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Modelling Full Duplex Antenna Array Systems for SatCom Applications

T van der Spuy(1), MT Behrens(1), R Maaskant(1), M Ivashina(1), and L Nyström(2)
(1) Chalmers University of Technology
(2) Satcube AB, Gothenburg, Sweden

Summary

Amongst the many benchmarks proposed for the roll-out of 6G is constant global internet connectivity. To achieve this, the satellite communication (SatCom) industry will need to expand into different constellations, including GEO, LEO, and MEO satellites. This imposes strict performance requirements on the antennas developed for these systems, including specifications on bandwidth, frequencies, cost, polarisation, and scanning capabilities. Furthermore, to practically realize "coverage everywhere", low cost terrestrial user-end transceiver terminals have to be developed that comply with radiation emission standards and size/weight requirements [1].

A signal processing model for such a user-end phased array transceiver system is presented in this work. It is used to derive optimum beamformer coefficients in terms of EIRP, Rx-Tx isolation, and radiation mask compliance. The performance of the model is calculated using the CAESAR combined electromagnetic and microwave solver software, which includes both a standard Method of Moments (MoM) electromagnetic solver as well as a Characteristic Basis Function Method (CBFM) implementation to allow for the analysis of large array systems. [2].

The simulated results for a modelled full duplex 256-element half-wave dipole antenna-transceiver are stated here. The system is dual-band, operating in the 26 GHz (receive) and the 29 GHz (transmit) bands. The optimal beamformer coefficients are calculated for both bands over a beam scan angle of up to 60°. It is seen that good isolation and side-lobe level (SLL) mask compliance can be achieved for only a slight reduction in gain performance.

1 Introduction

Modern communication systems have strict quality and emission standards, requiring high performance from systems that implement phased array solutions. In these systems, every aspect needs to be carefully designed and optimised, taking into consideration the interactions between the array antenna and the transceiver electronics. In this work the focus is to design optimum beamformer coefficients, which are generally different as to the uniform coefficients of conventional phased-steered arrays. Specifically, it is shown that optimal beamformer coefficients that produce higher antenna gain than their conventional counterparts can be calculated by considering mutual coupling effects (which can be modelled using the embedded element patterns (EEPs) of the array and the full impedance matrix of the antenna). Furthermore, by including a microwave system connected to the antenna in the calculation, beamformer coefficients that provide a maximum realized system gain can be found (see pages 144-145 in [3]). Lastly additional beamformer constraints, such as mask adherence and increased isolation between beamformer ports are implemented and performance trade-offs are investigated.

2 Modelled System

Current K/Ka-band terrestrial user terminal products with satellite tracking capabilities utilise array apertures of at least 30 x 30 cm. Assuming a 0.5 λ element spacing at 29 GHz, this would allow a 58x58 element array. However, simulating an array of this size is both RAM and time intensive. Instead, a 16x16 element array was simulated in this work, which is considered to be representative enough to allow general system performance and critical trade-offs to be evaluated [4].

The transceiver structure for this project is shown in Figure 1. It consists of both an Rx and a Tx subsystem that are connected through an ideal power splitter to the antenna elements. It is worth noting that this power splitter is modelled as an ideal, lossless parallel connection with a flat frequency response. This is done to model a "worst case scenario" in terms of coupling between the subsystems, as practical power splitters could offer some isolation between the two ports.

The dipole element spacing is half a wavelength in the y-dimension, and 0.52 wavelengths in the x-dimension such that the adjacent elements do not touch.

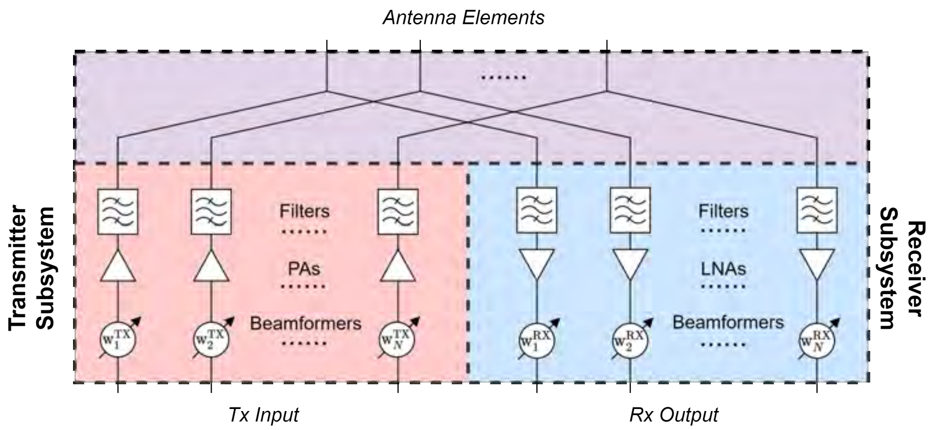

Figure 1. The general structure of the modelled system and the way in which the various components / subsystems are connected is illustrated.

3 Results and Conclusion

Four different sets of beamformer coefficients were derived in this work for different performance requirements: to maximize realized system gain, to adhere to SLL radiation masks, to achieve a set isolation between Rx and Tx, and a combination of the above. Note that the coefficients for mask adherence and isolation were chosen to achieve these metrics while also maximizing system gain. This was done by constraining the solution space to be close to the maximum realized system gain beamformer, and evaluating the gain cost of these additional pattern constraints.

The results showed that good Tx-Rx isolation could be achieved for a small gain cost. However, the resulting beamformer proved to be very sensitive to small amplitude and phase variations. Additionally, the achievable isolation at broadside (specifically within the broadside half power beamwidth) is significantly lower than at other scan angles. To address this, it is suggested that the algorithm is iterated incrementally between the Rx and Tx beamformers.

Similarly, the results show that good radiation mask adherence can be achieved for a small gain cost. The radiation masks applied in this algorithm were based on the ITU-R S.524-9 and 47 CFR §FCC 25.218(i) for transmit, from ETSI EN 301 459 for receive. The main beam width of these masks were appropriately adjusted to compensate for the smaller aperture of the simulated system. However, at high scan angles, the increased main beam width resulted in a significantly higher gain cost. This could be mitigated by choosing an aperture size and array geometry such that a sufficiently narrow beam is present at high scan angles. Alternatively, the design of a conformal array or the introduction of a curved radome could be used to address beam-widening at large scan angles.

Lastly, the combinations of the maximum gain, isolation and mask adherence beamformers showed that good performance metrics were attainable for a slight gain cost (< 1 dB for scan angles up to 30°, up to a maximum of 6 dB at 60°). The gain cost was dominated by the mask application beamformer, especially at high scan angles. The isolation performance remains very sensitive to even small changes in beamformer amplitude and phase.

References

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