POWER EFFICIENT BEAMFORMER WEIGHTING SETS FOR SMART ANTENNA PATTERNS WITH LOW SIDELOBES

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ABSTRACT

This paper discusses the design considerations of a unique antenna array distribution used for developing narrow beam antenna patterns with low sidelobes and high aperture efficiency. The distribution is referred to as the Constrained Least Squares (CLS) distribution function. In the CLS distribution, most of the radiating elements near the array center are set to their maximum value while only a few of the outer elements are tapered. Several methods for generating CLS distributions given constraints on both the peak element amplitude and the total effective radiated voltage (ERV) will be discussed. The design involves specifying the desired ERV and a weighting function that allows selectively suppressing sidelobes in specified regions. The effects of these design parameters on the far-field patterns are explored.

1. INTRODUCTION

The antennas proposed for many SDR applications include single element radiators that can be tuned for a variety of applications and functions as needed. Isolated antenna elements are an excellent choice for two-way communications applications where broad angular coverage is needed. In smart antenna applications and long-range communications applications, highly directional antenna patterns, such as though only achieved by beamforming multi-element antenna arrays are needed. SDR and mobile computing applications often include power conservation and energy efficiency constraints as well.

Traditional approaches toward designing beamformer weighting sets (or distribution functions) involve optimizing the far-field antenna patterns to have high directivity and low sidelobes. Generally, little consideration is given to the overall radiated voltage and thus efficiency at the radiating aperture. Furthermore, adaptive processing is used to place nulls in certain angular directions in order to minimize interference from clutter and other interferers. The unfortunate side to this approach in SDR is that adaptive beamforming is band-limited and new beamformer weighting sets must be computed and stored for each frequency range of interest.

In this paper, the results of the development of antenna distribution functions that provide very low sidelobes and high directivity, while at the same time providing a pre-determined effective radiated voltage (ERV) is given. While the initial motivation for this work was for the transmit mode patterns for active array antennas, the approach is useful for SDR and mobile communications.

Consider a smart antenna array configuration as shown in Fig. 1. This figure shows an active electronically scanned array where there is an individually controlled transmit/receive (T/R) module behind each radiating element. The T/R module allows for independent control of the phase and amplitude of each radiating element. Generally the phase distribution provides an angular scan to position the antenna pattern in space. The amplitude distribution controls the spatial power distribution of the pattern (i.e., gives directional patterns with low sidelobes.) Since there is independent control of the amplitude distribution, then the antenna pattern can be software controlled as conditions change. This allows for real-time adaptation to new frequency ranges of interest or when the external environment that affects good communications changes.

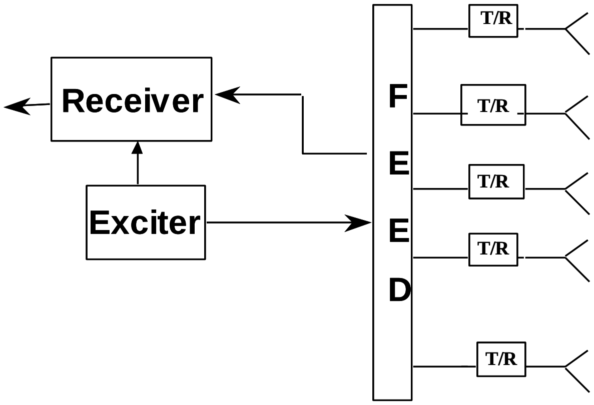

Fig. 1 Smart Antenna Array Architecture

2. ANTENNA DISTRIBUTIONS

Antenna distributions range from uniform, where all elements are equally excited, to tapered, where the amplitude of the elements are reduced starting with the elements immediately adjacent to the center elements. Tapering the distribution produces highly directive antenna patterns with reduced sidelobes, but it also reduces the overall effective radiated voltage of the array.

Fig. 2 shows the far-field radiation pattern for a 30 element array with half wavelength spacing and a uniform distribution. Fig. 3 shows the far-field radiation pattern for a 30 element array with a Taylor distribution. Fig. 2 shows that the sidelobes of the uniform array are much higher than those for the array with the Taylor distribution. To determine the efficiency of the distribution, the effective radiated voltage (ERV) is computed. The ERV is the normalized sum of the voltage excitations at the antenna elements. An alternative parameter, K, is introduced for convenience. K is equal to ERV/2. ERV and K indicate the aperture efficiency and the amount of tapering required to obtain a certain far-field pattern. For the uniform distribution, K =1, while the value of K for the Taylor distribution 0.649. The traditional approach to antenna design implies that in order to obtain the very low sidelobes in the Taylor patterns, one must sacrifice aperture efficiency.

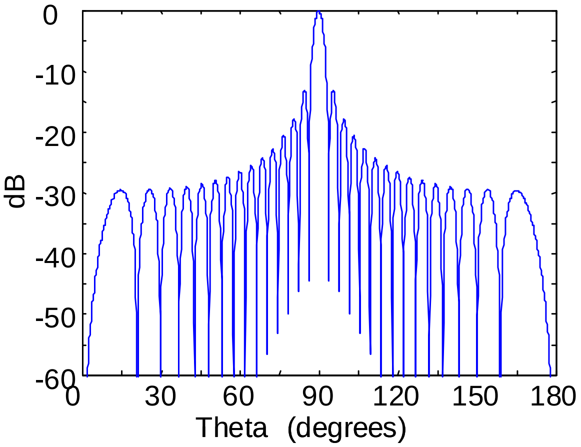

Fig. 2 Far-Field Radiation Pattern for 30 Element Array with a Uniform Distribution, K=1

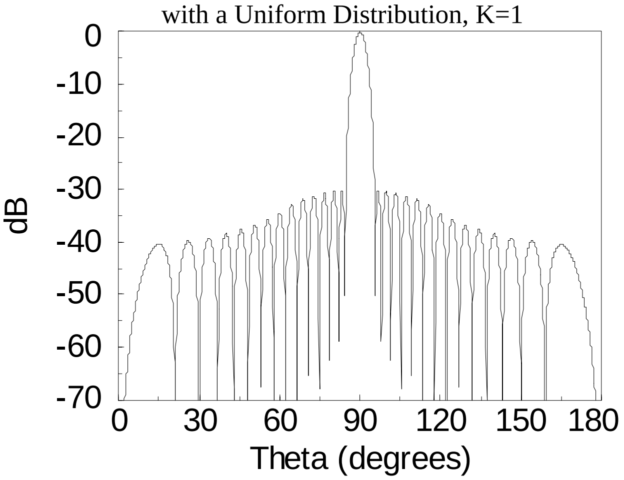

Fig. 3 Far-Field Radiation Pattern for a 30 Element Linear Array with a Taylor Distribution, K=0.649

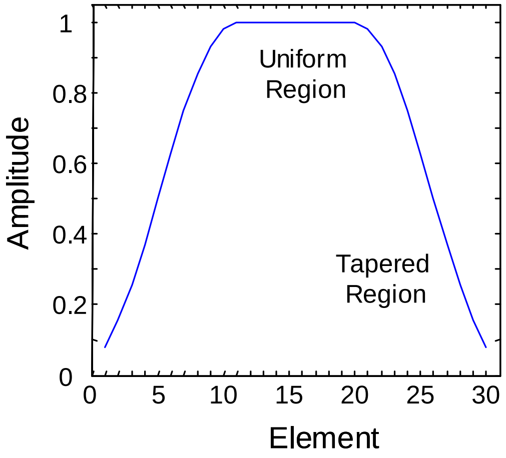

Fig. 4 Typical CLS Distribution

The CLS distribution is a new way of considering how to obtain low sidelobe patterns with high aperture efficiency. In the CLS approach, the distribution is divided into two regions as shown in Fig. 4. The elements in the uniform region at the center of the array are set to their maximum value, and the elements in the tapered region at the outermost part of the array receive some type of taper. The design parameters for this distribution are the number of elements in the tapered region and the associated distribution. The form of the distribution given in Fig. 4 is based upon the results of derivations for optimization problems in communications that are given in [1].

The design of the CLS distribution uses a constrained least squares optimization procedure. This optimization approach utilizes well-known optimization methods that employ Lagrangian multipliers. These methods minimize a function when subjected to defined constraints. In the CLS technique, the optimization goal was to minimize the overall sidelobe energy in the far-field pattern subject to peak and effective radiated voltage constraints in the distribution. In this work it is assumed that the antenna distribution is purely real and symmetric around the array center. The voltage constraints are: the normalized peak amplitude of each radiating element must be less than or equal to one to one and the total effective radiated voltage (ERV) in the array cannot go below a predefined value. The first constraint applies to an individual radiating element, while the second constraint applies to the array distribution as a whole. The resulting CLS distributions allow one to obtain good pattern performance as well as high array efficiency.

As part of the overall measure of pattern "goodness" two factors were considered. The primary design goal was to minimize the sidelobe energy in the far-field. The results show, however, that if one allows the first sidelobe closest to the mainbeam to remain high, that significantly lower outer sidelobes are obtained. This result is especially applicable to very wideband arrays and SDR applications. Since for a predefined ERV, significant lowering in the outer sidelobes is obtainable. This eliminates the need for adaptive nulling to cancel interference, which is inherently narrowband. The theoretical background and a procedure to synthesize CLS distributions is given in [2] and [3].

3. CLS ARRAY DISTRIBUTIONS AND PATTERNS

To demonstrate the results obtained by the CLS design process, several distributions and patterns were computed. Consider a discrete linear array with 30 elements with half-wavelength element spacing that is placed on the z-axis. Consider further that is desired to suppress all sidelobes except the first one on either side of the mainnbeam, while at the same time maintaining a specified effective radiated voltage. Recall that the surrogate we will use for ERV in this case is K. When K=1, a uniform distribution is obtained and none of the elements are tapered. Fig. 5 shows the far-field radiated pattern for a CLS distribution, when K=0.9. Fig. 6 shows the far-field radiated pattern for a CLS distribution when K=0.7. Fig. 7 shows the CLS array distributions when K=0.9, 0.8, and 0.7.

A comparison of Figs. 2, 5 and 6 show that significant tapering of the outer sidelobes is obtained by relaxing the ERV.

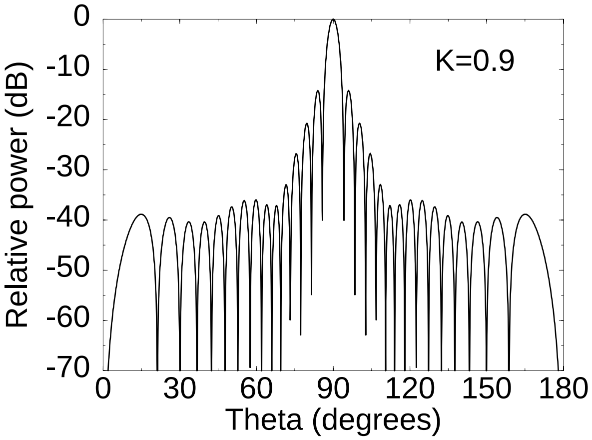

Fig. 5 Far-field CLS Pattern for 30 Element Linear Array with K=0.9

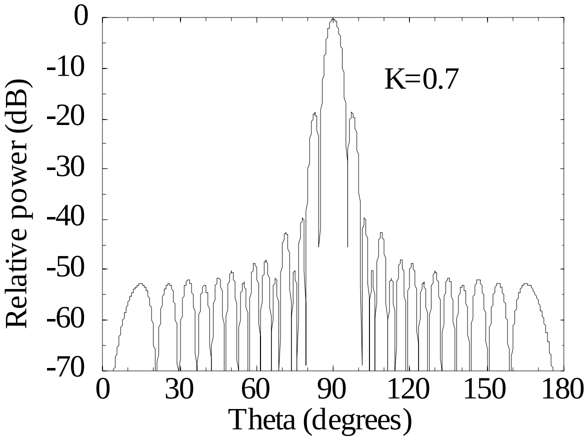

Fig. 6 Far-field CLS Pattern for 30 Element Linear Array with K=0.7

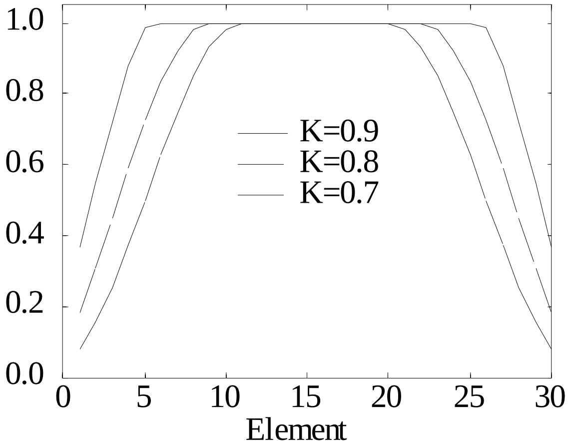

Fig. 7 CLS Distributions for 30 Element Linear Array

Fig. 6 shows that if the first sidelobe is allowed to remain high, it is possible to achieve good ERV and low sidelobes. Overall, the sidelobes in Fig. 6 are lower than the sidelobes in Fig. 3, even though the distribution used in Fig. 3 has a larger taper. Fig. 7 shows that when the value of K is relaxed, more of the array elements receive a taper.

4. COMPARISON OF CLS AND TAYLOR PATTERNS

This section compares the performance for the CLS distribution to a Taylor distribution. Taylor distributions are widely used to create low sidelobes patterns for a variety of applications. They are very well characterized [4], [5]. The theory of linear Taylor distributions assumes a continuous line source distribution. In order to determine the beamformer weights for a discrete array, the continuous Taylor distribution can be sampled at discrete points. Linear Taylor distributions require the specification of two parameters, *nbar*, and the peak sidelobe level. The value of *nbar* specifies how many sidelobes (near the mainbeam) will be at a specific peak sidelobe level height. The sidelobes beyond this will be lower. The Taylor approach only optimizes pattern performance, and the ERV is computed from the resulting distribution.

To provide an accurate comparison of Taylor and CLS patterns, several different Taylor patterns and the resulting ERV were computed. The Taylor patterns were computed for a 15λ long line source. This line source corresponds to a 30 element array with λ/2 element spacing.

Several CLS patterns were also computed. In this case, the ERV is specified at the beginning of the design process. In the CLS patterns, it was desired to have all of the outer sidelobes except the first one closest to the mainbeam be as low as possible.

Several different far-field parameters were compared. These include the directivity loss and the average sidelobe level. Directivity loss is calculated by dividing the directivity for the array (or line source) with the tapered distribution by the directivity of an equal length array (or line source) with a uniform distribution or

$$DirLoss_{dB} = 10\log_{10}\frac{Dir(tapered)}{Dir(uniform)}\,dB$$

This form is based upon the idea that the best directivity is obtained by a uniform distribution. Directivity loss accounts for the loss in directivity due to tapering the distribution. Fig. 8 compares the directivity loss as a function of K for the 15λ long Taylor line source and the 30 element CLS array. The results show that the Taylor pattern is just slightly more directive than the CLS pattern.

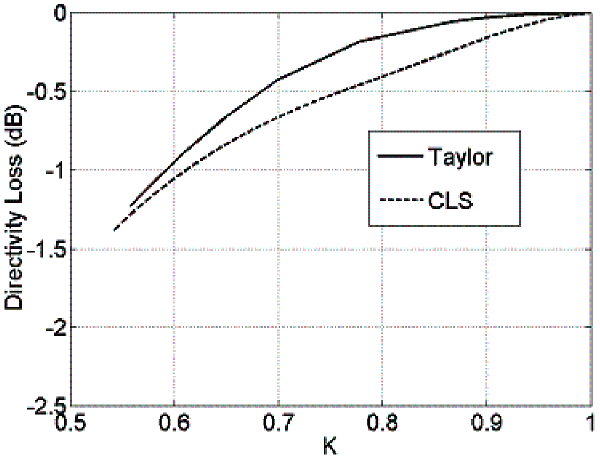

Fig. 8 Comparison of Directivity Loss for Taylor and CLS Distributions

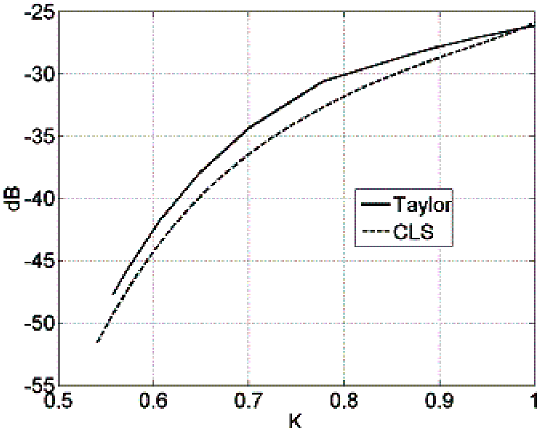

Fig. 9 Comparison of Average Sidelobe Level for Taylor and CLS Distributions

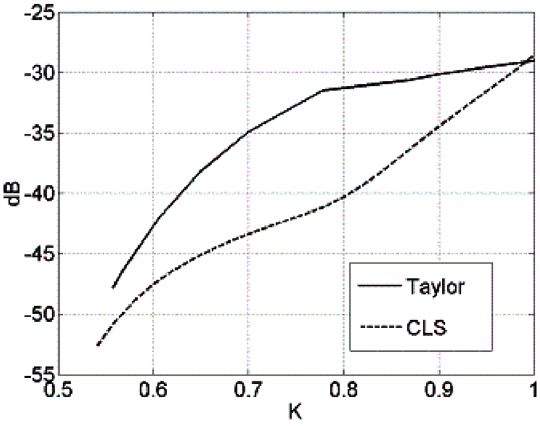

Fig. 10 Comparison of Average Sidelobe Level Excluding First Sidelobe for Taylor and CLS Distributions

Figs. 9 and 10 compare the average sidelobe level as a function of K for the Taylor and CLS patterns. In Fig. 9 the average sidelobe level includes the first sidelobe in the computation. The first sidelobe is excluded in the computation of average sidelobe level in Fig. 10, since in the CLS approach all sidelobes were lowered *after* the first sidelobe. Since the first sidelobe in the CLS array are allowed to remain relatively high, low average sidelobes values are due to very low outer sidelobes. These results show that the CLS distribution produces on average lower sidelobes than the Taylor distribution for a given ERV. Fig. 10 shows that in some cases that the average value of the outer sidelobes of the CLS pattern can be as much as 8dB lower than those for the Taylor pattern. These very low sidelobes are obtainable while maintaining high ERV in the antenna distribution. Since the sidelobes in some cases are already very low, then it may eliminate the need to compute beamformer weights for adaptive nulling purposes. This is especially useful for the case of wideband array operation. These figures show the relative performance tradeoffs between using a traditional Taylor distribution versus a CLS distribution.

7. CONCLUSIONS

An antenna distribution that achieves highly directive radiation patterns with low sidelobes and high aperture efficiency was presented. The general concept of the CLS distribution and how it performs was presented. Some pattern characteristics such directivity and average sidelobe level for the CLS distribution is compared to traditional Taylor patterns for a linear array. The results show that the CLS distribution produces patterns with only slightly lower directivity than Taylor patterns. The CLS patterns, however, have much lower outer sidelobes than the Taylor patterns for a given effective radiated voltage.

10. REFERENCES

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