Chapter XXIV
Wideband Smart Antenna Avoiding Tapped-Delay Lines and Filters

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ABSTRACT

This chapter introduces the alternative approach for wideband smart antenna in which the use of tapped-delay lines and frequency filters are avoidable, so called wideband spatial beamformer. Here, the principles of operation and performance of this type of beamformer is theoretically and experimentally examined. In addition, its future trends in education and commercial view points are identified at the end of this chapter. The authors hope that the purposed approach will not only benefit the smart antenna designers, but also inspire the researchers pursuing the uncomplicated beamformer operating in wide frequency band.

INTRODUCTION

In the past two decades, radio systems (also known as wireless systems) have grown with an unprecedented speed from early radio paging, cordless telephone, and cellular telephony to today's personal communication and mobile computing. This rapid expansion of radio systems has a profound impact on today's business world and people's daily lives. One undesired outcome is a heavy utilization of the available frequency spectrum. Because of this situation, a considerable interest has been shown in methods and techniques to overcome the limited frequency spectrum. One technique that is capable to increase the wireless system capacity without additional frequency spectrum is the smart antenna technique. Smart antennas are multiple element antennas accompanied by suitable signal processing algorithms either at the transmitter or receiver sides of a communication link. By pointing their beam towards a desired user and nulls or low side lobes towards interfering sources they are capable to considerably improve the quality of signal transmission in a multi-user environment. A significant value of smart antenna techniques in the efficient use of wireless spectrum has been addressed in (Kang, 2002; Jiang 1997). These multiple element antenna systems can also offer other advantages. These include the capability of minimizing the cost of establishing new wireless networks (Shao, 2003; Lee, 2005; Kawitkar, 2003), a better service quality (Hettak, 2000), and transparent operation across multi–technology wireless networks (Alexiou, 2004). It has to be noted that the benefits of smart antennas have been largely demonstrated for the case of narrowband communication systems. As the rapid growth of wireless technologies demands high bit rate data transmission, there is an interest in smart antennas which would operate over an increased frequency band. The design of such wideband intelligent antenna systems creates a challenge in terms of processing techniques and associated costs.

This book chapter gives a brief overview of wideband beamforming techniques. In particular, their advantages and disadvantages are discussed. As a result of these considerations the focus is on a wideband smart antenna system that relies on a fully spatial wideband beamforming technique. Full theoretical and experimental investigations into this wideband smart antenna system are presented.

The chapter is organized as follows. Firstly, shortfalls of narrowband smart antenna/beamforming techniques with respect to wideband signals are demonstrated via a suitable example. A number of wideband signal processing techniques are introduced and discussed to overcome this impairment. They are classified into three categories: space-time, space-frequency and fully spatial techniques. A brief comparison of these three wideband beamforming techniques is presented. As a result of this comparison, the fully spatial beamforming technique is selected for further considerations. Because of this choice, the main part of the chapter is devoted to a wideband spatial beamformer and its practical realization. The considerations commence with the introduction of configuration and the basic principles of operation of a wideband spatial beamformer that is created around a rectangular array of wideband antenna elements. The original beamforming algorithm, as reported in literature, is introduced and its shortfalls with respect to a small size array are pointed out. A suitable rectification of the original beamforming algorithm is proposed so it is valid for an arbitrary size array. The remaining considerations focus on small size arrays, which are easy to realize in practice. A 4×4 element wideband beamformer prototype is developed and tested over a specified frequency band. Various radiation patterns are realized by applying suitably devised signal weighting coefficients. The chapter is finalized with conclusions and remarks concerning future plans for wideband spatial beamformers.

BACKGROUND

Most of considerations concerning smart antennas that can be found in the antenna or wireless communication literature are devoted to the narrowband variety. In this case, an array antenna is usually of linear type and formed by identical antenna elements spaced by half-wavelength at the centre frequency of a narrow operational band. Other configurations of arrays, such as rectangular, circular, or hexagonal, are also used. However, the operation is easier to explain for the linear array case. In many applications, this antenna array is placed in the horizontal plane and is aimed to transmit or receive signals in azimuth directions. In order to enhance reception of a desired signal and discriminate against undesired signals, the antenna beam is pointed towards a desired direction and nulls or low side lobes towards undesired directions. Usually these directions are known before the beam is formed. They are determined by suitable search methods that are based on Direction Of Arrival (DOA) estimation techniques (Liberti, 1999). For the narrowband case, the beam pattern is obtained using constant complex weighting coefficients that are applied to the received or transmitted signals at individual antenna elements. This beamforming algorithm works well for signals having a Fractional Bandwidth (FB) of a few percents.

This narrowband beamforming scheme becomes faulty when applied to wideband signals (Hefnawi, 2000; Uthansakul, 2004). The undesired effects include a main beam squinting, shifting nulls' locations and increasing sidelobe levels in the produced radiation pattern. These, in turn, adversely affect the quality of communication link.

The shortfalls of a narrowband beamformer when it is applied to a wideband signal are illustrated by simulation results presented in Figure 1. In the considered example, a signal has FB of 27.3% (from 1.9 to 2.5 GHz). The beamformer uses a LMS algorithm (Liberti, 1999; Kawitkar, 2005), to follow the direction of a desired signal. The array is formed by four elements spaced by half-wavelength at 2.2 GHz. The desired signal is coming from 30° off the array's boresight direction. Figure 1 shows that when the frequency changes from 1.9 to 2.5 GHz, the main beam and nulls' locations are shifted.

Figure 2 shows the results for the main beam direction deviations as a function of the operational bandwidth when the desired signals is assumed to arrive from 10°, 30° and 45° off the array boresight. It is apparent that the error in pointing the main beam to the desired direction becomes larger as the bandwidth of the signal increases. Furthermore, the error also depends on the direction of a desired signal. Larger errors occur for the signals coming from the far directions off the array's boresight.

The simulation results presented in Figures 1 and 2 confirm that the narrowband beamforming scheme is unsuitable when applied to wideband signals and thus alternative beamforming schemes are required to resolve this shortfall.