# A Remark on Antenna Self/Relative Clearance

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## 1. Introduction

This paper presents a discussion on antenna clearance to clarify the electrical size of small antennas. A request to miniaturize electrical products makes their components small and inexpensive. Passive components treated as lumped circuits have been miniaturized by the development of high dielectric/magnetic materials and the improvement of manufacturing process, while the antenna size reduction causes the degradation in antenna performance. Because the antenna should convert excited fields to propagating modes in free space and it is impossible to reduce the length of wavelength of electromagnetic fields. As an empirical rule of electrically small antennas, the size reduction causes decrease in radiation efficiency, directivity gain and frequency bandwidth [1]. However, we do not have a clear definition of electrical size for antennas. A physical volume of antenna is given by the product of patch area and its height for a microstrip antenna and by a volume of cylinder for a half wavelength dipole. This volume is easy to calculate for simple shaped antennas, while, we can not define it clearly for a bent-wire antenna or a loop antenna.

Another definition of antenna volume is a sphere surrounding antenna introduced by Chu to find the theoretical limit of small antennas [2]. This sphere radius $a$ is used under the condition of $ka < 1$ to evaluate the fundamental $Q$ factor, where $k$ is the wave number in free space. This sphere has been originally applied to very small antenna in LF or VLF band, and then is expanded to discuss the antennas of not satisfying the condition above. To apply this theory to wire antennas, a prolate spheroid was also examined to obtain the value of $Q$ [3]. A discussion by Chu was how to realize an ideal antenna lying totally within a spherical surface of radius $a$, which is equivalent to how to use efficiently the inside space of the sphere. A typical example to match for this requirement is a spherical shaped antenna [4] exhibiting a $Q$ that closely approaches the fundamental $Q$-limit. In these discussions, antennas are isolated and no electrical and physical obstacles are existed. Unfortunately, small antennas are integrated with other electrical components on a small substrate and their characteristics are seriously affected. To include these effects in the antenna design, we are forced to develop antennas by taking into the electrical obstacles placed in the vicinity of antennas. To obtain a general theory of the effect of electrical obstacles near antennas, variations in input impedance characteristics and radiation patterns are carefully investigated.

The author proposed a concept of antenna clearance to evaluate the above effects, focusing the variation in characteristics into the antenna input impedance [5]. The antenna clearance is defined as a distance to give a specified value of the impedance variation, for example, the variation ratio of 50% has been used. These distances are varied by the relative position between the antenna and electrical obstacle, the shape and electrical size of obstacle. Then the antenna clearance provides the minimum space surrounding the antenna to have a stable resonance, that means electrical obstacles should be placed out side the boundary defined by the clearance. On the other hand, the discussion on antenna $Q$ factor devotes the antenna performance without these obstacles. This is a major difference between two discussions.

In this paper, we define two kinds of antenna clearance as self-clearance and relative-clearance to evaluate the minimum space for the stable antenna resonance. This paper also presents several examples of the clearance and shows how large space is required for the antenna not affected by the electrical obstacles. The self-clearance of a short dipole is derived by the field expression of an infinitesimal current element and H and C shaped antennas are also examined numerically.

## 2. Definition of Self Clearance

As an electrical obstacle, we use a conducting wire with length $L$ and place near a test antenna as show in Fig. 1 (a) to define the relative-clearance and an identical shaped resonator without a feed for the self-clearance in Fig. 1 (b). In the presence of electrical obstacles, the antenna input impedance is changed and the variation ratio in input impedance is defined as,

$$\delta = \frac{|Z_i - Z_{if}|}{Z_{if}} \qquad (1)$$

where $Z_{if}$ is the antenna input impedance in free space and $Z_i$ is that in presence of the electrical obstacle [5]. The criterion of $|\delta|=0.5$ to define the antenna clearance is used throughout the paper in the following reason. If the $Z_{if}$ matches with the characteristics impedance of feeding transmission line, the $Z_i$ with $|\delta|=0.5$ increases the input VSWR (Voltage Standing Wave Ratio) up to 2. This VSWR is acceptable value to use small antennas. By neglecting the effect of feeding transmission line, an observation frequency is at series resonance of the test antenna and its radiation resistance is $Z_{if}$, where the radiation resistance coincides with the characteristics impedance of transmission line.

As the wire length $L$ for the relative-clearance, we adopt $L=0.5\lambda$ and $1.0\lambda$. The wire of $L=0.5\lambda$ is placed in parallel with a radiating element and that of $L=1.0\lambda$ is in parallel with non-radiating element as shown in Fig. 2 [5]. By moving the wire in the vicinity of the test antenna, we could draw the shape of clearance boundary. It often has a complicated shape because of the mutual coupling between the wire and radiating element of the test antenna which has a matching stub to obtain the impedance matching at an antenna feed position. For the simple discussion of the electrically occupied space of test antennas, we use the self-clearance evaluated by an electrical obstacle of identical shaped resonator with the test antenna in the following. The electrical obstacle of resonator has the same feed structure and gives a simple shape of clearance boundary which is larger than that of relative clearance.

As examples of test antennas, we use H/C-shaped antennas for test antennas which have matching stubs to obtain series resonances. The radiating elements of these antennas may be approximated as a short dipole, and then its self-clearance is derived here. Assuming the center fed short dipole with the length $2h$ and a same length conducting wire of $L=2h$ arrayed in parallel with the distance $d$, the input impedance of the dipole $Z_i$ is given by using the normalized mutual impedance $\hat{z}_{12}$ and the wave number in free space $k_o$ as follows.

$$Z_i = 1 - \hat{z}_{12}^2, \qquad \hat{z}_{12} = \frac{3}{2}\left\{\frac{u^2-1}{u^3} + j\frac{1}{u^2}\right\}, \qquad u = k_o d \qquad (2)$$

We used field expressions of an infinitesimal line current to derive above, which is easily found in text books. To normalize the impedance, we use a radiation resistance of short dipole, provided its reactance component is cancelled by an ideal matching circuit to obtain the series resonance. The impedance variation is given as $\delta = -\hat{z}_{12}^2$, and is shown as a function of $d$ in Fig. 3, and the distance of $\delta=0.5$ is $0.21\lambda$. In addition, the $\delta$ takes zero at $d=0.26\lambda$, where the strength of a radiation component is equal to that of the reactance components for the short dipole, that is $1/u = 1/u^2 + 1/u^3$.

The value of $0.21\lambda$ is a reference distance to discuss the self-clearance of the following other small antennas. Fig. 4 shows the placement of identical shaped resonators to evaluate the self-clearance of H-shaped antenna. We may consider an infinite number of combinations in these layouts, and have selected typical ones to simplify discussion here. Three placements are shown in Fig. 4 and the ones in negative regions along the x and z axes are excluded because of their symmetries. Both of the negative and positive regions in the y axis are shown to clarify the effect of feed probe.

## 3. Self Clearance of H/C-shaped Antennas

The value of $0.21\lambda$ is a reference distance to discuss the self-clearance of the following other small antennas. Fig. 4 shows the placement of identical shaped resonators to evaluate the self-clearance of H/C-shaped antenna. We may consider an infinite number of combinations in these layouts, and have selected typical ones to simplify discussion here. Four placements are shown in Fig. 4 and the ones in negative regions along the x and z axes are excluded because of their symmetries. Both of the negative and positive regions in the y axis are shown to clarify the effect of feed probe. Table 1 shows the distance of self clearance defined in Fig. 4, where the antenna height *2h* is changed as an evaluation parameter.

The distances of $d_x/\lambda$ in Table 1 are almost the same with that of the short dipole, which shows small antennas in Fig. 4 have the same clearance boundary for the identical resonator arrayed in parallel. In this layout, a test antenna coincides with a resonator in the yz plane. The minimum clearance distance is obtained by $d_y/\lambda$ for the C-shaped antenna because a feed probe hides from the resonator by a matching stub as shown in Fig. 4 (b). The clearances in Table 1 are calculated by taking the distance between feed probes, which are often larger than the reference clearance value of $0.21\lambda$. However, the spacings between the edges of antennas are smaller than this reference value as shown inside parenthesis in Table 1. In general, the self-clearance is larger than the relative-clearance, and then the above results show that the clearance of H/C-shaped antenna depends on the feed probe and its value is almost the same with the short dipole. We should consider the position of feed probe not to be disturbed by the electrical obstacle near the antenna.

## 4. Conclusion

This paper presented two kinds of antenna clearance to evaluate the minimum space for the stable antenna resonance. The relative clearance is evaluated by the conducting wire with length 0.5λ and 1.0λ, and the self clearance by the identical shaped resonator with the test antenna. As a reference of clearance distance, we showed an example of self-clearance for short dipole, which explained the clearance of H and C-shaped antennas dominated by the mutual coupling between feed probes. The antennas require the space in their surroundings and the clearance distance is 0.21λ evaluated by the short dipole. The visualization of clearance boundary and its physical explanation are left for the future problem.

## References

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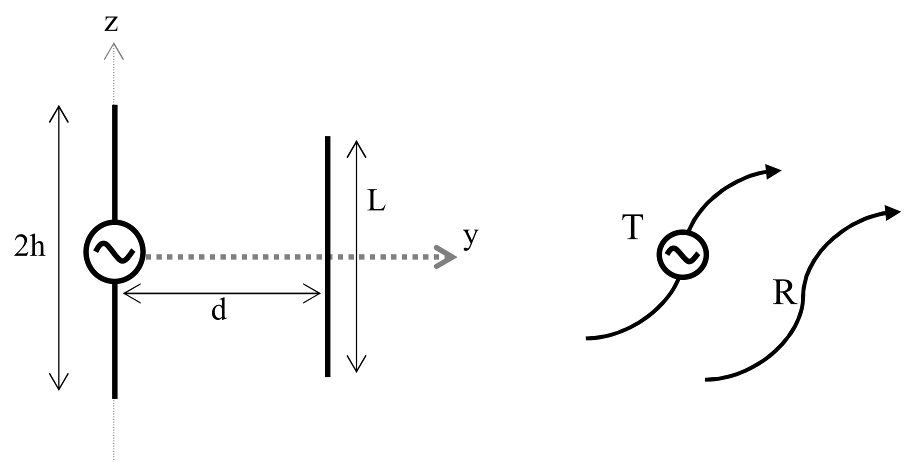
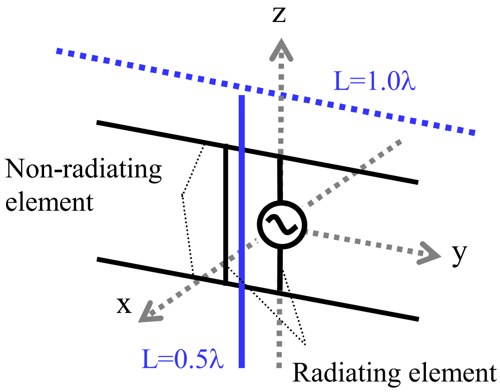



(a) Relative-clearance (b) Self-clearance

Figure 1 Electrical obstacle for antenna clearance



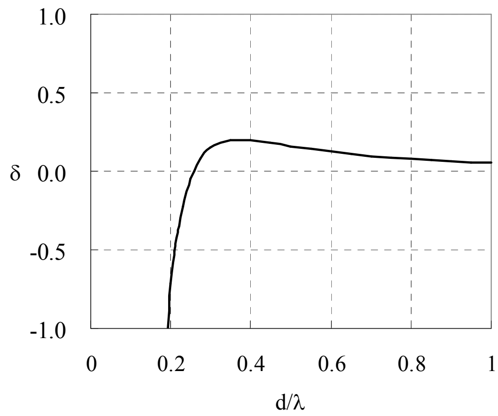
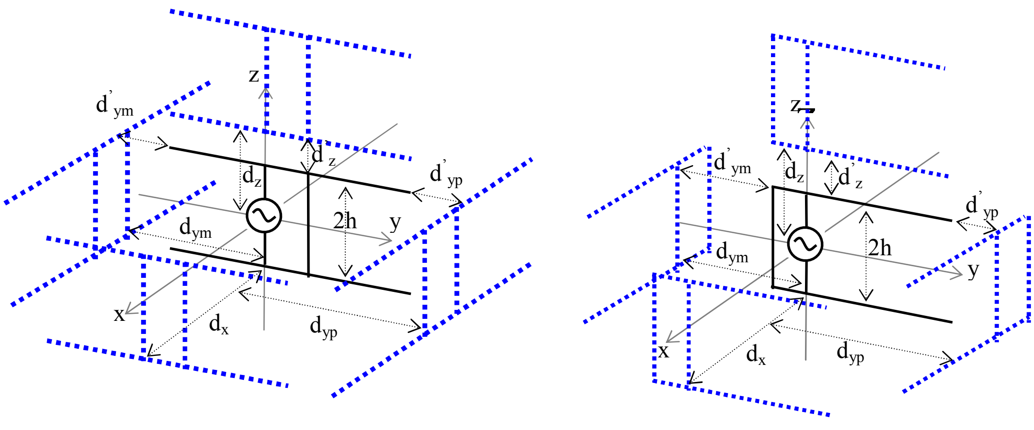




Figure 2 Wire arrangements for relative clearance

Figure 3 Impedance variation of short dipole




(a) H-shaped antenna

(b) C-shaped antenna

Figure 4: Resonator arrangements for self clearance

Table 1: Clearance distance of H/C shaped antenna
Inside parenthesis denotes $d'_{ym}$, $d'_{yp}$, $d'_z$, respectively

| H-shaped antenna | | | | | C-shaped antenna | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $2h/\lambda$ | $d_x/\lambda$ | $d_{ym}/\lambda$ | $d_{yp}/\lambda$ | $d_z/\lambda$ | $2h/\lambda$ | $d_x/\lambda$ | $d_{ym}/\lambda$ | $d_{yp}/\lambda$ | $d_z/\lambda$ |
| 0.10 | 0.21 | -0.31(0.12) | 0.27(0.08) | 0.25(0.20) | 0.10 | 0.22 | -0.18(0.17) | 0.36(0.16) | 0.21(0.16) |
| 0.13 | 0.21 | -0.31(0.14) | 0.27(0.10) | 0.29(0.22) | 0.12 | 0.22 | -0.18(0.17) | 0.34(0.15) | 0.21(0.15) |
| 0.15 | 0.21 | -0.30(0.14) | 0.26(0.10) | 0.26(0.19) | 0.15 | 0.26 | -0.18(0.16) | 0.36(0.18) | 0.21(0.13) |
| 0.17 | 0.21 | -0.29(0.13) | 0.26(0.10) | 0.26(0.17) | 0.18 | 0.21 | -0.17(0.14) | 0.37(0.20) | 0.21(0.12) |