Feasibility Study on Utilization of Stub Loaded Miniature Monopole Antenna for Forwards Scattering Micro-Radar (FSR) Network Project

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***Abstract*—A feasibility study on concept of stub loaded miniature dual band VHF/UHF antenna design is proposed in this research. The main application of the antenna is purposely for the Forward Scattering Micro-Radar (FSR) network project which had been carried out by some other researchers from University of Birmingham during the last few years. The simulation result of the miniature antenna design by using the Computer Simulation Technology (CST) Studio Suite software will be analyzed and performance analysis will be conducted by comparing with the Commercial Off-The-Shelve (COTS) antenna which had been used before for the prototype of the sensor network. The performance parameter which would be evaluate consists of the operating frequency, the wavelength, return loss (S_{11}), antenna gain, beamwidth, line impedance and Voltage Standing Wave Ratio (VSWR). The result obtained from both execution of Genetic Algorithm (GA) optimization and Parameter Sweep analysisis presented and conclude by future work recommendations for the continuity of this research.**

***Keywords*—A**ntenna miniaturization, Genetic Algorithm (GA) optimization, parameter sweep, VHF/UHF antenna.

I. INTRODUCTION

The utilization of the wireless sensor network has been growth extremely for the last few decades comprising a number of unattended sensors for wide area surveillance and monitoring. Such networks have found applications in monitoring environmental, meteorological and seismic parameters, tsunami and volcanic activities, facilities and road traffic control, alarm systems and remote asset monitoring, as well as other commercial applications. For these applications, different physical principles (acoustic, seismic, thermal, magnetometer, electromagnetic, optical, biological, chemical, etc.) are typically used in the network sensors. The capability of modern sensors to detect ground targets has increased interest in the development of a sensor network for defense applications such force and perimeter protection, border security and situational awareness.

Motivating from that factor, a research on a ground-based micro-sensor Forward Scattering Radar (FSR) network for situational awareness in [1] and [2] has been conducted at the University of Birmingham during the last few years. The network has been developed to detect and classify ground targets such as personnel on foot and vehicles entering the network coverage area. In this ad hocwireless network each sensor (node) has a separate receiver and transmitter with omni-directional antennas, so that the transmitted signals are received by neighboring nodes, creating the netted forward scatter radar configuration.

Based on the conceptual experiment which had been done before, there was a significant need of the dual frequency miniature VHF/UHF monopole antenna to optimize the operational of the sensor radar network as a whole. The objectives of this paper are to investigate and analyze the key factors which significantly could influence the performance of the stub loaded miniature monopole antenna. By running the GA optimization method and Parameter Sweep analysis, the sectional structure of the antenna will be identified based on the $S_{11}$and the VSWR output data. At the end of this paper, there will be an extensive analysis and several recommendations that need to be considered is proposed in designing more comprehensive dual frequency miniature VHF/UHF monopole antenna.

II. ANTENNA DESIGN CONCEPT

The basic parameters that need to be considered in designing the antenna is the operating frequency, the wavelength, return loss, antenna gain, beamwidth and Voltage Standing Wave Ratio (VSWR) which all closely related to the applications. The concept of FSR that had been introduced in [1] and [2] was to have a small size monopole antenna with an omni-directional radiation pattern which could establish the communication network between the nodes of sensor network among the coverage area. Due to uneven surface of the ground, the sensor should probably need to have multiple antennas which only one unit will operate during activation.

The unique method on designing the miniature multiband monopole antenna as shown in Figure 1 had been introduced in [3]. The approaches to miniaturization the antenna design by developing new methodology that applies a robust Genetic Algorithm (GA) optimization technique to perform a novel designs for miniature multiband whip-type antenna. Base on the result in [3], by adopting GA techniques, the size of the monopole antenna design could be reduced approximately down to 30%.

The optimization technique which has been introduced in [4] is proposed to be implemented in this project. By utilizing GA technique, a number of selection strategies have been developed in [4] will be utilized for optimization. These strategies are generally classified as either stochastic or deterministic. GA technique differ from other conventional techniques in that 1) they operate on a group (or *population*) of trial solution in parallel, 2) they normally operate on a coding of the function parameters (*chromosome*) rather than on the parameter themselves, and 3) they use simple, stochastic operators (*selection*, *crossover* and *mutation*) to explore the solution domain in search of an optimal solution. Several of the more important and most widely used of these selection strategies will be adopted for this project.

In [5], the miniaturization technique has been discussed and there were several limitations of antenna miniaturization with respect to their gain, bandwidth, and antenna size. The radiation characteristic is the most importance properties that most of the antenna engineer try to manipulate and have to compromise.

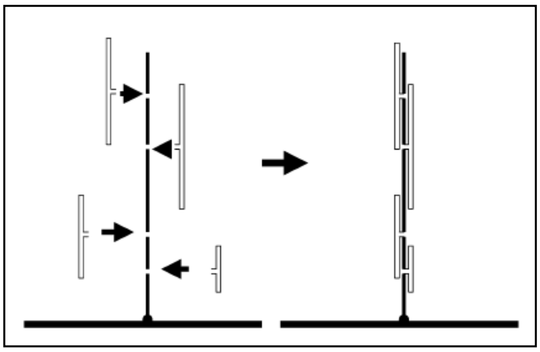


Figure 1: Stub-loaded miniature whip antennas.

III. DESIGN METHODOLOGY

Figure 2 below show the flow chart of the antenna design procedure followed by the simulation and their data analysis.

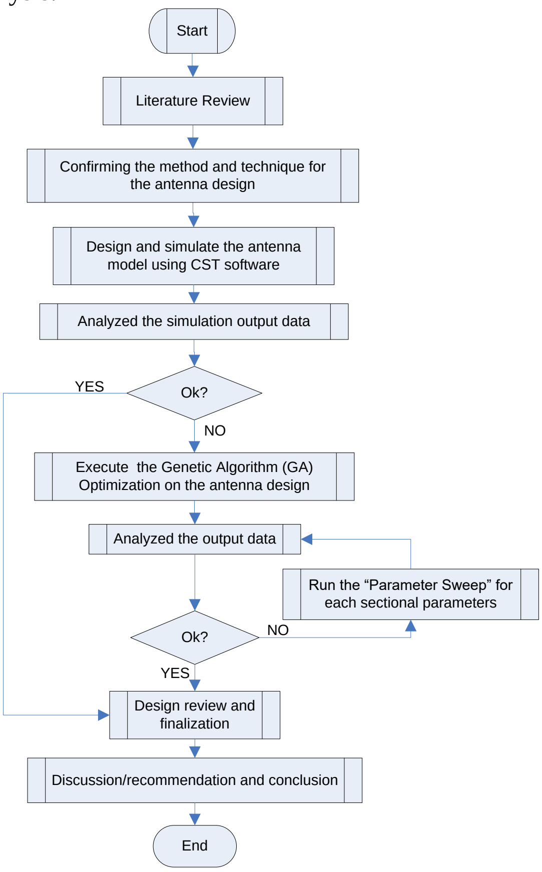
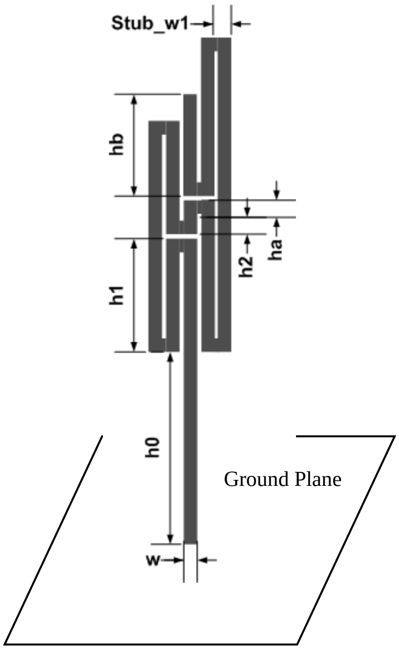


Figure 2: Design flowchart

The extensive of literature review had been carried out and the design of the miniature stub loaded VHF/UHF monopole antenna has been finalized. By using the CST software, the antenna design has been adapted with several parameters setup and followed by simulation process. The GA optimization and parameter sweep analysis has been executed before final result being compiled and analyzed. The performance analysis is discussed in detail and some recommendationshad been made as a conclusion.

A. Antenna design and geometry

The proposed antenna consists of a combination of the conventional monopole antenna and the 2 stub designslots as shown in Figure3. The material characteristics that had been used in the design are shown in Table Iand the design objectives is shown in Table II.



*t = thickness of the antenna strip

Figure 3: Stub-loaded miniature antennastructure

TABLE-I MATERIAL CHARACTERISTICS

NO.	COMPONENTS	MATERIAL
1	Antenna and stub	PEC
2	Ground Plane (finite) 500 mm x 500 mm	copper (annealed)
3	Port Design	SMA Type

TABLE-IIANTENNA DESIGN OBJECTIVES

NO.	PARAMETER	DESIGN GOALS
1	Center frequency (MHz)	151 and 434
2	Return loss , S11 (dB)	<-10
3	VSWR	<2
4	Line impedance (Ω)	≈50
5	Gain (dB)	>3
6	Total length (cm)	<50

The overall structure of the stub loaded antenna had been divided into 8 sub elements (parameters) which each of the parameters had been analyzed by using the CST software. The identified cut-off frequencies which been set for this analysis were 151 MHz (VHF band) and 434 MHz (UHF band). The frequency range which been set in the analysis was from as minimal as 100 MHz to a maximum frequency 450 MHz.

B. Simulation setup

This section will discuss the result from the simulation process which been done by the CST software. It will be divided into two parts which consist of the "Genetic Algorithm (GA) Optimization" phase in the first part and followed by the "parameter sweep" phase. The parameter setting for both analyses is shown in Table III. The final parameter obtained after finalization by executing the GA optimization was indicated in original column.

For the GA Optimization phase, the analysis was focus on the antenna performance once the optimization had been finalized. There were four basic parameters will be discuss in this phase which are the return loss (S_{11}), Voltage Standing Wave Ratio (VSWR), farfield analysis and the line impedance.

For the parameter sweep phase, there were two basic parameters of the antenna performance that will discuss which are the return loss (S_{11}) and the Voltage Standing Wave Ratio (VSWR). The process of the parameter sweep had been run independently on each of the parameters.

TABLE-III PARAMETER SETTING

PARAMETER	PARAMETER SWEEP SETTING (5 samples for each parameter)		
	Min (mm)	Max (mm)	Original (mm)
h0	215	235	227.5
h1	57.5	77.5	67.5
h2	3.5	11.5	7.5
ha	5	15	11.875
hb	10	40	23..625
Stub_w1	1	9	5
t	0.2875	1.0875	0.6875
w	0.4	1.2	1.6667

IV. RESULT

There are two phases of the analysis that had been carried out in this paper which consists of:

A. Genetic Algorithm (GA) optimization

The main objective of the GA optimization process is to obtain the best 8 parameters setup which been indicate before to archived the design goals of this project. The base line for the S_{11} is -10dB while for the VSWR is 2:1 at both operating frequencies. Figure 4 show the result obtained from the CST output data based on the design goals stated in previous section.

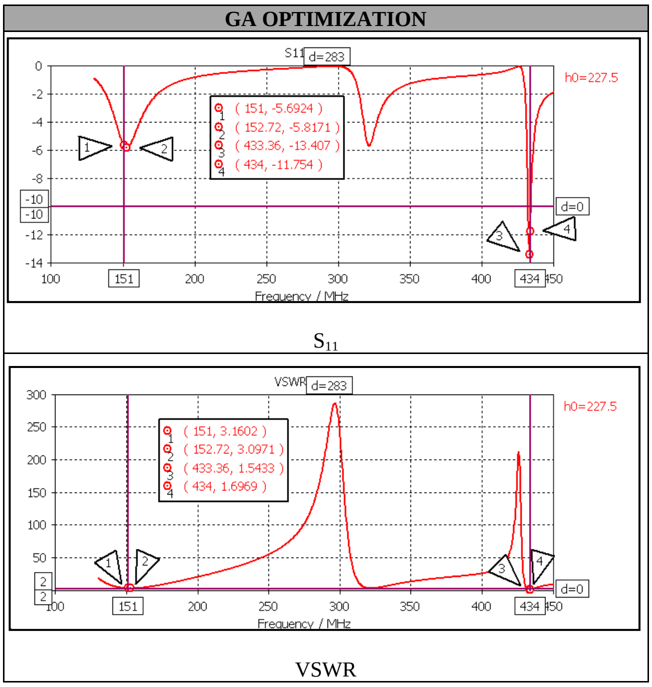


Figure 4: S_{11} and VSWR of GA optimization

From Figure 4, the best S_{11} readings had been recorded was -5.8171 dB at 152.72 MHz (VHF) and -13.407dB at 433.36 MHZ (UHF). Meanwhile, the best VSWR readings had been recorded was 3.0971 at 152.72 MHZ (VHF) and 1.5433 at 433.36 MHZ (UHF).

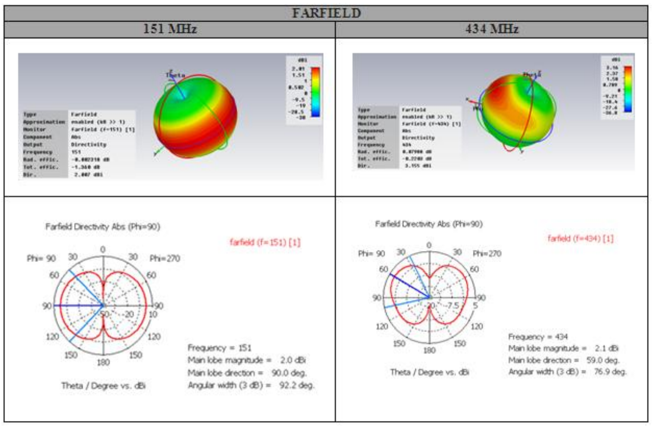


Figure 5: 2D result for GA optimization

Figure 5 above shows that the antenna gain could achieved up to 2.0 dBi at 151 MHz (VHF) and 2.1 dBi at 434 MHz (UHF). Meanwhile, the 3 dB beamwidth for 151 MHz (VHF) was 92.2 degree and for 434 MHz (UHF) was 76.9 degree.

The port design used for this design was SMA type which been design as per industrial specificationstandard. From the GA optimization simulation result, the line impedance of the antenna was in a range of 50.18 Ω (minimum) to 50. 24 Ω (maximum).Figure 6 show that the line impedance is 50.2304 Ω at 151 MHz (VHF) and 50.1834 Ω at 434 MHz (UHF).

LINE IMPEDANCE

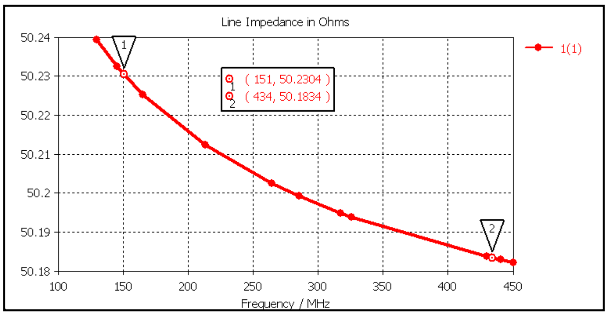


Figure 6: Line impedance for GA optimization

In general, after executing the GA optimization process, it can be conclude that the antenna is only feasible and practical for the FSR application operating in UHF band. The tunable transceiver is required in order to have more accurate center frequency during operation.

B. Parameter Sweep analysis

All results for Parameter Sweep analysis obtained from the CST had been summarized as per Table-IV for VHF band and Table-V for UHF band.

TABLE-IV PARAMETER SWEEP RESULT (VHF Band)

PARAMETER	VHF			
	mm	MHz	S_{11} (dB)	VSWR
h0 (215mm – 235mm)	235	149.52	-5.7781	3.1166
h1 (57.5 mm – 77.5mm)	57.5	160.08	-5.999	3.01
h2 (3.5mm – 11.5mm)	3.5	154.96	-5.8424	3.0847
ha (5mm – 15mm)	5	157.52	-5.9542	3.0309
hb (10mm – 40mm)	32.5	152.08	-5.7747	3.1183
Stub_w1 (1mm – 9mm)	1	180.56	-7.7251	2.3951
t(0.2875mm – 1.0875mm)	1.0875	153.36	-5.8764	3.0681
w (0.4mm – 1.2mm)	1.2	172.24	-7.1688	2.5593

TABLE-V PARAMETER SWEEP RESULT (UHF Band)

PARAMETER	UHF			
	mm	MHz	S_{11} (dB)	VSWR
h0 (215mm – 235mm)	215	432.72	-20.093	1.2196
h1 (57.5 mm – 77.5mm)	67.5	431.76	-13.94	1.5027
h2 (3.5mm – 11.5mm)	11.5	428.56	-18.185	1.2811
ha (5mm – 15mm)	12.5	431.12	-14.676	1.4527
hb (10mm – 40mm)	17.5	431.12	-15.106	1.4262
Stub_w1 (1mm – 9mm)	5	431.76	-13.946	1.5024
t (0.2875mm – 1.0875mm)	1.0875	432.72	-14.722	1.4498
w (0.4mm – 1.2mm)	0.4	426.64	-11.409	1.7355

Based on the simulation result of the parameter sweep, the extracted data could be interpreted by plotting the S_{11} and/or VSWR versus parameter graphs as follows. It is possible to have 8 different graphs since the parameter sweep process for each 8 different parameter had been carried out independently.

h0

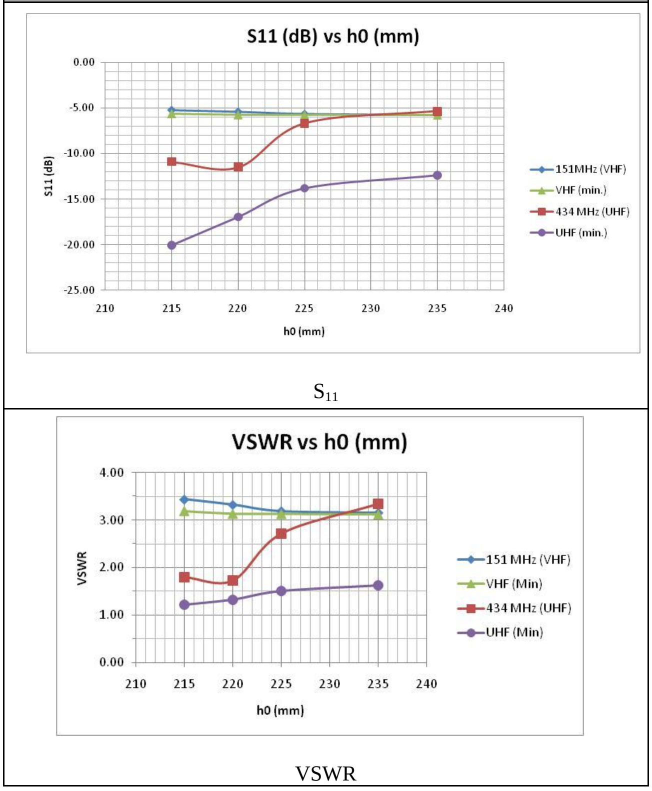
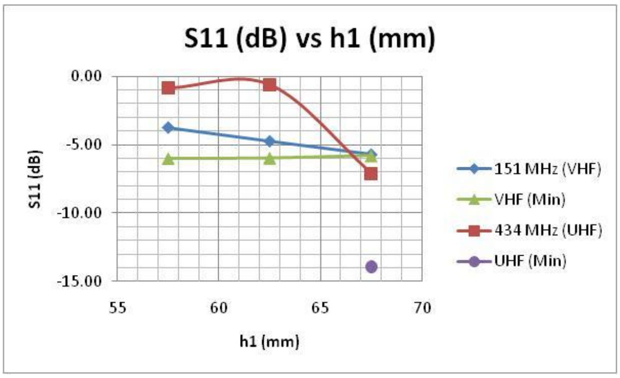


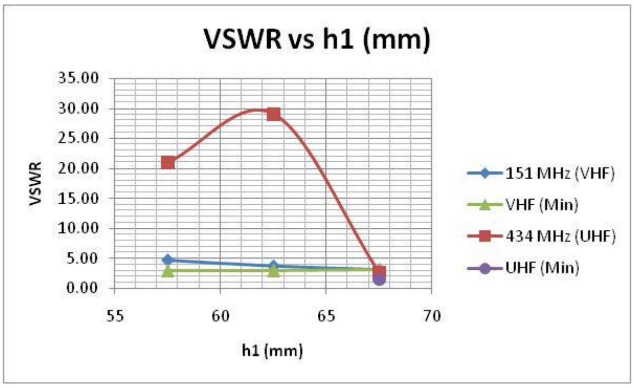
Figure7:Parameter sweep analysis for *h0*

From Figure 7 above, the typical summary that can be conclude that the *h0* was obviously not a design factor which could significantly influence the performance of the antenna. It is because there was no any unique pattern exists from the above graphs when the parameter sweep executed tabulated. In general, the performance of the antenna would be better when the *h0* at the minimum level.

h1



S_{11}

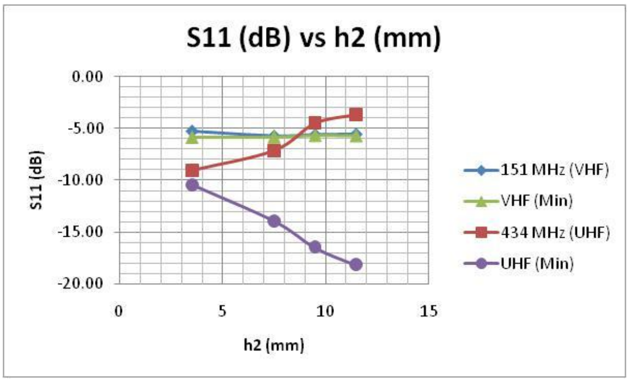


VSWR

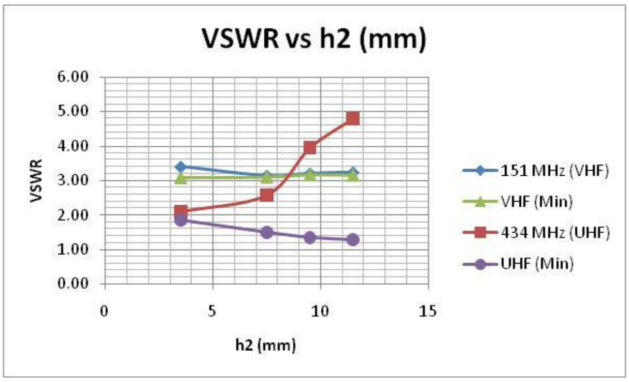
Figure 8:Parameter sweep analysis for *h1*

As shown in Figure 8, both readings in UHF had fulfilled the design criteria for this project. It can be conclude that the *h1* could be one of the design factors which could significantly influence the performance of the antenna. The gap between each pick was greater at the higher frequency when the parameter sweep executed. The length of the *h1* is vital in determining the size of the both stub.

h2



S_{11}

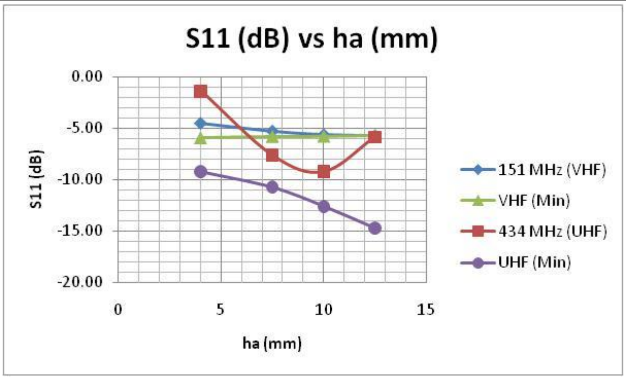


VSWR

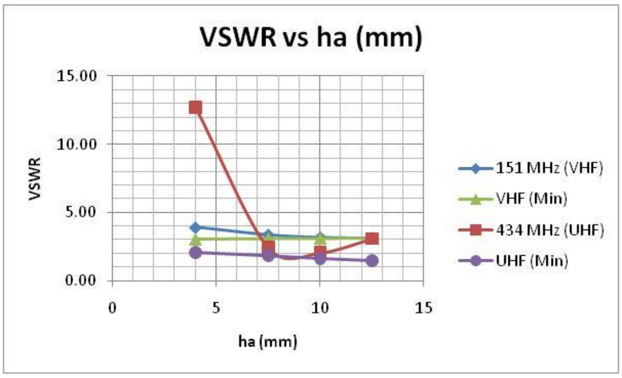
Figure 9:Parameter sweep analysis for *h2*

In general, the dominant curve which UHF (min) had meet the design objective and from Figure 9 it shows that the antenna performance could be better at the higher *h2*. The contras response in UHF band was diverse at the higher *h2* was due to the result response from the simulation itself. The narrower shape in UHF was occurred comparing in UHF band.

ha



S_{11}

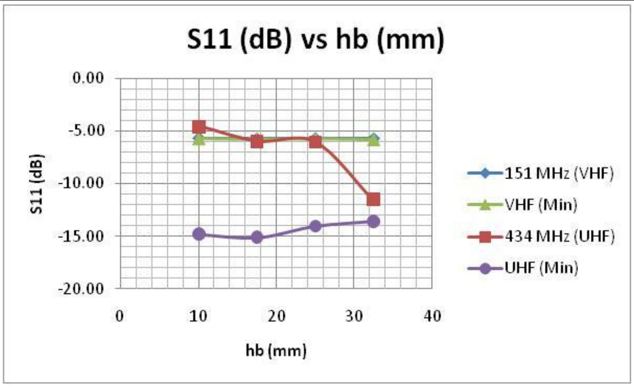


VSWR

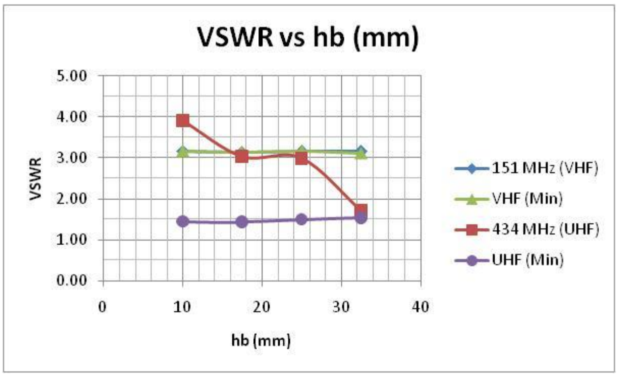
Figure 10:Parameter sweep analysis for *ha*

In general, from Figure 10 it shows that the dominant curve which UHF (min) had meet the design objective and the antenna performance could be better when the *ha* is higher than the 7.5 mm.

hb



S_{11}

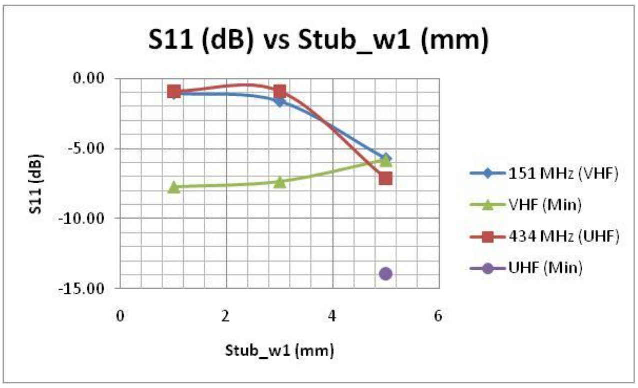


VSWR

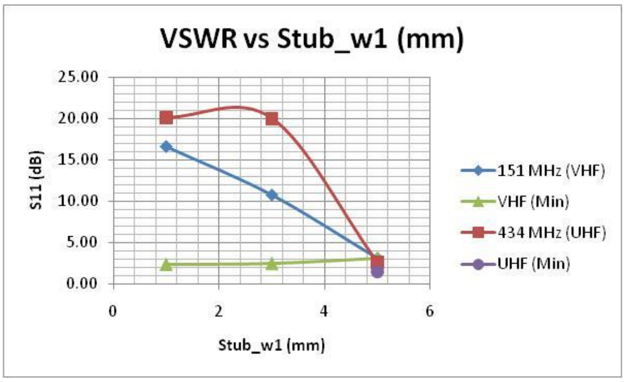
Figure 11:Parameter sweep analysis for *hb*

From both observations in Figure 11 above, the typical summary that can be conclude that the*hb* was obviously not a design factor which could significantly influence the performance of the antenna. There was no any unique pattern exists from the above graphs when the parameter sweep executed.

Stub_w1



S_{11}

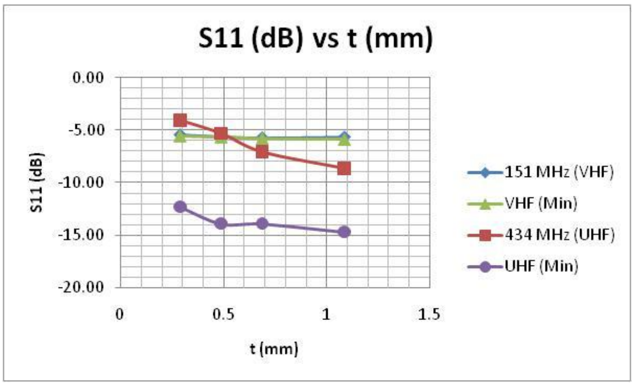


VSWR

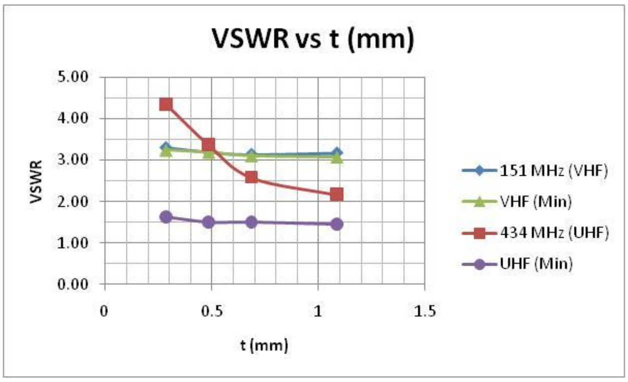
Figure 12: Parameter sweep analysis for *Stub_w1*

In Figure 12, there was only one curve seem to be feasible practical to be used in this project which when the *Stub_w1* is 5 mm. Base on the current design, the maximum value of *Stub_w1* should be 5mm because the antenna structure will touching each other become one strip plate when the *Stub_w1* is higher than 5mm.

t



S_{11}

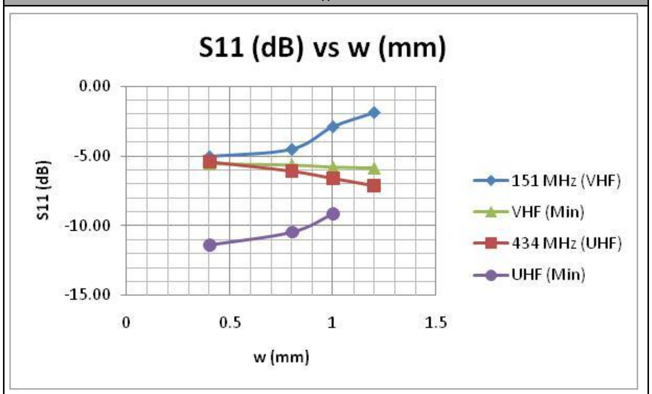


VSWR

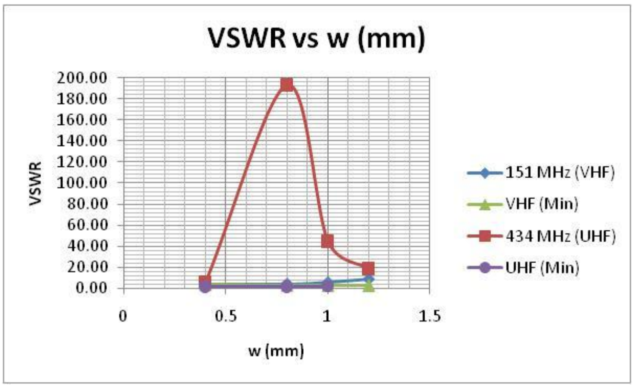
Figure 13: Parameter sweep analysis for *t*

The gap between the every single pick point was seemed to be consistent. In general, the performance of the antenna in dominant curve UHF (min) would be better at the higher *t* as shown in Figure 13.

w



S_{11}



VSWR

Figure 14:Parameter sweep analysis for *w*

The fluctuation occurs in VSWR reading is due to occurrence of the pick curve when *w* = 0.8 mm much earlier (at lower frequency) compare with other curve.From Figure 14 above, it can be concludethat the w could be one of the design factors for this antenna design. The existence of a unique pattern during the parameter change could make a *w* more relevant compared with other parameter. In general, the performance of the antenna in dominant curve UHF (min) would be better at the lower *w*.

V. SUMMARY AND CONCLUSION

The finalization of the antenna design is based on the GA optimization process. Based on the GA output data, TABLE VI show the analysis of the antenna performance compared with the design goals of this research which been predefined at the beginning of this paper.

TABLE VI: GA ANALYSIS OF THE ANTENNA PERFORMANCE

PARAMETER	GOALS	ACTUAL RESULT			
		151 MHz		434 MHz	
		VALUE	± %	VALUE	± %
Center frequency (MHz)	151 and 434	152.72	+1.139%	433.36	-0.147%
Return loss , S_{11}(dB)	<-10	-5.8171	-41.829%	-13.407	+34.07%
VSWR	<2	3.0971	-54.855	1.5433	+22.835%
Line impedance (Ω)	≈ 50	50.2304	+0.468%	50.1834	+0.3668%
Gain (dB)	>3	2.0	-33.33%	2.1	-30%
Total length (cm)	<50	41.125	+17.75%	41.125	+17.75%

(green) - Acceptable
(red) - Unacceptable

It is obviously indicate that the antenna design presented in this paper is more relevant and practical to be used only for the UHF band operation. While for the VHF band operation, the antenna couldn't meet the two main criteria which are the return loss (S_{11}) and the VSWR. There are some other techniquesto increase the gain of the antenna but it may jeopardize other parameters which could result unpractical for the FSR application.

A stub loaded monopole antenna design in this project had been analyzed in various angles. The predetermined and a standards design parameter had been used as a benchmark to study the performance of the antenna. The utilization of the CST software had simplified the analysis process to achieve the design objective especially when running the Genetic Algorithm (GA) optimization which originally embedded in the standard installation kit of CST software.

From the CST simulation result, it show that there are several parameters that could play as an important role in determining the performance of the antenna while the others could be classified as not significantly relevant as a key factor of the antenna design.

The dimension of each parameter would influence the current distribution along the components itself. For instance, the higher length of the monopole antenna would increase its resonant frequency corresponding decreases.

The stub loaded methodology is used in this antenna design hastheir own specific function in theory. It would be different in application when it was used either in short wire or long wire monopole antenna. In varies design, determination of the stub size is in accordance with the size of the wavelength as a reference. The stub size at short wire performed as effective end-loads for achieving miniaturization at the lowest band while at higher band, the stub acted as resonant trap and, in some cases, even as array elements. Meanwhile in the long wire antenna, the stubs not only serve to constrain the potentially large side lobes and consequently retain high gain in the main beam, but also work to compensate the input impedance in order to achieve the desired VSWR performance.

As a conclusion, the physics behind the multiband performance of this antenna had been studied and can be better understood by examining the behavior of its current distribution at each of the predetermined design frequencies.

At lower frequency (VHF band), the current is distributed over the entire length of the antenna in a way similar to that of a conventional monopole loaded with an end cap or top hat. In this case the stubs are behaving as end-loads thereby allowing the overall height of the monopole to be reduced. However, when operating at the higher frequency bands (UHF band), the current is most intense on the stub wires which become resonant. A more comprehensive study focusing on the current distribution along the antenna structure in a varietyof operating frequencies is needed in conjunction with the continuity of this research. A prototype model could be fabricated for performance validation.

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