

# Digital Compensation for Distortion

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## Problem Statement

The U.S. Navy and Joint Tactical Forces require high linearity, state of the art digital communications systems for ships, submarines, aircraft, space and terrestrial sites. It is the intention of the Fleet to transition all existing communications systems from the existing analog to digital technology within the next ten years. In order to efficiently implement this transition and satisfy information transmission needs, the application of digital linearization will be a necessity.

This SBIR program is developing a versatile digital signal synthesizer and integrated digital predistortion linearizer (DSS/PDL) with much greater bandwidth ( $> 500$  MHz) and performance ( $> 40$  dB of distortion correction) capability than has been achieved by earlier designs. Many new technologies within the communications industry require increased bandwidth. Information is being transmitted and received at ever increasing rates and speeds. Presently, the Navy finds itself in a position where larger amounts of information are being processed and the needs of day-to-day operations require that this information be processed at increasingly greater speeds.

## Who Can Benefit

The U.S. Navy is in the process of modernizing its radio communications with the implementation of digital technology in all RF transmission systems. These systems will be compliant with the Joint Tactical Radio System (JTRS) Program. The Navy will be teaming with the Army and Air Force to establish this new JTRS compatible infrastructure, determine specifications and provide for procurement of the required hardware and software. Boeing has been named the Prime Contractor for the amplifier components to be implemented into the JTRS Program. At this juncture, both the Air Force and the Army are also seeking distortion correction solutions through Phase I SBIR efforts to achieve basically the same goals as the Navy. All systems to be developed must be compliant with the projected JTRS technology. LTI's digital distortion correction technology will be of great value in virtually all new communications systems utilizing digital signaling for both government and commercial applications, and especially for space communication systems where weight and power efficiency is critical.

## Baseline Technology

The current practice to achieve a particular level of power amplifier linearity uses a device capable of delivering much more power than is actually needed, and then operate the amplifier at a reduced power level. Linearity is improved because only the linear portion of the transfer curve of the amplifier is used. The amount of power reduction depends on the linearity required, and each system has its own figures.

Another approach to improve linearity is the use of analog techniques. The most common ones are predistortion and feed-forward. In predistortion, the signal is distorted before it is applied to the non-linear amplifier in such a way that the transfer characteristic of the predistorter has inverse magnitude and opposite phase to that of the amplifier. The limitation of this approach is that it is very difficult to create a precise predistorter transfer characteristic using analog components to achieve a high degree of cancellation (>15 dB), and to maintain this characteristic in time. In feed-forward, the cancellation of the distortion products takes place at the output of the non-linear amplifier. An auxiliary amplifier supplies the cancellation signal. Although a higher level of cancellation can be achieved (> 20 dB), it is more complex, less efficient (< 12 %) and cannot easily be added to existing systems.

### **Technology Description**

This SBIR program is developing a versatile digital signal synthesizer and integrated digital predistortion linearizer (DSS/PDL) with much greater bandwidth (> 500 MHz) and performance (> 40 dB of distortion correction) capability than has been achieved by earlier designs. This DSS/PDL will generate complex waveforms and predistort these waveforms so as to compensate for the distortion of high power amplifiers (HPAs) and other system components. All signal generation and processing will be done digitally. The use of digital processing for predistortion (PD) allows precise complex transfer waveforms to be more easily generated. It also allows greater flexibility in tailoring and modifying these responses.

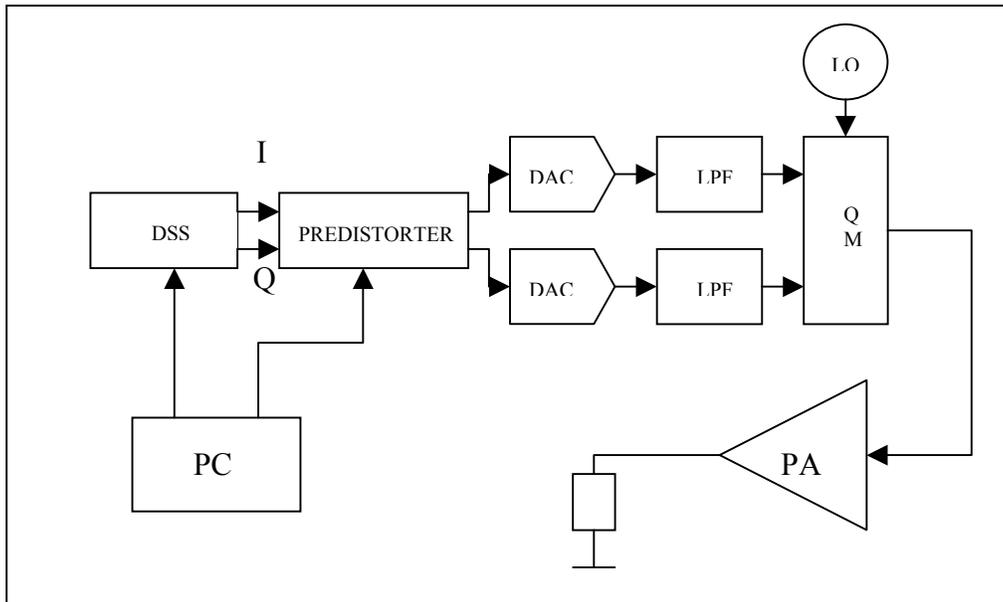
The need for digital correction of distortion is primarily a consequence of the high linearity required by modern communications systems. In the past, simple modulation schemes were utilized in digital and analog communications, making highly linear amplifiers unnecessary. Examples of such modulations are FM, FSK, GMSK, etc. These modulations have a near constant envelope. The efficiency of the amplifiers used with these modulations was high, because they could be operated at or near saturation.

Today's modern communications systems make use of more complex modulation schemes in which the peak to average power ratio is high, producing a non-constant envelope. Amplifiers made for these modulations must be highly linear in order to minimize distortion that can negatively affect adjacent channel signals and signal quality (the bit error rate). To achieve the required level of linearity, it is a common practice to operate amplifiers at a small fraction of the power capacity (or at a high power back off). The consequence of this approach is a very low efficiency (in the order of 5 to 15%). The relation between extra cost, different size, and extra heat generation versus back-off level cannot be related using a simple linear equation due to the multiple variables involved (frequency, output power, desired distortion level and device technology), but it is a continuously increasing function. Sometimes all of these facts together make a communication system impractical to implement, particularly for portable and power-consumption-sensitive applications in which the available power source is not sufficient to obtain a given output power level. Many linearization techniques have been implemented. Almost all of these systems use analog technology. With the advent of very high-speed logic devices, digital signal processing is moving closer to the antenna, and slowly replacing hard to tune and unstable analog circuits.

The integration of PDL into shipboard communications systems is estimated to be priced in the range of \$100 for a simple low power HF or VHF transmitter to more than \$10K for a complex millimeter wave HPAs and depends on bandwidth and performance requirements. Installation costs for existing systems could be substantial and would have to be performed by contractors or Navy personnel with significant experience and training. In addition, we must also contact the manufacturers of the equipment that the PDL will be integrated with in order to determine the necessary operating parameters and interfaces.

PDL hardware is not a part of the current communication platforms and is not sold as a separate item in the current government business model. The cost savings attributed to a PDL approach will accrue over the entire lifecycle of the system, because upgrades can be made via software downloads, the logistics associated with making the upgrades will be very small because no hardware will be involved and the

required personnel must be trained only to perform the downloading process. Our digital linearizer research platform is a multi-purpose system that allows us to perform virtually any required test for linearity with virtually all types of RF/microwave transmission systems. Linearization and equalization algorithms tests can be performed without any hardware changes. The hardware consists of a DSS, a PDL, an upconverter (UPC), and ancillary equipment – see Figure 1. A standard Personal Computer (PC) is used to upload the operating parameters to the system.



**Figure 1. Digital signal synthesizer/predistortion linearizer configuration**

**Digital Signal Synthesizer (DSS)** - This unit generates the baseband signals. Basically, it consists of a memory where samples of the baseband signal are stored. The unit sequentially accesses the memory, and outputs those samples. The samples are pre-calculated with a computer program, so virtually any kind of signals can be constructed. A complex lowpass baseband signal is generated with in-phase (I) and quadrature (Q) components. The quantization level is  $2^{16}$  (16 bits).

**Predistortion Linearizer** - In this unit, the complex signal from the DSS is multiplied by a complex number, which is a function of the magnitude of the input signal. This function is the predistortion described above. This signal is intended to cancel out the IMD caused by the non-linear device (power amplifier). The predistortion functions are calculated by the PC and uploaded to the PDL unit.

**Digital to Analog Converters (DAC)** - The output of the PDL unit consists of two 16 bit wide bit streams (I and Q). Two DACs are used to convert these digital signals into analog ones that can be applied to the upconverter. Lowpass filters (LPF) are implemented at the output of each DAC in order to filter out frequency components above the Nyquist frequency (one half the sampling rate). The DACs currently used feature an internal 2x interpolator that multiplies by two the system clock, LPFs the signals to avoid aliasing, and fills up the new samples with zeros. In this way, the Nyquist frequency is doubled, easing the specifications of the LPFs.

**Quadrature Modulator Upconverter (QM)** - This unit converts the baseband lowpass signal into an RF bandpass signal. An external RF generator provides the up conversion signal.

Description	Analog Predistortion	Analog Feed-Forward	Digital Predistortion
Bandwidth	Large	Narrow	Moderate
Chance of increased bandwidth in future with new technologies	Low	Low	High
Cancellation of distortion	Low	High	High
Cost	Low	Moderate	Moderate
Complexity	Low	Moderate	Moderate
Cancellation of memory effects	No	Yes	Yes
Implementation in existing systems	Easy	Difficult	Easy
Stability with time	Low	Moderate	High
Field adjustment complexity	High	Moderate	Low
Aging effects	High	Moderate	No
Implementation possible as stand alone unit	Yes	No	Yes

FEATURE (specification)	ADVANTAGE (qualitative)	BENEFIT (quantitative)
Wider Bandwidth than existing digital solutions	Extends range of possible applications for digital applications	5 – 10 X advantage over digital techniques currently in use.
Flexibility	Can be tailored to a wide range of applications	Parameterized for virtually all custom applications. Competitive systems do not exist.
Intermodulation Distortion correction	Can achieve very high C/I	> 35 dB of reduction of IMD products
Incorporates Techniques for the correction of Memory Effects	Memory effects degrade Linearizers performance in many types of amplifiers.	80% of HPAs have some form of degradation due to memory effects.

### Current State Of Development

A demonstration unit (DU) employing a multi-signal synthesizer and a Cartesian configuration with memory effect correction was initially fabricated and was tested with both a GaAs and LDMOS SSPAs and TWTAs. It provided more than a 35 dB reduction in 2-tone intermodulation distortion at 3 dB output power backoff. An example of the achieved results is shown below and the worst case performance for all amplifiers is given in the following table.

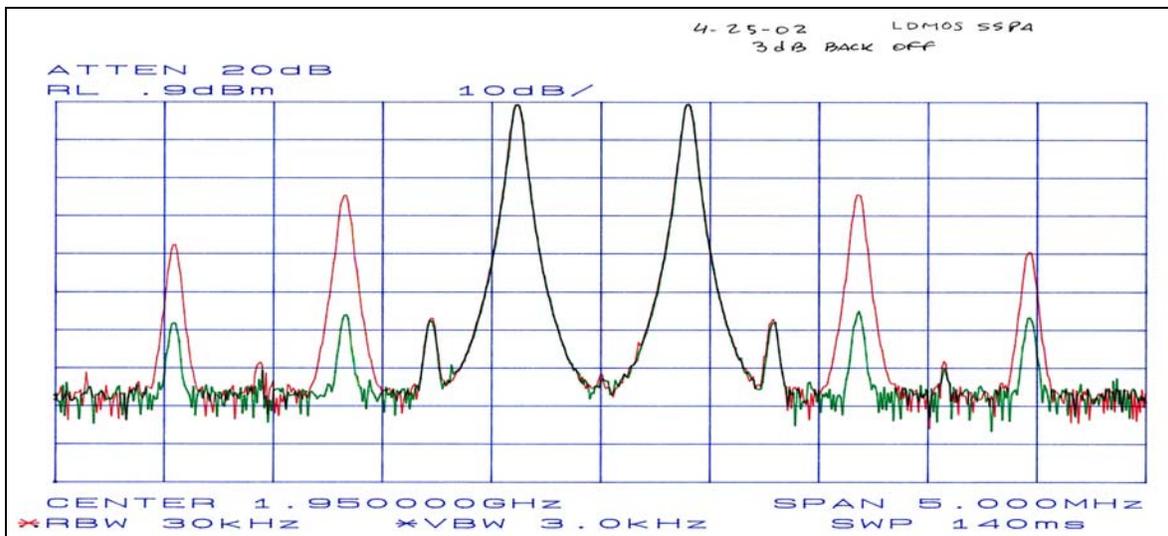


Figure 2. > 30 dB reduction in IMD at 3 dB from Saturation LDMOS SSPA.

**Table I. Worst Case Linearizer Performance at Different Output Power Backoff (OPBO).**

DB Back Off	3 <sup>rd</sup> IMD with predist.	3 <sup>rd</sup> IMD no predist.	Improvement
3	52	18	34
7	62	24	38
10	70	30	40

A second generation DU has been fabricated and is now in test. It will provide correction over a bandwidth of > 500 MHz and greater than 40 dB of distortion correction. It employs the latest and densest FPGA high-speed logic devices and our latest algorithms for faster numerical computations and thus faster transmission of information.

We have completed the following:

1. Demonstrated the ability to suppress IMD products using DSP by more than 40 dB with LDMOS, GaAsFET and bipolar SSPAs and TWTAs.
2. Fabricated a 2<sup>nd</sup> generation demonstration unit that utilizes the highest speed and densest FPGA commercially available logic devices.
3. Developed and implemented a 2<sup>nd</sup> generation unit with new algorithms that can provide up to a ten fold increase in numerical computation.
4. Produced techniques and related physical hardware for the correction of degradation in linearity due to frequency memory effects, QM imperfections and linear distortion of the signal paths.
5. Conceived and presently implementing a new more efficient method for the characterization of non-linear devices that enables the up to a five fold improvement in the speed and accuracy of correction table parameters reducing computing time by more than 50 times, and providing continuous information on the behavior of the system.

### **Technology Availability**

At this time, our TRL is 5 and close to 6. The development technology from our II SBIR program will be ready for transition in January 2004, when the TRL level will be at 7. We are currently seeking the first opportunity to evaluate this technology in the host platform in a formal test environment.

### **About The Company**

The mission of **Linearizer Technology Inc. (LTI)** is develops, manufactures, markets and supports solutions of problems involving the non-linearity of RF/microwave components and systems. We primarily address the production of proprietary linearizers for high power microwave amplifiers for the communication, broadcast and satellite markets.

**History:** Dr. Allen Katz together with several of his former students incorporated LTI in 1991. The decision to begin manufacturing linearizers was made in 1990 when a telecommunications client required a high power amplifier for use in satellite ground stations with performance that exceeded units then in the market place. In the following year, LTI introduced the first commercial wideband Linearizer. Today, thousands of LTI linearizers are in service in the USA and throughout the world. Users include virtually all TWTA and Klystron amplifier manufacturers, satellite system operators, major teleports and satellite users. LTI linearizers have also been applied in terrestrial, PCS, cellular, radar and government services.

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