Lightning Protection Design of Transceiver Based on Radio Altimeter

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Abstract: Lightning is a great threat to aircraft flight safety. The lightning protection test of aircraft and the ability of aircraft and its parts to withstand direct and indirect effects are investigated and verified by simulating the real lightning environment in the laboratory. According to the requirements of GJB lightning test, this paper analyzes the lightning grade and introduces several lightning protection designs commonly used in engineer practice.
Keywords: lightning effect, ceramic discharge tube, λ of quarter wavelength, transient voltage suppression diode

1. Lightning effect

Direct lightning effects refer to the physical effects of aircraft and/or equipment caused by direct attachment of lightning channels to aircraft and/or conduction of lightning currents, including surface and the structure of the insulation breakdown, explosion, bending, melting, burning and vaporization and so on, which also include voltage and current directly injected into control cables and other conducting components of wiring pipes.

2. Requirements for lightning test

Lightning test is divided into pin damage tolerance test and functional disturbance test. The equipment should work normally after completing the test according to the specified voltage/current waveform and test level level, and should work normally in the process of functional disturbance test. Lightning pin injection damage tolerance test is the most severe, lightning protection circuit design can be approved according to the lightning test grade.

The product shall be tested for pin injection of the components under test in accordance with the requirements of Chapter 22 of the Environmental Conditions and Test Methods for DO-160G Airborne Equipment. Waveform group A is selected for pin injection test, and the pin injection test grade is 3[2]. The destructive tolerance is verified by applying the selected transient waveform directly to the RF port of the component when the tested component is in working state during the pin injection test. The test grade and level of pin injection test are shown in Table 1, and the test waveform is shown in Figure 1. After the test, the test component performance index should meet the technical requirements.

Table 1. Grade and level of pin injection test

Grade	Oscillograph	
	3/3	4/1
	Voc/Isc	Voc/Isc
3	600V/24A	300V/60A

Note: 1. Voltage and current are not required to be in phase; 2. The waveform may be sine or cosine.

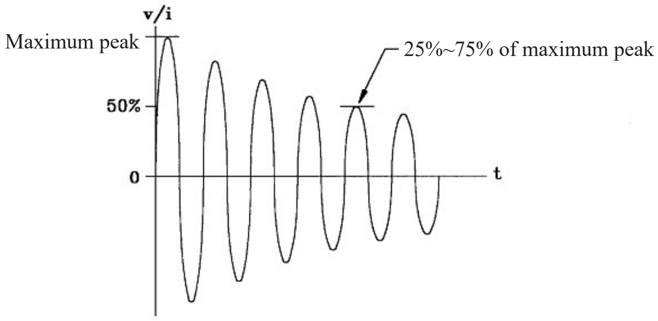

Figure 1. Voltage/current waveform of Waveform 3

This article takes the voltage/current waveform and test level specified by DO-160E, Level 3 as the design input.

3. Common lightning protection design and application examples

3.1 Transient voltage suppressor diode

Transient voltage suppressor diodes (TVS devices for short), when subjected to a high energy transient overvoltage pulse under specified reverse application conditions, the operating impedance will be reduced to a very low conduction value. Its operating impedance will be reduced to a very low conduction value, allowing high current through, and voltage clamping to a predetermined level, thus effectively protecting electronic components in the electronic circuit from damage

In the selection of TVS devices, the specific situation of the circuit to be protected must be considered. Generally, the following principles should be followed:

A) $V_{C(max)}$: Not greater than the maximum allowable safe voltage of the protected circuit;

B) V_{RWM}: Not less than the maximum working voltage of the protected circuit, generally can be selected equal to or slightly higher than the maximum working voltage of the protected circuit;

C) P_{PR}: It must be greater than the maximum transient surge power in the circuit, and meet the requirements of temperature derating in the working environment;

D) The unipolar TVS device should be selected for the DC circuit, and the bipolar TVS device should be selected for the AC circuit.

3.2 Ceramic gas discharge tube

Ceramic gas discharge tube: An enclosed device whose inner part is composed of one or more discharge gaps filled with inert gas. When the voltage added to the two electrodes reaches the breakdown of the gas in the ceramic gas discharge tube, the discharge begins from high impedance to low impedance, so that the surge voltage is short-circuited to near zero voltage, and the overcurrent is released into the ground, so as to protect the subsequent circuit.

This kind of ceramic gas discharge tube is used as lightning protection design for RF front end of a certain radio altimeter. Since there is no feed at the RF output end, the RF connector is connected to the RF circuit inside the module through a high voltage capacitor. Because the high resistance of the high voltage capacitor is open circuit for lightning energy, the voltage withstand value of the high voltage capacitor is greater than 1000V, which is higher than the maximum voltage 600V required by lightning protection experiment, so the high voltage capacitor will not be damaged. The capacitance of high voltage capacitor is 10pF, and the voltage pulse of lightning protection experiment changes to microsecond level, so the pulse frequency is less than 10MHz. 10pF capacitor has a very low pulse passing rate of 10MHz, so it will not affect the rf circuit inside the module. Meanwhile, a ceramic gas discharge tube is placed at the RF output end to improve the lightning protection ability. Can withstand 2000A 8/20us, 4kV 10/700us surge current, meet iec61000-4-5 lightning surge standards, prevent lightning energy higher than 1000V into the damage of the high voltage capacitor.

3.3 Quarter wavelength Line RF SPD

When the length of the microstrip line is equal to a quarter of the wavelength, and for the RF signal, the output short circuit, the input is open (high impedance); The output is open, and the input is short-circuit (zero impedance); A quarter wavelength resonance acts as a high-pass filter to filter out low-frequency signals.

A certain type of radio altometer is equipped with a quarter wavelength, 0.3mm wide short path to the ground at the RF input and output terminals, the quarter wavelength short path for RF signal is open, the signal through the quarter short path after total reflection, theoretically no loss of microwave power; As the pulse frequency of the lightning test is below 1MHz, it is short-circuit grounding for low frequency and DC signal through a quarter of the wavelength line.

3.4 The microstrip line width of the transmission path is greater than 0.5mm

A certain type of radio altimeter is provided with a cavity filter at the front end. The lightning protection design in the filter cavity adopts a microstrip line with a width of 0.5mm at the RF input and output ports. The cavity filter is cut from the metal as a whole, and the structure is firm. The external RF coaxial connector is connected with the internal resonant rod of the cavity filter by welding through the microstrip line with the width of 0.5mm copper wire. Because the cavity filter is a metal integral cut, the inner resonant rod is connected with the outer shell metal, and the microwave component, radio altimeter common ground, when the direct current generated by lightning test through the cavity filter, the current is released to the ground through the transmission line.

In the case of ensuring 50Ω impedance matching, the wider the copper wire width, the better. The medium of the microstrip line is made of polytetrafluoroethylene, and the dielectric constant $\varepsilon=2.55$. When the dielectric thickness d of the microstrip line is 0.4mm and the width w of the metal sheet is 0.5mm, after impedance calculation, Z0= $\frac{120\varepsilon}{\sqrt{\varepsilon}\left[\frac{w}{d}+1.393+0.667*\ln\left(\frac{w}{d}+1.444\right)\right]}$ =51Ω. The breakdown voltage of the microstrip line at this time is V=Ed*d=200kV/mm*0.4mm=80kV. Among them, Ed is the breakdown field strength at room temperature and pressure. After many tests and verifications, the use of a microstrip line with a dielectric thickness of 0.4mm and a copper wire width of 0.5mm can meet the above-mentioned lightning strike test requirements.

3.5 Application example — HB6096 input protection

HB6096 input protection circuit is designed with SA6.0CA bipolar transient voltage suppressor diode. Circuit design is shown in Figure 2:

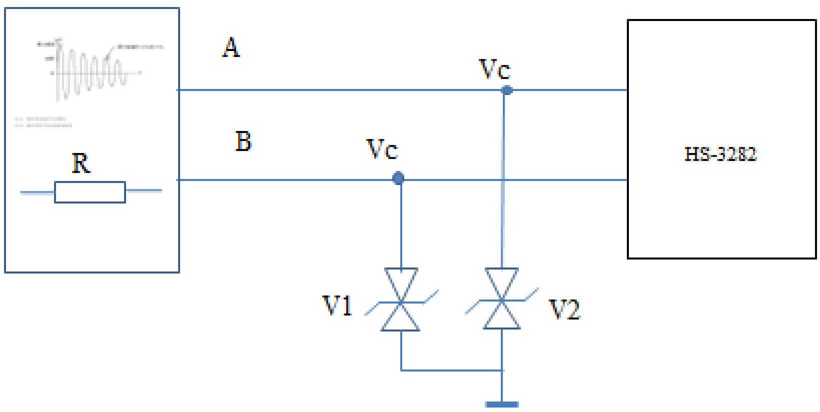

Figure 2. Schematic diagram of HB6096 lightning protection design

Table 2. SA6.0CA 500W bipolar TVS diode parameters

$V_{(BR)}$			$I_{R(max)}$ (μA)	V_{RWM} (V)	$V_{C(max)}$ (V)	I_{PP} (A)
V_{min} (V)	V_{max} (V)	$I_{(BR)}$ (mA)				
6.67	7.37	10.0	600.0	6.0	10.3	48.5

A) Calculating VC under the action of lightning wave 3

Internal resistance R=Voc/Isc=600/24=25Ω

The clamping voltage of SA6.0CA bipolar transient voltage suppressor diode is calculated by Formula (1), and the maximum peak current is calculated by Formula (2).

$$V_C= VBR_{max}+(V_{cmax}- V_{BRmax})/(I_{PP}- I_R)\times I_P \quad (1)$$

$$I_P=(V_{oc}-V_C)/R=(600-V_C)/25 \quad (2)$$

Substituting V_{BRmax}, V_{cmax}, I_{PP}, I_R in SA6.0CA parameter Table into Formula (1) to solve the equations:

V_C =8.8V

I_P= 23.6A

B) Calculating the peak pulse power P_{PR} under the action of lightning waveform 3 (Waveform 3)

The voltage/current waveform of Figure 1 waveform 3 can be equivalent to a triangle wave with maximum peak current IP of 24A and pulse width TP of 4μs after rectification.

Lightning wave 3 Peak power P_{PR}(Waveform 3)= VC •IP

= 8.8×23.6

≈0.21kW

C) Calculating the rated pulse peak power P_{PR} of SA6.0CA under the action of lightning waveform 3

The thunder waveform 3 is equivalent to a typical triangular wave, with waveform coefficient K1=2.8, assuming that the ambient temperature TA=80°C and the temperature derating coefficient K2=0.633, according to Formula (3)

$$P_{PR}(1ms)=K1 \cdot K2 \cdot V_C(max) \cdot I_{PP} \tag{3}$$

The rated pulse peak power $P_{PR}(1ms)$ of SA6.0CA at t_P=1ms=K1•K2•V_C(Max) •I_{PP}=2.8×0.633×10.3×48.5=885W was calculated. After the shaping of waveform 3 is equivalent to a typical triangular wave pulse, the width t_P=4μs, t_P and $P_{PR}(1ms)$ are substituted into Formula (4).

$$lg(P_{PR(tp)})=k*(lg(t_p)-lg1000)+lg(P_{PR}) \tag{4}$$

The peak pulse power $P_{PR}(4\mu s)$ of SA6.0CA under lightning wave 3 was calculated to be $P_{PR}(4\mu s)$=10(lg(0.885)+1.302–0.434lg(4))=9.7kW.

D) Conclusion under the action of lightning waveform 3

Under the action of lightning waveform 3, the voltage V_C suppressed by transient voltage suppression diodes V1 and V2 and the pulse power of lightning waveform 3 to be borne in the circuit are both lower than the maximum allowable operating voltage of the circuit and the pulse power V1 and V2 can bear, which meet the design requirements.

Table 3. Lightning protection design index compliance

HB6096 input protection circuit input and lightning waveform 3 action to withstand the pulse power			Main parameters of transient voltage suppression diode SA6.0CA and the ability to withstand pulse power of lightning wave 3		
Maximum normal operating voltage	Maximum allowed input range	Requirements on withstanding impulse power	M Maximum reverse operating voltage V_{RWM}	Maximum clamping voltage V_C	Requirements on withstanding impulse power
-5.5V ～ +5.5V	-29V ～ +29V	0.21kW	-6.0V ～ +6.0V	-8.82V ～ +8.82V	9.7kW

4. Conclusion

The lightning protection design of aircraft should be a part of the development of new aircraft. This paper provides the methods of data interface of airborne equipment and lightning protection of RF front-end. According to the characteristics of data interface circuit, the appropriate TVS tube can be selected for design. Considering the reliability and economy of the airborne equipment, the appropriate RF front-end lightning protection design is selected to ensure that the airborne equipment suffers from direct lightning hazards during use. At present, a variety of domestic new research models have passed the lightning test. In the design of a radio altimeter, the above methods are used for lightning protection design, and the lightning test is carried out with the whole machine.

References

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