Resistively Loaded Wire Bow-tie Antenna for Microwave Imaging By Means of Genetic Algorithms

S. W. J. Chung, R. A. Abd-Alhameed, P. S. Excell, C. H. See, D. Zhou and J G Gardiner

Abstract—**The initial design of a wideband non-dispersive wire bow-tie antenna using GA is presented here, primarily for microwave imaging application. The wire bow-tie antenna is designed to operate from 4 GHz to 8 GHz which is essential for microwave penetration into biological tissue. Backscattered signal is then received and analyzed to detect any possible object within the medium. Resistively loading method is implemented to reduce late-time ringing cause by the antenna internal reflections. Results with optimised antenna geometry and different number of resistive loads are presented and compared with and without existence of scatterers. Prototype of the design has also been developed and the experimental results are presented alongside with the simulations outcome.**

Index Terms—**Genetic Algorithm (GA), microwave imaging, resistively loading, wideband, wire bow-tie antenna.**

I. Introduction

THE non-dispersive and wideband characteristics of the bow-tie antenna has made it widely adopted in many applications from subsurface radar to microwave imaging. Such applications require antenna that capable to transmit and received a relatively short pulse with minimal internal reflections. The lack of adaptive characteristic of the conventional solid bow-tie antenna have motivated [1] to represent it in wire form for better performance in GPR application. Further 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 and enhance the performance [3,4].

Here the initial WBT antenna design using GA is presented where the fundamental requirement for near field imaging tools such as for microwave breast cancer detector is defined. This can be done by specify certain crucial goals on GA in order to obtain the optimum results. Further analysis is conducted in time domain by using efficient and accurate computational software package where the resistive loading will also be implemented. For experimental 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 criteria:

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

II. GA Optimization of the WBT Antenna

Over the past decade, GA has been the favorite of many engineers and scientists as their primary optimization tool in handling electromagnetic related problems. This is because GA has been proved to be robust and deliver relatively accurate and efficient outcomes. Several works [5-9] reported show the reliability and potential of this powerful optimization tool can offer.

Various potential antenna designs for microwave imaging that been proposed [10-17] showing very promising outcomes. However, these antennas are much complicated to be built and realized. Here a WBT antenna is developed and optimized using microgenetic algorithms for microwave imaging. The main concern is to achieve suitable antenna geometry with consistent input impedance across the operating frequency in order to minimize any late-time ringing cause by the antenna internal reflections. GA has also been applied to seek the optimum value of lumped resistors used to suppress unwanted clutter of the antenna.

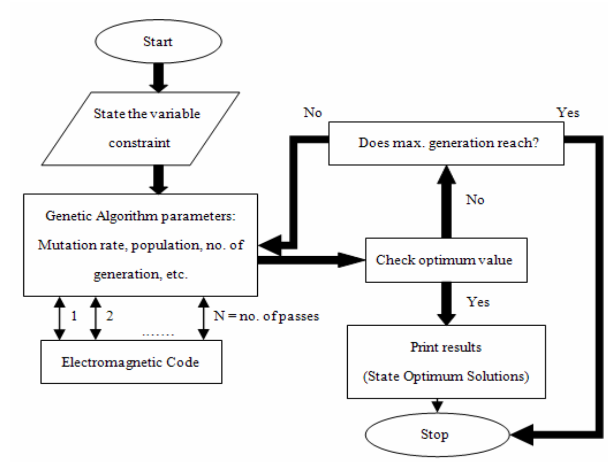

Fig. 1 Flow chart of the GA tools applied to optimize the WBT antenna design.

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The general flow chart of the applied GA is illustrated in Fig. 1 and it shows how the implemented GA tool is incorporated with the electromagnetic code as the simulator. In this paper, the antenna radiating elements are 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 property of the differential Gaussian pulse adopted from [5] is expressed as below:

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

Where f = 6GHz, τ = 0.133 ns, $t_o = 4\tau$ and V_0 is the voltage amplitude. Hence in frequency domain:

$$V(j\omega) = -j\tau\sqrt{\pi}e^{-j\omega t_0}.e^{-\tau^2}(\pi^2 f_0^{\ 2} + 0.25\omega^2)\sinh(\pi\omega f_0\tau^2) \quad (2)$$

$$I(j\omega) = V(j\omega) / Z(j\omega) \quad (3)$$

$$I(t) = IFFT\ \ (I(j\omega), n) \quad (4)$$

Where n = number of frequency samples proposed in GA.

GA has also been applied to optimize the matching impedance over the operating frequency bandwidth. The goal or the cost function is expressed as the following:

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

Where:

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

$$\Gamma(f_i) = \frac{Z_L(f_i) - Z_0}{Z_L(f_i) + Z_0} \quad (7)$$

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.

III. COMPUTATIONAL RESULTS

The parameter values in the algorithm were shown in Table 1 while the optimum values of the antenna design's parameters in free space are depicted in Table 2. The total length of the antenna as well as the load impedance acquired from the GA is to be 77.2 mm and 188 Ohm respectively. The prototype design is shown in Fig. 2(a) in which each radiating element (single arm) is loaded with resistors acquired from genetic algorithm. Note that the location of these resistors has been identified prior to optimization process. The input impedance as well as the voltage standing wave ration (VSWR) of the antenna in free space is then computed using different simulation tools and plotted in Fig. 3 and Fig. 4 for comparison. These results show good agreement in terms of the variation of the input impedance across the operating frequency and optimised matched load of 188 ohms (found by GA). Further investigation is conducted by placing a scattered object at a various distances below the antenna about the z-axis. The scatterer was represented by a 5 mm in length cross short dipoles, parallel to the WBT and both having the conductivity of 9 S/m. Fig. 5 shows 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 where the scatterer 9 cm below the antenna is depicted in Fig. 6, in which, a clear indication can be observed the presence of the scatterer.

TABLE I
PROPERTIES OF THE APPLIED GENETIC ALGORITHMS

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 THE 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	4.0
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

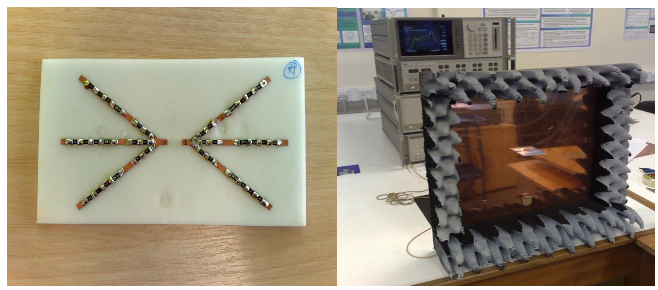
(a) (b)

Fig. 2 Basic geometry of the proposed antenna; (a) prototype resistively loaded antenna and (b) compact chamber for the antenna test.

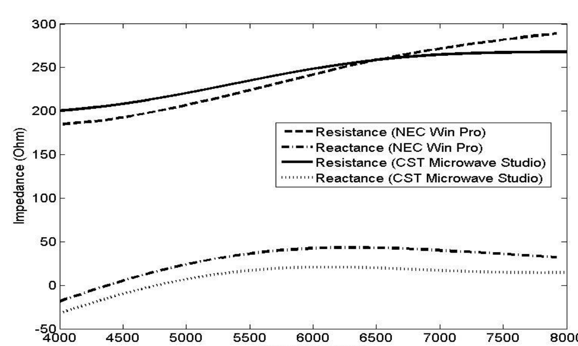

Fig. 3 Frequency response of the antenna input impedance.

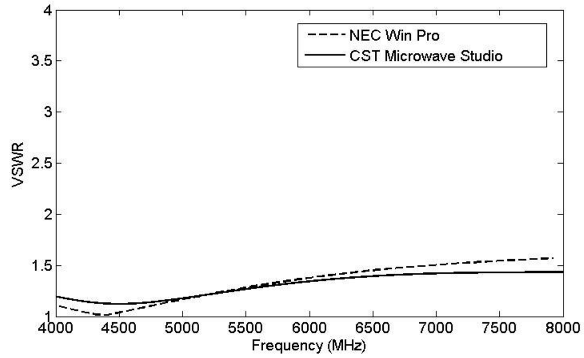

Fig. 4 Voltage standing wave ratio (VSWR) versus operating frequency of two computational tools.

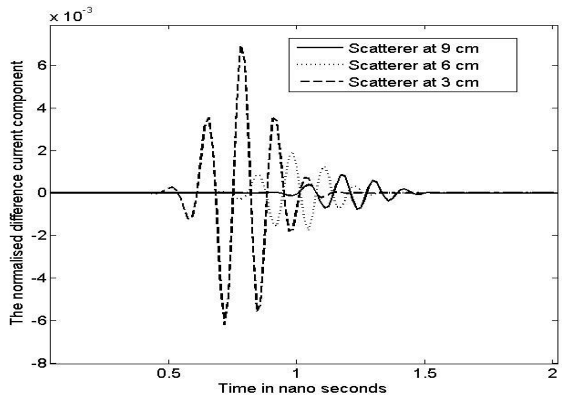

Fig. 5 Time variations of the normalised difference current component subject to various scatterer distances along z-axis.

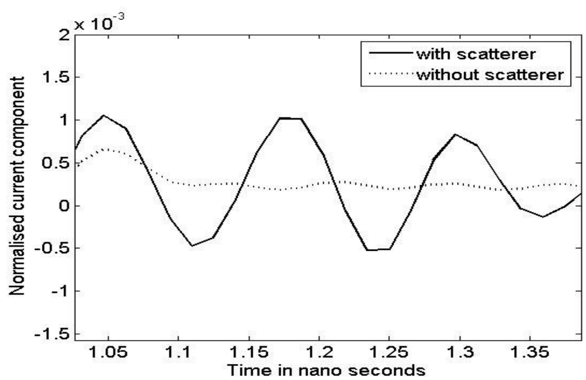

Fig. 6 Time variations of the normalised current component observed from a scatterer object placed at 9 cm along z-axis below the antenna.

The antenna is later immersed inside a medium that is characterized by relative dielectric permittivity ε_r = 9.0, and conductivity σ = 0.4 S/m for further optimization and the results are tabled in Table 3. The optimum length of each antenna arm and the match load were found to be 35mm and 190 ohms respectively. Lastly, a scatterer (or target) represented in spherical form that has a radius of 5mm and characterized by ε_r = 36 and σ = 9 S/m was placed at different distances below the antenna as illustrated in Fig. 7. Fig. 8 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 1.5cm and 3cm scatterer distances.

IV. Experimental Measurement

Due to the unavailability of balun at time of publish, the prototype is tested as a monopole where half of the antenna is mounted on a finite ground of size 50 cm x 50 cm in free space. Absorbers are placed on each side of the plate as seen on Fig. 2(b) to avoid any reflections caused by the edge of the ground plate. A metal plate with the size of 1.5 cm x 1.0 cm is placed at a distance of 5 cm, 10 cm and 15 cm below the antenna. The measured input impedance and the normalised current is computed and plotted based on the input impedance obtained from the measurement is depicted in Fig. 9 and Fig. 10 respectively. Although it shows some promising results, it is not quite clear to indicate the precise location of the object due to inconsistency of the ripple. This may caused by the reflection from the surrounding and might contribute to the internal ringing received from the antenna. Another possible explanation to this is due to the impedance mismatch between the antenna and the feeding networks due to the un-radiating surface antenna part that is considered by the loads. However, the measurements show quite encouragement in terms the existence of the reflections and their location from the pulse transmitted.

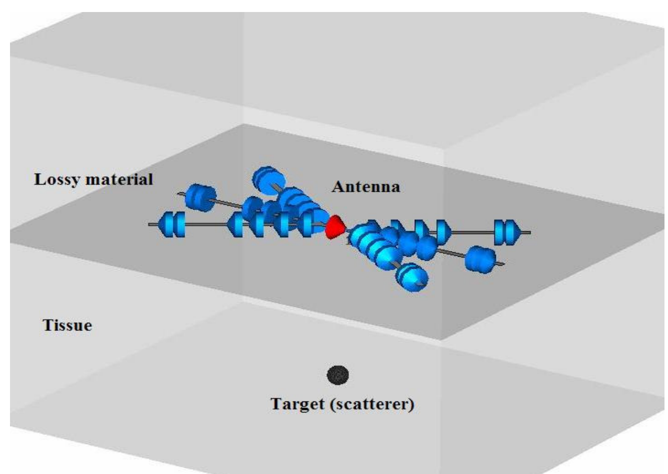

Fig. 7 Configuration of the proposed WBT antenna immersed in medium with relative dielectric permittivity ε_r = 9.0, and conductivity σ = 0.4 S/m

TABLE 3
INPUT LOAD PARAMETERS, THEIR ASSOCIATED LOCATIONS AND THE OPTIMUM VALUES WITHIN THE MEDIUM ε_R = 9.0, AND CONDUCTIVITY = 0.4 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

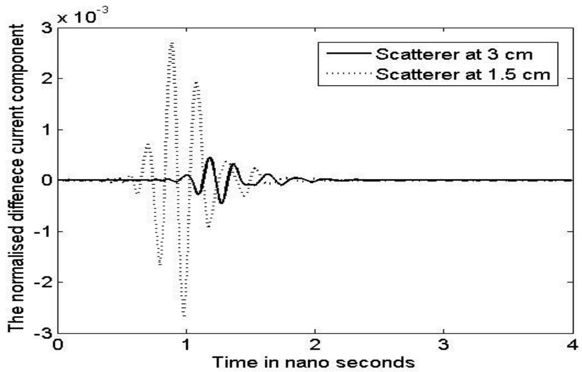

Fig. 8 Time variations of the normalised difference current components when the antenna and scatterer surrounded by a lossy medium.

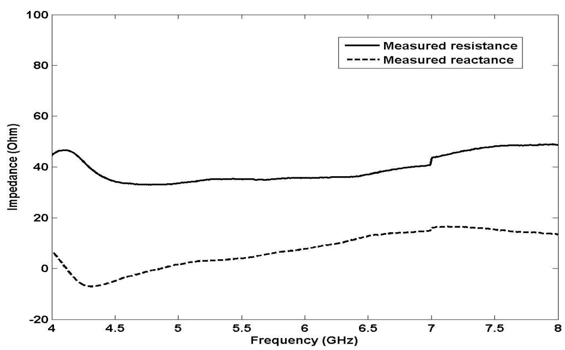

Fig. 9 Measured input impedance of the half WBT antenna.

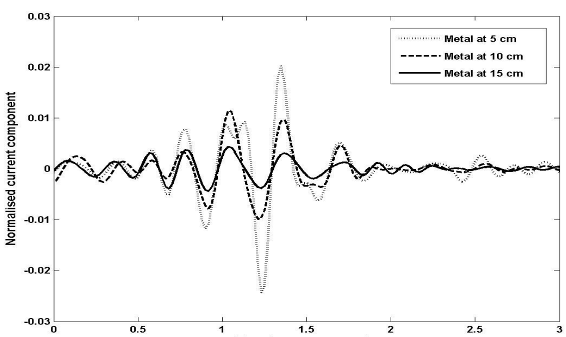

Fig. 10 Measured normalised current components for different scatterers distances.

IV. CONCLUSION

A resistively loaded WBT antenna design for microwave imaging using GA as the primary optimization tools has been presented. The design concept of resistively loaded WBT in free space as well as in lossy medium was discussed and the optimum load values and their locations in free space were addressed. The computed optimum design was compared using two different simulation tools shows good agreement in terms of the variations of the input impedance and the VSWR across the frequency range considered. For measurement purpose, the prototype was fabricated as microstrip form and the measured results show reasonable agreement with the computed outcomes. 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.

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