Comments and Reply

Comments on "Pattern Characteristics of Harmonic and Intermodulation Products in Broad-Band Active Transmit Arrays"

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Active array antenna patterns at harmonic and intermodulation (IM) frequencies have been studied in [1]. In particular, the beam directions have been found at IM and harmonic frequencies for different scenarios. The basic equation, which was used to find the beam directions, is [1, eq. (6)]. However, as a detailed analysis shows, the right-hand side of [1, eq. (6)] is not necessarily zero. A more general form of this equation is

$$kd\sin\theta - \Delta\varphi = \frac{2\pi l}{m}$$

where l is an integer number $(0, \pm 1, \pm 2, \ldots)$, and m is order of the nonlinearity (i.e., $m = 1$ for fundamental tone, $m = 2$ for second-order product, and $m = 3$ for third-order product). The case $l = 0$ corresponds to [1, eq. (6)], but when $l \neq 0$ the fundamental $(m = 1)$ and higher order $(m > 1)$ patterns are steered in different directions. A similar statement is true for the case of two signals. Multiple beams may also exist at IM and harmonic frequencies (corresponding to different values of l).

In fact, this problem has been already analyzed in detail in [2]–[5], and the results were summarized in [9]. Closed-form expressions for the array pattern at IM frequencies, the IM beam directions and beamwidths have been obtained in [2] using a power-series model of the amplifier nonlinearity, and the third- and fifth-order responses were analyzed in details. In particular, it was found that multiple beams (i.e., "grating IM lobes") may exist at IM frequencies (the same is of course true for harmonic frequencies). A detailed analysis of the existence conditions for multiple IM beams has been given in [3]. While the analysis in [2]–[5] was carried out for a receiving array, it applies, due to reciprocity, to a transmitting one as well. It was found that interference immunity (i.e., the ability of the array to suppress unwanted signals coming from directions different from that of the wanted signal) of an active array can be severely degraded due to IM products [2], [9]. It is also interesting to note that, in general, different IM products are not correlated with each other and, hence, the total IM power is the sum of powers of individual products provided that the phases of the signals that generate these IM products are independent [2].

While the power-series analysis above is straightforward to do and closed-form analytical solutions are available, it may not be accurate in many cases. In particular, a third-order power series model is not accurate for predicting IM and harmonic amplitudes, especially for amplifiers operating close to 1-dB compression point [6], [7]. If a power-series model is adopted, it must be of a sufficiently high order (in practice, from 15 up to 45–50) to produce accurate results [6], [8]. Alternatively, more sophisticated numerical simulation techniques may be used to predict the amplitudes of nonlinear products accurately. Some of such techniques have been described in detail in [7]–[9].

Another important issue in finding beam directions at IM and harmonic frequencies is the amplitude-to-phase (AM–PM) conversion in amplifiers, which may significantly change the directions from those predicted by models ignoring this conversion. It has been also proved that, in some cases, AM–PM conversion may affect significantly the amplitudes of nonlinear products and, hence, should be taken into account from this viewpoint as well. These two effects are especially pronounced for power amplifiers operating close to 1-dB compression point.

Manuscript received October 2, 2002; revised December 16, 2002.
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Digital Object Identifier 10.1109/TAP.2003.813644

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Authors' Reply

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Pointing out that a multiple signal transmit array with grating lobes will have intermodulation (IM) lobes associated with the grating lobes, as well as with the main lobe, is an important point. In some array applications, this can be very significant. Also, an array with significant energy radiated at a harmonic could support "harmonic grating lobes" even if the fundamental pattern does not have grating lobes.

Manuscript received December 9, 2002.
Digital Object Identifier 10.1109/TAP.2003.813645

The analysis presented in Loyka's references 2–5 is for active receive array IM effects. There are similarities to the analysis presented in [1] for transmit arrays. Loyka presents a useful graphical procedure for showing the possible location of receive IM lobes which are "created" when two or more strong sources impinge on an active receive array. His analysis is based on third- and fifth-order polynomial models for the receive amplifier response.

The third-order polynomial model used in [1], and by Loyka, is widely used to model transmit and receive amplifier nonlinearities and has useful accuracy for operations backed off from the 1-dB compression point. Low-order polynomials do not faithfully match amplifier voltage out/voltage input response through 1-dB compression and into hard saturation. Other modeling techniques need to be used for saturated operation.

How much, if any, of the spatial distribution effects predicted by the polynomial model for backed-off operation carry forward to saturated operation has not been fully explored to my knowledge.

References

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