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Space Fed Subarray Synthesis Using Displaced Feed Location[*]

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Introduction

Wideband space-fed subarray systems are often proposed for large airborne or spaceborne scanning array applications. These systems allow the introduction of time delay devices at the subarray input terminals while using phase shifters in the array face. This can sometimes reduce the number of time delayed controls by an order of magnitude or more.

The implementation of this technology has been slowed because the feed network, usually a Rotman Lens or Butler Matrix, is bulky, heavy and often has significant RF loss. In addition, the large lens aperture is necessarily filled with phase shifters, and so it introduces further loss, weight , and perhaps unacceptable phase shifter control power.

These systems are currently viewed with increased interest because combination of low loss, low power MEMS phase shifters in the main aperture and solid state T/R modules in the feed might lead to large scanning arrays with much higher efficiency then previously realizable.

Unfortunately, the conventional system design imposes an extremely large dynamic range requirement when used in the transmit mode, and requires very high output power from the T/R modules. This paper presents one possible solution to this problem using a modified feed geometry.

Wideband Subarray System Configurations

Figure 1 shows the classic configuration of this wideband system, as consisting of a large equal path length objective lens fed by an M x M Fourier Transform (multiple beam) feed, either a Butler Matrix or a lens with (approximately) orthogonal multiple beams (Rotman Lens). The purpose of the complex feed is to form subarrays that overlap across the objective lens, and that radiate pulse-shaped subarray patterns. The subarray input ports are shown at surface "D" in the figure, and these ports are time delayed as appropriate for transmit and receive. The transmission lines between surfaces "A" and "B" contain "N" phase shifters to steer the pulse-shaped subarray pattern to the desired angle at center frequency. The array of subarrays forms a time-delayed beam that points in the desired direction at all frequencies, but the subarray patterns are phase-steered, and so they narrow and move toward broadside at the higher frequencies. They broaden and move toward end-fire at the lower frequencies. This sliding window determines the system bandwidth limits.

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Since the M x M transform feed network is lossy, the most efficient system is obtained using T/R modules at the face of the feed (Surface C). However, amplifiers at this location face a severe dynamic range and transmit power issue. This is understood by considering that the M x M transform network, fed by input signals J_m at each m'th input port, produces output signals I_i at every output port

$$I_i = \sum_m J_m e^{-jK(2\pi)\left(\frac{m}{M}\right)i} \tag{1}$$

where $K = \lambda_o/\lambda$ for a perfectly time delayed lens feed with orthogonal beams at λ_o, and $K = 1$ for an orthogonal beamforming network (Butler Matrix). The input signals J_m contain a time delay factor and a phase term to subtract out the phase at the center of each subarray. For a beam at frequency rf_o, scanned to an angle θ_o with direction cosine $u_o = \sin\theta_o$, the m'th subarray input signal to a network is:

$$J_m = |J_m|\, e^{-j2\pi m u_o \frac{D_o}{\lambda_o} K\left(1-\frac{1}{r}\right)} \tag{2}$$

for D_o the inter-subarray distance at center frequency.

With all M input signals applied, one can show that there are scan angles for which nearly all the signal power is focused to a single port (I_i). This condition occurs at

$$u_o = \frac{-i\lambda_o}{D_o M}\,\frac{r}{r-1} \tag{3}$$

for output ports with i taking on the values ±1/2, ±3/2.... . If the network is orthogonal, the signals out of all other ports are zero for these scan angles, while for time delayed networks they are small but non-zero.

There are two severe problems with this focusing. First, the dynamic range of T/R devices at these i'th ports is very large, and secondly the transmit power is no longer distributed across the feed array, so the actual power requirement for individual transmit amplifiers is very severe.

Subarrays with a Displaced Feed

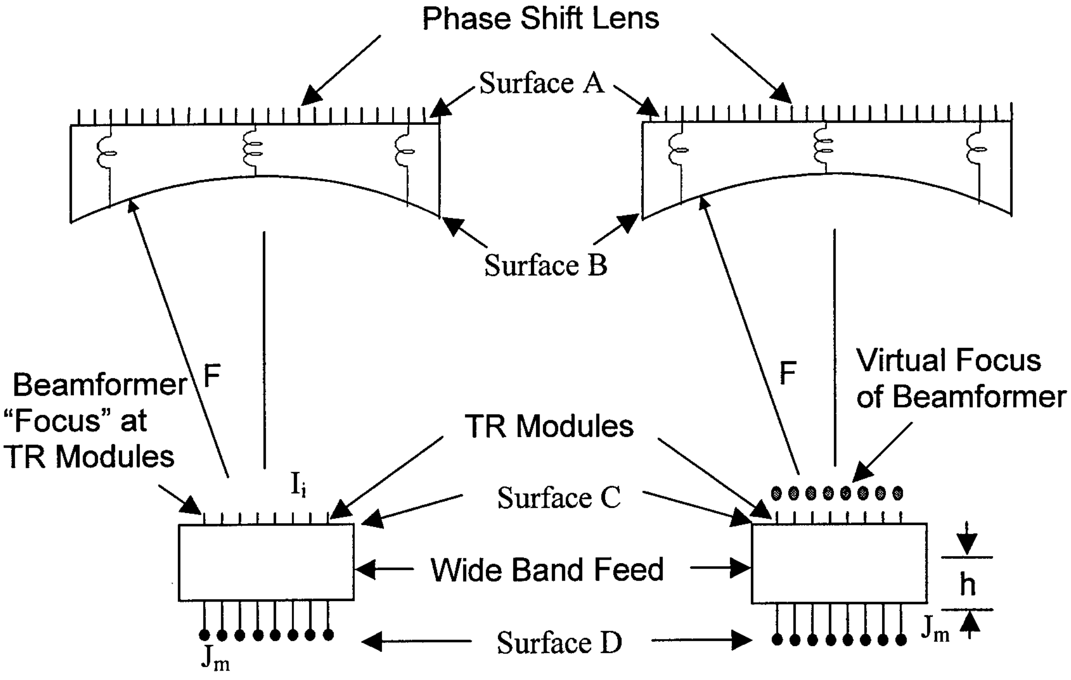
One solution to the dynamic range problem is to displace the feed output elements back from the focal plane as indicated in Figure 1. The feed network is then assumed to be a digital beamformer, instead of an analog feed, and the digital weights synthesized to have nearly the same subarray patterns as the original feed that was located at the focus. This synthesis was accomplished using a projection method, and places focal spots in front of the feed network instead of at the feed as indicated in Figure 1. The front face of the feed has currents that correspond to a converging wavefront.

The figures show some results for a system of 8-subarrays using a lens with cylindrical backface, $L=128\lambda_o$, $F/L = 0.65$ and half-wave inter-element spacing. The feed has 8-elements and forms 8 subarrays spaced 16λ apart at the main lens. Figures 2a and 2b show the feed output currents for the conventional focal plane feed and the feed mounted 2 wavelengths outside of the focal plane. The scan angle chosen is one of the critical ones and Figure 2a shows nearly all the signal focused to a signal feed element, but 2b shows that the displaced fed, re-synthesized to produce good subarrays, has most elements excited. The phase required to produce the virtual focus in front of the feed is not shown, but has the appropriate converging wavefront.

Figure 3 shows that for any scan angle the displaced feed concept always has more elements contributing to the radiation than the conventional feed, and has no scan angles where only a single feed element radiates significant power. Subarray and array patterns are not shown, but the results are nearly as good as produced by the focal plane feed.

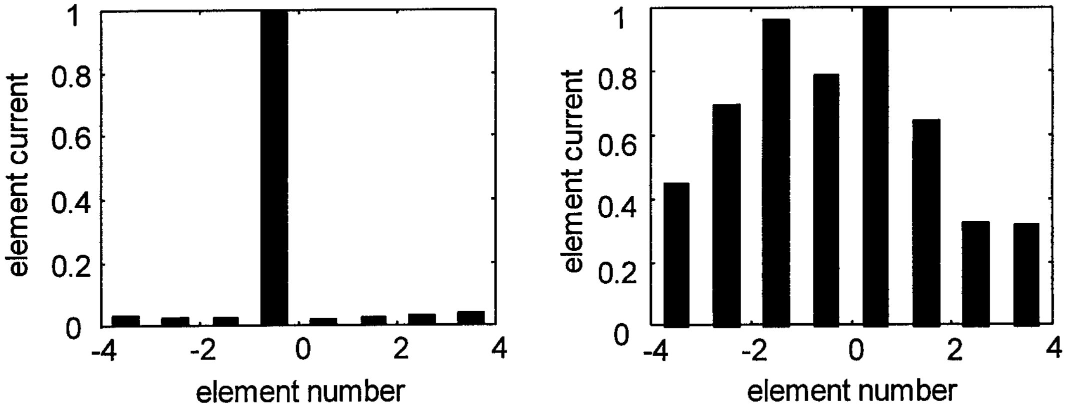
Conclusion

This paper has presented a new technique producing overlapped subarrays by means of a transform feed displaced from the focal planes. The results indicate that the method avoids the focusing problem associated with conventional feeds, while producing radiation behavior that is nearly as high quality as that from the focal plane feed.



$$I_i = \frac{1}{\sqrt{M}} \sum_m J_m e^{j2\pi \frac{m}{M} iK}$$

Figure 1. Conventional Subarray Beamformer and Beamformer with Displaced Feed



Normalized Current on Elements at u_o and 1.025 with Conventional Beamformer (h = 0)
(a)

Normalized Current on Elements at u_o and 1.025 * f_o with Optimized Beamformer (h = 2)
(b)

Figure 2. Relative Currents at Feed Output for Conventional and Optimized Beamformers

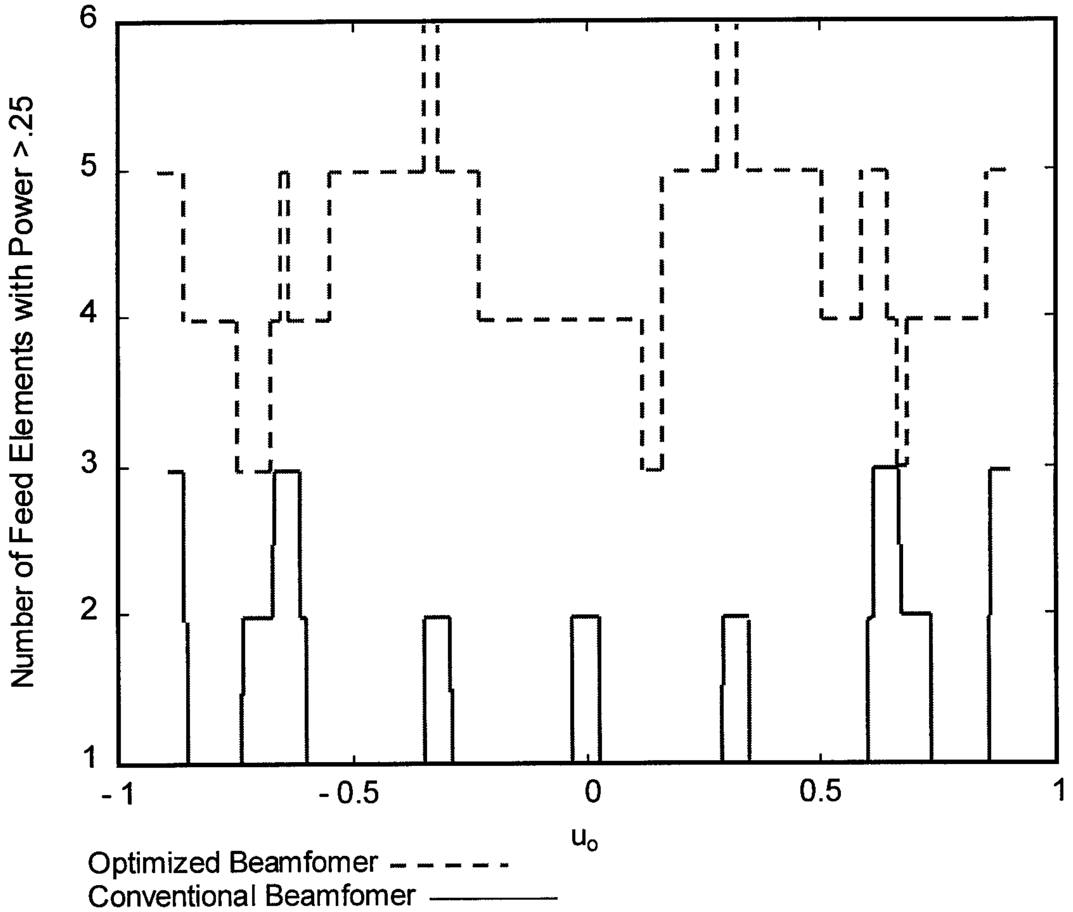


Figure 3. Feed Elements with Relative Power > 0.25. Comparing Conventional Beamformer and Optimized Beamformer