Novel Internal High Gain Loop Handset Phone Antenna Design for Satellite and Terrestrial Integrated Mobile Communications System Applications

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***Abstract*—This article presents a novel internal high-gain handset phone antenna design for STICS system application. STICS is the Satellite and Terrestrial Integrated Mobile Communication System in the 2GHz band in Japan. This article demonstrates that 1.5 wavelength folded loop radiator is a very promising antenna solution for the future STICS mobile phone terminals for satellite-link functions. The proposed antenna can be closely integrated at the top side-edge of a corner of a handset ground plane with an internal-type and low-profile antenna size (3 mm height only protruded from the side-edge). A broadside fan-shape radiation pattern toward the sky can be formed successfully by the proposed antenna in the desired 2GHz band. Besides, the radiation pattern can achieve a wide coverage with 3 dB beamwidth over 150 degree and peak antenna gain over 4.5 dBi in the vertical plane cross the handset ground plane. The constructed prototype has been studied in this paper.**

Keywords—STICS; mobile phone antenna; 1.5 wavelength loop radiator; internal high-gain antenna; NICT; ITRI

I. INTRODUCTION

National Institute of Information and Communications Technology (NICT) has conducted the research and development on Satellite/Terrestrial Integrated Mobile Communications System (STICS) [1-3]. STICS shares the same 2 GHz frequency bands between satellite and terrestrial systems to improve spectrum efficiencies [3]. In STICS, a single mobile phone terminal can has dual-communication functions for being connected to either terrestrial or satellite link [1-3]. Therefore, STICS will be especially useful for emergency disasters such as large earthquakes or tsunami when terrestrial systems are damaged. Besides, for the satellite communication link, a large-scale deployable antenna (LDR) with a diameter of 30 m will be installed in the geostationary satellite of STICS for achieving 100 high-gain (over 47 dBi) multi-beams coverages and reducing minimum antenna gain requirement of mobile phone terminals (over 0 dBi) in the link budget [3]. With the relatively much lower minimum antenna gain requirement of STICS handset phones compared to the other satellite mobile communication systems [4-6], it has advantages of relatively lower RF power consumption and smaller antenna form factor for implementing and integrating STICS satellite-link function into the commercial smart phone devices with simpler, lower cost and more aesthetic considerations. In [1-2], the satellite/terrestrial cooperative control technology and the technology on interference avoidance between satellite and terrestrial systems have been studied and presented by NICT. This paper will propose a novel internal-type high-gain loop mobile phone antenna for STICS satellite link applications developed and cooperated by NICT in Japan and ITRI in Taiwan.

Loop-type antennas have been demonstrated to be attractive for mobile phone applications [7-12]. Because their excited surface current paths are in a closed form [7-9, 12-14], which is different from the conventional mobile phone antennas such as the monopoles, planar inverted-F antennas (PIFAs) or inverted-F antennas (IFAs), whose excited surface current paths are in an open form [7-9, 12-16]. Hence, the possible coupling between the loop antenna and the system ground plane of a mobile phone can be much smaller than that of the conventional mobile phone antennas. In [7-9], it showed that 0.5λ (unbalanced) mode of loop antennas can be excited successfully when the loop structure is connected to the PCB of a handset phone. And the 0.5λ loop mode is possible to be designed for covering the required bandwidth of lower WWAN/LTE systems. In [10-11], 0.25λ (unbalanced) loop mode is excited successfully with internal matching circuit technologies for more compact resonant size. In [12], it demonstrated that the 1.0λ (balanced) loop antennas can be closely integrated with other nearby radiators for MIMO applications because coupling current of PCB between antennas can be greatly reduced. And in [13], it proposed a 1.0λ (balanced) dual-loop antenna design to achieve high-gain performance in 2.4/5.2/5.2 GHz band for MIMO access point device applications. In [14], it presents that 1.0λ (balanced) loop-type antennas can generate wide 3-dB beamwidth patterns successfully for MIMO access point device applications.

In this paper, it demonstrates that 1.5λ-type folded loop radiators would be a promising and attractive antenna solution for STICS handset phone applications to achieve satellite-link functions. The proposed antenna can be designed with high-gain and wide-coverage radiation pattern successfully, and furthermore it can be closely integrated at the short side-edge of a corner of a handset phone PCB with a low-profile and internal-type antenna size. The constructed antenna prototype has been studied and analyzed in the following paragraphs.

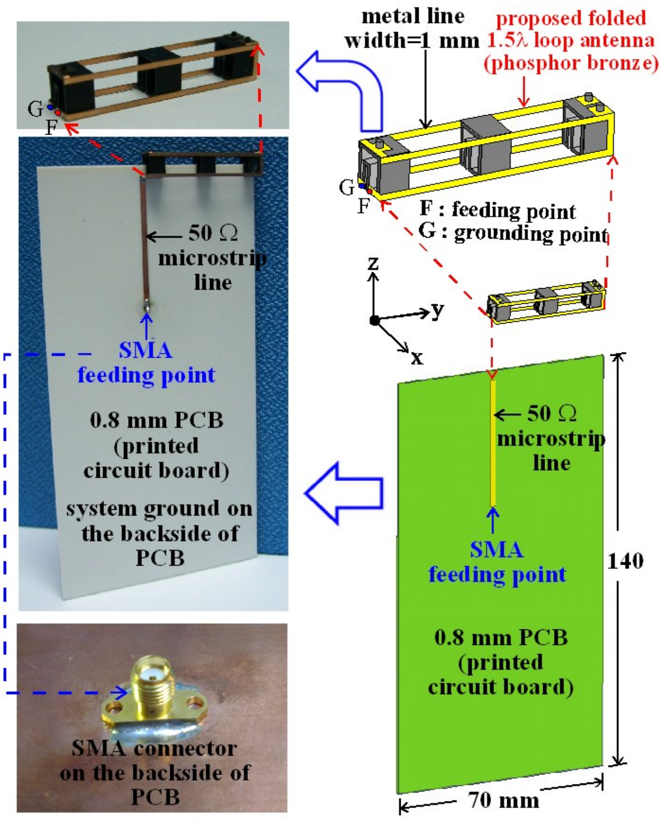

Fig. 1 Geometry and experiment photos of the proposed internal-type high-gain loop antenna for STICS mobile phone applications.

II. Antenna Design

Fig. 1 shows geometric structures of a constructed prototype for the proposed internal high-gain loop antenna for STICS mobile phone applications. It is mainly formed by a closed loop metal path with phosphor bronze material and with a narrow metal line width of 1 mm, and to be folded becoming a low-profile overall antenna size. The phosphor bronze metal is a good conductor with tenacity and elasticity. A 0.8-mm thick PCB (Rogers 4003C) substrate is used as the system circuit board of a STICS mobile phone, and a full system ground plane of 70 × 140 mm^2 is printed on the backside of the PCB. The proposed antenna is closely integrated at the top short side-edge of a corner of the ground plane with a protruded height only 3 mm from the same side-edge of the PCB, which is a very attractive and promising architecture for internal-type antennas in the practical mobile phone applications. And in order to firmly fix the folded loop metal path, three supporters with PC and ABS mixed materials were designed to be integrated between the antenna structure and the PCB substrate.

The constructed loop antenna prototype can generate a resonant mode with good impedance matching levels (better than 10 dB) to cover the RX band (2170~2200 MHz) of STICS for satellite-link operations. Fig.2 (a) and (b) show the detail dimensions of the proposed antenna and the three supporters. It is important to mention that the proposed loop antenna is chosen to be designed operating in the 1.5 λ resonant mode (unbalanced) for achieving high-gain and wide-coverage pattern performance successfully to fulfill practical requirements in the RX band of STICS operations [1-3]. The total length of the loop metal path is about 186 mm, which is close to but slightly shorter than the 1.5 λ of 2185 MHz (the center frequency of the RX band of STICS) because of frequency down-shifting effects caused by the relatively higher ε_r (3.5) of the three supporters (PC+ABS). The proposed closed loop antenna has two end terminals: one is a feeding point (point F in Fig. 1 and 2) connected to a 50 Ω microstrip line printed on the front surface of the PCB (as shown in Fig. 1), and the other one is a grounding point (point G in Fig. 1 and 2) connected to the system ground plane printed on the backside of the PCB (as shown in Fig. 1). The other end of the microstrip feeding line is electrically connected to a 50 Ω SMA connector at the backside of the PCB for RF signal feeding and antenna performance testing.

For the 1.5λ loop mode, the loop current resonant path will exist three current-null spots [7-9]. By simply and properly bending the 1.5λ loop resonant path, it is demonstrated in this paper that directive (maximum antenna gain better than 4.5 dBi) and wide-coverage (3dB beamwidth over 150 degree in the x-z plane in Fig. 1) radiation pattern toward the sky (+z direction in Fig. 1) can be achieved successfully. The simulation and measurement results for the constructed prototype are presented and described in the section III.

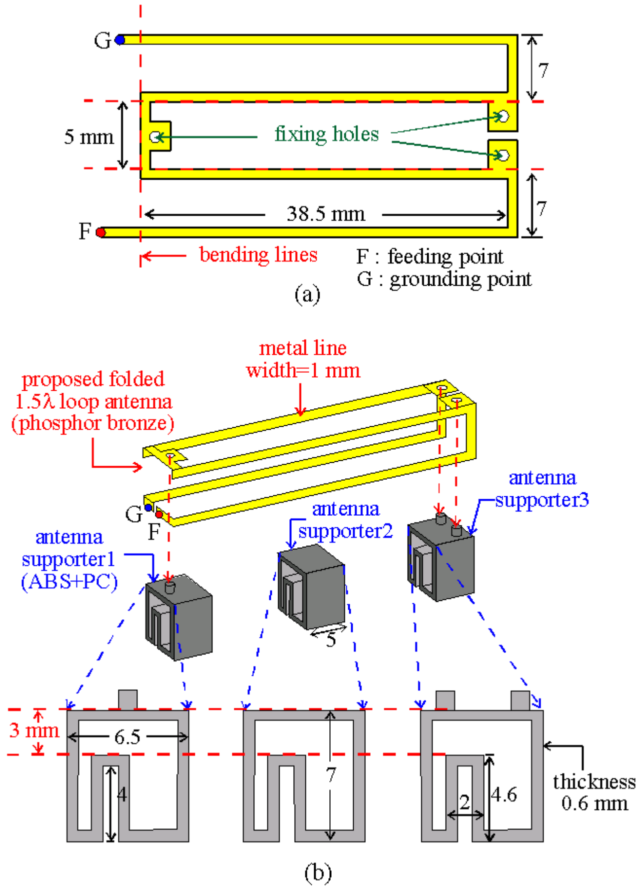

Fig. 2 (a) Proposed loop antenna un-bent in a planar structure and (b) proposed folded 1.5λ loop antenna and supporters.

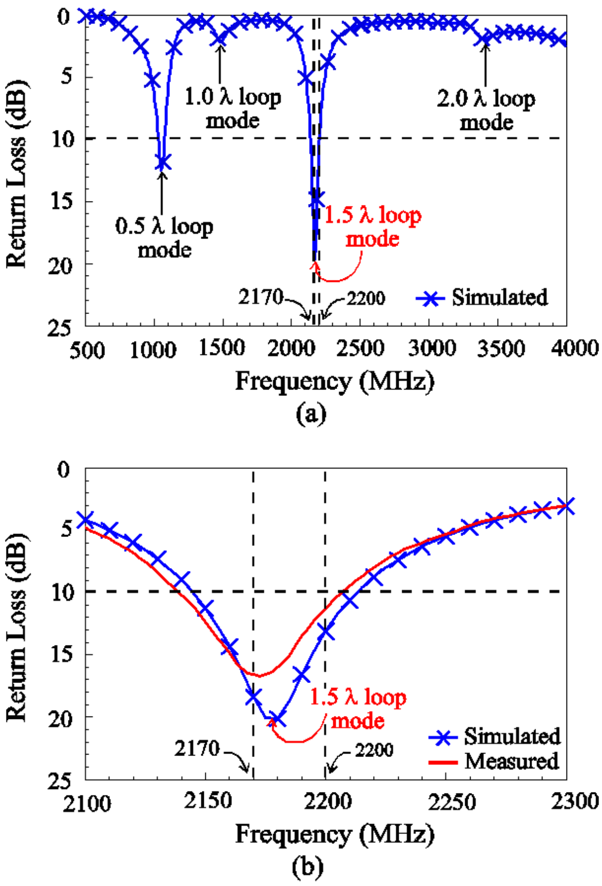

Fig. 3 (a) Simulated return loss of the proposed antenna in the 500~4000 MHz frequencies and (b) measured and simulated return loss of the proposed antenna in the 2100~2300 MHz frequencies.

III. Results and Discussion

Fig. 3(a) presents the simulated return loss of the proposed loop antenna in the 500~4000 MHz frequencies. It can be seen that the operating mode chosen and designed for covering the desired 2 GHz STICS band is the 1.5λ loop resonant mode. Fig. 3(b) shows the simulated and measured return loss for the proposed loop antenna in the 2100~2300 MHz frequencies.

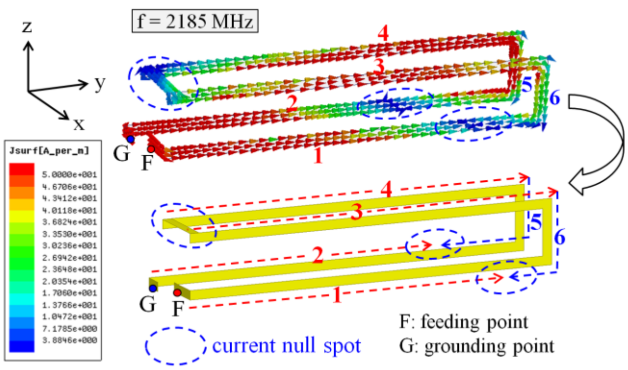

Fig. 4 Simulated current distribution on the proposed 1.5λ loop antenna at 2185 MHz.

From the results in Fig. 3(b), good agreement between the trend of measurement and simulation data is seen. And the 1.5 λ resonant mode of the constructed antenna prototype can be generated with good impedance matching levels (better than 10 dB) to cover the RX band (2170~2200 MHz) of STICS for satellite-link operations [1-3].

Fig. 4 shows the simulated surface current distribution on the proposed folded loop antenna at 2185 MHz (the center frequency of the desired RX band of STICS). It can be seen that there are three current-null spots to be formed on the folded loop resonant path. And because of the folded type and architecture proposed in this paper, the marked resonant currents 1, 2, 3, 4 (as shown in Fig. 4) can be formed in parallel to each other and the top short side-edge of a ground plane (as shown in Fig. 1). Besides, the marked resonant currents 1, 2, 3, 4 are also formed to resonate or flow in the same direction to form an equivalent 4-current array [15-16]. The close and paralleled top short side-edge of a ground plane (as shown in Fig. 1) could perform as an effective reflector structure for enhancing the directivity and maximum antenna gain of the equivalent 4-current array (marked resonant currents 1, 2, 3, 4) toward the sky (+z direction).

Fig. 5 shows the simulated and measured radiation efficiency and peak antenna gain for the proposed 1.5 λ folded loop antenna in the desired Rx band of STICS. From the results, good agreement between the measurement and simulation trends is also obtained. And it can be seen that the measured radiation efficiencies exceed 80%, and the measured peak realized antenna gains are over 4.5 dBi in the desired 2170~2200 MHz frequencies.

Fig. 6 (a) and (b) present the measured far-field 2D and 3D radiation patterns of the proposed antenna respectively at 2185 MHz (the center frequency of the RX band of STICS). From the Fig. 6(a) and (b), it can been seen that a broadside fan-shape radiation pattern toward the sky (+z dierction) can be formed successfully by the proposed antenna. Besides, the radiation pattern can achieve a wide coverage with 3 dB beamwidth about 150 degree (peak antenna gain about 4.63 dBi) in the x-z plane (the vertical plane cross the handset ground plane). And it can achieve a good coverage with 3 dB

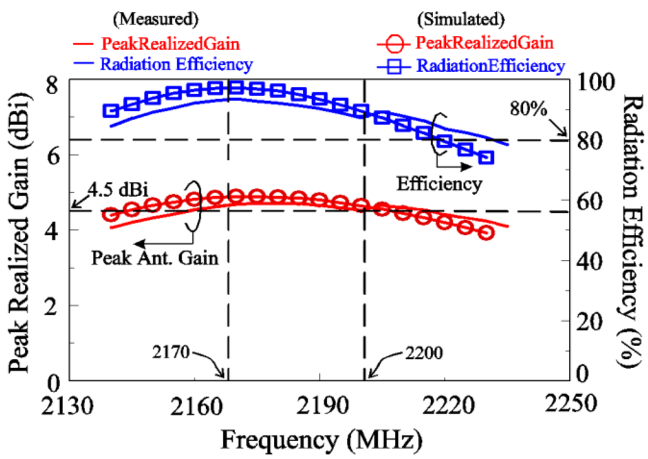

Fig. 5 Simulated and measured radiation efficiency and peak antenna gain of the proposed loop antenna in the desired Rx band of STICS.

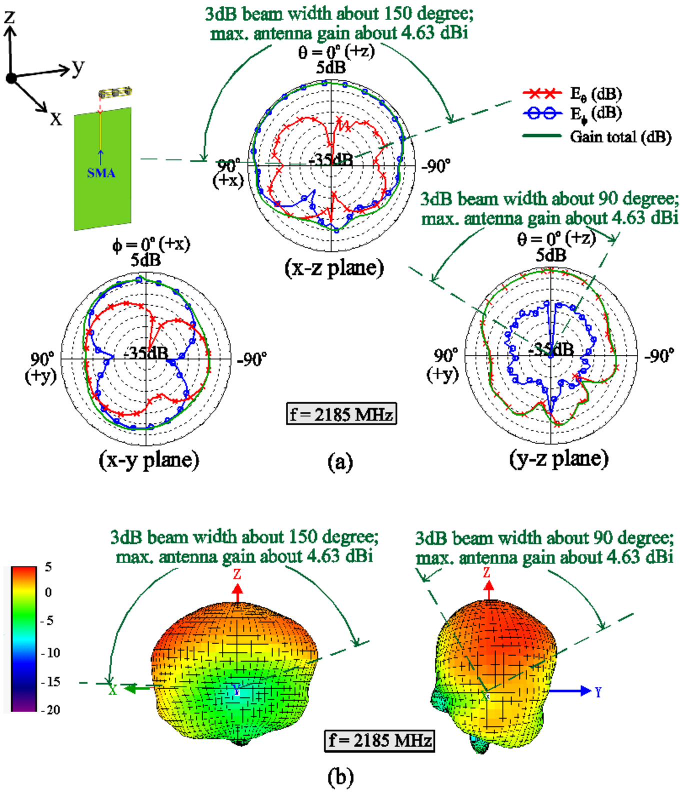

Fig. 6 (a) Measured far-field 2D radiation pattern and (b) 3D radiation pattern of the proposed folded 1.5λloop antenna.

beamwidth about 90 degree (peak antenna gain about 4.63 dBi) in the y-z plane (the vertical plane parallel with the handset ground plane). For the minimum link budget requirement of handset phone antenna gain (over 0 dBi) in STICS system for satellite-link operations [1~3], the proposed antenna can achieve pattern coverage about 180 degree in the x-z plane, and about 100 degree in y-z plane. Therefore, it demonstrates that the proposed low-profile 1.5λ loop radiator is a very promising antenna solution for the future STICS mobile phone practical applications. Owing to the limitation of 4-page paper length, only the proposed 1.5λ loop mode is discussed in the paper. The detail radiation performance about the folded loop radiators operating in the 0.5λ, 1.0λ and 2.0λ resonant modes compared to the proposed 1.5λ loop antenna design would be presented and discussed in the ISAP2015. The far-field antenna radiation characteristics are measured by anechoic chamber with chamber room size of 3×3×5 m^3.

IV. Conclusion

A novel internal-type high-gain mobile phone loop antenna design for STICS applications has been proposed and discussed. The proposed folded loop antenna is chosen to be designed operating in the 1.5 λ resonant mode. By simply and properly bending the 1.5λ loop resonant path, it is demonstrated that an equivalent 4-current array can be formed successfully for achieving high-gain and wide-coverage pattern toward the sky (+z direction). The proposed antenna can achieve a fan-type radiation pattern with a wide 3 dB beamwidth over 150 degree in the x-z plane (the vertical plane cross the handset ground plane) and a good 3 dB beamwidth over 90 degree in the y-z plane (the vertical plane parallel with the handset ground plane). And the measured radiation efficiencies and maximum antenna gains in the desired 2 GHz RX band of STICS are over 80% and 4.5 dBi respectively. Besides, the proposed antenna can be closely integrated at the top short side-edge of a corner of a handset PCB with a protruded height only 3 mm from the same side-edge of the PCB, which makes it to be a very attractive and promising solution for internal-type antennas in the future practical STICS mobile phone applications.

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