

Advanced Antenna Array Beamformers

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PROBLEM STATEMENT

The radome on the E-2D aircraft within NAVAIR's PMA-264 contains a combination of primary UHF surveillance radar and secondary IFF radar operating at L-band. Structural support members of the radome were found to cause severe interference to the IFF patterns. In particular, the difference channel sidelobe pattern no longer covered the sum pattern well enough to provide the necessary blanking function. A technique was needed that could repair both patterns via optimized phase commands sufficiently well (a minimum of 2 dB difference-to-sum sidelobe patterns margin was required, and no sum-over-difference stick-throughs were acceptable except at very low sum sidelobe values that are mostly met at the back hemisphere.) to render the system operational.

TSC has provided such corrective phase commands: one set per each frequency / electronic-steering-angle combination. The commands have been generated via TSC's local optimization technique: an extremely efficient optimization technique that has proven applicability in areas far beyond this specific application. The alternative approach of eliminating the structural members would have entailed a redesign of the radome and, probably, changing of the original mold line as the result. This would have been a large effort and would have entailed quality of flight issues and recertification, and would have been too lengthy and expensive to contemplate. (Up to \$100 million of added cost were estimated by Navy cost specialists had TSC's technique not been available.)

WHO CAN BENEFIT?

The optimization technique that TSC has used to solve the problem is extremely robust and is easily adaptable to other antenna problems, such as failure compensation in active phased array, pattern notching and other modifications. It can be used by all phased array radar users, whether of the active or passive variety, which support radar, communications, or EW applications. Army, Navy, Air Force, FAA, and Homeland Security are all potential beneficiaries of that technique. In

the Navy, it includes any PMS or PMA that supports development and support of such systems. In addition to array applications, it has also been used successfully in radar waveform and mismatched filter developments including spectral control and spectral notching. Some spectrally notched waveforms developed by TSC using this technique have been successfully inserted in the Army's synthetic aperture TRACER radar and were demonstrated through flight tests. Synthetic aperture radar systems, military and commercial, utilize exceptionally broad bands to obtain the specified range resolution. This places them in RF radiation conflicts with other RF based systems operating in the same vicinity. Tailored spectral control, which does not degrade the time domain performance, can help avoid such conflicts. Many potential radar users and radar platforms exist in every DOD service and in the FAA.

Another very large body of potential users is the communications community and its respective platforms. Radar programs such as the USMC Ground/Air Task Oriented Radar (G/ATOR,) the Air Force 3 Dimensional Expeditionary Long Range Radar (3DELRR,) the joint Air Force / Navy Cobra Judy Replacement (CJR,) the Joint Strike Fighter Radar (JSF), the Advanced Tactical Fighter radar (ATF), etc. can all use many of the techniques made available by TSC's Local Optimization technique.

BASELINE TECHNOLOGY

The baseline technology utilizes secondary radar patterns which are too distorted to be usable in actual operation. Removing the radome structural support members will entail a totally different radome design in with the mold line that, in all likelihood, could not be preserved. This would entail significant schedule slip and added certification flight tests which could result in added expenses of up to \$100M.

TECHNOLOGY DESCRIPTION

The corrective phase commands employed by TSC utilize the existing radar hardware. They require the storage of some tables of modest size in existing computer memory, and very slight addition to existing antenna range testing. These corrections derive from innovative mathematical algorithms based in optimization theory. The strength of the approach is rooted in its flexibility, its power and robustness, and its low cost to implement. It is low cost due to its algorithmically-based approach which, given today's powerful, low cost, and widely available digital computing, is coupled with the off-line nature of this algorithm. The extremely deep and low cost memories available today, coupled with the low storage requirements of the corrective phases, make its on-line implementation extremely easy and simple.

Taking the broader field of applicability of TSC's algorithms, they are low cost to run and easy to implement in the service of various end-uses. They are extremely fast and can, therefore, solve problems that appear to be intractable, or near intractable without them. As such they avoid expensive hardware and provide systems with many options that are easy, robust, and re-configurable. They do not require special interfacing equipment or facilities, but use available desk top digital technology. Several examples of the technology applications, other than the E2-D IFF, are shown below. One example consists of the computation of broad horizon notches in extremely large phased array radar (tens of thousand of individually controlled elements.) Whereas others took, sometime, many hours or days on super-computers to come up with desired notches, TSC was able to compute better notches in fractions of a second.)

The features, advantages, and benefits of TSC's algorithms follow:

Features	Advantages	Benefits
Use COTS computers	No expensive hardware required	Lower cost to run
		Easy to implement
		Extremely fast
		Solves problems appearing intractable
Optimized pulse compression Codes and mismatch filter	Generates large volume of codes of exceptional peak and integrated sidelobes	Enables very efficient radar operation, tailoring codes to the environment
Orthogonal waveforms	Supports Multiple-In-Multiple-Out (MIMO) approach and many others	Suppresses mutual interference from near-by systems. Enables signal separation by code.
Temporally notched waveforms	Applies to temporal sidelobe nulling – prevents weak target suppression by large time sidelobe discretises	Separates large and small objects in close proximity
Spectrally notched and low sidebands waveforms	Suppresses RF interference within and outside of band without noticeable performance sacrifices	Can operate in the vicinity of other radiating RF systems
Notched and failure compensated antenna pattern	Compensates pattern for active array module failures and other error sources. Tailors array pattern to environment.	Reduces terrain clutter and interference from radars, jammers and communication systems. Enables continuation of normal operations by compensating for error and failure

Example 1: Code and Mismatch Filter Development: Developing radar codes of good peak and integrated time sidelobes has always been considered extremely challenging computation problems. The best codes take extremely long time to find. Using its extremely fast Local Optimization technique, TSC was able to come up with extremely large numbers of codes whose performance pushes the state of the art. Three groups of 25,000 codes each are shown. They include a group, in blue, that utilizes a matched filter; a group, in green, that optimizes codes and mismatched filters sequentially; and a group, in red, that optimizes codes and mismatched filters simultaneously. These 75 thousand codes were selected as best codes from a total population of around a million codes: all computed via TSC’s Local Optimization technique. This example demonstrates TSC’s capabilities of generating large volume of pulse compression codes and mismatched filters of exceptional peak and integrated sidelobes.

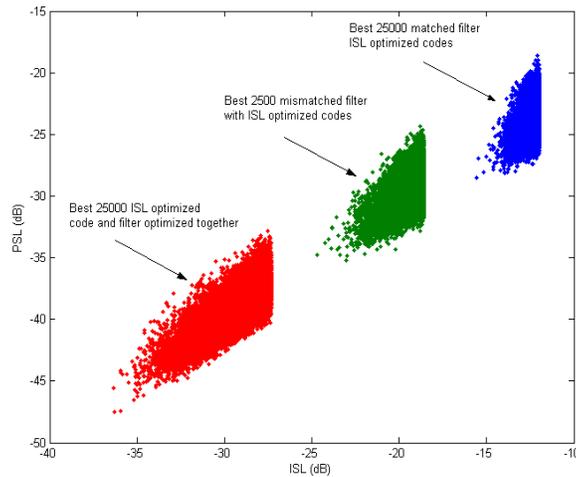


Figure 1.1: ISL versus PSL for length-32 ISL optimized matched filter codes (blue), ISL optimized MMF-processed codes (green), and co-optimized ISL optimized code / filter pairs (red)

Example 2: Orthogonal Waveforms: Orthogonal codes families are even harder to generate since they include performance constraints both on individual and on cross correlation functions. TSC has generated many orthogonal code families for many customers. It is currently supporting an OTH radar application that requires large number of orthogonal code families in order to support a Multiple-In-Multiple-Out (MIMO) approach. In addition to the plain orthogonality, TSC has also developed waveforms families that have controlled degree of correlation: i.e., that become decorrelated gradually rather than abruptly. This example demonstrates TSC’s capability to generate orthogonal code families. (TSC has generated many much larger families and corresponding mismatched filters in very short processing times.)

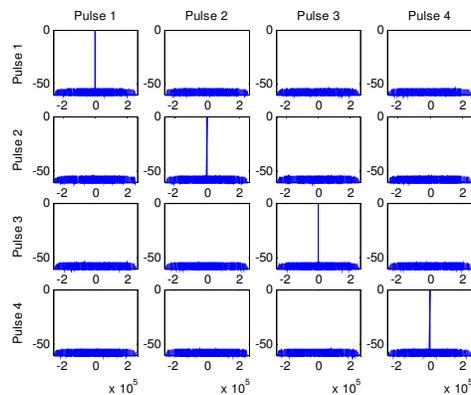


Figure 1.2 Matched filter properties of four codes optimized to have -55 dB autocorrelation and cross-correlation sidelobes

Example 3: Temporally Notched Waveforms: This is an example demonstrating TSC’s optimization algorithms applied to temporal sidelobe nulling. It is a property essential for the separation of large and small objects in close proximity.

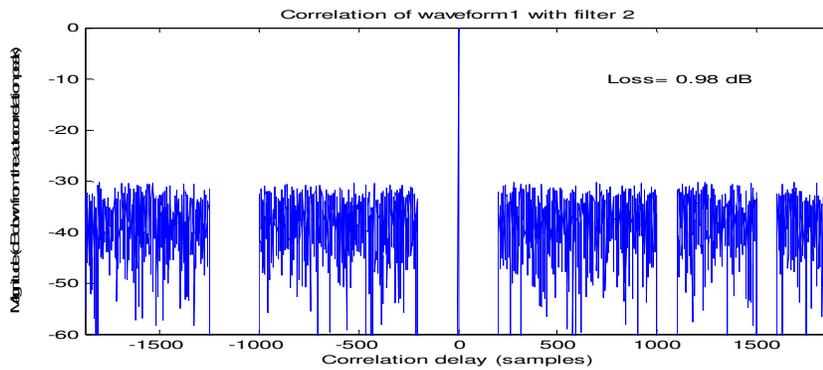


Figure 1.3 Forensic Sidelobe Nulling

Example 4: Spectrally Notched Waveforms: The issue of mutual RF interference is becoming very acute with the proliferation of RF systems and with the addition of the relatively new Wi-Fi communication bands, etc. Synthetic aperture radars are particularly vulnerable owing to their broad instantaneous band. Figure 1.4 shows a wideband synthetic aperture radar waveform with 15 spectral notches within its band. Figure 1.5 shows the measured waveform after being implemented in the TRACER radar hardware. Figure 1.6 shows a synthetic map obtained with this spectrally compliant waveform. In this process only a matched filter was used. Since this picture was taken the TSC's mismatched filter was tried and was proven extremely successful in cleaning up the picture beyond what other canned windows were able to do. This proves that, using TSC's algorithms, synthetic aperture applications can operate in the vicinity of other radiating RF system while tailoring their spectrum to prevailing radiation bands that are geographically dependent, without having to make noticeable performance sacrifices.

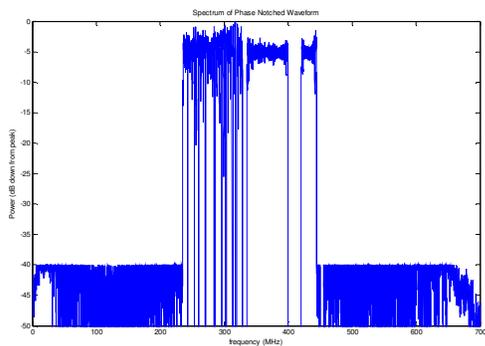


Figure 1.4 A TSC generated waveform with a sequence of notches across a 210 MHz band

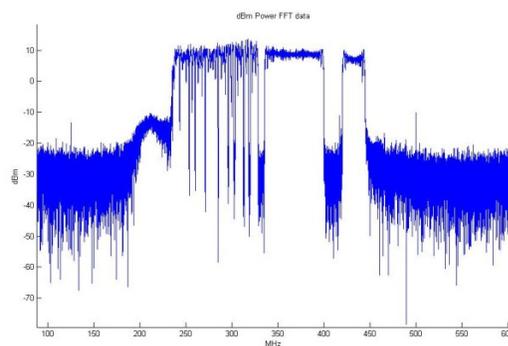


Figure 1.5: Screen shot of the Spectral output when the waveform of Figure 1.10, measured at the antenna inputs, was transmitted from the Army TRACER antenna



Figure 1.6: SAR image created using a TSC-generated, spectrally-compliant waveform

Example 5: Notched Antenna Pattern: Horizon notches in phased array radar help reduce the interference from extreme ground clutter with said radar in above horizon beam elevations. This becomes an essential feature especially in applications of extreme detection sensitivity. When the beams are high enough, no Doppler waveforms are required, which help release resources to search and track. These notches also help prevent interference from radars, jammers and communication systems located near the horizon. Figure 1.7 shows a horizon notch created in a very large (over 15,000 element) array pattern. It is a broad notch, not far removed from the mainbeam. The array was shipboard mounted and experienced the pitch, roll, and azimuth steering angle shown in the figure caption. This notch, like many others for that system, was created in very short time on a common desk top personal computer (PC.)

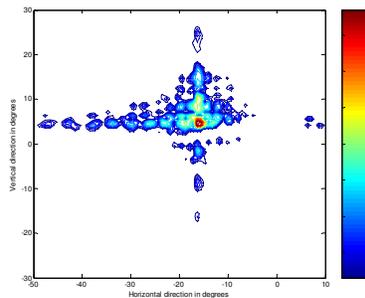


Figure 1.7: A contour plot of a typical notch. This corresponds to a scenario where roll is -10 deg., pitch is 5 and azimuth is -15 deg

CURRENT STATE OF DEVELOPMENT

The IFF capability has a TRL level 5. It has been tested and proven many times in antenna test ranges and has been flown on two aircraft using prototype arrays and domes. The spectral notching technique is at TRL level 6. It has been flown and demonstrated on a prototype TRACER system. Array notching application and other waveform development techniques are available. They have not yet been used in actual hardware, but are expected to perform well when they do get tested.

The technology can be used right away. The IFF phase compensation technology is now considered by NAVAIR and by Northrop Grumman Corp. (NGC) to be an integral part of the E2-D program.

During Phase I of the current SBIR program corrective phases have been generated based on measured element patterns and have undergone limited testing in an antenna range. During Phase II the notching technique has been further developed and better tuned to the requirements. Five different arrays and radome combinations have been extensively tested and the technique has been streamlined for implementation and demonstrated once and again in two different antenna ranges (at a Randtron range and at St. Augustine, FL.) In addition, the notches were implemented and testing begun on two prototype air platforms. TSC has also developed an optimization technique on receive that will involve amplitude and phase together. To implement amplitude control, the beamformer will need to be redesigned. TSC is funding its sub-contractor, BAE – the designer of the current beamformer - to redesign the beamformer in line with its amplitude attenuation requirements. Studies to-date have shown that it is possible to obtain significant additional performance improvement on receive, using amplitude and phase together, without significant additional losses. More antenna range tests are also expected during this period.

REFERENCES

The best reference is the TPOC on this effort. He can be reached at (301) 342-2637. He can provide all of the information concerning the tests at Randtron Antenna Systems (RAS) antenna range and at St. Augustine antenna range as appropriate.

ABOUT THE COMPANY

TSC was founded in 1966 by Dr. Peter Swerling. It is an employee-owned, high technology company engaged in providing engineering services and specialized products to U.S. Government agencies and private industry. TSC's engineering and research support spans the system life cycle from advanced concept development through operations including integrated logistics support. TSC's specialized products include sensor and subsystem prototype development and demonstration, electronic circuit board manufacture, test devices, computer applications for radar siting, geographic information services, and sensor/system modeling and simulation. Since becoming an employee-owned company in 1993, TSC's annual sales have grown from \$18M to over \$75M at the end of FY 08.

TSC will be successful in this project because of our track record in these fields. At present TSC knows of no other company that possess anything remotely competitive with its robust optimization capability, much less a capability so many times and in so many different applications demonstrated and proven.