ENABLING ANTENNA TECHNOLOGIES FOR THE SDR

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ABSTRACT

Antenna systems that would enable seamless mobility using portable Software Definable Radios include a wide variety of technologies, ranging from multi-band, to tunable, to multiple-input multiple output (MIMO) antenna systems. Depending on the specific SDR application and the expected spectrum coverage, some technologies are more suitable to fulfill performance, size, complexity, and cost requirements. An overview of SDR antenna technologies suitable for mobile-phone form factors is illustrated and several technologies are comparatively analyzed. Multi-band internal antennas such as the Planar Inverted F-Antenna (PIFA) and the Folded Inverted Conformal Antenna (FICA) provide simultaneous coverage of discontinuous communication spectra. Compact antenna components that can be tuned over multi-octave frequency ranges while maintaining good radiated efficiency provide the ability to shrink antenna size while enhancing the ability to cover multiple bands selectively. Multi-antenna structures can provide ways to implement advanced communication features such as diversity or MIMO. Practical approaches for enabling a portable SDR antenna system are outlined.

1. INTRODUCTION

An FCC NPRM defines the Software Definable Radio as "…the result of an evolutionary process from purely hardware-based equipment to fully software-based equipment…" In a SDR, waveforms are software definable, and the radio is reprogrammable and upgradeable in the field via the air-interface. This concept is frequently associated to that of *cognitive radio*, a smart device that is aware of its location, learns usage patterns and uses them to predict communication requests and prepares for them by selecting the available air-interface that is most suitable to provide the required cost/speed performance. Arguably, cognitive radios will allow maximizing the spectral efficiency of the wireless communication infrastructure while allowing the user seamless mobility, and could also enable the formulation of a business case for a spectrum commodity market.

The SDR antenna system should allow seamless operation across many different air-interfaces, simplex and duplex, symmetrical or asymmetrical, based on terrestrial or satellite networks. Simultaneous communication through more than one air-interface should be enabled.

These requirements pose quite a design challenge, especially when the SDR features have to be implemented on a handset device. The limited space available and the interaction with the user dramatically limit the design options. In this context, it is not realistic to look for an antenna system capable of delivering all the possible SDR functionality on a handset. A more sensible approach is to identify which technologies are best suited to implement a subset of key SDR requirements, which are characteristic of a given system or device class. For example, a multiband operation requirement leads to radically different antenna solutions if the bands have to be covered simultaneously or one at a time.

Controlling the radiation pattern over a wide band for a mobile-phone form factor device is very difficult, if not impossible. The ability of covering a given portion of the spectrum is the key aspect to be considered in the analysis of different technologies suitable for handheld SDR devices. Different options to achieve wideband and/or multi-band coverage in very compact form factors characteristic of mobile phones will be illustrated.

A review of fixed multi-band integrated antenna technologies is presented, with particular focus on PIFA and FICA, which are the most commonly used on today cellular phones.

Multi-octave frequency ranges in an extremely compact form factor can be obtained by using tunable components. Results are presented illustrating the performances achieved by using tunable structures in combination with a switched reactive network.

As an alternative to switching between different reactive loads, active components can be used to synthesize the desired tuning reactance, thus providing a wide instantaneous bandwidth. This solution poses challenging technological hurdles that are discussed in the paper.

Finally, the use of wideband structures, such as tear-drop monopoles, fed against the main radio PCB is discussed, to set a benchmark and quantify the cost and benefits of using more compact and integrated solutions.

2. MULTI-BAND TECHNOLOGIES

The first step toward a SDR will probably be a radio capable of using diffrent communication standards, such as GSM, CDMA, UMTS, etc. In this scenario, the antenna should only provide a fixed multi-band response, limited to the portion of the spectrum allocated for the covered services. The multi-band antenna technologies developed for cellular phones offer a well tested and cost effective solution. The Planar Inverted F-Antenna (PIFA) is the most commonly used by cell-phone manufacturers.

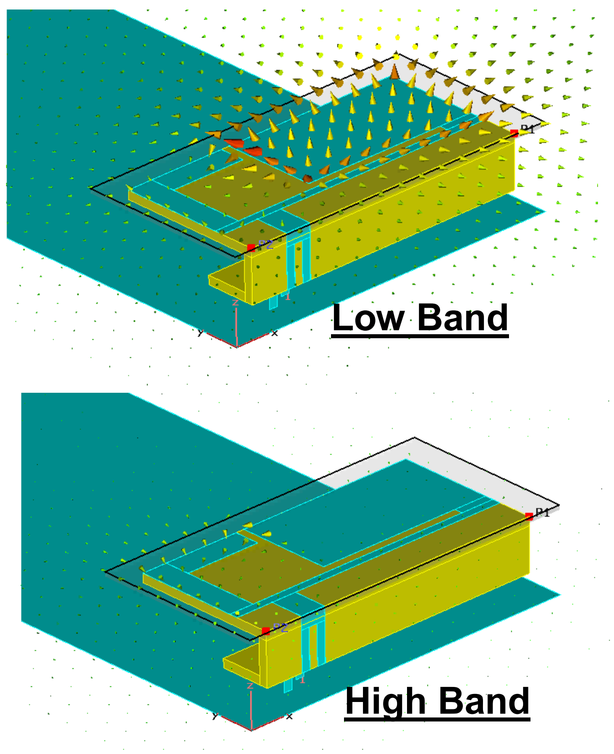

Figure 1. Example of dual band PIFA.

The basic structure is derived by a quarter-wave patch, where multiple resonance frequencies are introducing by cutting open slots in the planar surface of the antenna, thus creating a multi-arm geometry. One particular, beneficial feature of PIFAs is their ability to be designed to cover bands that are not necessarily in harmonic relation. It is important to note that while introducing a slot allows covering an additional band, the bandwidth of each resonance becomes narrower. This can be easily understood by observing that the effective volume for each resonant mode is reduced, to make room for the new arm. As example of dual band PIFA, where the low and high band arms are clearly visible is shown in figure 1.

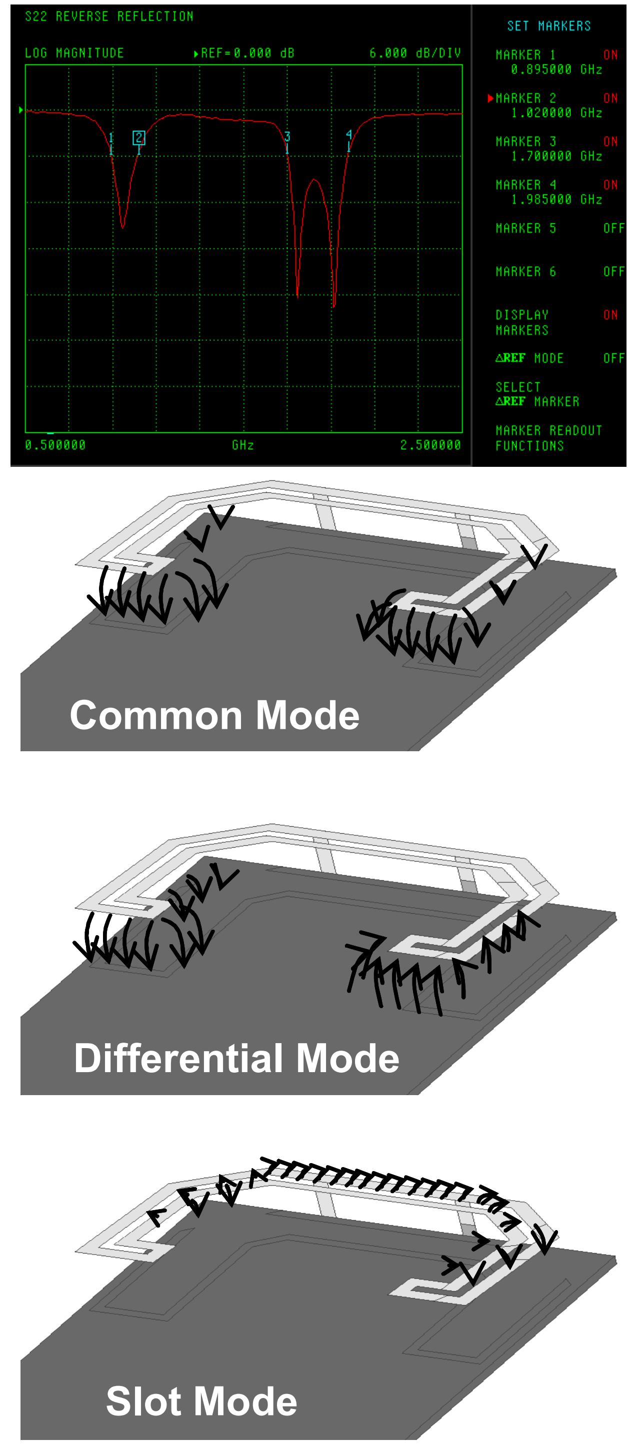

Figure 2. Typical frequency response of FICA and sketch of the configurations of the three resonant modes.

The Folded Inverted Conformal Antenna (FICA), recently invented at the Motorola Corporate EME Research Laboratory, represents the new state-of-the-art in multiband integrated antenna technologies for cellular handsets. It is based on a "volume reuse" concept that overcomes the basic limitation of multiband PIFAs, namely, the inability to use the whole antenna volume simultaneously in all operating bands. The volume reuse concept in the FICA is based on the synthesis of multiple resonant modes that occupy the same volume, just at different frequency bands corresponding to the natural resonant frequencies of the handset structure (antenna element plus PCB ground). A typical FICA geometry with a sketch of the three resonant modes, labeled as *common* mode, *differential* and *slot* modes, along with a typical frequency response is shown in figure 2. These modes make use of the entire antenna volume, thus achieving the desired operation in an optimal manner. Additional resonances can be added to the structure with minor structural modifications, to further enhance the fre2uency coverage.

3. TUNABLE TECHNOLOGIES

There are two basic approaches to implement tunability. One is to act directly on the radiating structure, by modifying its geometry or by activating parasitic elements. This approach presents serious challenges in a practical implementation, as it requires switching components to be placed on the antenna, i.e., in a radiated-wave environment where switching components and control lines may strongly interact with the antenna reactive field. In a second approach, the antenna is synthesized as a multi-port structure where the ports are physically placed on the PCB ground. Very broadband tuning can be achieved by switching between different reactive loads placed at one or more ports in a guided-wave environment where conventional switches are designed to operate, thus achieving an effective separation between radiating and control circuitry. Switched schemes could be implemented in feeding networks, e.g., in broadband reconfigurable matching networks, or by using multiple selectable ground and feeding contacts. Both single band and multiband structure can be used as basic building block. Figure 3 presents the frequency response of a single band PIFA, when the reactive load of its tuning port is changed. A multi-octave coverage is obtained with a very compact and simple structure. By properly choosing the tuning port location a good match to 50 Ohm is obtained across the band. The performance of the structure in terms of efficiency strongly depends on the quality of the switching devices used. However a proper design of tuning network can deliver very good efficiency even with average quality switches.

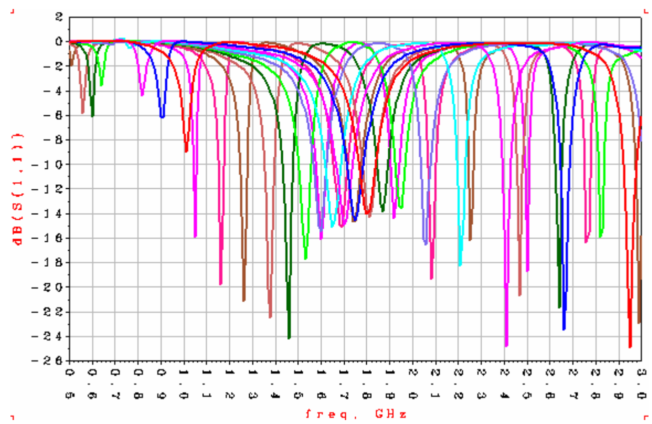

Figure 3. Frequency response of a simple PIFA with a tuning port, when the reactive load is changed

4. WIDEBAND STRUCTURES

In handheld applications the volume constraints for the antenna element are usually pretty tight. Wideband response requires a significant volume and the most effective way to obtain it is to mount the antenna on the top or on a corner of the radio PCB, as commonly seen in two-way radio or cellular devices. One of the structures most frequently encountered in UWB publications is a tear-drop shape monopole mounted on a flat, large ground plane. In this paper the same structure is fed against the PCB, as shown in figure 4.

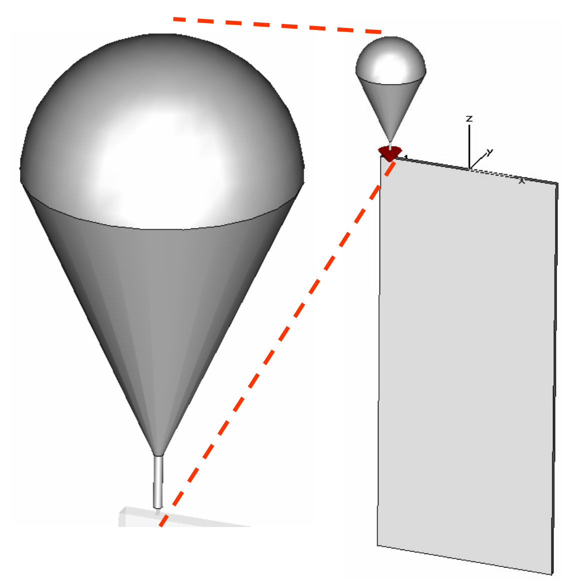

Figure 4. Gemetry of a tear-drop monopole mounted on a corner of a PCB

The basic geometry of the monopole is modeled by the union of a trunk of a cone, characterized by its height, initial and final radius and a hemisphere having the same radius as the final radius of the cone, as shown in the enlarge detail of figure 4.

Height, initial radius, and final radius are varied to evaluate their effect on frequency response of the antenna. Figure 5a shows the return loss response as a function of frequency for different values of the upper radius. The reference impedance used in the calculation was 100 Ohms, since it provides the best matching. It can be observed that impedance matching improves as the upper radius increases or alternatively the reactive part of the impedance decreases with larger upper radii. The height is the primary factor controlling the lower end of the band covered by the antenna. It can be seen clearly in figure 5b showing the return loss for different heights, for given lower and upper radii.

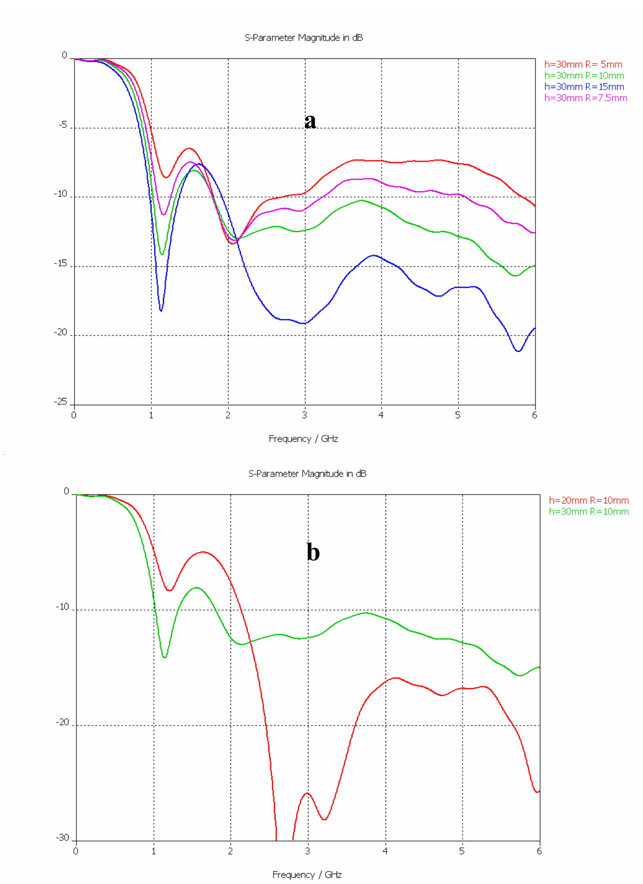

Figure 5. a) Return loss of a drop-shape monopole on a 40 mm by 90 mm board for different values of the upper radius. Lower radius = 1 mm, Height = 30 mm. 100 Ohm reference impedance is used. b) Return loss of a drop-shape monopole on a 40 mm by 90 mm board for different values of the height. Lower radius = 1 mm, upper radius = 10 mm. 100 Ohm reference impedance is used.

5. CONCLUSION

An overview of SDR antenna technology suitable for mobile-phone form factor devices has been presented. Due to the stringent volume limitations and the limited control of the radiation pattern shape typical of handheld devices, the main emphasis has been devoted to band coverage.

Depending on the specific applications, different technologies can provide the best solutions. The state of the art in terms of multi-band integrated antennas for cellular phone applications certainly represents a viable solution for the first generation of SDR devices.

Tunable antenna system can give more flexibility and greatly expand the frequency coverage, while marinating very compact size. However, tunability can preclude in some cases the simultaneous access to different portion of the spectrum. Depending on the specific system this limitation can be unacceptable.

Finally a more conventional wideband external antenna solution is given for reference. In general a wideband solution requires overall bigger devices and might introduce some practical problems in terms of mechanical robustness and usability.