Signal Flow Graph model for Distance-dependent Transfer Function between two antennas in Short-Range Communication

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***Abstract* - The validity of proposed SFG model was verified by comparing our theoretical results of S_{21}, S_{11} to originally obtained values. We also introduced weighted averaging method to improve parameters estimation accuracy.**

***Index Terms* — signal flow graph, antenna parameters, S parameters, estimation.**

1. Introduction

Offloading to the short-range wireless communication system has been considered as one of the solutions to explosive mobile traffic. In order to evaluate short-range wireless communication system, complex values of transmitting (Tx) and receiving (Rx) antenna parameters, and S-parameters are needed. We have constructed a novel Signal Flow Graph (SFG) model to express wave transmission and reflection characteristic between Tx-Rx [1]. Using SFG transfer function, antenna gain and antenna radar cross section (RCS), port reflection can be related with the r dependency of S_{21}, S_{11} for variety of distance r between Tx-Rx, from the near rannge up to the far fields.

We simulated Tx-Rx model for $S_{21}(r)$, $S_{11}(r)$ at three different distance r and extract the parameters for each group of r. In addition, we also introduced an averaging method by adopting larger number of data $S_{21}(r)$ at different r, to enhance the stability in parameters estimation.

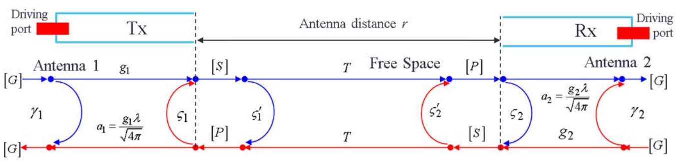

Fig. 1 SFG of Tx-Rx in short-range

2. Transfer functions from SFG

Let us denote i = 1,2 as index referring to Tx and Rx, and r as distance between phase center of Tx-Rx. g_i, ς_i, γ_i are antenna gain coefficient, RCS coefficients, and antenna port reflection. $T(r)=\exp(-jkr)/\left(\sqrt{4\pi}r\right)$ is propagation-attenuation function. r-dependent transfer functions are expressed as in (1), (2) [1].

Identical antenna was used for both Tx-Rx. For a given position of r, we extract desired antenna parameters. Consecutive data of $S_{21}(r-\Delta r)$, $S_{21}(r)$, $S_{21}(r+\Delta r)$ were used to solve for g, ς, ς', and $S_{11}(r)$ for this given γ. This procedure is repeated with the distance r of interest. Extracted antenna parameters are expected to converge as r increases.

$$S_{21}^{SFG}(r)=\frac{g_1T(r)a_2}{\left(1-\varsigma_1\varsigma_1'(r)\right)\left(1-\varsigma_2\varsigma_2'(r)\right)-\varsigma_1\varsigma_2T^2(r)} \quad (1)$$

$$S_{11}^{SFG}(r)=\gamma_1+\frac{g_1a_1\left[\varsigma_1'(r)+\left(T^2(r)-\varsigma_1'(r)\varsigma_2'(r)\right)\varsigma_2\right]}{\left(1-\varsigma_1\varsigma_1'(r)\right)\left(1-\varsigma_2\varsigma_2'(r)\right)-\varsigma_1\varsigma_2T^2(r)} \quad (2)$$

3. Valid range of transfer functions

Patch antenna model (at 2.45 GHz) were used for demonstration. S-parameters were acquired on various r from 0-10λ at Δr = 0.125λ step. Far-field starts from r = 3.6λ. At the neighborhood of r = 9.5λ, we obtained g, ς, ς', γ then substituted to (1), (2) to calculate theoretical values of S_{21}, S_{11} as function of r. These were compared to independently originally obtained values of S_{21}, S_{11}. Relative error graph was plotted, to show from which distance theoretically calculated values are close to originally obtained values.

In Fig. 2, both lines were seen to match well from the range of r = 3λ onward. Fig. 3 shows relative error of calculated value using a SFG model to originally obtained values:

$$\Delta S_{i1}/S_{il}=\left(S_{i1}^{SFG}-S_{il}\right)/S_{il} \quad (3)$$

From r = 3λ, relative errors decreased below 5%. (1) showed attenuated S_{21} with ripple similar to ones in original values. As for (2), good agreement was also shown in S_{11} results, with ripple were successfully reproduced as a function of r. Since S_{11} is reflected power from Tx-Tx, it is severely affected by RCS of Rx when Tx-Rx is too close. Influence of RCS appeared in form of spatial ripple.

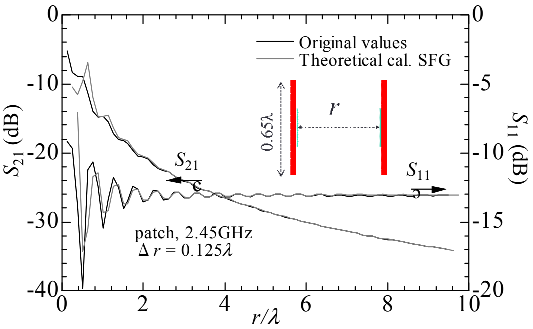

Fig.2 S-parameters of patch antenna

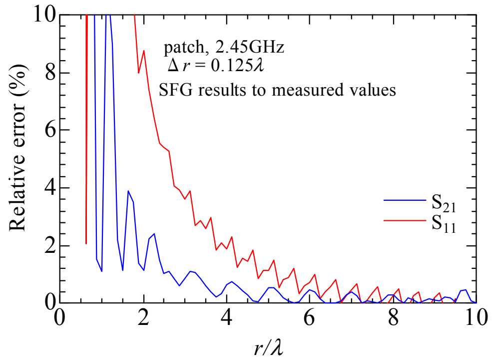

Fig. 3 Relative error of SFG calculation to original values

4. Weighted averaging

g, ς estimated using (1) are supposed to be independent of r. However, estimated RCS ς was fluctuating even at large r [1]. Error is due to computational matrix's conditional number dramatically increases at large r. Inaccurate input of S_{21} at large r is another possible reason. Recursive weighted averaging was introduced in order to reduce inaccuracy of parameters' determination by utilizing more S_{21} data.

Averaging of consecutive S_{21} data centering r will provide more precise $g(r)$ estimation in far-field measurement [3]. In similar manner, we calculate arithmetic mean of complex $S_{21}(r-\Delta r)$, $S_{21}(r)$, $S_{21}(r+\Delta r)$ by assigning each data with a certain weighting factors. Because (1) is capable of representing r-characteristic of received power as shown in Fig.2, weighting factor is based on (1):

$$w_1 = \frac{S_{21}^{SFG}(r)}{3S_{21}^{SFG}(r-\Delta r)},\ w_2 = \frac{1}{3},\ w_3 = \frac{S_{21}^{SFG}(r)}{3S_{21}^{SFG}(r+\Delta r)} \quad (4)$$

$$S_{21}^{\ 1}(r) = S_{21}(r-\Delta r)w_1 + S_{21}(r)w_2 + S_{21}(r+\Delta r)w_3 \quad (5)$$

$S_{21}^{\ 1}(r)$ is the averaged data at r after one recursion. $S_{21}^{\ 1}(r-\Delta r)$, $S_{21}^{\ 1}(r)$, $S_{21}^{\ 1}(r+\Delta r)$ are used to calculate $S_{21}^{\ 2}(r)$. The recursion process of weighted averaging is repeated as:

$$S_{21}^{\ n}(r) = S_{21}^{\ n-1}(r-\Delta r)w_1 + S_{21}^{\ n-1}(r)w_2 + S_{21}^{\ n-1}(r+\Delta r)w_3 \quad (6)$$

g, ς, ς' for (1) was found as in section 3 then input into (4) to calculate weighting factors. $S_{21}^{\ n}$ input data was averaged by n recursion, shown in Fig. 4. The averaging process with (4) weighting factors generated converging ripple at small r. These ripples at S_{21} represent RCS influence from opposite antenna, are necessary to calculate RCS. Fig. 5 showed gain results converged to separated far-field result. Fig. 6 demonstrated that estimated RCS's fluctuation reduced as recursion increases. Level difference to far-field RCS result was considered due to different in wave excitation.

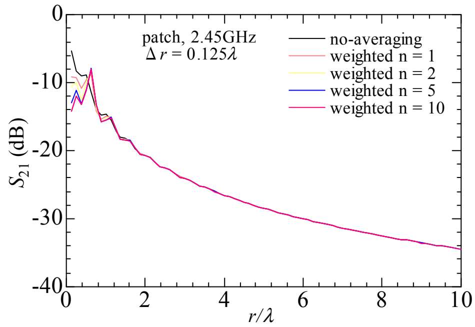

Fig.4 Averaged S_{21}

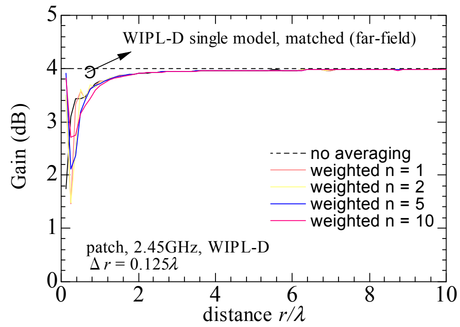

Fig.5 Estimated antenna gain

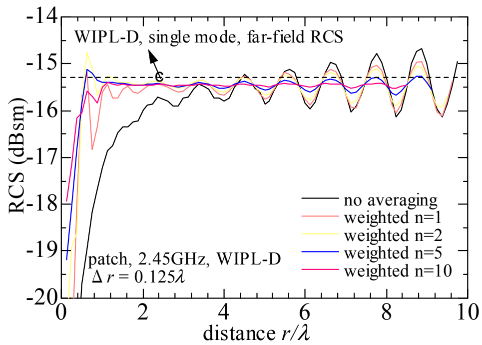

Fig.6 Estimated antenna RCS

5. Conclusion

Proposed SFG model was shown to correctly express distance characteristic of inter-antenna S parameters. The model was valid from r = 3λ range, smaller than far-field distance of analyzed antenna. Weighted averaging is shown to reduce unwanted fluctuation in estimated RCS results. However, the fluctuation might have certain physical interpretation, which will be investigated further.

References

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