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# Design Optimization of an Enhanced Stop-band UWB Bow-Tie Antenna

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## Abstract

An improved design of Ultra Wide Band(UWB) Bow-Tie antenna, which can control an enhanced wide stop-band, is presented. The mutually coupled slot-pair improves and controls the rejection band. The UWB antenna is composed of an electromagnetically coupled Bow-Tie patch and a parasitic ground patch, whose working frequency is extended to full UWB range in this work. By adding slot-pairs on the main patch and optimizing, they can give any requested wide rejection bands and sharp skirt characteristics, as is often required for UWB antennas and multi-band antennas. All the parameters are precisely calculated by an adequate optimization method. The Particle Swarm Optimization(PSO) technique is appropriately adopted. The proposed design and method is proved to give and control the sharp-skirt wide stop-band to UWB Bow-Tie antennas.

*Key words : Antennas, Band Stop characteristics, UWB(Ultra Wide Band), Bow-Tie Antenna, Optimization*

## Ⅰ. Introduction

The UWB technology is very useful in IoT application for the shortage of free frequency range in these days. The UWB antenna is required to work in a wide-band (3.1-10.6 GHz), but there are several other existing services which occupy frequency bands within the UWB bandwidth. A few examples of hostile systems are WiMAX (3.3 - 3.7 GHz), Wireless LAN 5GHz (5.15 - 5.825 GHz) and ITU 8 GHz (8.025 - 8.4 GHz) band. A multi-band system also deals with a wide frequency band and has to have stop-bands to filter out non-service bands to avoid interferences. The stop-band is a rather wide range and needs a sharp-skirt gradient for a better quality. Several UWB antennas with band rejection characteristics have been proposed [1]-[5], but the skirt property was not fully considered.

In this paper, we propose a novel Bow-Tie Antenna (BTA) which has a wide sharp-skirt rejecting band property and is operated in a full UWB range. By embedding two horizontal parallel resonant slots as a pair and adjusting the dimensions of the slots and the mutual coupling values between them, the characteristics of the notch response, such as the center frequency and

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the band rejection skirt gradient, can be controlled. Therefore, the optimized slots can give the required wide rejection band and sharp skirt characteristics, as is often required for UWB antennas and multi-band antennas, compared to the conventional one with one slot or no one. This technique allows a wideband antenna to be a multi-band antenna, and many systems to be compactly designed without adding extra components such as notch filters. There reside so many design factors, so that a proper design tool is needed to handle them. The Particle Swarm Optimization (PSO) is utilized to optimally determine the parameters [6]. And the PSO is successfully applied to enhancing the operating frequency range too.

## II. Design Process

### 2.1. Primary Research

The first wide-band BTA model is based on the previous work [7] as illustrated in Fig. 1. The antenna is composed of an electromagnetically coupled Bow-Tie patch and a parasitic ground patch. The Bow-Tie patch needs to be fed by direct or proximity coupling. A proximity coupling from an embedded feed line within the substrate gives better bandwidth than a direct coupling [8]. The antenna, with a width W = 22 mm and a height H = 22 mm, is constructed on a Taconic RF60-A substrate of which thickness of 0.64mm, dielectric constant of 6.15 and loss tangent of 0.0028. It is fabricated and mounted on a rectangular finite (80 x 80 mm) ground plane. A 50 Ω SMA connector, centrally mounted from the back of the ground plane, is used to excite the antenna.

The return loss characteristics are shown in Fig. 2. But the model did not provide the full UWB range (US FCC : 3.1~10.6 GHz) even for variety changings of design parameters.

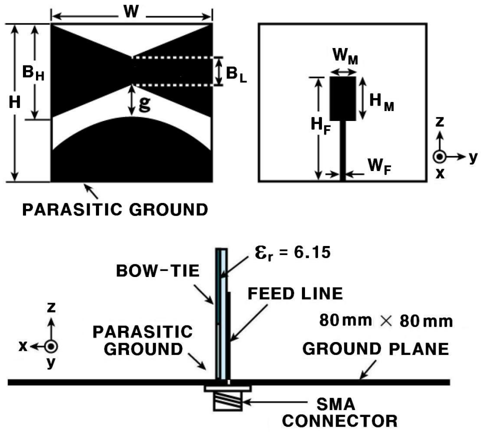



Fig. 1. The base model of the Bow-Tie antenna.

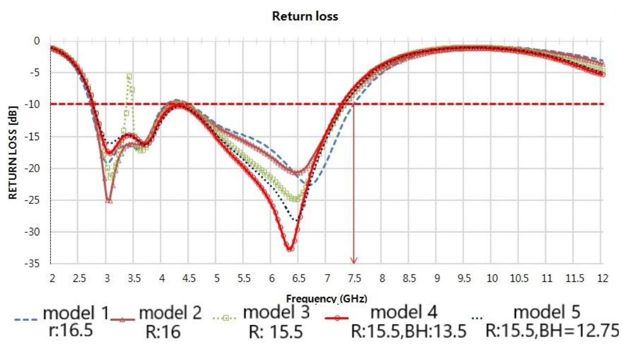
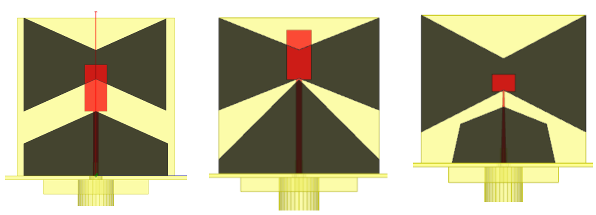



Fig. 2. The return loss characteristics of model in Fig. 1.

Thus, the primary research is focused on finding a full range Bow-Tie base model for UWB application. The several test models and their return loss graphs are shown in Fig. 3 and 4. Among the test models, only the model in Fig. 3 c) gives a feasible result, which can sustain the return loss under -10dB for the whole UWB range as shown in Fig. 4 c). Then, we try to calculate the optimal parameters for the model c) in Fig. 3.

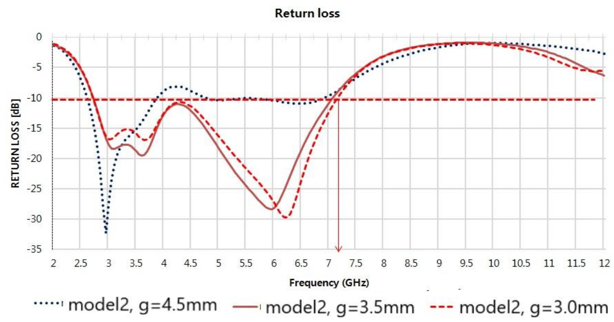


a) A BTA with parallel slant ground

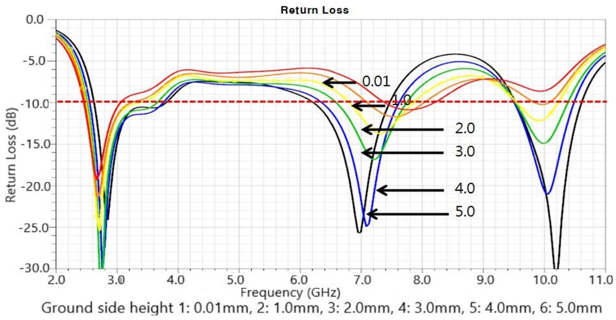
b) A BTA with aslant ground

c) A BTA with cut-off Ground

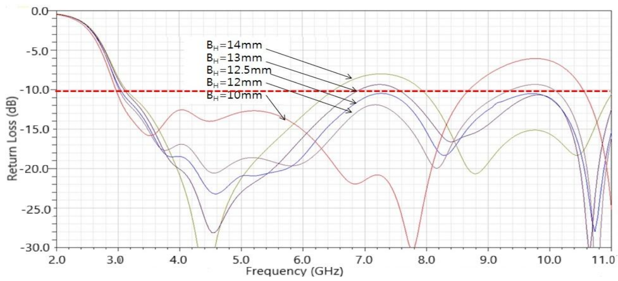
Fig. 3. The Bow-Tie antenna (BTA) models under test.




a) The return loss graph of model a) for ground-patch gap variation




b) The return loss graph of model b) for ground side variation




c) The return loss graph of model c) for the patch & the ground variation

Fig. 4. The return losses of the test models of Fig. 3.

### 2.2 Optimal Design of UWB Base for BTA

The design variables are $B_H$, $B_L$, $W_m$, $H_m$, $W_{f1}$, $W_{f2}$, $H_f$, $g$, $H_G$, $S_G$ and $W_G$ which are the side-height and the neck-width of main patch, the width and the height of feed plate, the width of tapered feed line, the height of feed line, gap between the main patch and the parasitic ground, the width of the shoulder width, the height from the shoulder and the bottom width of the parasitic ground as shown in Fig. 5. The feed line width is tapered to match the feeding connector, but it also affects the performance of antenna.

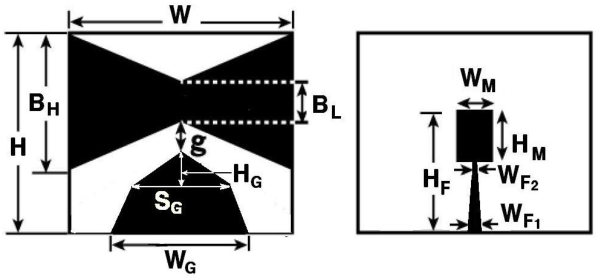



Fig. 5. The design parameters for UWB Bow-Tie Antenna Base.

The design variables are optimized by PSO with the fitness function (1)

$$F_1(\vec{x}) = \begin{cases} \int_{f_1}^{f_2} (s(\vec{x}, f) - s_1)^2 \, df & if \;\; s > s_1 \\ 0 & if \;\; s \le s_1 \end{cases} \qquad (1)$$

where s(·) denotes the return loss at the defined frequency f, s1 the upper limit and x is the vector of design variables. The fitness function is defined in bandwidth basis. It is more useful than the conventional one of the point form formulation, for it is easier to comprehend that the values do not exceed the limit over the whole band. And the values which are already satisfied the requirement may produce too much value to the integral one, it should be adjusted to a proper amount in the manner of minimizing the objective function. As a numerical treatment, we let the calculated value to 0 when it satisfied the required limit as (1). It provides more controllable band adjustment and less iteration to PSO. The PSO algorithm is implemented in Visual Basic, and connected to HFSS[9] for the Finite Element analysis of antenna. The frequency range marks the full UWB range as $f_1$ = 3.1 GHz and $f_2$ = 10.6 GHz. The converged solution denotes a good agreement with the purpose as shown in Fig. 6 where the measured values are also shown together. The final values of design parameters for the UWB basement are presented in Table I. Note that the whole size of the BTA is decreased according to the final values.

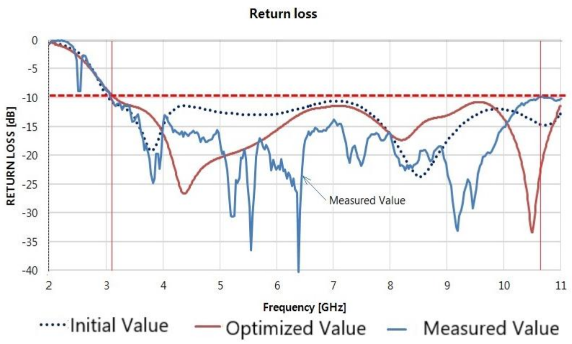



Fig. 6. The return loss of the finally optimized design for the 3c) basement of Bow-Tie antenna, which satisfies the full UWB range operation.

### 2.3. Implementation of the stop band

To add a band-stop property to the BTA, parallel slots are installed on the main patch of the BTA.

The band reject operation is achieved when the length of the embedded slot is approximately one-half wavelength of the desiring rejection frequency. A slot-pair which consists of two adjacent horizontal resonant slots is added to the original model to enlarge the width of the stop-band and enhance the property of the band. The each slot of the slot-pair has slightly different length to enlarge the bandwidth of the stop-band.

TABLE Ⅰ. The Parameters of UWB antenna basement [mm]

| parameter | value | parameter | value | parameter | value |
|---|---|---|---|---|---|
| $B_H$ | 11.2 | $W_{F1}$ | 0.1 | $H_G$ | 3.9 |
| $B_L$ | 6.92 | $W_{F2}$ | 0.69 | $S_G$ | 15.48 |
| $W_m$ | 2.57 | $H_f$ | 9.86 | $W_G$ | 21.74 |
| $H_m$ | 3.96 | $g$ | 0.1 | | |

The merit of combining two slots is obvious as shown in Fig. 7. The one-slot systems (denoted by dotted line) have a very narrow stop-band or a very wide slack edge compared to the two-slot system, as expected. The gain of the antenna with two slots has two rejection peaks and is reduced steeply at the border of rejection bandwidth, compared to the antenna using one slot. It is clear that the proposed antenna provides improved band rejection characteristics with the wider rejection bandwidth and sharp skirt characteristics. Considerable enhancement of the coupling between slot resonators and improvement of the magnitude difference of two notch peaks are observed when the slots are closely placed to each other. But the additional components also affect the mutual combination characteristics of the slots.

The band rejection characteristic is improved by inserting additional small slots in the center of the band-notch slots. The coupling decreases as the size of the inserted center slot becomes larger. We could find also that the rejected center frequency barely moves when the gap between resonators is varied, but its movement depends on the height of the inserted slot more. The submerging feature is shown in Fig. 8 and it comes from various factors.

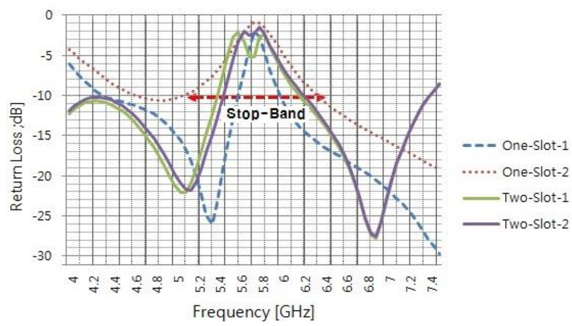
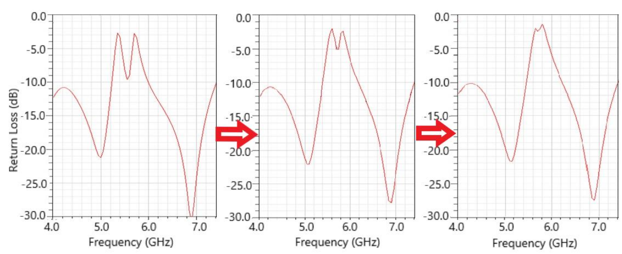



Fig. 7. Comparison of the one-Slot notch filter and the Two-Slot one.




a) $g_s$:0.4,$H_c$: 0.5 $W_m$: 0.24 mm b) $g_s$:0.3,$H_c$: 0.5 $W_m$: 0.24 mm c) $g_s$:0.3, $H_c$: 0.5 $W_m$: 0.20 mm

Fig. 8. The submerging effect of two adjacent single notch filters (Parameters are denoted in Fig. 9.).

Thus, we must define new design variables and manipulate together using an optimization method. The shape of the insert slot is as shown in Fig. 9. The design variables are defined as $H_S$,

$H_C$, $W_S$, $g_S$, $L_{S1}$, and $L_{S2}$ which are the position of the upper slot from the top of the main patch, the height and the width of center notch of the slot, the gap between two slots and the lengths of the two slots respectively.

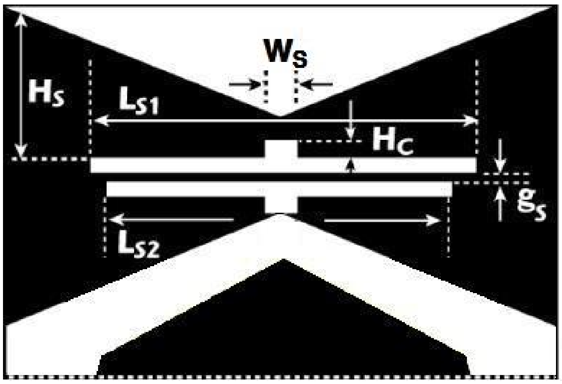



Fig. 9. The design parameters for a slot-pair.

The fitness function is defined as a multi-band basis[10] for this stop-band installation as (2).

$$F_2(\vec{x}) = w_1\int_{f_1}^{f_2} S_U(\vec{x})df + w_2\int_{f_3}^{f_4} S_L(\vec{x})df + w_3\int_{f_5}^{f_6} S_U(\vec{x})df$$

$$S_U(\vec{x}) = \begin{cases} (s(\vec{x},f)-s_U)^2 & if\ s > s_U \\ 0 & if\ s \le s_U \end{cases}\Bigg|_{band1,3} \quad (2)$$

$$S_L(\vec{x}) = \begin{cases} (s(\vec{x},f)-s_L)^2 & if\ s < s_L \\ 0 & if\ s \ge s_L \end{cases}\Bigg|_{band2}$$

The upper limit of return loss $s_U$ for operating band 1 and 3 is set to -12dB and the lower limit $s_L$ for notch band 2 to -8 dB for the test. The band frequency positions are set to $f_1$ = 3.1 GHz, $f_2$ = $f_3$ = 5.1 GHz, $f_4$ = $f_5$ = 5.9 GHz and $f_6$ = 10.6 GHz in this case. The weighting factors $w_1$, $w_2$ and $w_3$ are the inverse of the each bandwidth respectively for normalization.

The solution is converged in a few iterations for the optimizing scheme was split in two procedure of enhancing the working frequency band and the stop-band to have less design parameters as accomplished in the sub-session B & C.

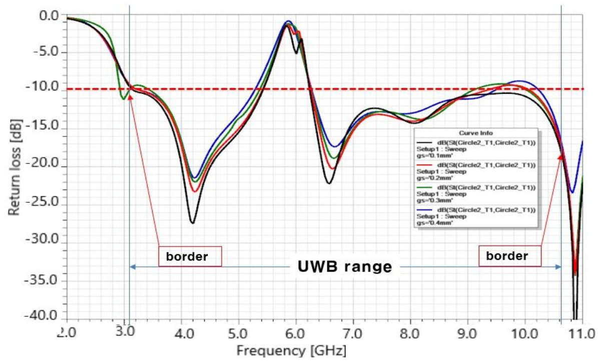



Fig. 10. Variations of return loss by slot-pair and parameters change.

The appropriateness is also obvious in Fig. 10 that the UWB borders of working frequency are barely changed as the new design variables are varied. Thus, it is quite reasonable to separate the design procedure into two categories, i.e. 1) Widening the working range and 2) Controlling & Enhancing the stop-filter property.

We placed 15 particles only and gave humble initial data producing bad return losses as shown in Fig. 11 for a sample. But it is converged to an acceptable range within only 8 iterations. The converged value of the design parameters are shown in Table II and the resultant return loss is also shown in Fig. 11 with the radiation patterns as Fig. 12.

TABLE II. The Parameters of Band-Stop UWB Antenna [mm].

| parameter | value | parameter | value | parameter | value |
|---|---|---|---|---|---|
| $H_S$ | 4.0 | $W_S$ | 1.0 | $L_{S1}$ | 16.0 |
| $H_C$ | 0.95 | $g_S$ | 0.18 | $L_{S2}$ | 13.86 |

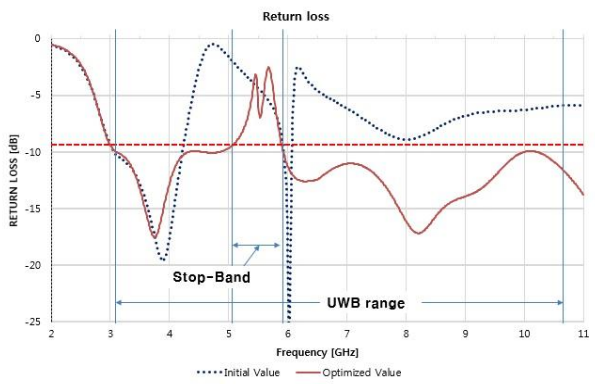
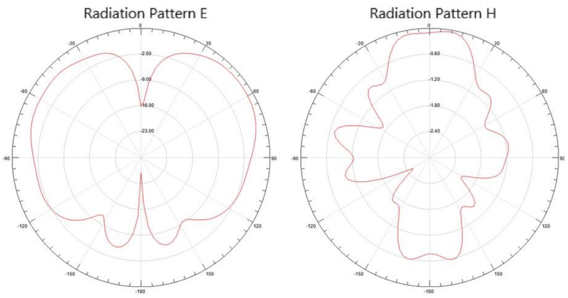



Fig. 11. The return losses of the initial and the converged design.




a) E-Field Pattern b) H-Field Pattern

Fig. 12. The radiation pattern of proposed antenna.

Note that the stop-band is moved and installed at desired band position exactly. The values of the return loss at skirts are little bit risen because the limit was set as -8dB rather than -10dB. You can control the border by adjusting the limit values $s_U$ and $s_L$, and the band intervals $f_1, \cdots, f_n$. The radiation pattern is almost same with no-slit cases. The measurement result from a proto-type fabrication is presented in Fig. 13.

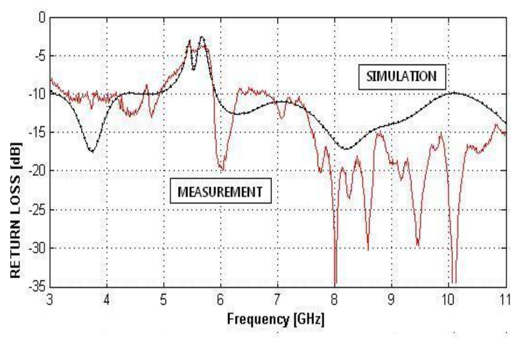



Fig. 13. Comparison between the simulation result and the measurement.

## Ⅲ. Conclusion

A full range UWB Bow-Tie antenna which has an enhanced wide stop-band is developed using PSO optimizing technique. The conventional Bow-Tie structure is re-constructed to have wider range operation and the design parameters are obtained successfully using the optimization procedure with band-basis fitness function. The broad rejection band is installed by embedding two horizontal resonant slots and adjusting their mutual coupling, which takes two-pole response and improved notch skirt characteristics. All the parameters are optimized using PSO algorithm. The fitness function is developed as a multi-band type to define the width of stop-band distinctly. The results satisfy the design goal satisfactorily. The proposed technique will be useful in improving and/or controlling the band rejection characteristics of wideband antennas for many applications including UWB and multi-band systems.

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