

HOW DO YOU SELECT THE BEST ANTENNA FOR YOUR UWB SYSTEM?

Tharaka Dissanayake⁽¹⁾, and Karu P. Esselle⁽²⁾

⁽¹⁾ *CELANE, Department of Electronics, Macquarie University, NSW2109, Australia, tharaka@ics.mq.edu.au*

⁽²⁾ *As (1) above, esselle@ics.mq.edu.au*

ABSTRACT

In addition to impedance matching of the antenna, the stability of the radiation pattern in the operating frequency band is crucial to achieve good performance from a UWB system. How do you know your antenna pattern is stable enough for your UWB application? How do you pick the antenna that has the most stable pattern? To address these and several other related issues, we first define a new figure of merit – the pattern stability factor (PSF)- to quantify pattern stability of a wideband antenna. Then several practical UWB antennas are assessed from the stability point of view to demonstrate the use and advantages of the PSF in UWB system design.

INTRODUCTION

The FCC (Federal Communications Commission) in the USA has allocated the frequency band from 3.1GHz to 10.6GHz for ultra-wideband (UWB) communication, and telecommunication authorities in other countries are considering similar moves. When developing UWB antennas, matching its impedance (usually to a 50 Ohm transmission line) [1], is not the only challenge. It is important to have a constant or stable radiation pattern, in the operating directions of the antenna, within the entire band of operation. This is not easy to achieve even with non-dispersive antenna elements, and most practical antennas are far from ideal in this respect. Hence there is a need to define a quantitative measure to assess the pattern stability of various antennas for a given application.

In this paper we present a new figure of merit– the pattern stability factor (PSF)- to quantify pattern stability of a wideband antenna. It allows the UWB designer to compare different antenna choices and find the one with the best overall pattern. The PSF also helps one to identify quantitatively the stable angular range of an antenna for a given frequency range of operation, stable frequency bands of an antenna for a given angular range of operation, the improvement or deterioration of pattern stability when an antenna is integrated to a system, etc. Furthermore, in UWB system design and optimisation, the antenna is represented by a single transfer function, but the transfer functions of all wideband antennas depend on direction. Our theoretical analysis helps the UWB system designer to find the best transfer function of the antenna for system design and optimisation.

In the case of *dual band* antennas, a figure of merit can be defined by comparing two radiation patterns at two different frequencies, one in each band [2]. However, UWB antennas require comparison of multiple radiation patterns within a continuous band. Antennas can be characterised in the frequency domain with spatial radiation patterns or in time domain with concepts like fidelity or correlation patterns [3]. Recently in [4] time domain correlation energy and pulse energy concepts were revived to define parameters similar to traditional antenna gain. Using the concepts of antenna directional transfer functions [5], those values can be calculated in the frequency domain. As such calculations are directly related to pattern stability, we developed a correlation-based figure of merit in the frequency domain to define the pattern stability of antennas. Since the pattern stability of an antenna can then be given by a single value, called the pattern stability factor or PSF (which is another performance figure like the gain of an antenna), the antenna pattern stability bandwidth can be defined along with the impedance bandwidth. Then two antennas with the same impedance bandwidth can be compared for radiation performance. Furthermore, improvement or deterioration in pattern stability due to various modifications (such as integration of the antenna to a device or a metal case) can be quantitatively assessed.

Some UWB antennas may suffer from unstable radiation in certain directions while other directions are relatively stable. Unless a quantitative assessment is done, as detailed in this paper, engineers may not be able clearly distinguish between those two sets of directions. In addition, our analysis helps the UWB system designer to identify the best reference direction of the antenna. When the antenna is modelled by a single transfer function in UWB system design

and optimisation, the transfer function of the antenna in this reference direction should be used to ensure best overall performance in all directions of interest.

We shall develop the basis for the pattern stability factor (PSF) in the following section. An example application will then be given on the radiation analysis of a wide slot antenna presented in [6].

BASIS

In [3] correlation energy (U_C) and total energy (U_E) of a pulse are defined as:

$$U_E = \frac{1}{\eta} \int_{-\infty}^{\infty} |e(\vec{r}, t)|^2 r^2 dt \quad (1)$$

$$U_C = \frac{\left[\frac{1}{\eta} \int_{-\infty}^{\infty} e(\vec{r}, t) T(t) r dt \right]^2}{\int_{-\infty}^{\infty} |T(t)|^2 dt} \quad (2)$$

where η is the free space wave impedance, $e(\vec{r}, t)$ is the electric field in a position in the far field given by the vector $|\vec{r}| = r$ and $T(t)$ is the template function with which the correlation is calculated. Let the template be the radiated pulse in a selected direction \vec{R} , known as the *reference direction*. Now we can define a factor:

$$f^2(\vec{R}, \vec{r}) = U_C / U_E = \frac{\left[\int_{-\infty}^{\infty} e(\vec{r}, t) e(\vec{R}, t) dt \right]^2}{\int_{-\infty}^{\infty} |e(\vec{R}, t)|^2 dt \int_{-\infty}^{\infty} |e(\vec{r}, t)|^2 dt} \quad (3)$$

Note that a factor similar to $f^2(\vec{R}, \vec{r})$ can be defined and calculated in the frequency domain as:

$$F^2(\vec{R}, \vec{r}) = \frac{\left| \int_{BW} E(\vec{r}, f) E^*(\vec{R}, f) df \right|^2}{\int_{BW} |E(\vec{r}, f)|^2 df \int_{BW} |E(\vec{R}, f)|^2 df} \quad (4)$$

where BW stands for the bandwidth of the UWB system and superscript * stands for complex conjugate. The integral is real, especially for antennas with linear non-dispersive radiation. Note that maximum F^2 is reached when

$$E(\vec{r}, f) = K(\vec{r}) E^*(\vec{R}, f) \quad (5)$$

where $K(\vec{R})$ is a constant with respect to frequency. Equation (5), on the other hand is the condition of ideal pattern stability. Therefore, for an ideal pattern stable antenna, $F^2(\vec{R}, \vec{r})$ calculated for any two directions, one being a reference direction, will be unity. In other words for a pattern stable antenna it is possible to achieve 100% correlation energy in all directions, just by selecting the template function equal to the pulse radiated in a reference direction. Thus we define PSF as:

$$PSF = \frac{\int_{\Omega} C(\vec{R}) ds}{\int_{\Omega} ds} \text{ where, } C(\vec{R}) = \frac{\int_{\Omega} F^2(\vec{R}, \vec{r}) ds}{\int_{\Omega} ds} \quad (6)$$

where Ω is the angular range of operation of the antenna. This can be either a sphere surrounding the antenna or a segment of it. Integration is carried out over vectors \vec{r} for C and over the vectors \vec{R} for PSF. After the averaging processes in (6) it is obvious that if condition (5) is true for all the directions, the value of PSF is unity. Even though it may be impossible to achieve in practical UWB applications, we can consider it as a reference when assessing practical antennas. We name the function $C(R)$ in (6) as the frequency domain correlation pattern of the antenna. It represents how well the radiation in the reference direction R is correlated to all other directions within the angular range (Ω) and frequency range (BW) of the application. The direction for which $C(R)$ is maximum is the best reference direction of the antenna. In UWB system design or optimisation, when the antenna is simply represented by one transfer function, the transfer function in this direction should be used.

We can define the PSF bandwidth as follows. Note that within a sufficiently narrow frequency band, the radiation pattern of any antenna is stable. That is,

$$\lim_{BW \rightarrow 0} F^2(\vec{R}, \vec{r}) = 1; \quad \lim_{BW \rightarrow 0} PSF = 1 \quad (7)$$

We define the maximum bandwidth within which $PSF \geq \alpha (0 \leq \alpha \leq 1)$ as pattern stability bandwidth or a PSF bandwidth. Similarly a PSF beamwidth can be defined.

APPLICATIONS

The concept developed in the previous section is applied to the design of an integrated slot antenna previously presented in [6]. Two such antennas are as shown in the Fig. 1. One is on a finite planar ground plane where as the other is supported by sidewalls of 40mm ($Z=0$ to $Z=-40$) height on two sides.

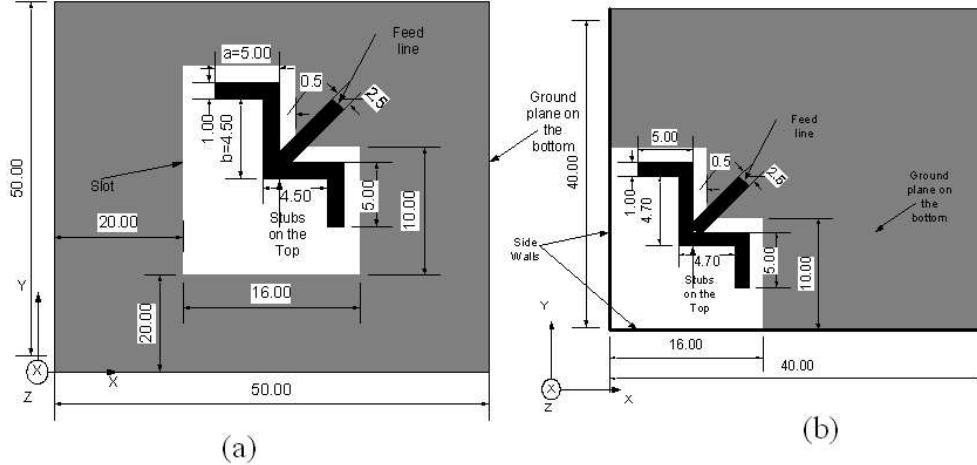


Figure 1. Wide slot antennas fed with a W-stub; a) on finite ground; b) with sidewalls.

Frequency domain radiation of the two antennas are shown in Fig. 2. Constant frequency cross section of these diagrams are radiation patterns as we have traditionally known. Similarly the directional transfer function can be obtained by considering a constant angle cut on the 3D plot. Obviously patterns have lost stability with the introduction of sidewalls, especially beyond 180 degrees. As a result we may also see that the coherence of transfer functions are lost beyond 180 degrees. Using above equations we can convert these observations into numerical values.

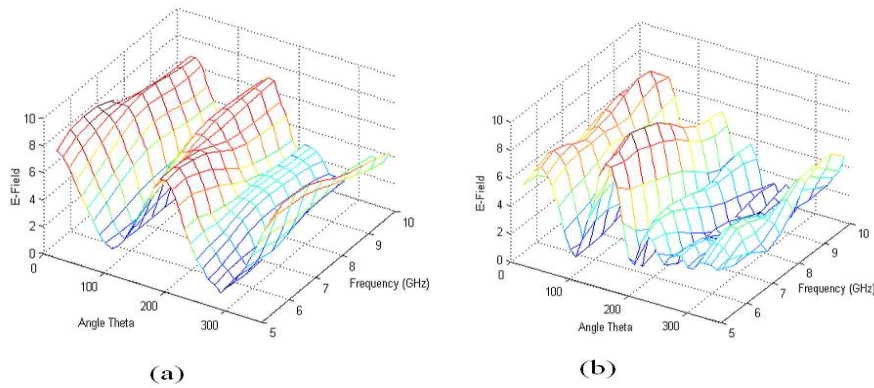


Figure 2. Space frequency E_0 radiation plots on the XZ plane; a) L slot; b) Modified L slot.

Table 1 show the operating bandwidths and PSF values for the E_0 components in the XZ plane. The introduction of sidewalls has reduced the PSF. When the operating angular range is limited to 180 degrees to avoid unstable regions beyond 180, the PSF increases as expected, for the antenna with sidewalls. Thus we can identify pattern stable beams for a given antenna using PSF.

Table 1. PSF values of slot antennas

Antenna	Bandwidth	Angular Span	PSF
L-slot	5.5-10GHz	0-360 Deg	0.941
Modified L-slot	5.5-10GHz	0-360 Deg	0.827
L-slot	5.5-10GHz	0-180 Deg	0.969
Modified L-Slot	5.5-10GHz	0-180 Deg	0.855

Based on (7) we calculated the 0.95 PSF bandwidth within the impedance matched band of the antennas and the results are presented in Fig. 3. (Value of α is selected as 0.95 in this case.) Obviously, the 0.95 PSF pattern bandwidth of the antenna with sidewalls, for an application that depends on E_0 from 0 to 360 degrees on the XZ plane, is always less than 1.5GHz. For the L slot antenna with planar ground, 0.95 PSF pattern bandwidth can be as large as 3.8GHz. Note that the linear relationship between the bandwidth and the lower limit of the frequency implies that upper limit of the 0.95 PSF band is bounded by the upper limit of the impedance-matched band (i.e. 10 GHz).

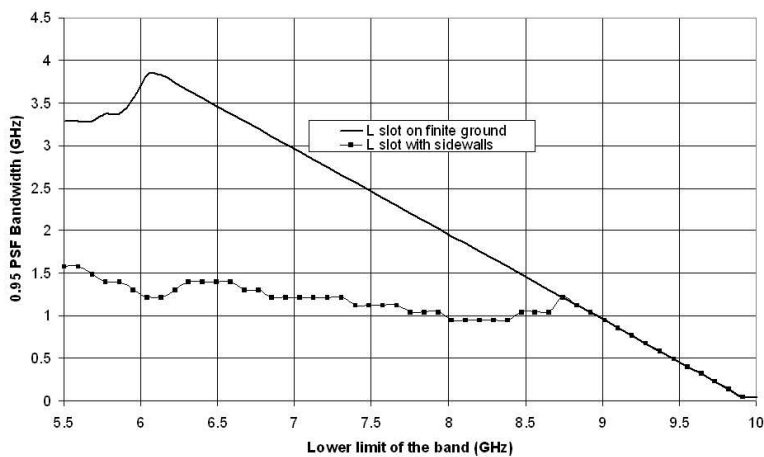


Figure 3. 0.95 PSF bandwidth for L Slot and Modified L slot

CONCLUSION

The pattern stability factor is useful in comparing different UWB antennas (considered for a given UWB application) as well as in assessing the effects of external modifications on antenna performance. It also shows how the selection of the operating angular range affects the pattern stability performance of an antenna. The PSF bandwidth gives the frequency range within which an antenna pattern behaves well within a given operating angular range, and the PSF beamwidth gives the angular range within which an antenna pattern behaves well within a given operating frequency range. The pattern stability analysis of two wide slot UWB antennas indicates that the changes to the ground plane, cases and metal walls etc can significantly alter not only the PSF but also the PSF bandwidth of an antenna. For antennas with relatively unstable patterns the radiation pattern bandwidth and impedance bandwidth can be quite different.

REFERENCES

- [1] Tharaka Dissanayake, Karu Esselle, and Yuehe Ge, "A Printed Triangular-Ring Antenna With a 2:1 Bandwidth", *Microwave and Optical Technology Letters*, Vol. 44, No. 1, January 5 2005, pp. 51-53.
- [2] Juan M. Rius, Maria C. Santos, and Josep Parron, "Figure of Merit for Multiband Antennas", *IEEE Transactions on Antenna and Propagation*, Vol. 51, No. 11, November 2003, pp. 3177-3180.
- [3] David Lamensdorf, and Leon Susman, "Baseband-Pulse-Antenna Techniques", *IEEE Antenna and Propagation Magazine*, Vol. 36, No. 1, February 1994. pp. 20-30.
- [4] James S. McLean, Heinrich Foltz, and Robert Sutton, "Pattern Descriptors for UWB Antennas", *IEEE Transaction on Antenna and Propagation*, Vol. 53, No. 1, January 2005, pp. 553-559
- [5] B. Scheers, M. Acheroy, and Vander Vorst, "Time Domain Simulation and Characterization of TEM Horns Using a Normalized Impulse Response", *IEE Proceedings on Microwave Antennas & Propagation*, Vol. 147, No. 6, December 2000, pp. 463-468.
- [6] T. Dissanayake, K. P. Esselle, Yuehe Ge, "Integrated compact ultra-wideband L-shaped wide slot antenna", (submitted and accepted) Asia Pacific Microwave Conference, December 2005.