Emerging Technologies for Steering Narrow Antenna Beams in Modern Radio Systems

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Abstract—**In many modern wireless radio systems, tight link budgets demand the two antennas in the transmitting and receiving terminals, or at least one of them, to have high antenna gains, which in turn require highly directive (narrow) antenna beams. In this invited presentation, we will review some currently used and emerging methods for steering continuously such antenna beams, with focus on non-specialist audience who are expected to attend this conference, including electrical and electronic engineers practicing in relevant industries.**

I. INTRODUCTION

Due to long distances involved, high-gain antennas with narrow radio-frequency (RF) beams are widely used in satellite communications. Spot beams are sometimes used at the satellite end itself. On the other hand, antennas at the user end in user terminals, and those in gateway stations on ground, almost always require highly directive (*aka* "pencil") beams in order to achieve high data throughput within the available spectral bandwidth of the satellite transponders. other common examples for wireless radio systems with highly directive antenna beams include point to point microwave communication links, wireless backhauls for mobile communication base stations including those in modern microcells and picocells of 5G networks, satellite TV receivers, RF communication links between satellites other spacecrafts, Wi-Fi and Wi-Gig extenders and repeaters, and the base-station side of 5G extender/repeaters. These systems may operate over a wide range of frequencies from lower microwave to millimetre wave bands, and even in terahertz bands in the future.

Not all these systems require beam steering. For example, to receive satellite TV directly broadcasted from a geostationary (GEO) satellite, a simple, inexpensive, fixed dish antenna is sufficient. When the satellite itself is not geostationary, as in the case of emerging low earth orbit (LEO) and medium earth orbit (MEO) constellations, even a stationary (fixed) user terminal needs to steer its highly directive antenna beam (transmitting and receiving) that only a few degrees wide (3dB beamwidth) at an accuracy of a fraction of a degree in order to maintain the communication link with the non-geostationary satellite that "moves" in space.

II. BEAM-STEERING TECHNOLOGIES

A. Tall Dome Systems with Mechanical Tilting and Rotation

A common example for this decades-old well established technology is the reflector dish antenna inside a radome (aka the dome). They are commonly used on ships (civil cruise ships as well as Navy frigates) and other marine platforms such as yachts for Internet connectivity and/or satellite TV reception. Elegant tracking methods such as mono-pulse tracking has been incorporated in some of these antenna systems to maintain the beam direction towards the satellite even when the vessel itself becomes highly unstable at high sea states [1].

A modern and unconventional example is 2D phase arrays in which beam steering is fully electronic, implemented using a large number of application-specific phase shifters integrated to transmitter and receiver ICs, but the radiating array panel is mechanically tilted and rotated towards an optimal direction using mechanical means [2]. Such flat panel antennas do not require Dome-shaped radomes.

B. Medium Height Systems

For platforms where tall antenna systems have severe disadvantages, such as aeroplanes, aforementioned mechanical steering technology has been modified to reduce the height of the antenna system by replacing the reflector dish antenna with a rectangular flat panel, composed of an array of radiating elements [3, 4]. Yet the panel itself has a fixed beam, and it is steered by tilting and rotating using sophisticated mechanical means.

In other types of antenna systems that belong to this category, methods have been developed to steer the antenna beam in two dimensions that is azimuth and elevation, still using mechanical means but *without tilting* any parts of the system. As a result, the overall height of the antenna system has been reduced significantly.

Nearly all of them have a horn antenna or similar medium gain antenna as the main radiator, and a few planar or conformal, 2-dimensional, engineered surfaces, positioned at the distance of several wavelengths from the main radiator. These surfaces do behave as planar lenses and hence reduce the width of the beam and increase directivity an antenna gain.

To steer the beam of this type of antennas, several vastly different methods have been invented. depending on the beam steering method, antenna systems in this category have been given different names including transmitarrays. Among them are:

a. Antenna systems where both elevation and azimuth angles of the beam are changed independently by rotating two phase shifting surfaces [5];

b. 2-bit/multi-bit electronically controlled transmit arrays [6]; and

c. Transmitarrays where the elevation angle of the beam is changed by mechanical translation and the azimuth angle is changed by mechanical rotation [7, 8].

C. Thin Systems

These include fully-electronic beam steering methods including conventional 2D phased arrays with a large number of radio frequency phase shifters [10], and unconventional holography-based antennas in which the beam is steered by electronically controlling a large number of scatters in the antenna aperture [9].

Another example in this category is the variable inclination continuous transverse stub antenna (VI-CTS) where some parts of the radiating antenna (and a polarizer when circular polarisation is required) are rotated relative to each other to steer the beam in both elevation and azimuth [11-14].

A more recent example is an implementation of “near field phase transformation,” which is also sometimes called Near-Field Meta Steering. Using this highly versatile method, the fixed beam of any antenna can be steered continuously and, in both planes (elevation an azimuth) independently, by placing two thin near-field metasurfaces very close to the aperture of the fixed antenna, and rotating them around the common axis independently using simple mechanical means such as low cost, low power stepper motors [15-19].

These methods will be discussed with more details at the conference.

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