

高频电子设备机壳散热孔电磁辐射特性分析

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摘要 随着高频电子设备的增多和布局越来越密集,为使设备间能够互不干扰的正常工作,兼顾设备的散热性和电磁兼容性就成了一个非常突出的问题。该文从高频电子设备机壳散热孔的辐射场入手,对机壳上所常开的矩形孔、圆形孔的辐射场采用解析法进行了分析计算,并对二者的辐射场进行了分析比较,在电子设备机箱上开散热孔,若已知外来电磁波频率,即波长一定时,所开的矩形孔的宽边尺寸应控制在 $w \leq 0.1\lambda$ 以下,矩形缝隙的尺寸越小越好,且缝隙的长宽比 l/w 越大越好。在开孔面积相同的条件下,圆形孔的辐射比矩形孔的辐射要小,所以尽量开圆形散热孔,且孔的直径尽量控制在 $2a \leq 0.1\lambda$ 以下,此时孔的辐射比较小,对外部设备及对内部电路的影响比较小。

关键词 高频电子设备;机壳;散热孔;辐射场

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Analysis of EM Radiation Characteristics at Louvers on HF Electronic Equipment Enclosures with Apertures

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Abstract: In order to enable equipments to be noninterference in each other's normal work among equipments, consideration must be given to both the heat dissipation of equipments and the electromagnetic compatibility of equipments with the increase of HF electronic equipments and their dense distribution. This paper analyzes and calculates the radiation fields of the louver of HF electronic equipments, the common rectangular and circular louver's radiation field by analytical method, and then compares the both field results. Under condition that louvers are made in HF electronic equipments, and the outcome electromagnetic wave's frequency is known, i.e. the wavelength is constant, the width of rectangular louver should be less than or equal to 0.1λ , and the smaller the size of rectangular louver, the better the its performance, and the bigger the length-width ratio, the better the its performance. In the condition of same area of louver, the radiation fields of circular louver are smaller than that of rectangular one. The best way is to make a circular louver, and the diameter of a louver should be less than or equal to 0.1λ as far as possible. In this case the radiation field of louver is the smallest, and its influence on external equipments and internal circuits is comparatively weak.

Key words: high frequency electric equipment; cabinet; louver; radiation field

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高频电子设备在一个大型系统中愈来愈多,分布愈来愈密集,电子、电气设备机壳用于抵抗机壳内部的电磁场泄露以及来自机壳外部的电磁干扰,保护内外部电子设备,必须满足电磁兼容性(EMC)要求,同时还要保证设备正常的通风散热以使其正常工作,就需要在设备机壳上开孔以保证通风散热^[1-3]。如果设备机壳上的散热孔开设不当,一方面有可能设备自身内部产生的高频杂散信号通过机壳上的孔辐射出去造成对其它设备的干扰,另一方面又有可能通过孔缝使外部的干扰电磁场透入到设备机壳的内部空间,造成对自身电路的干扰,严重时影响到自身的正常工作^[4]。因此,研究如何在设备机壳开设合适的孔缝具有重要的理论意义和实际应用价值。

对机壳上孔缝的分析常用的是对机壳屏蔽效能的计算,屏蔽效能(Shielding Effectiveness, SE)是评价设备电磁兼容性的重要技术指标,其定义为没有屏蔽体时观测点的场强幅度与存在屏蔽体时同一观测点的场强幅度之比,以分贝表示为 $S_e = 20\lg(E_0/E_s)$ ^[5]。等效传输线法提供了一种设计者能够分析设计参数对屏蔽效能的影响、以及快速计算屏蔽效能的方法^[6]。Dehkhoda P 等提出了分析含孔阵矩形金属空机壳屏蔽效能的波导等效电路模型^[6]; W.P.David^[7]和 M.P.Robinson^[8]等提出了分析含单孔矩形金属机壳屏蔽效能及其内置物加载效应的等效电路方法。对机壳屏蔽效能的计算实质是对孔缝的场的计算,本文从常见的机壳上开设的矩形孔、圆形孔入手,应用解析方法对矩形孔、圆形孔所建的数学模型,对各种不同尺寸的孔缝进行了辐射场分析计算,并对其辐射场的强弱进行了分析比较,从而得出在机壳上开设孔缝的指导性结论。

1 理论分析

1.1 矩形孔的辐射场计算

设在一个平面上,有一矩形孔,尺寸为 $l \times w$, 建立图 1 坐标系,在孔外有一点 $P(R, \theta, \varphi)$, 矩形小孔缝的辐射场主要由衍射产生,从而可得矩形孔的衍射场为^[9]:

$$E_p = j \frac{ke^{jkR}}{4\pi R} (1 + \cos\theta) \int_{S_0} E_0 e^{jk(x'\sin\theta\cos\varphi + y'\sin\theta\sin\varphi)} dx' dy' \quad (1)$$

式中: (R, θ, φ) 为 P 点的球坐标; l 为孔长; w 为孔宽。转换成直角坐标为:

$$E_p = j \frac{E_0 \omega k e^{jk\sqrt{x^2+y^2+z^2}}}{4\pi(\sqrt{x^2+y^2+z^2})^2} \sqrt{x^2+y^2}$$

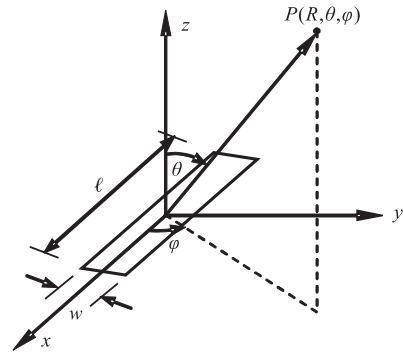


图 1 矩形孔示意图

Fig.1 Rectangular aperture diagram

1.2 圆形孔的辐射场计算

由文献[9]可得圆形孔的衍射场:

$$E_p = -j \frac{ke^{jkr}}{4\pi r} (1 + \cos\theta) E_0 S \frac{2J_1(ka \sin\theta)}{ka \sin\theta} \quad (2)$$

式中: J_1 为一阶贝赛尔函数; a 为孔半径; r 为空间场点到圆孔中心的距离; S 为圆孔的面积 $S = \pi a^2$, $k = 2\pi/\lambda$ 为传播常数。

2 计算实例

2.1 矩形孔的辐射场分布

将前述式(1)经过推导可得距缝隙中心 (x, y, z) 的 P 点处电场的表示式为:

$$E_p = \left| \frac{\omega l k e^{jk(x^2+y^2+z^2)^{\frac{1}{2}}} j \sqrt{x^2+y^2}}{4\pi(x^2+y^2+z^2)} \right| \quad (3)$$

算例 1: 波长 $\lambda = 3$ cm(X 波段), 缝长 $l = 10\lambda = 30$ cm, 距缝隙 $z = 10\lambda$ 处(30 cm) 处的电场分布见图 2。

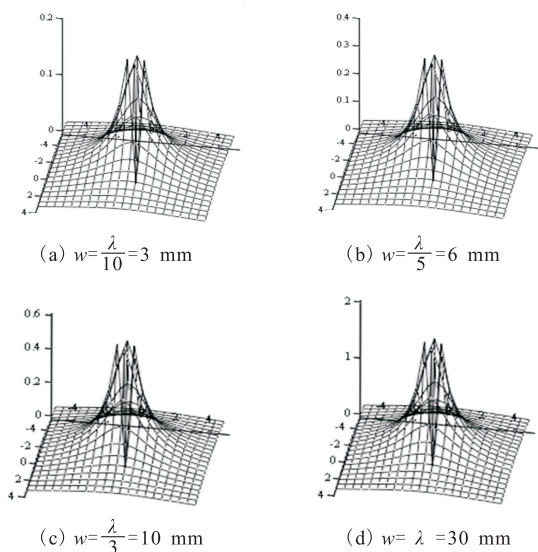


图 2 X 波段不同缝隙宽度时的辐射场

Fig.2 X band radiation field of different width aperture

算例 2: 波长 $\lambda = 5$ cm(C 波段), 缝长 $l = 10\lambda =$

30 cm,距缝隙 $z = 10\lambda$ 处(50 cm) 处的电场分布见图 3。

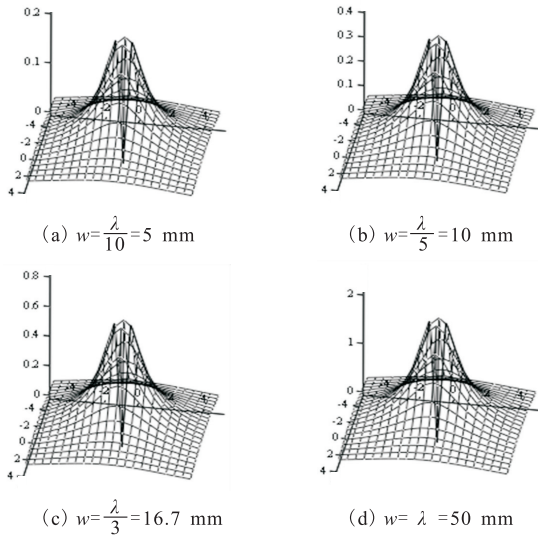


图 3 C 波段不同缝隙宽度时的辐射场

Fig.3 C band radiation field of different width aperture

算例 3:波长 $\lambda = 10$ cm(S 波段),缝长 $l = 10\lambda = 100$ cm,距缝隙 $z = 10\lambda$ 处(100 cm) 处的电场分布见图 4。

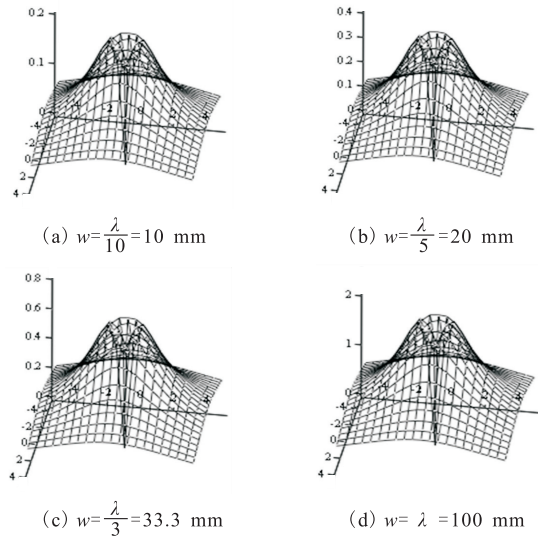


图 4 S 波段不同缝隙宽度时的辐射场

Fig.4 S band radiation field of different width aperture

从以上的分析计算可以看出,对于矩形缝隙来说,辐射场的最强方向在矩形缝平面的法线方向上,在一定波长和缝的长宽比一定时,缝越窄,辐射场越弱,辐射场的副瓣较多,且波束较窄;随着缝宽的增加,辐射场越来越强,副瓣越来越少,主瓣亦随之变宽。可见,要想获得方向性较高的辐射场,矩形缝就要开窄一些,但辐射场较弱;要想获得辐射场强但方向性差一些就要将矩形缝开宽一些;若二者要兼顾,就要进行折中优化考虑,选择矩形辐射缝合适的长宽尺寸。结论与文献[10~11]一致。

2.2 圆形孔的辐射场计算

式(2)经过推到可得圆形孔在空间的辐射场的幅度表示式为:

$$|E_p(\theta)| = \left| k \cdot e^{jkr} [1 + \cos(\theta)] \pi a^2 2J_1(ka \sin(\theta)) \frac{j}{4\pi rka \sin(\theta)} \right| \quad (4)$$

取工作波长 $\lambda = 3$ cm,距离圆孔圆心轴线上方 $r = 10\lambda$ 处的辐射场进行计算,分别计算不同圆孔半径下的辐射场分布见图 5(非归一化)。

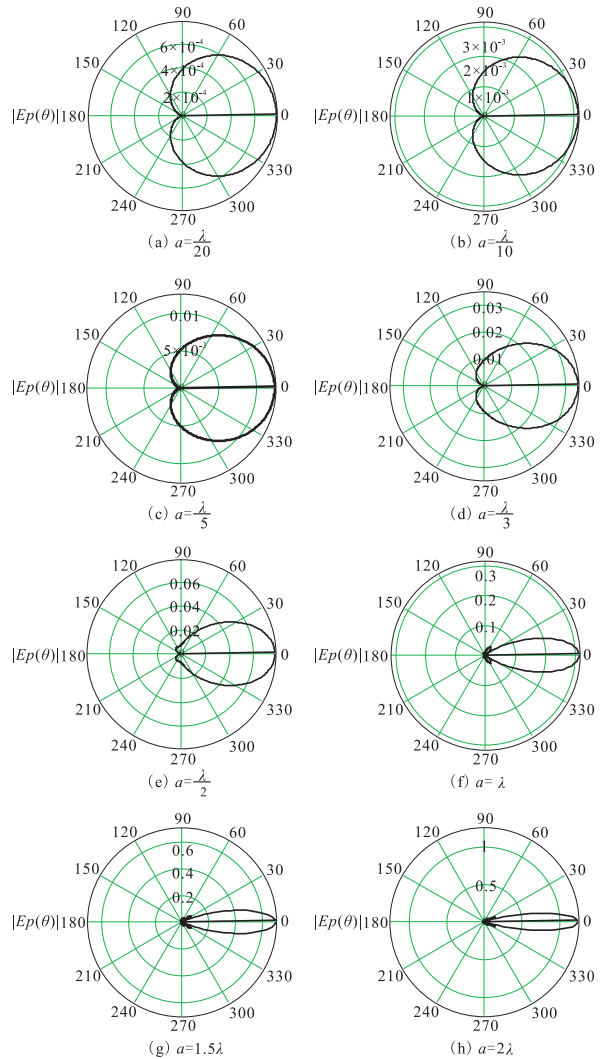


图 5 X 波段不同直径尺寸的圆形孔的辐射场

Fig.5 X band radiation fields of different diameter circular aperture

通过对不同半径尺寸的圆孔辐射场的分布图可以看出,圆孔的法线方向辐射场始终是最大的,在波长一定的情况下,圆孔的直径越小,辐射场越弱,圆孔直径越大,辐射场越强;在直径 $\le 1\lambda$ 的情况下,辐射场只有一个主瓣,没有副瓣,且随着直径尺寸的逐步减小,主瓣越来越宽,辐射场越来越弱;在直径 $\ge 1\lambda$ 的情况下,辐射场开始出现副瓣,且随着直径尺寸的逐步增大,主瓣越来越窄,辐射场越来越强;副瓣个数增多,但副瓣电平并不高。

3 结论

由以上的计算结果可以看出,要在电子设备的机箱上开散热孔,在已知外来电波频率的情况下,即在波长一定的情况下,所开的矩形孔的宽边尺寸应控制在 $w \leq 0.1\lambda$ 以下,矩形缝隙的尺寸越小越好,且缝隙的长宽比 l/w 越大越好。在开孔面积相同的条件下,圆形孔的辐射比矩形孔的辐射要小,所以尽量开圆形散热孔,开圆形散热孔时,孔的直径尽量控制在 $2a \leq 0.1\lambda$ 以下,此时孔的辐射比较小,对外部设备及对内部电路的影响比较小。

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