Tunable Antenna Introductions, Challenges and Opportunities

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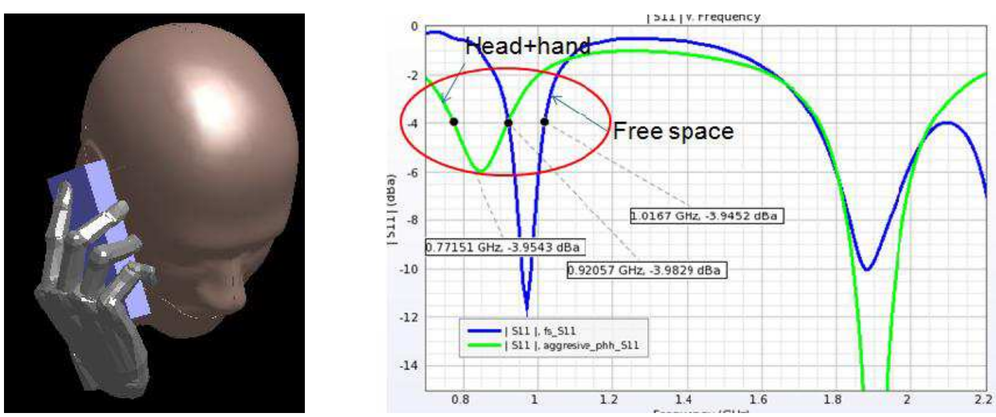
Abstract— In this paper we systematically summarized tunable technologies in mobile terminal applications with various aspects, including the advantages, popular applications techniques, tunable switch and capacitor selections, closed and open loop tunable system architecture as well as the future opportunities and challenges.

1. INTRODUCTION

With the rise of the 4G mobile technology, LTE (long term evolution) technology has been adopted in modern mobile terminal for the better broadband and multimedia service than traditional WWAN mobile network, which means that, in addition to GSM850 (824–894 MHz), GSM900 (880–960 MHz), DCS1800 (1710–1880 MHz), PCS1900 (1850–1990 MHz), UMTS (1920–2170 MHz), the LTE antenna also need to support LTE700 (704–787 MHz) and LTE2600 (2500–2690 MHz) for global applications. This is a big challenge for slim phones with limited space for antenna. On the other hand, more and more carriers require not only free space TRP and TIS, but also phantom head, head+hand performance. Because the head, hand could detune antenna resonance, traditional passive antenna is getting very difficult to balance performances at all these conditions. Fig. 1(a) showed the head and hand position defined in the CTIA standard. Our study showed that head and hand could shift low band frequency significantly at the tight grip situation in Fig. 1(b) which could cause 4 dB efficiency reduction.



(a) (b)

Figure 1: Head and hand (a) position defined in the CTIA standard, (b) detuned antenna S_{11}.

Tunable antenna is the trend to overcome the passive antenna limitations to support (1) more bandwidth and bands and (2) minimize the head and hand or the user environment impacts. In this paper, we will briefly introduce tunable antenna technologies in application, element selection, antenna design and system integration etc..

Tunable antenna can be used for any antennas such as WAN, WLAN, RFID, mobile TV etc.. In this paper we only focus on the WAN antenna because it is the most challenge we are facing. The other antenna applications will be similar.

2. TWO COMMON TUNING TECHNIQUES

Tunable matching is to put switch (connected with inductor or capacitor, or grounded) or tunable capacitor in series or shunt to the antenna feeding structure as indicated in Fig. 2(a). At each stage, a different inductance or capacitance can be applied to the antenna impedance matching therefore shifted frequency to what we planned, for example, from GSM 850 to LTE 700. To reduce the

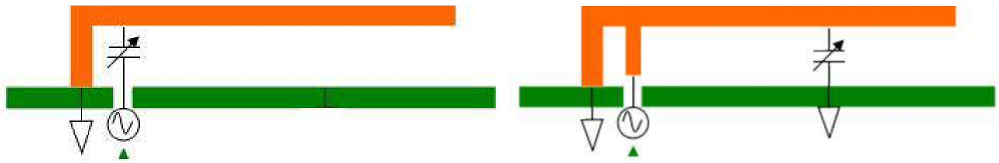


Figure 2: Two common tunable methods, (a) at matching, (b) at antenna structure.

additional loss, usually shunt element positioning is preferred. The antenna matching can improve S_{11} and system efficiency accordingly but do not improve the antenna radiation efficiency because antenna structure is not changed. Tuning antenna structure, for example, Fig. 2(b), is to put tunable component on antenna structure (connect or disconnect an arm when Switch is ON and OFF) or between PCB and antenna grounded leg to change the antenna radiation principle. If used properly, in experiment we saw less loss than tunable matching and could improve antenna radiation efficiency. Which method to select is totally depending on user's practical situation, including tunable frequency required range, tunable element increased loss to system, tunable element harmonics, ease of manufacturing, cost etc..

3. TUNABLE SWITCH AND CAPACITOR

After decided the methods to tune antenna, the next important thing is to select proper tuning element, RF switch or tunable capacitor. Thanks to the global R&D from different companies, we have options to use digital tunable capacitor, BST varactor diode, RF switch, MEMS etc.. Which company solution to use varies depending on the application requirements as shown in Table 1. According our experience, most switch and tunable capacitor can support frequency up to 3 GHz and support power more than 35 dBm with physical size of 2×2 or 3×3 mm. Usually the claimed loss is 0.5 dB or less, but be careful that the loss could be much higher if not used properly. For tunable capacitor, the typical tuning range is from 1 to 5 pF.

Table 1: Tunable switch or capacitor selection parameters.

Parameters	Target	Parameters	Target
Insertion loos (dB)	0.2–0.3	Harmonics (LB/HB) fREQ 2xf. (dBm)	< -40
Capacitor tunable range (pF)	1–5	Supply Voltage	3
IP3 (dBm)	$> +65$	Switching time (μs)	
Operation Freq (GHz)	> 3	Size (mm)	2×2
Power Handling (dBm) (Low Band/Hi band)	35/32	Q	

4. OPEN LOOP AND CLOSED LOOP

In terminal system level, tunable component can be controlled by so called open loop or closed loop. What we saw in the market is typically open loop tunable antenna. The simplest case of open loop is like a switch with ON and OFF two stages. more advanced open loop antenna has a look-up table with pre-measured data installed in the device to react at defined situation, such as that at free space the tunable capacitor set value at 1 pF and at head+hand case to set value to 3 pF etc.. The main limitation is that it only works at the pre-defined situation and can't be adjusted dynamically. Closed loop will be much better, means that at anytime whenever antenna is detuned, the system will noticed it and tune the antenna resonance to normal, it will be more complicated in terms of return loss S_{11} detection and system level support.

Figure 3 showed our proposed closed loop including tunable capacitor, coupler, power detector and CPU/microcontroller. The Coupler is used to detect the incident and reflected RF power and give to power detector to convert to DC respectively, then microcontroller is used to calculate the return loss S_{11} and decide how to change the tunable capacitor value to optimize S_{11}. Based on this concept, we have developed a cellular phone WAN antenna supporting 6 bands

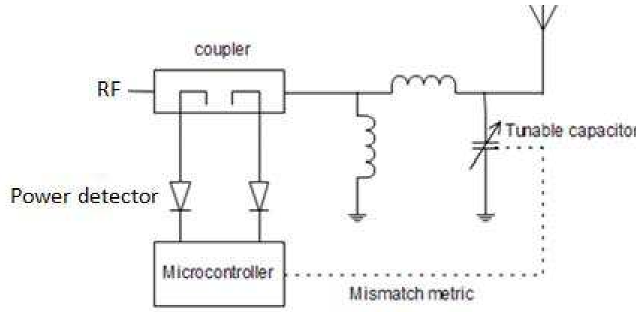


Figure 3: Proposed closed loop structure.

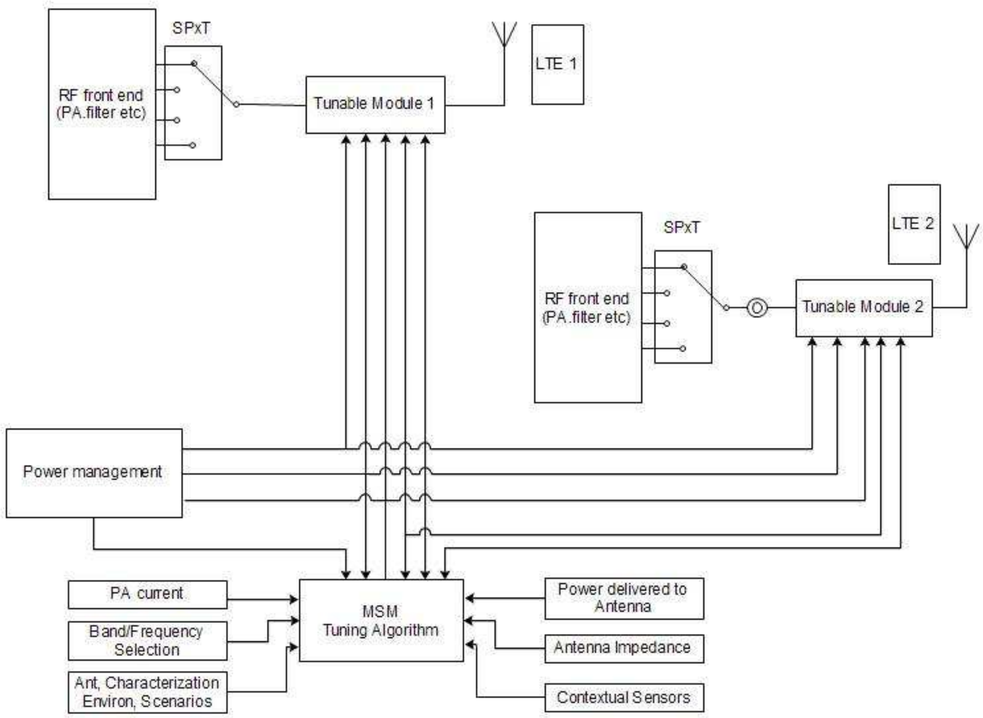


Figure 4: Closed loop antenna architecture for LTE MIMO system.

(700/850/900/1800/1900/2100) for global LTE application. This prototype includes antenna, tunable capacitor, coupler, power detector, microcontroller, filter and other RF and EE component. Given any hand, head, or environment changes causing antenna frequency shift, the system can adjust the antenna resonance back to original condition with milliseconds. The design details and video will be demoed in the conference presentation.

After proving the closed loop concept, our next step is to develop a RF tunable module to integrate the closed loop tuning circuits within a 2×2 mm size so that it can be used in more convenient and powerful ways. For example, the LTE MIMO system can be designed as a smart tuning system as shown in Fig. 4. In this system each antenna is connected with a tunable module. How tunable module will operate is based on the calculation results from MSM, where it is connected and determined by many input information like PA current, phone operation band, power to antenna, sensors etc. we are working with cellular phone company at platform level to implement this breakthrough technology. The outcome of this research will completely change the terminal device design principle and users experience to prevent drop call and better voice and data signal quality experience.

5. CONCLUSIONS

Smart tunable antenna is the trend to support more bandwidth and bands, minimize antenna size, and reduce user condition like hand, hand effects. With the maturity of the RF switch and tunable capacitor and proper integration to antenna, it becomes possible and is already started to implement on mobile terminals. Currently antenna tuning is mainly used as open loop to support different bands. Next big thing will be closed loop tunable solution to dynamically optimize antenna performance, it will come soon when more mobile terminal developers are developing new solutions.

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