has to be carried out after the RSM and in support to this analysis and tests comes the military standard MIL –STD-464A for Severe Strikes. It gives the parameters of an extremely violent lightning strike.

Our aim is to recreate the wave shapes of this strike, of the so-called A, B and C pulses. By the “A pulse” we mean the beginning discharge of a lightning stroke. The current of the A pulse has a fast rate of ascend, a peak value reaching 200kA ± 10%, and an action integral $\int i^2 dt = 2 \cdot 10^6 A^2 s$.

The total duration of the A pulse is about 200μs and the rise time of the current from 0 to 200kA is around 10μs. The A pulse is instantly followed by an intermediate pulse, a 100 times smaller, the B pulse. It last longer than the first, around 4.5 to 5 ms, but its peak current only reaches 2kA ± 10%. This second pulse can be considered a flat pulse, having almost the same current intensity during its entire duration. The last pulse, the C pulse, is the smallest looking at the peak current, but is also the longest. The total duration reaches from 0.25 to 1s and the current is between 200 to 800 Amps. The equivalent charge of this C pulse is around 200 Coulombs.

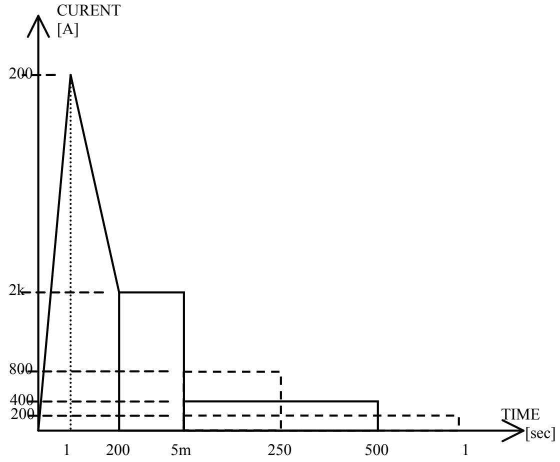

Fig. 5 - The A, B, C and D pulses of a lightning

In some very rare cases, there is a fourth current, the re-striking current, who has a reduced peak current and also a reduced action integral. It is the D pulse. The four pulses represented above, can be considered as one of the most destructive lightning strokes. However, the probability for such a severe strike is very low.

A - PULSE CIRCUIT

In the case of a lightning, the current has only one polarity, and in almost 80% of cases, this characteristic is negative.

In this case, the setup consists of a series of normal capacitors storing electrical energy, and discharging trough an inductive load circuit. The test circuit has its own internal inductance, offering a gradual discharge of the circuit in a damped periodic manner. Described by the following equations:

$$i = \frac{e}{\omega_p L} \sin \omega_p t \cdot \exp\left[-\frac{R}{2L} t\right]$$

$$\omega_p = \sqrt{\left[\frac{1}{LC} - \frac{R^2}{4L^2}\right]}$$

If the circuit resistance (damping) is increased, the equation becomes aperiodic.

$$i = \frac{e}{\omega_a L} \sin \omega_a t \cdot \exp\left[-\frac{R}{2L} t\right]$$

$$\omega_a = \sqrt{\left[\frac{R^2}{4L^2} - \frac{1}{LC}\right]}$$

To find the transition between the two conditions, we use the following relations, for the critically damped case:

$$i = \frac{e}{L} \cdot \exp\left[-\frac{R}{2L} t\right]$$

$$\varphi = \frac{1}{R}\sqrt{\frac{L}{C}} = 0{,}5 \cdot$$

And the action integral is: $\int i^2 dt = \frac{e^2 C}{2R}$ and the initial rate of change for the current is: $\frac{di}{dt} = \frac{e}{L}$

These can be explained in numbers, using an impedance L = 5μH, a current I = 200kA and an electric field energy of 100kJ. The capacitor bank can have 120kJ in a low damped circuit, which is enough. In order to have the required current for the experiment, the stored energy by the capacitors has to reach 2.2MJ.

Using a crowbar gap in parallel to the capacitor bank, the above problems are solved. And when the current reaches the necessary peak value the gap is triggered. Also, in this way, the current decays exponentially by the L/R time constant of the circuit, while another condition to have the desired results is that this L/R time constant is sufficiently long.

When we think of protection, we think about avoiding a misfire of the gap when the capacitors reach a high voltage level. If the gaps are triggered in air, the percentage of the lowest value to trigger and the withstand voltage is around 30%.

B - PULSE CIRCUIT

As power supply for the B pulse we use an artificial line, realized by a number of L.C sections the artificial line provides an easily obtained flat-topped current. To reach voltages between 10 and 30 kV, the bank energy is 100 to 200kJ. During tests, the arcing voltage depends on the length of the arc. A 1 to 5 cm arc is considered normal, but larger arc length is better to avoid the fixation of the arc to the electrode. A 1400V arc has a length of almost 30cm and gives the possibility to be maintained. A very compact pulse-shaping network can be realized by 6 capacitor groups of 16 × 100μF each and 5 coils of 160 μH each. An HV single layer coil of 80μH represents the end coil and forms the coupling element to the DUT (Device under Test).

C - PULSE CIRCUIT

A 200C charge needed for the C pulse is delivered by another pulse shaping network. The requirements for this pulse are: an average value of 400A, duration of 0.5 sec. at a driving voltage of 1400V in total, 140mF and 140kJ. In order to be more economic, the use of electrolytic capacitors and clamping diodes to avoid a voltage reversal is imperative. The use of lead batteries is an option.

The use of a synchronous generator with a step – up transformer and rectifier diodes is advised for this part of the process. For example, the 380V/ 125A local network and a 15kVA transformer operated in short run conditions with 100A LV fuses for protection. In order to generate and maintain a 30cm arc the circuit is provided with a 16mH smoothing air core reactor and 6 pulse bridge diodes.

The last coil of the B circuit connects the DUT to the entire workbench. A spark gap and a series of metal – oxide varistors represent the protection against excessive over voltages and a series diode realizes the decoupling between the B circuit and the C circuit, and also prevents the chopping instability of the arc into the large input capacitances of the B circuit.

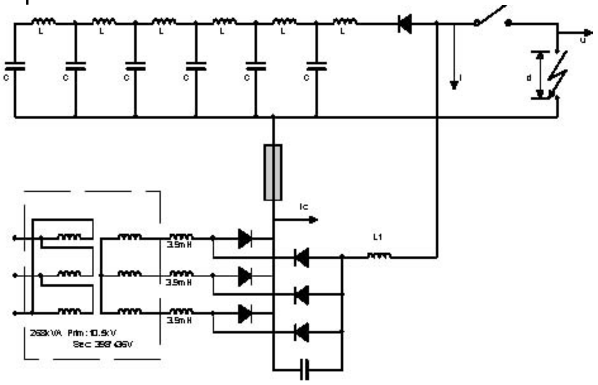

Fig. 6 – Simplified circuit for the B and C pulse

SHIELDING EFFECTIVENESS

In order to assure that the equipment can and will handle the indirect threat, the effects of the electric, and in our case with most interest, of the magnetic components need to be calculated.

An assessment to the magnetic field leads us with the use of Ampere's law to calculate the magnetic field strength: $H(t)=\frac{I(t)}{2\pi \cdot R}[A/m]$, and the flux density will be $B=\mu_0 \cdot H[T]$.

For the cables and wires placed inside various designated structures the voltage induced into a loop formed inside those structures is determined with the use of Faraday's Law: $V_{Loop}=\frac{\partial \Phi}{\partial t}$, with Φ - the flux coupled into the loop. It is safe to use a ∂t of 10 [μs], the rise time of the 200[kA] - A pulse.

With the use of conductive paint or other shielding materials (SHIELDEX), on the outer hull of the radar, a reduction in the coupling is intentioned. Simply the use of composite panels doesn't provide any shielding capabilities, so the use of some other shielding methods is a must. The total weight of the shielding method is another determinant factor in the final selection. For example 20μm of copper or Shieldex adds 3.8kg to the weight of the structure, while 200μm of stainless steel, 33.4kg. A thicker layer of Shieldex or copper (500μm) adds 95.3kg and 1mm of aluminum 23.1kg.

From calculations, we found as most satisfying values in our quest, for shielding, the 500μm layer of Shieldex and the 1mm thick aluminum layer.

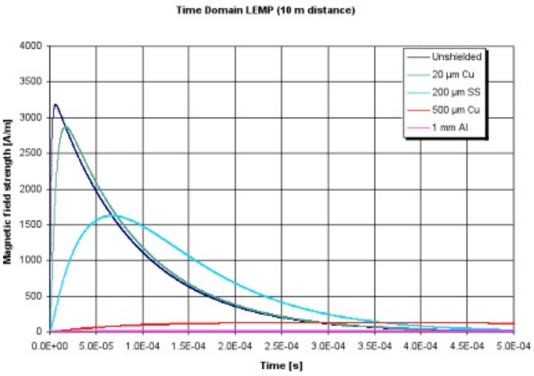

Fig. 7 – Calculated shielded effectiveness of SHIELDEX

With a strict reference to Shieldex, from 100Hz to 10kHz the level of attenuation is between 50 and close to 100 dB. For higher frequencies, over 10 MHz, the threat level in these conditions can be neglected. With the values for induced voltages being very low, do not represent any threat for cables and PCBs housed into these composite structures.

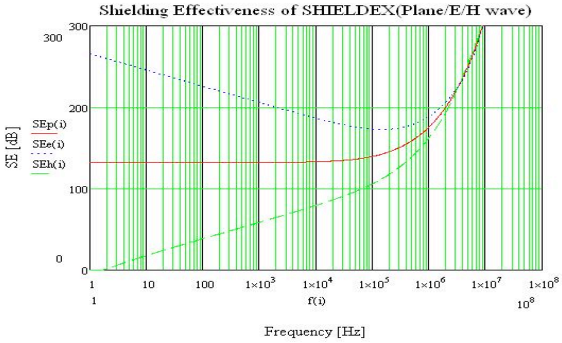

Fig. 8 – Calculated shielded effectiveness of Shieldex

CONCLUSIONS

The currents through the structure of the Long Range Radar were determined using the rolling sphere method. The lightning rods will handle the maximum current. A test bench generating the A, B and C lightning pulses has been built to test the lightning rods and the interaction between lightning fields and the whole radar assembly. To support the results from the results from the rolling sphere method were performed. A final confirmation to these calculations and simulations will come in the next months after the real test will be performed with the test setup.

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