Intermodulation Beam Spreading in Distributed Communication Systems

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Abstract

In an active multiple-beam distributed communication system, a number of power amplifiers are shared between the different beams, creating the condition of multi-tone operation of the amplifiers. Although the amplifiers are backed up to operate close to the linear region, efficiency considerations require operation in somewhat non-linear region of the input/output curve. The non-linearity results in the creation of undesirable intermodulation components within transmit and receive bands of the communication channels. The coherent radiation of the intermodulation components follow certain beam patterns with special distributions that are different from the main beams in the system. This paper discusses the formation of the intermodulation beams and their spread over the coverage area. The special spread is such that the interferences caused by the intermodulation products occur at reduces values and contribute minimally to the reduction in the system signal to over-all noise and interference ratio. Analysis and measurements are presented and show agreements in predicting the locations and levels of the intermodulation beams.

1. Introduction

Multiple-beam distributed communication systems are used in communication satellite payloads that require simultaneous multiple beams over the coverage area. One of their key features is the sharing of power amplifiers among the beams and among the radiating elements in the antenna structure. Figure 1 shows a block diagram of such system, where n beams share the power of m amplifiers that feed k radiating elements. The m amplifiers are arranged in a M-matrix amplifier, resulting in an M for m redundancy, thus increasing the reliability of the system versus the amplifier per beam arrangement. The k radiating elements may form a phased array that is controlled by the phase shifters in the beam-forming matrix (or network) and the output network. They can also be independent radiators that provide the required coverage. The amplifier power sharing leads to the creation of intermodulation products that depend on the operating point on the non-linear input/output curve. Intermodulation products contribute to the noise and interference components that degrade the signal to noise ratio in the communication system [1]. Other contributors to the transmission impairment and system degradation include co-channel interference caused by frequency re-use [2], adjacent-channel interference caused by filter functions, high antenna temperature caused by antenna losses and un-optimized antenna pattern, along with other component noise temperatures.

2. Intermodulation Products

Figure 2 shows typical transfer functions of a group of power amplifiers to be used in the distributed system shown in Figure 1. The nonlinear device has been characterized here in terms of the input and output envelops. Two functions are necessary to completely describe the properties of such nonlinearity: the nonlinear amplitude g and phase f functions at the operating point, ρ. The envelope characterization is used because the laboratory measurements necessary to characterize the nonlinearity involve only the fundamental component. The characteristics of the nonlinear device are derived from the laboratory measurements of the output power, P_o and phase ψ_o, and the input power, P_i for a single carrier. The complex output envelope is approximated by the Bessel function expansion [3] as shown below:

$$g(\rho)\exp\left[jf(\rho)\right] = \sum_{s=1}^{L} b_s J_1(\alpha s\rho) \qquad \ldots(1)$$

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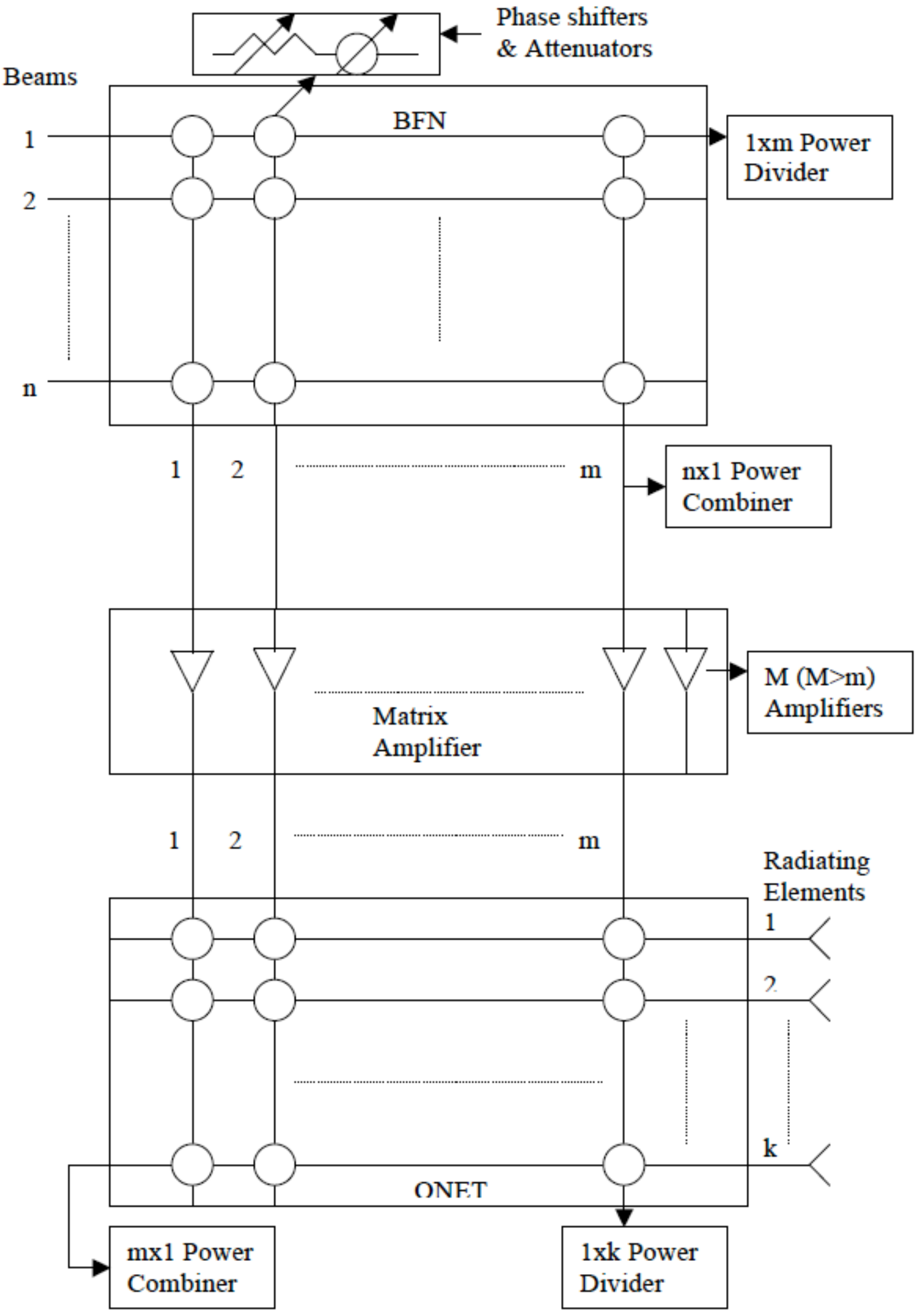

Figure 1. Multiple-Beam Distributed Communication System

where b_s are complex Bessel coefficients. The real and imaginary components of equation (1) are:

$$g(\rho)\cos f(\rho) = \sum_{s=1}^{L} b_{sr} J_1(\alpha s \rho) \qquad \ldots(2a)$$

$$g(\rho)\sin f(\rho) = \sum_{s=1}^{L} b_{si} J_1(\alpha s \rho) \qquad \ldots(2\mathrm{b})$$

respectively. It has been found that 10 terms are sufficient for typical nonlinear characteristics. The normalized envelope levels corresponding to the measured input and output power levels are relative to the levels at saturation:

$$\bar{\rho} = \sqrt{\frac{2P_i}{P_{is}}} \qquad \ldots(3a)$$

$$\bar{g} = \sqrt{\frac{2P_o}{P_{os}}} \qquad \ldots(3b)$$

$$\bar{f} = \psi_o, \text{ in radians} \qquad \ldots(3c)$$

where P_{is} and P_{os} are the input and output power levels at saturation. A procedure has been included in the algorithm for the determination of the appropriate values of b_{sr} and b_{si} from a set of measured values for P_i, P_o and ψ_o.

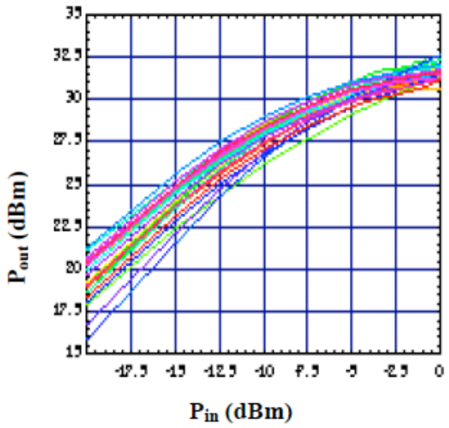

Figure 2. Transfer Characteristics of SSPA Models

The representation of the amplifier nonlinear performance in terms of Bessel function expansion is used to calculate the intermodulation components at the amplifier output [3]. The amplitude and phase functions, *g(ρ(t))* and *f(ρ(t))* are assumed to be independent of frequency, i.e. memoryless. The amplitudes and phases of the intermodulation components are fed into the array configuration to produce the radiation patterns that correspond to the intermodulation beams. These can be compared with the beams of the fundamental signals. The result is an estimation of the signal to intermodulation ratio in the desired signal beams, which translates into calculating the degradation of the overall signal to noise ratio due to the nonlinear operation of the power amplifiers.

3. Intermodulation Beams

The amplitude taper and phase shifts imposed at the junctions in the beam forming matrix and the output network are set to form the beams that operate at different frequencies. Following the matrix amplifier, intermodulation components at deterministic frequencies are subjected to the amplitude and phase coefficients at the outer network junctions and form beams. These beams' locations are functions of their frequencies and the array configuration in wavelength at these frequencies. The individual intermodulation beams fall on a grid that is formed around the primary signal beams [4]. The additional amplitude changes and phase shifts in the intermodulation components caused by the amplifier response cause slight shifts or defocusing of these beams. Suppression techniques of intermodulations in shaped beam systems have been reported [5]. However, the natural spreading of the intermodulation beams as a result of the beam forming at directions other than the main signal beam directions, and the low level of such beam peaks minimize their effects on the signal to noise ratio of the system. Predictions of the intermodulation beam locations and levels show such effects. Measurements of radiation patterns of a multiple-beam active phased array at Ku-band show the beam grid [6, 7]. Comparison of the predicted and measured beam locations and levels is shown in Figure 3 and indicate good agreement.

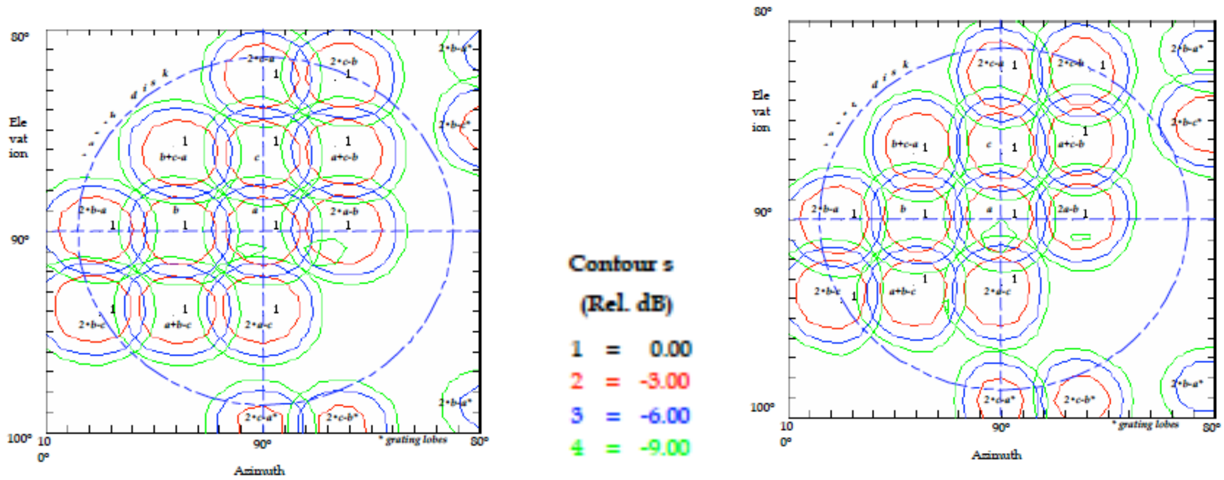

Figure 3. Predicted (left) and Measured (right) Radiation Pattern Contours of Intermodulation Beams [1]

4. Conclusion

Active multiple-beam phased arrays use a single power amplifier behind each radiating element, or a matrix power amplifier with redundancy that shares the amplifier power between a number of beams that use all radiating elements in the array. The nonlinear transfer functions of the amplifiers are analyzed using 10-term Bessel function series expansion that is used to estimate the intermodulation product amplitude and phase levels. Feeding the intermodulation components as additional signals in the distributed communication system, results in the prediction of intermodulation beam levels and locations. The spreading of such beams reduces their harmful effects on the system's signal to noise ration. Predictions of the beam spatial spreading and power levels were verified by measurements for a Ku-band array.

5. References

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