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Wideband Loaded Wire Bow-tie Antenna for Near Field Imaging Using Genetic Algorithms

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Abstract— The potentially broad application area in engineering design using Genetic Algorithm (GA) has been widely adopted by many researchers due to its high consistency and accuracy. Presented here is the initial design of a wideband non-dispersive wire bow-tie antenna using GA for breast cancer detection applications. The ultimate goal of this design is to achieve minimal late-time ringing but at higher frequencies such as that located from 4 to 8 GHz, in which is desire to penetrate human tissue for near field imaging. Resistively loading method to reduce minimal ringing caused by the antenna internal reflections is implemented and discussed when the antenna is located in free space and surrounded by lossy medium. Results with optimised antenna geometry and different number of resistive loads are presented and compared with and without existence of scatterers.

1. INTRODUCTION

Due to the non-dispersive and ultra-wideband characteristics, the bow tie antenna has been applied on various applications; from Ground Penetrating Radar (GPR) to biomedical imaging tools. The bow-tie antenna play crucial roles in these applications by transmitting and receiving a relatively short transient pulse with minimum distortion and a low level of late time ringing. The lack of adaptive characteristic on the solid bow-tie antenna have motivated [1] to represent it in wire form in order to make it more suitable for GPR application. Drastic improvement is later been made by [2] by representing the typical solid bow tie antenna with a series of wires by means of Genetic Algorithm (GA). The Wire Bow-Tie (WBT) antenna is found more adaptive and advantageous as it is easily loaded with lumped elements to accommodate certain applications need while preserve its characteristics [3, 4]. Further improvement has also been done by the same group by resistively loading the design to minimize late-time ringing. Nevertheless, loading lump elements on wires is somehow impractical and difficult to achieve.

In this paper, a WBT antenna design is reported using GA as the main optimization tool. The antenna is designed based on the fundamental requirement for near field imaging tools such as for microwave breast cancer detector. This can be done by specify certain crucial goals on GA in order to obtain the optimum results. The design is then been analysed in time domain for further inspection using efficient and accurate computational software package where the resistive loading will also be implemented. For the sake of practical measurement, the design will then be transformed to microstrip to realize resistive loading method by using Surface Mount Resistors (SMR). Ideally, the successful antenna design should satisfy the following:

1. Operate at large bandwidth (4 to 8 GHz) to accommodate short pulses.
2. Late-time ringing less than 10^{-4} dB.

2. ANTENNA DESIGN USING GENETIC ALGORITHM

Figure 1 shows the general flow chart of the GA tools being implemented. Notice that the GA is incorporated with the electromagnetic code as the simulator. In this paper, the antenna wing is represented by 3 wires on each side with the radii of 0.5 mm. The total length is initially ranging from 50 to 120 mm while the flare angle is set to be 70°. These parameters will be computed in order to satisfy the pre-defined goal. Both wings are connected to a common feed point at the center of the antenna. The differential Gaussian pulse is adopted from [5] which has the following property:

$$V(t) = V_o \sin(2\pi f_o(t - t_o)) e^{-((t-t_o)/\tau)^2} \quad (1)$$

where $f = 6\,\text{GHz}$, $\tau = 0.133\,\text{ns}$, $t_o = 4\tau$ and V_o is the voltage amplitude. In frequency domain the following equations is defined:

$$V(j\omega) = -j\tau\sqrt{\pi}e^{-j\omega t_o} \cdot e^{-\tau^2}(\pi^2 f_o^2 + 0.25\omega^2)\sinh(\pi\omega f_o \tau^2) \tag{2}$$

$$I(j\omega) = V(j\omega)/Z(j\omega) \tag{3}$$

$$I(t) = IFFT(I(j\omega), n) \tag{4}$$

where n = number of frequency samples proposed in GA.

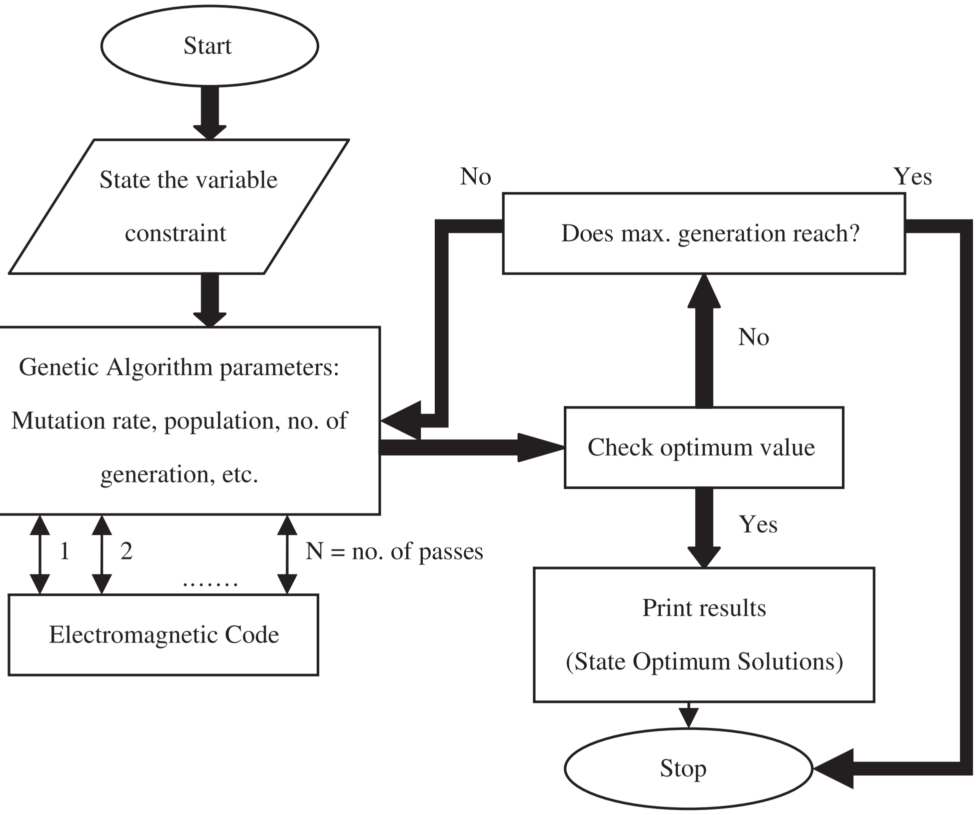

Figure 1: Flow chart of the GA tools applied to optimize the WBT antenna design.

Here, the GA has been pre-defined to optimize the matching impedance over the operating frequency bandwidth. The goal or the cost function is expressed as the following:

$$F = \sum_{i=1}^{n}\left(w_1 \frac{1}{VSWR(f_i)} + w_2 \frac{1}{1 + (\zeta(f_i) - \zeta_c)^2}\right) \tag{5}$$

where:

$$VSWR(f_i) = \frac{1 + |\Gamma(f_i)|}{1 - |\Gamma(f_i)|} \tag{6}$$

$$\Gamma(f_i) = \frac{Z_L(f_i) - Z_o}{Z_L(f_i) + Z_o} \tag{7}$$

Note that w_1 and w_2 are the weighted coefficients, $Z_L(f_i)$ is the input impedance at the operating frequency f_i, Z_o is the reference load, $\zeta(f_i)$ is the radiation efficiency at operating frequency f_i and ζ_c is the reference radiation efficiency.

3. NUMERICAL RESULTS

Table 1 shows the properties of the applied genetic algorithm while Table 2 shows the optimum values of the antenna design's parameters in free space. The optimum total length of the antenna as well as the load impedance acquired from the GA is to be 77.2 mm at 188 Ohm. The antenna design is depicted in Fig. 2 in which each radiating element (single arm) is loaded with resistors acquired from genetic algorithm. Note that the position of these resistors has been identified prior to optimization process.

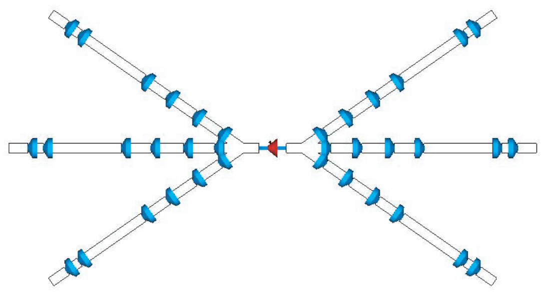

Figure 2: Geometry of the resistive loaded antenna design model.

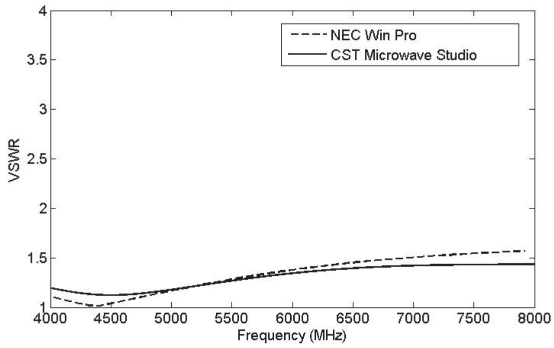

Figure 3: Voltage standing wave ratio (VSWR) versus the operating frequency of two computational tools.

Table 1: Properties of the applied Genetic Algorithm.

GA parameters	
Population size	4
Maximum number of parameters	8
Probability of mutation	0.02
Maximum generation	100
Number of possibilities	2^{15}

Table 2: Input load parameters, their associated locations and optimum values in free space.

No. of resistors	Min.	Max.	Location of resistors (segment number)	Resistors value (Ohm)	Maximum fitness
1	5	300	8	280	4.00
2	5	300	7, 9	6, 260	4.11
3	5	300	3, 8, 9	297, 150, 165	5.18
4	5	300	2, 3, 8, 9	300, 300, 133, 157	6.06
5	5	300	2, 3, 7, 8, 9	300, 297, 116, 65, 40	6.09
6	5	300	2, 3, 6, 7, 8, 9	295, 296, 43, 66, 69, 130	6.08

The antenna is later being optimised inside a medium that is characterized by relative dielectric permittivity $\varepsilon_r = 9.0$, and conductivity $\sigma = 0.4\,\mathrm{S/m}$ for further investigation and the results are tabled in Table 3. The optimum length of each antenna arm and the match load were found to be 35 mm and 190 ohms respectively.

The respective voltage standing wave ratio and the input impedance of the antenna in free space are computed using different simulation tools and plotted as shown in Fig. 3 and Fig. 4 respectively. Both results show good agreement in terms of input impedance stability across the operating frequency and optimised matched load of 188 ohms (found by GA).

Further free space investigation involving a scattered object placed at various distances below the antenna along the z-axis. The scatterer was considered as cross short dipoles of length 5 mm, parallel to the WBT and both having the conductivity of 9 S/m. Fig. 5 shows the frequency spectrum of the received signal with and without the presence of the scatterer where as Fig. 6 shows

Table 3: Input load parameters, their associated locations and optimum values within the medium $\varepsilon_r = 9.0$, and $\sigma = 0.4\,\mathrm{S/m}$.

No. of resistors	Min.	Max.	Location of resistors (segment number)	Resistors value (Ohm)	Maximum fitness
1	5	300	8	300	3.86
2	5	300	7, 9	8, 298	4.02
3	5	300	3, 8, 9	5, 278, 7	4.32
4	5	300	2, 3, 8, 9	110, 6, 84, 184	4.96
5	5	300	2, 3, 7, 8, 9	164, 8, 37, 260, 173	5.23
6	5	300	2, 3, 6, 7, 8, 9	109, 7, 11, 113, 120, 219	5.22

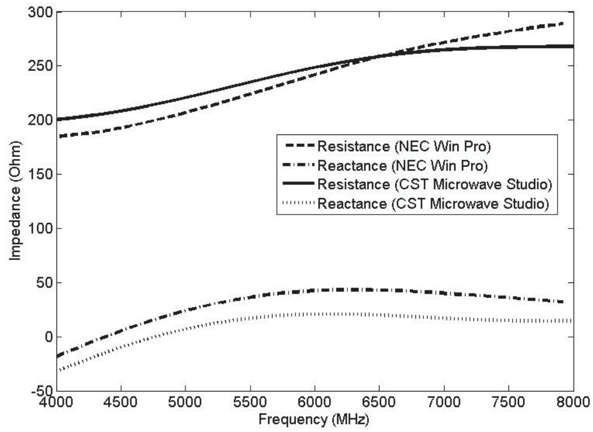

Figure 4: Input impedance of the antenna.

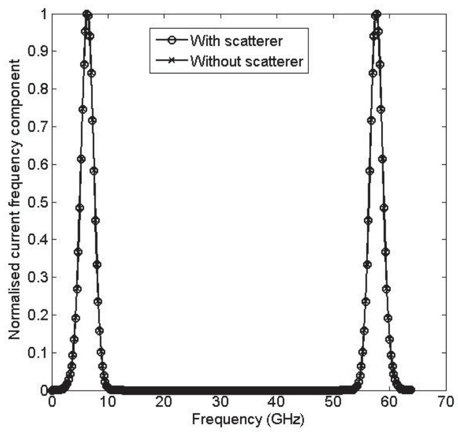

Figure 5: The frequency spectrum of the current component.

the time variations of the normalised difference current components (i.e., the components associated with and without scatterer) observed when the object is placed at 3 cm, 6 cm and 9 cm below the antenna geometry. An enlargement figure time response of the normalised current component due to a scatterer object placed at 9 cm below the antenna is depicted in Fig. 7, in which, a clear indication can be observed the present of the scatterer.

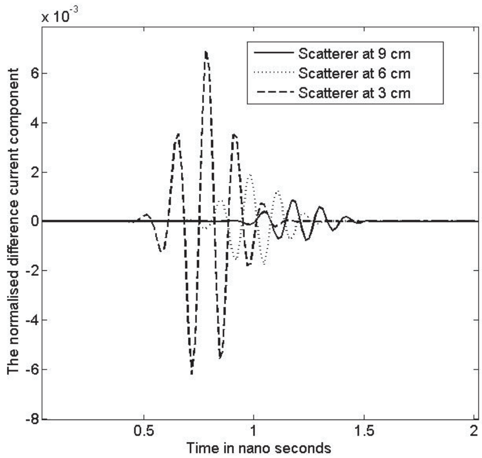

Figure 6: Time variations of the normalised difference current component subject to various scatterer distances along z axis.

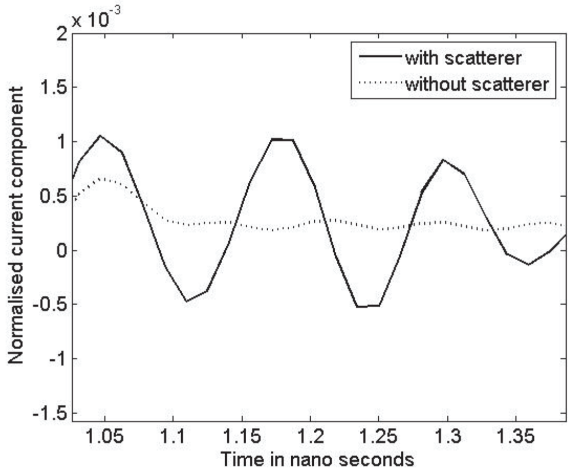

Figure 7: Time variations of the normalised current component observed from a scatterer object placed at 9 cm along z-axis below the antenna.

Finally, the optimised antenna configurations surrounded by lossy medium was tested with the presence of scatterer located below the antenna at different distances as shown in Fig. 8. The scatterer (or target) has spherical geometry of radius 5 mm and characterized by relative dielectric permittivity of 36 and conductivity of 9 S/m. Fig. 9 shows the normalised difference current components for two scatterer distances in which each antenna arm loaded by six resistors as stated in Table 3. The variations effects of the back scattered fields from the scatterer on the currents values clearly indicated the expected position of the target. The relative peak values (that represents the maximum normalised reflections) of these variations normalised to the maximum current component were found to be 68 to 60 dBs respectively to 1.5 cm and 3 cm scatterer distances.

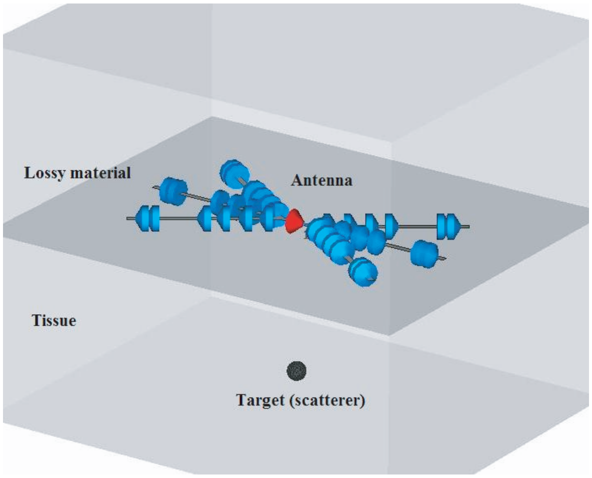

Figure 8: Resistive loaded BTW with scatterer surrounded by a lossy medium.

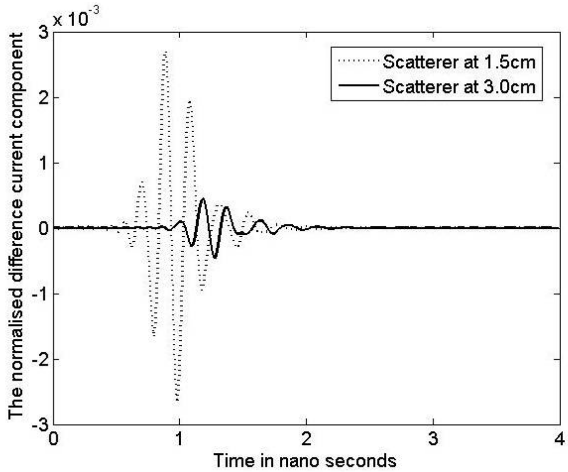

Figure 9: Time variations of the normalised difference current components when the antenna and scatterer surrounded by a lossy medium.

4. CONCLUSION

A WBT antenna design for near field imaging using GA as the primary optimization tools has been presented. The design concept of resistively loaded WBT in free space and when surrounded by lossy medium was discussed. The optimum load values and their locations for each space medium were addressed. The computational results of two softwares using the optimum design were found in good agreement in terms of the variations of the input impedance and the VSWR across the frequency range considered. A reasonable reflection levels that describe the back scattered fields from scatterer located underneath the antenna were also recorded. More improvements are still in progress where it involves increment the number of radiating elements on both arms and matched to a lower system load. Enhancing the antenna by placing two WBT in a cross polarization position is also being considered to improve its imaging capability.

REFERENCES

1. Lestari, A. A., A. G. Yarovoy, and L. P. Lightart, "Adaptive antenna for ground penetrating radar," *Proceedings of the Tenth International Conference on Ground Penetrating Radar*, Vol. 1, 121–124, 2004.
2. De Jong van Coevordon, C. M., A. R. Bretones, M. F. Pantoja, F. J. G. Ruiz, and R. G. Martin, "GA design of a thin-wire bow-tie antenna for GPR applications," *IEEE Trans. Geosci. Remote Sensing*, Vol. 44, No. 4, 1004–1010, April 2006.
3. Uduwawala, M. N. D., P. Fuks, and A. W. Gunawardena, "A deep parametric study of resistor-loaded bow-tie antennas for ground-penetrating radar applications using FDTD," *IEEE Trans. Geosci. Remote Sensing*, Vol. 42, 732–742, April 2004.
4. Lestari, A. A., A. G. Yarovoy, and L. P. Ligthart, "Adaptive wire bow-tie antenna for GPR applications," *IEEE Trans. Antenna Propagat.*, Vol. 53, 1745–1754, May 2005.
5. Hagness, S. C., A. Taflove, and J. E. Bridges, "Three-dimensional FDTD analysis of a pulsed microwave confocal system for breast cancer detection: Design of an antenna-array element," *IEEE Trans. Antennas Propagat.*, Vol. 47, 783–791, May 1999.