Near Field to Far Field Conversion for an Infinite Ground Micro-Strip Trace Using Genetic Algorithm

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Abstract – In this paper, an efficient combination of the near field to far field (NF-FF) transformation and the genetic algorithm (GA) is suggested for investigating of a microstrip trace on an infinite ground plane. Parameters of a set of ideal electric and magnetic dipoles are estimated by GA based on finite samples of near field data in the radiation region. Then, the far field pattern is determined, using the electromagnetic (EM) fields of equivalent ideal dipoles. The commercial software Ansoft High Frequency Structure Simulator (HFSS) is used for both, computing the near field data and validation of the proposed method. In addition, the influence of number of dipoles on the convergence rate is studied.

Index Terms – Genetic algorithm, microstrip, and near field to far field transformation.

I. INTRODUCTION

Open area test site (OATS) measurement is the most direct and universally accepted standard approach for measuring radiated emissions (RE) and radiation susceptibility (RS) of equipments. However, OATS is not always possible, due to space limitations. Therefore, number of measurement facilities and procedures have been developed to carry out such measurements in laboratories; e.g., microwave anechoic chamber, transverse electromagnetic cell (TEM cell), and reverberation chamber (RVC) [1]. These methods are costly and require complex processes such as calibration. The near field to far field (NF-FF) transformation is a low-cost and flexible alternative method for radiated emissions (RE) in electromagnetic interference (EMI) [2]. This method is often combined with an optimization strategy to properly estimate the FF. The large number of optimization parameters suggests application of stochastic optimization methods such as GA [3-9]. A comprehensive introduction to GA and its relation to traditional optimization methods can be found in [10].

In [11], the FF pattern of a printed circuit board (PCB) modem is determined based on the amplitude of the NF data, only. In 2007, Fan demonstrated the capability of GA in estimating the FF pattern by the NF-FF method [6]. He has also applied this combination to a grounded microstrip trace [3], using the uniqueness theorem.

In this paper, it is shown that the convergence rate can be increased by eliminating the need for applying the uniqueness theorem. Consequently, the CPU time is decreased while the accuracy is preserved in an acceptable level. To do this, radiation fields of the trace in NF radiation region are sampled. Then, employing only the magnitude data, parameters of ideal electric and magnetic dipoles are optimized by GA. Finally, the FF pattern is estimated based on analytic expressions of dipoles' EM fields.

II. SETTING UP THE OPTIMIZATION

A. Hybrid-coding

GA is used to optimally produce the parameters of N ideal dipoles for reconstructing the NF data at M observation points. Each individual includes N infinitesimal ideal dipole. The qth dipole, D_q, has the following parameters [2, 4, 7, 12, 13]:

- Dipole type: K_q, which is zero for magnetic and one for electric type, and thus, is a binary parameter.
- Dipole position: (x_q, y_q, z_q).

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- Dipole complex moment: $m_q.e^{j\beta q}$, where m_q and β are real dipole moment and initial phase, respectively.
- Dipole direction: (θ_q, φ_q).

Therefore, each individual S_K = $\{\mathrm{D_q}\}^N{}_{q=1}$, includes N dipoles, and each dipole $\mathrm{D_q}$ has a binary gen and seven real-coded gens, i.e.,

$$\mathrm{D_q} = \{\mathrm{K_q},\ \mathrm{m_q},\ \beta_q, \mathrm{x_q}, \mathrm{y_q}, \mathrm{z_q}, \theta_q, \varphi_q\}. \quad (1)$$

To simplify the software implementation and increase the convergence rate, the binary parameter can be eliminated by considering half of the dipoles to be magnetic and the rest being electric; leading to seven gens for each dipole. For more than two dipoles this simplifying assumption considerably decreases the computational cost.

As in [3], a 210 mm × 2.5 mm × 0.017 mm grounded microstrip is studied in this work, which is depicted in Fig. 1. The conductivity and relative permittivity of the substrate medium are σ = 0.0046 S/m and ε_r = 4.7, respectively. The structure is located above an infinite ground plane. Following [3] and for the purpose of comparison, the applied voltage to one end of the strip is 1.78 V, while the other end is terminated to a 22 pF capacitor.

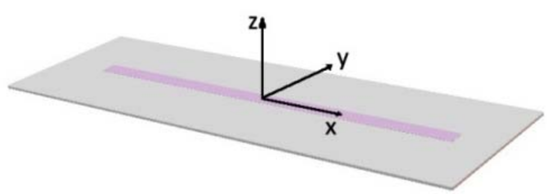


Fig. 1. Microstrip layout.

The variation ranges of gens are given by,

$$\begin{cases} -135\ mm \le x \le 135\ mm \\ -30\ mm \le y \le 30\ mm \\ 0\ mm \le z \le 5\ mm \\ 0\ \le \theta_q \le \dfrac{\pi}{2} \\ 0\ \le \varphi_q, \beta_q \le 2\pi \\ K_q = 0, 1 \end{cases} . \quad (2)$$

B. Fitness function

The fitness function of each individual, which is minimized by the GA is defined as,

$$T_m^{NF}(\mathrm{S_k}) = \frac{20}{\mathrm{M}} \sum_{\mathrm{m}=1}^{\mathrm{M}} \left|\log \mathrm{E}_m^{NF} - \log \mathrm{f}_{m,k}^{NF}\right|, \quad (3)$$

where $\mathrm{f}_{m,k}^{NF}$ is the NF intensity of k^{th} individual at m^{th} observation point and E_m^{NF} is the magnitude of the corresponding NF. These field values can be calculated by analytical relations and proper coordinate transformations[14-15]. The unknown parameters are determined by running the optimization process until the averaged value of the fitness function over all points becomes less than 1.5 dB. It is worth mentioning that such a criteria is selected based on the most recognized electromagnetic compatibility (EMC) standards, e.g., CISPR 16 [16].

Since the fitness function does not include the phase information, it is not possible to make use of the uniqueness theorem. Therefore, there will be no unique dipole arrangements. Such a definition, also, leads to a smooth optimization space with less local minima compared to what introduced in [3]. Consequently, the convergence rate increased.

C. Estimating the FF pattern

Whenever unknown parameters of equivalent dipoles are determined, the FF pattern of the grounded microstrip can be simply estimated based on well-known analytical expressions [14]. The tolerance can be estimated by [3]

$$T^{FF}(S_k) = \frac{20}{M} \sum_{m=1}^{M} \left|\log \mathrm{E}_m^{FF} - \log f_{m,k}^{FF}\right|, \quad (4)$$

in which E_m^{FF}'s are the FF simulated data, and $f_{m,k}^{FF}$'s are data predicted from FF pattern. In this study, simulated data are generated by Ansoft HFSS. T^{FF}'s are the tolerances between the simulated and predicted data. Lower values ofT^{FF} means better predictions.

III. CALCULATING EM FIELDS OF THE STRUCTURE

The EM fields of the structure can be computed by the infinite ground assumption and direct application of the image theorem [3]. This simplification is valid because the ground size is considerably greater than the microstrip transmission line. The parameters corresponding to the image of the q^{th} dipole is given in Table 1. As before, EM fields of ideal dipoles and their images are calculated based on an analytical expressions [14].

The input impedance of the structure is depicted in Fig. 2, which shows two pseudo-resonant frequencies in the range of 30 MHz to 1000 MHz. Ensuring proper matching condition, f_1 = 100

MHz, f_2 = 300 MHz, and f_3 = 700 MHz are selected as test frequencies.

Table 1: Parameters of diploes' images.

Main dipole	Image dipole	
K_q	1	0
$m_q e^{j\beta_q}$	$m_q e^{j\beta_q}$	$m_q e^{j\beta_q}$
(x_q, y_q, z_q)	$(x_q, y_q, -z_q)$	$(x_q, y_q, -z_q)$
θ_q	θ_q	$\pi - \theta_q$
φ_q	$\varphi_q + \pi$	φ_q

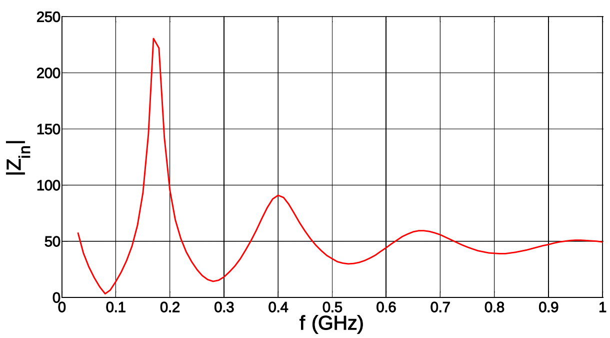


Fig. 2. Input impedance of the grounded microstrip.

The number of ideal dipoles is an important factor in estimating of the FF pattern and depends on the ratio of the largest antenna dimension (D) to the operating wavelength (λ) [3, 5]. In this study, D = 254 mm. Thus, at f_1, the condition of D << λ is satisfied and the PCB can be properly approximated by an ideal dipole. In this case, N = 2 leads to acceptable result. However, at f_2 and f_3, the PCB has a moderate size, $\lambda/10 \leq D < \lambda$. In these cases, it is observed that N = 8 is a suitable choice. It should be noted that this method, is practical when $D < \lambda$. Furthermore, it is observed that the speed of the optimization process can be considerably increased by assuming equal number of electric and magnetic dipoles. For the problem at hand, this can be achieved by dividing PCB into four equal sections and considering two dipole, one electric and one magnetic, in each section.

IV. NF SAMPLING

For extracting amplitude and phase information of NF two planes are employed, which are positioned at z_1 = ± 200 mm and z_2 = ± 300 mm. These planes with their images are depicted in Fig. 3. It can be easily verified that at f_1, both of z_1 and z_2 are placed in the NF reactive range. At the second test frequency, z_1 and z_2 are located in reactive and radiation regions, respectively. Finally, at f_3, both planes are placed in the radiation NF. Based on [17], the dimension of each plane is selected to be 774 mm × 774 mm.

It should be noted that, the number of observation points depends on the number of dipoles and the number of dipoles depends on the electrical size of PCB. Thus, as mentioned earlier, when $D < \lambda/10$, it is sufficient to use two dipoles, which corresponds to 14 unknowns. When $\lambda/10 \leq D < \lambda$, employing eight diploes suffice, which leads to 56 unknowns. In addition, for properly handling of the optimization process, the number of observation points is selected to be more than twice the number of unknowns.

V. COMPARISON OF SIMULATED DATA WITH GA ESTIMATION

NF data on observation planes, computed by Ansoft HFSS, are used as reference values. These data are compared to NF data of the optimized equivalent dipoles. Figure 4 shows the NF data of the main source and those of the equivalent dipole at f_1. The NF and FF tolerances for this case at f_1 are 0.8 dB and 0.81 dB, respectively. It should be noted that in the most EMC standards, the limit for this tolerance is ±1.5 dB [16].

Figure 5 shows the radiation pattern of the original sources and the equivalent dipoles in 3 m range at f_1. At f_2, four dipoles are used. In this case, NF and FF tolerances are 0.45 dB and 1.04 dB, respectively. Reducing the number of dipoles from 8 to 4; halves the number of unknowns and consequently, multiplies the speed of the optimization process. Figures 6 and 7 show the FF radiation pattern of the original sources and the equivalent dipoles in 3 m range at f_2 and f_3, respectively. Table 2 presents T^{NF} and T^{FF} for test frequencies and parameters of equivalent dipoles are reported in Table 3.

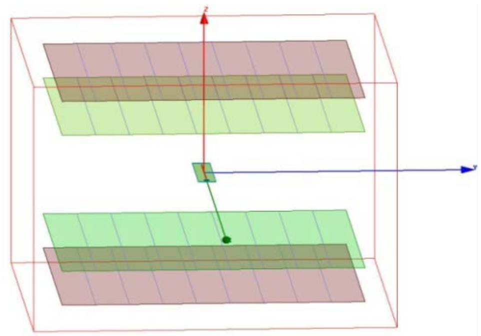
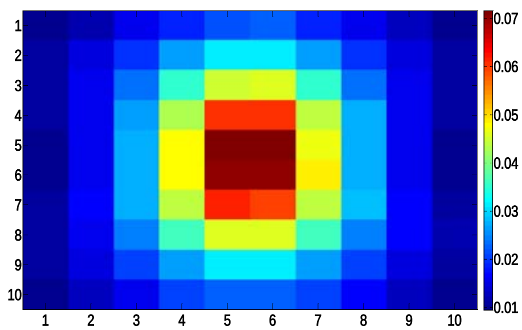
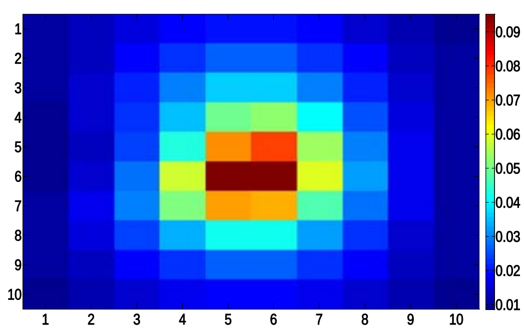


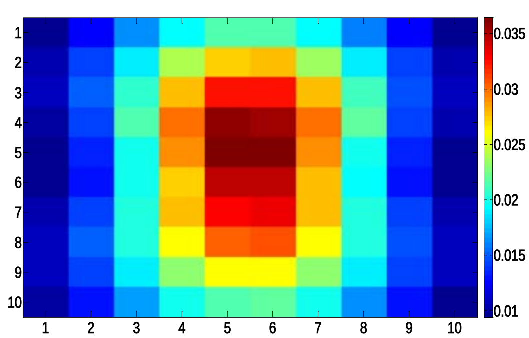
Fig. 3. HFSS simulation setup.



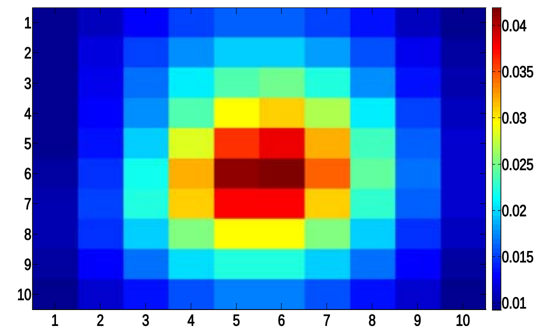
(a) Reference data at z_1.



(b) GA data at z_1.



(c) Reference data at z_2.



(d) GA data at z_2.

Fig. 4. Magnitude of the NF on the observation planes at f_1 with $N = 2$ and $T^{NF} = 0.8$ dB.

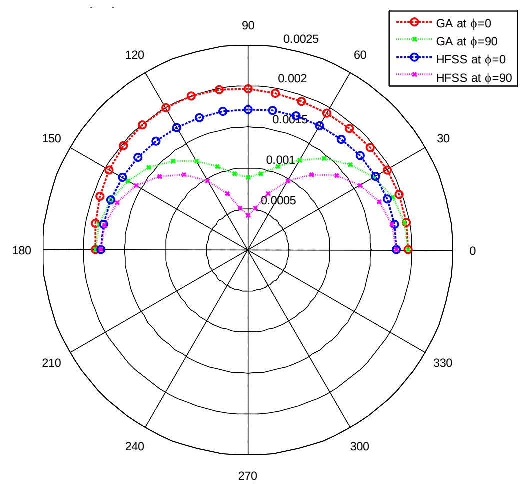


Fig. 5. FF radiation pattern at $f = 100$ MHz, $\varphi = 0^o$, 90^o with $N = 2$ and $T^{FF} = 0.81$ dB.

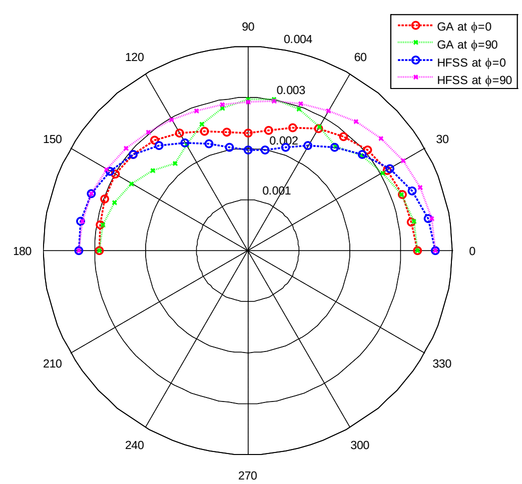


Fig. 6. FF radiation pattern at $f = 300$ MHz, $\varphi = 0^o$, 90^o with $N = 4$ and $T^{FF} = 1.04$ dB.

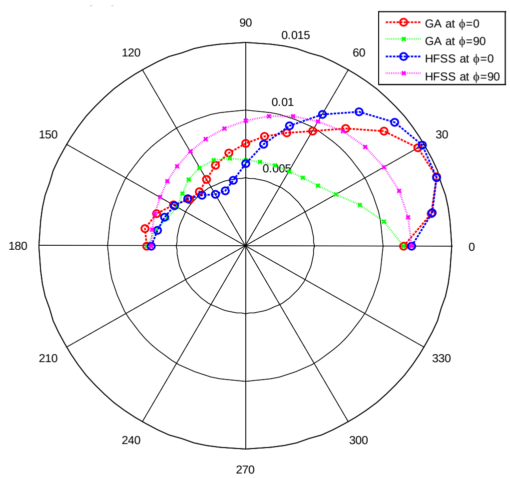


Fig. 7. FF radiation pattern at f =700 MHz, $\varphi = 0^o$, 90^o with N = 8 and T^{FF} =1 dB.

Table 2: NF and FF tolerances.

Frequency	**N**	T^{NF} **(dB)**	T^{FF} **(dB)**
f_1	2	0.79	0.81
f_2	4	0.45	1.04
f_3	8	0.45	1

Finally, Table 4 compares the results of the present work with those of [3], which properly validate the proposed method.

Table 3: Parameters of the ideal dipoles in GA model.

N	Frequency	K	m	β (rad)	x (m)	y (m)	z (m)	θ (rad)	φ (rad)
2	f_1	1	7.7×10^{-6}(m.A)	0.19	0.031	-0.02	0.004	0.014	1.96
		0	2.19×10^{-5}(m^2.A)	0.57	0.005	-0.002	0.0015	1.57	0.7
4	f_2	1	1×10^{-6}(m.A)	0.86	-0.134	-0.03	0.003	0.63	1.71
		0	3.1×10^{-7}(m^2.A)	0.9	-0.109	-0.012	0.004	1.64	1.47
		1	9.95×10^{-6}(m.A)	0.92	0.028	0.03	0.005	2.77	0.187
		0	5×10^{-6}(m^2.A)	0.42	0.05	-0.001	0.004	0.85	0.015
8	f_3	1	1.49×10^{-5}(m.A)	1.41	-0.11	0.018	0.0029	0.045	2.87
		0	5.4×10^{-7}(m^2.A)	0.68	-0.12	0.023	0.004	1.93	1.099
		1	1.2×10^{-5}(m.A)	1.74	-0.018	0.0005	0.0003	0.019	0.213
		0	1.17×10^{-6}(m^2.A)	0.629	-0.066	0.018	0.0014	0.466	0.199
		1	1.8×10^{-5}(m.A)	0.63	0.05	0.027	0.0028	1.6	0.04
		0	1.5×10^{-7}(m^2.A)	0.614	0.033	-0.03	0.0026	1.62	0.004
		1	1.3×10^{-5}(m.A)	1.22	0.092	0.002	0.005	0.031	0.005

Table 4: Comparison of the proposed method with [3].

f (MHz)	N	T^{NF} (dB)	T^{FF} (dB)
100	2	0.79	0.81
300	4	0.45	1.04
700	8	0.45	1
300	8	0.11	0.12
600	8	0.34	0.48
900	8	0.77	0.80

VI. INFLUENCE OF NUMBER OF DIPOLES ON CONVERGENCE RATE

The effect of number of dipoles, on CPU time and tolerance, is studied by considering the microstrip PCB at f_1. Figure 8 shows the required CPU time. Clearly, doubling of the N leads to considerable increase in the CPU time. Table 5 shows the influence of N on the simulation time and NF/FF tolerances. In all cases, number of generation is 400. Simulations are carried out on an Intel Core™2 Duo processor with CPU 2.8 GHz and 4 GB RAM.

Table 5: Influence of *N* on the convergence rate.

Frequency (MHz)	No. of dipoles	T^{NF} (dB)	T^{FF} (dB)	Number of points	Time to equivalent dipoles (min)	Number of generations	Initial population
100	2	0.79	0.81	66	7	400	62
100	4	0.39	1.39	66	25	400	102
100	6	0.43	1.23	100	55	400	102
100	8	0.41	1.3	100	70	400	102
100	10	0.41	1.5	200	180	400	132

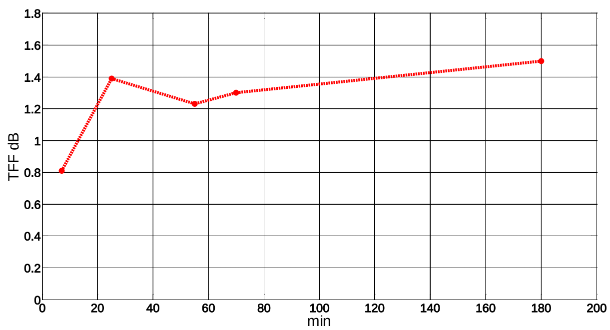


Fig. 8. Influence of *N* on the CPU time.

VII. CONCLUSION

A new combination of NF-FF transformation and GA is proposed for efficient FF pattern estimation of a grounded microstrip PCB. The method is independent of the uniqueness theorem and is just based on the magnitude information of the observation points, which has led to substantial decrease in the simulation time.

Acknowledgement

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