Beam steering control using the excitation coefficient decision method
for an onboard phased-array-fed reflector antenna

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1. Introduction

Recently, onboard phased-array-fed reflector antennas have been developed for advanced mobile communication services that use very small hand-held terminals. We are developing an onboard phased-array-fed reflector antenna that has an aperture diameter of over 10 meters [1]. A large deployable reflector that consists of several modules with mesh surface and a deployable truss structure, provides this antenna with a high gain, and a large number of beams can be formed by using a phased-array feed that promises to provide low sidelobe, beam steering and shaping flexibility. However, for practical purposes, it is very difficult to steer and shape the desired beam exactly in this antenna system because the performance index for the beam forming control has various uncertain factors, such as excitation coefficient errors, misalignment between the feed and the reflector, mesh surface errors, and so on. Accordingly, the optimum excitation coefficient for forming the desired beam cannot be calculated analytically.

This paper proposes an excitation coefficient decision method for these antenna systems that can form beams under the above-mentioned factors and shows the results of a beam steering experiment for a receiving antenna system using this method.

2. Excitation coefficient decision method

Figure 1 shows the concept of the excitation coefficient decision method for onboard phased-array-fed reflector antennas in the case of the receiving antenna. The beam direction is intended to be in the direction of a transmission antenna. The RF signal radiated from the transmission antenna is received at each phased-array element, and the signals from the elements are synthesized into one signal in the beam forming network (BFN). This synthesized signal power is measured and is used as the performance index. Figure 2 shows the flowchart of our excitation coefficient decision method. Each attenuator and phase shifter in the BFN is controlled by the D/A converters. The D/A converters are controlled by digital commands. This method is started from a lower resolution (i.e. bit number is lower) than the maximum resolution (i.e. bit number is maximum) that is able to set in the D/A converters. After the optimal condition is found at this bit number condition, the bit number is incremented by 1. This process is repeated until the optimal condition is found for the maximum bit number. The most interesting feature of this method is that it uses a matrix of special conditions to find the optimal excitation coefficient for each bit number. This special condition matrix is composed of the various excitation conditions, most of which are generated by the gradient of the excitation coefficient but some of which are generated
by genetic algorithm (GA) operations [2, 3]. In the genetic operations, the evolution strategies are the elitist preserving selection type, and new excitation coefficients are generated by crossing the elite conditions that have been selected as the parents from the preceding generation. Mutation also occurs in this process. This mutation has a beneficial effect on the GA operation. Every performance index is measured when the excitation coefficients are set. Elite conditions are only left and used as parents in genetic operations. This procedure is repeated when the performance index reaches its maximum value. This algorithm, as verified by simulation, is faster and stronger versus local minimums than is the normal GA. It can form a beam in the desired direction even if the optimal excitation coefficient cannot be found by the analytical method.

3. Experiment

3.1 Experimental setup

Figure 3 shows the setup of the main beam direction control experiment for a receiving phased-array-fed reflector antenna. This reflector was composed of a 31-element phased-array feed and two hexagonal deployable mesh reflector modules [4] that had an aperture diameter of 4.8 meters. The transmission antenna was located on the roof of NTT Yokosuka R&D center; a semi-open-type anechoic chamber holding the receiving antenna system was located about 1.6 kilometers away. The boresight direction of this receiving antenna was adjusted toward the transmission antenna using a 3D digital photogrammetry system and an RF sensor in advance. The beam direction was controlled by using a BFN that could change the excitation coefficient of the phased-array feed. This BFN is composed of voltage-controlled attenuators and phase shifters [5]. The excitation coefficient can be varied by the added voltage for these circuits, and these voltages are controlled by 8-bit D/A converters.

3.2 Experimental Results

The beam steering control was started from the 6 bit's initial excitation coefficient. This initial excitation coefficient was determined as follows. At first, all attenuators were set at maximum attenuation. Next, one attenuator was set at minimum attenuation, and the phase of the signal was changed by the phase shifter on that attenuator’s path. The phase shifter was adjusted using the loop shown in Figure 1 until the received power of that signal was at a maximum. This procedure was repeated until all 31 paths were included in the loop. This initial excitation coefficient was determined for both beam directions. The 8 bit's optimal excitation coefficient was found by the proposed excitation coefficient decision method. We used the one-point crossover in the genetic operations, and the crossover point was selected at random. The mutation rate was initially set at 0.1 percent but it was changed adaptively because the Hamming distance was over 5 bits. Figure 4 plots the received power when only the reflector was turned in the azimuth direction. In this figure, the horizontal axis shows the angle of the reflector with respect to the boresight. To convert to the angles observed at the primary feed, the horizontal axis values have to be multiplied by two. The dashed line shows the target beam steering direction, i.e., the direction of the transmission antenna. The beam controlled direction was in good agreement with the desired direction. Figure 5 shows the beam steering performance of our method. In this figure, the horizontal axis shows the angle of the reflector with respect to the boresight. The triangles show relative gain using our method at each measured angle, and the circles show the gain reduction curve when the reflector was turned in the azimuth direction while keeping the boresight beam condition. This result demonstrates that our
developed method can compensate gain reductions within about plus-minus 1 degrees, which are caused a misalignment between the feed and the reflector.

4. Conclusion
This paper proposed an excitation coefficient decision method for onboard phased-array-fed reflector antennas and reported on the results of beam steering experiment on such a receiving antenna. The results indicated that our decision method could adequately form a beam in the desired direction for the phased-array-fed reflector antenna and has the ability to compensate the gain reductions by mechanical alignment errors.

References

Fig 1. Excitation coefficient decision method for phased-array-fed reflector antennas.
Fig 2. The flowchart of the proposed method.

Fig 3. The experimental setup for controlling the beam direction for a phased-array-fed reflector antenna.

Fig 4. Beam forming result for the boresight.

Fig 5. Beam steering performance.