Effect of dual antenna transmission on mobile terminal specific absorption rate

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***Abstract*- Mobile transmit diversity (MTD) is one of the techniques used to enhance the up-link speed and system capacity of cellular mobile communication systems. A simple MTD scheme comprises of two transmit antennas whose feeds have a tunable phase difference. A study on how this phase difference affects the localized volume-averaged Specific Absorption Rate (SAR) is carried out. SAR variations as much as 4.8 dB and 3.0 dB are observed in 900 MHz and 1800 MHz bands, respectively. At the 900 MHz band, the peak SAR of a mobile terminal with dual transmit antennas can be larger than SAR of a mobile terminal with a single transmit antenna. This fact should be considered in future development of standardized protocols for SAR evaluation of mobile terminals.**

I. Introduction

Multiple antennas can mitigate multipath fading of the received signal envelope and suppress interferences, thereby improving performance and system capacity of wireless networks [1, 2]. While antenna array techniques have been traditionally deployed in base stations, there is a recent trend to incorporate antenna arrays at mobile terminals to lift the limits on high-speed wireless data services. To improve down-link capacity, Transmit Diversity (TD) at the base stations [3] and Mobile Receive Diversity (MRD) at the mobile terminals [4] have been adopted in the ITU endorsed 3G systems W-CDMA and CDMA 2000. Field trials of the MRD phones by Sprint have shown improvement of more than 3 dB in the system capacity for the CDMA 2000 standards [4]. Commercial CDMA phones with the MRD antennas have been built. Complimentarily, to enhance the up-link performance, Mobile Transmit Diversity (MTD) antennas can be utilized at the mobile terminals. The Multiple Input and Multiple Output (MIMO) systems employ multiple antennas to achieve transmit and receive diversity at both base stations and mobile/fixed terminals.

A simple TD scheme among many outlined in [3], comprises of two transmit antennas whose feeds have a tunable phase difference. This can be seen as two-element antenna beamforming. One of the questions related to this approach is how it will impact the specific absorption rate (SAR) of the mobile terminal.

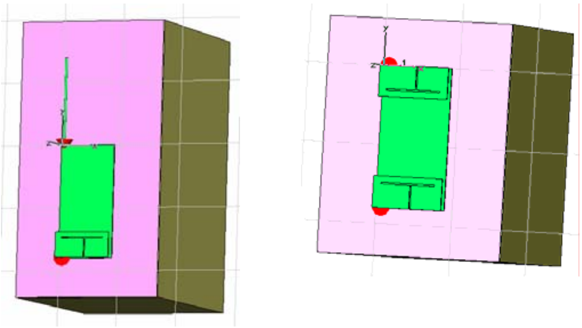
Transmit antenna phases have strong effects on the SAR of mobile handsets. A study has been done to reduce the SAR using a phased antenna array made of two monopoles on a mobile phone at 1.8 GHz [5]. Another study on two PIFA antennas on a mobile phone at 1.9 GHz has revealed that the phase difference between the TD antennas has a significant impact on the SAR, changing it by over 50% [6]. The two PIFAs were located at the top of the mobile phone.

In this paper, we present a study on how phase difference between MTD antennas affects the localized volume-averaged SAR at both 900 MHz and 1800 MHz bands. It is shown that using two phased antennas could result in larger SAR than a single-fed MTD antenna with the other antenna match terminated for a given total output power in the 900 MHz band. This phenomenon is due to the alignment of induced Printed Wiring Board (PWB) currents from individual antennas as well as the coupling of the two antennas via the PWB. Examples of whip-PIFA and PIFA-PIFA antenna configurations are presented to illustrate the findings.

II. Models

We consider two configurations of MTD antennas, i.e., a) a $\lambda/4$ monopole whip at the top and a dual-band PIFA at the bottom of the PWB, and b) two dual-band PIFAs at the top and the bottom of the PWB, as shown in Fig. 1. The symmetric property of configuration b is helpful in understanding the effects of the antenna phase difference on current distributions and SAR. The size of the PWB is 45 mm x 90 mm. The size of the PIFAs is 45x20x7 mm^3. The input power into each MTD antenna is fixed to 0.5 W and the antenna phase difference varies from 0 to 360 degrees. For comparison, the input power to single antenna is 1 W.

A box phantom model consisting of two layers representing the phantom shell and tissue simulant is used to study the effects of the antenna phase on the SAR. The shell parameters are: relative permittivity $\varepsilon_r = 4$, relative permeability $\mu_r = 1$, conductivity $\sigma = 0\,\mathrm{S/m}$, density $\rho = 1800\,\mathrm{kg/m^3}$, and thickness of 2 mm. The tissue simulant parameters are: $\varepsilon_r = 41.5$, $\mu_r = 1$, $\sigma = 0.97\,\mathrm{S/m}$, $\rho = 1000\,\mathrm{kg/m^3}$, and thickness of 150 mm. The distance between the PWB and the phantom surface is 10 mm.



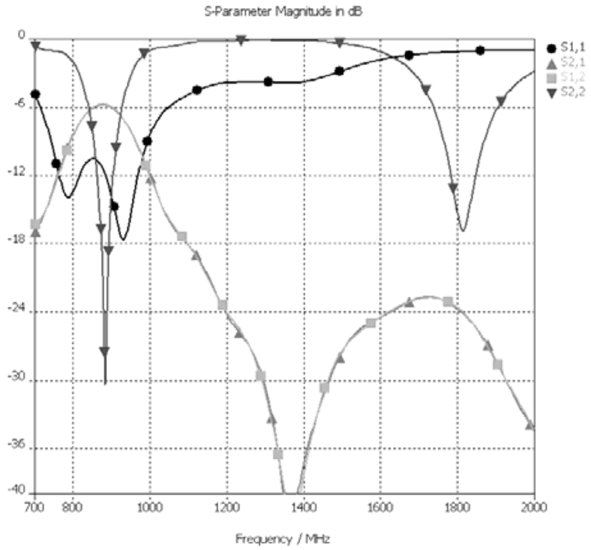
(a) (b)

Figure 1. MTD Antenna configurations: (a) whip-PIFA and (b) PIFA-PIFA

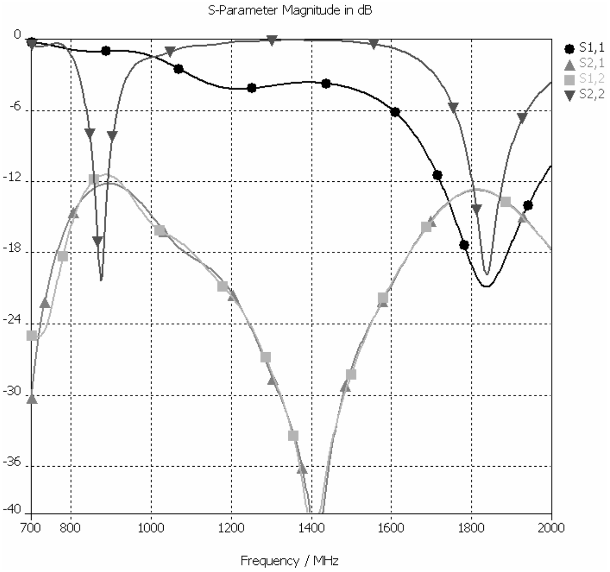
III. RESULTS

A. *Return Loss and Coupling*

Return loss and coupling for MTD antenna configuration (a) are shown in Fig. 2. The return loss values are larger than 12 dB in 900 MHz and 1800 bands. The coupling levels are about -6 dB in the 900 MHz band and -18 dB in the 1800 MHz band. The whip antenna shows a dual resonance due to the coupling to the PIFA in the 900 MHz band.



(a)



(b)

Figure 2. Return loss and coupling of whip-PIFA configuration:
(a) 900 MHz band and (b) 1800 MHz band
Whip = port 1 and PIFA = port 2

The return loss and coupling for MTD antenna configuration b are shown in Fig. 3. The return loss is less than 20 dB at both bands. There is a strong coupling between the antennas, about -4 dB in the 900 MHz band.

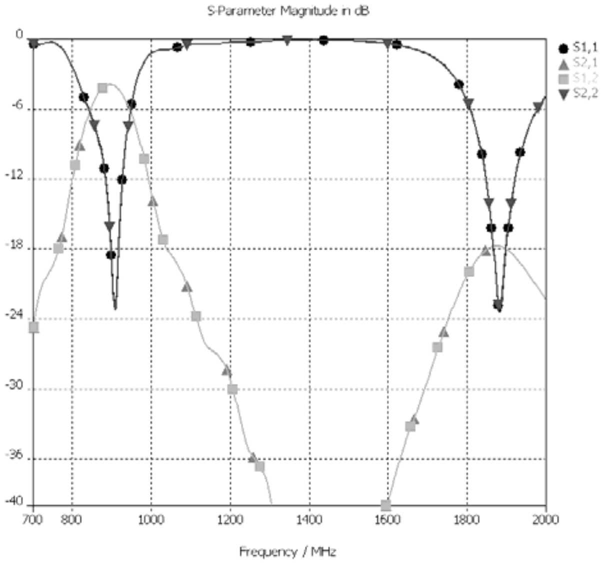


Figure 3. Return loss and coupling of PIFA-PIFA MTD configuration

B. *SAR Effects*

The input power to each antenna is kept at 0.5 W while the antenna phase difference changes from 0 to 360 degrees. It is noted that each antenna is assumed to be perfectly matched - considering the return loss data shown in Figures 1-3, this assumption will provide a good enough accuracy for the purposes of this study. Both antennas have the same reference feed direction with respect to the ground plane.

For comparison, two cases of single-fed antennas are studied. In the first case, there are two antennas on the PWB. One of the antennas is fed with 1 W input power, while the other antenna is terminated either with 50 ohm load, open, or short. The open termination here refers to the open end between the antenna feed and the ground, not electrical open circuit. It is noted that the matched termination represents the best practical case for the MTD antennas. In the second case, there is only a single antenna on the PWB, either a whip or a PIFA, fed with 1 W input power.

1) Whip-PIFA MTD Antennas

SAR values with respect to the antenna phase difference (PIFA leads the whip) at the frequency of 884 MHz are listed in Table 1. It is observed that the MTD antennas have the minimum SAR for 0 degree phase difference and the maximum SAR around phase difference of 225 degree.

Table 1 SAR vs. antenna phase difference of whip-PIFA configuration at 884 MHz

Phase diff. [deg]	0	45	90	135	180	225	270	315
SAR(10g)[W/kg]	0.94	1.36	1.78	2.03	2.32	2.84	2.72	1.95

For comparison, SAR values of the single-fed MTD antenna with the other antenna terminated in match, open, and short are given in Table 2 and 3. The resonant frequency of PIFA is constant regardless of the termination types of the whip antenna. However, the whip has a dual resonance when the PIFA is terminated with an open or a short. Return loss of the whip antenna when the PIFA is terminated with a short is shown in Fig. 4.

Table 2 SAR (10g) of PIFA with whip terminated

whip matched	whip open	whip short
1.04 @ 884 MHz	2.50 @ 894 MHz	2.51 @ 894 MHz

Table 3 SAR (10g) of whip with PIFA terminated

PIFA matched	PIFA open	PIFA short
2.15 @ 884 MHz	2.89 @ 782 MHz/ 4.01@ 910 MHz	3.08 @ 804MHz/ 4.03 @ 956 MHz

Note that the maximum SAR of the whip-PIFA dual-fed MTD antennas is larger than the SAR of single-fed MTD antennas, either whip or PIFA, with the other antenna match terminated in the 900 MHz band.

In the 1800 MHz band, SAR values of the whip-PIFA MTD antennas versus the phase difference are listed in Table 4. Since the PWB length of 90 mm is close to the half wavelength of 82 mm, the maximum SAR occurs around 45 degree and the minimum SAR around 225 degree, as opposite to the case in the 900 MHz band.

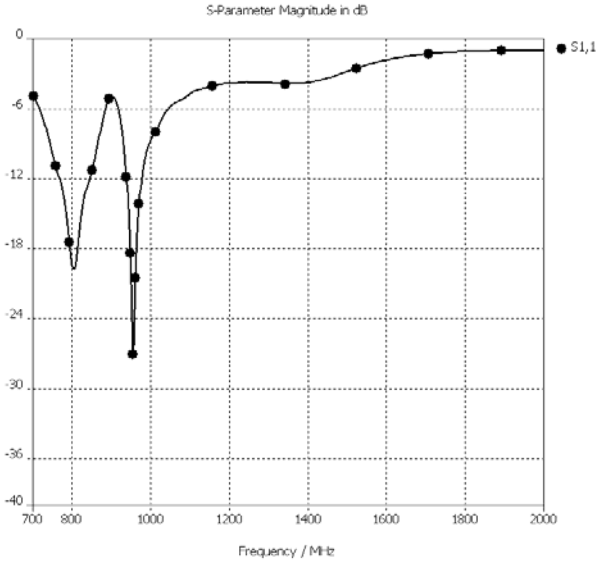


Figure 4. Dual resonance of whip antenna when PIFA is short terminated

Table 4 SAR vs. antenna phase difference of whip-PIFA configuration at 1838 MHz

Phase diff. [deg]	0	45	90	135	180	225	270	315
SAR(10g)[W/kg]	3.97	4.24	3.66	2.84	2.50	2.14	2.37	3.02

Table 5 and 6 give the SAR values of single-fed MTD antennas with the other antenna in various terminations. It is observed that the maximum SAR of the dual-fed MTD antennas is less than the maximum SAR of single-fed MTD antennas in the 1800 MHz, as opposite to the case in the 900 MHz band.

Table 5 SAR (10g) of PIFA with whip terminated

whip matched	Whip open	Whip short
2.32 @ 1838 MHz	2.25 @ 1830 MHz	2.27 @ 1830 MHz

Table 6 SAR (10g) of whip with PIFA terminated

PIFA matched	PIFA open	PIFA short
4.83 @ 1838MHz	5.29 @ 1872 MHz	4.97 @ 1793 MHz

2) PIFA-PIFA MTD Antennas

To check the effect of the antenna type on the studied phenomenon, we consider the symmetrical PIFA-PIFA configuration. In the 900 MHz band, the MTD antennas have the minimum SAR at 0 degree phase difference and the maximum SAR at 180 degree phase difference, as listed in

Table 7. The reason for this is that the 180 degree phase difference induces a wave mode to the PWB that produces a strong current density maximum in the middle of the PWB. The plot of SAR distributions for the 180 degree phase difference is shown in Fig. 5. The even mode with zero phase difference produces the minimum SAR value.

Table 7 SAR vs. antenna phase difference of PIFA-PIFA antenna at 909MHz

Phase [deg]	0	45	90	135	180	225	270	315
SAR(10g)[W/kg]	0.56	0.95	1.30	1.64	1.79	1.65	1.31	0.96

For a power unbalanced case of 0.36 W into one PIFA and 0.64 W into the other PIFA and the phase difference of 180 degree, the SAR is 1.76 W/kg, slightly smaller than the maximum SAR value for the differential mode. It thereby shows that the odd mode with phase difference 180 degree generates the maximum SAR.

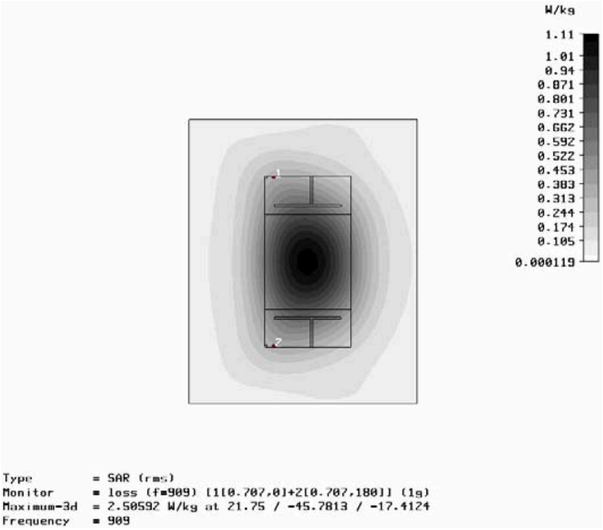


Figure 5. SAR distributions of the PIFA-PIFA MTD antennas for the phase difference of 180 degree

Table 8 lists the SAR values of one PIFA fed with 1W input power and the other antenna is terminated with matched, open, and short load. Similar to the whip-PIFA MTD antenna configuration, the SAR for the matched termination is less than the maximum SAR for the odd mode. The open and short terminations generate dual resonance in the 900 MHz band and their SAR values could be larger than the maximum SAR of the odd mode.

Table 8 SAR of one PIFA with other PIFA terminated

PIFA matched	PIFA open	PIFA short
1.0 @ 909 MHz	2.5 @ 841 MHz/ 1.0 @ 918 MHz	3.0 @ 868 MHz/ 1.6 @ 949 MHz

In the 1800 MHz band, the maximum SAR occurs around the phase difference $\pm 45^{o}$ while the minimum SAR around the phase difference $\pm 135^{o}$, as listed in Table 9. It is similar to the whip-PIFA MTD configuration. This is caused by the space phase difference of the PWB length. The SAR values fluctuate less as compared to in the 900 MHz band.

Table 9 SAR vs. antenna phase difference of PIFA-PIFA MTD antennas at 1884MHz

Phase [deg]	0	45	90	135	180	225	270	315
SAR(10g)[W/kg]	1.80	2.01	1.84	1.36	1.43	1.36	1.84	2.01

The termination type of the second PIFA affects SAR as well as the resonant frequency of the first PIFA, as given in Table 10.

Table 10 SAR (10g) of one PIFA with other PIFA terminated

PIFA matched	PIFA open	PIFA short
2.03 @ 1884 MHz	1.93 @ 1886 MHz	2.17 @ 1832MHz

3) *Single Antennas*

We also calculated SAR values for configurations with a single antenna on the PWB, either whip or PIFA, with the same dimensions as the ones for in the dual antenna configurations. The SAR values of the single antenna configurations are given in Table 11. It is highlighted that the maximum SAR values for the dual-antenna configurations are all less than the maximum SAR values of the single antenna configurations at both of the two frequency bands. There are two factors contributing to this fact. First, the coupling loss of about 6 dB for the whip-PIFA MTD antennas and 4 dB for the PIFA-PIFA MTD antennas reduces the total power radiated and dissipated, as compared to the single antennas. Secondly, the presence of the two antennas in the dual antenna configurations makes the local fields more evenly distributed over the space, thereby reducing the SAR values.

Table 11 SAR (10g) of single antennas

Single PIFA	Single PIFA	Single Whip	Single Whip
3.2 @888 MHz	3.3 @1885MHz	4.4 @852 MHz	8.1 @1856MHz

IV. Conclusions

Phase difference between two transmit antennas of a mobile terminal may affect the terminal SAR values significantly. This is mainly due to the change in the current density distribution induced to the PWB. The ratio of the maximum and minimum SAR values could be as much as 4.8 dB and 3.0 dB at the 900 MHz and 1800 MHz bands, respectively. It has been shown that in the 900 MHz band, the peak SAR of a mobile terminal with two transmit antennas can be larger than that of a single-antenna terminal for a given total transmit power. However, in general, introducing another antenna element on PWB will typically reduce SAR.

The SAR variation due to transmit antenna phase difference is larger than the target total measurement uncertainty of SAR evaluation systems (±30%, or +1.14 dB, -1.55 dB standard uncertainty at 95 % confidence level), as defined in [7] and [8].

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