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Digital Predistortion for Phased Array Radar

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Introduction

In phased array radar system, power amplifier (PA) is crucial part in transmitter. PA is inherently nonlinear device, especially operated in saturated region. The nonlinear effects give rise to degradation of performance in the system. In band and out of band distortions are significantly matter. The amplitude and phase distortion of high power amplifier are investigated and demonstrated in [1]. Nonlinear distortion in each element cause inaccurate beamforming [2].

Every PA has different amplitude and phase error which provides impairment of main beam in the direction. To improve linearity, several techniques have been introduced for the decades. Back-off was popular in PA design, but lost efficiency. Feedforward and Radio Frequency Predistortion did (RFPD) not provide accurate result in practical. Digital predistortion (DPD) is one of cost effective solution and provides good efficiency for the PA. DPD technique is now widely used in communication system. It is used only for single transmitter channel. Combined feedback signal from observation receiver channel of single hybrid transmitter provides learning model and DPD structure with memory effects [3]. Single feedback from multiple PA's output is also proposed instead of separate feedback [4]. In this case, more computation is needed than conventional DPD algorithm.

A crest factor reduction (CFR) is a popular technology to reduce peak to average power ratio (PAPR). Simple CFR technique limited desired signal to reduce peak power and filtered out-of-band distortion [5][6]. The trade-off between in-band and out-of-band may need to trade off the desired performances.

In this paper, different pulse waveforms are employed to 2.8GHz and 5.4GHz direct conversion transceiver to verify DPD performance. Each frequency band is measured with DPD and waveforms. Observational receiver channel is used to have feedback which is calibrated before transmitting. The CFR technique is used to improve sidelobe level with nonlinear frequency modulation (NLFM) waveform. Finally, antenna array simulation is provided that how AM/PM distortion affects antenna beam pattern over the beam angle. Future work will be presented.

Digital Predistortion for High Power Amplifier

The operation of high power amplifier at saturated region have strong nonlinear effects and limitation of output power. Such in-band distortion and out-of-band emission are matter in the system. In phased array radar, these distortion deteriorates sidelobe level and antenna performance. To mitigate this nonlinear distortion, DPD is a simple solution. Conventional analog predistortion did not provide sufficient linearization. Baseband DPD purely operates on digital domain and corrects error through observational channel. It is allowed to linearize distorted signal with inverse distorted signal. Calibration process is easy and simple over the frequency and temperature.

Linearization is a solution to improve linearity and efficiency of PA by diverse techniques. Conventional solution is to use analog type by radio frequency signal. Power backed off results in lower efficiency. RF predistortion is sensitive for frequency and thermal drift. Feedforward is using delay line to cancel distorted signal. It is also sensitive to drift. Recently, DPD is popular and widely used in communication system. This technology is also promising to weather radar system with phased array antenna. With calibration, look up table (LUT) is generated with I and Q which is combined with predistorter. In general, DPD is adopted memoryless and memory model. Memoryless polynomial model focuses on current output depends on current input. In memoryless model, AM/AM and AM/PM of PA are function of current input. Memory polynomial (MP) model exhibits memory effects which can be caused by bias, frequency behavior, and thermal effects. It means current output depends on not only current input, but also past input. To achieve linearized performance, DPD stores all variations in the memory through the calibration process. LUT includes these information with respect to AM/AM and AM/PM value. In this paper, DPD algorithm and calibration are not a scope. Instead, we focused on using DPD and CFR with different waveforms and measured performance by MP model For the measurement of DPD performance. The maximum output power was set over the compression point for DPD operation. LFM pulse width was 50 microsecond in this measurement. Once PA is turned on, DPD was enabled. Adjacent channel leakage ratio (ACLR) and error vector magnitude (EVM) were measured with spectrum analyzer. ACLR result is shown for both frequency band on next part. Initially, AM/AM and AM/PM curves were deteriorated at compression region without DPD. When DPD was activated, AM/AM and AM/PM curves were linearly extended and shown better EVM. Finally, sidelobe level and in band distortion were improved with DPD. We will research a phased array antenna beam pattern and subarray with DPD later. 300kW PA design will be a next step.

Linearization with CFR

CFR is one of linearization technique and typically uses with DPD. In modern digital communication system, they have high peak to average power ratio with modulation schemes. PA output has to be operated for the peak power. This technique clips off the peak signal of waveform. Reducing peak to average power ratio (PAPR) is helpful to improve out of band emission such as adjacent channel leakage ratio (ACLR). Adjusting PAPR is allow power amplifier to operate saturated region with more efficient. Possible CFR techniques are available on baseband and IF stage with clipping and filtering. However, CFR degrades error vector magnitude of in band signal within bandwidth. Therefore combining with DPD and CFR is a good option for transmitter system.

In phased array antenna system, CFR may result in inaccurate beamforming. Because CFR does not provide correction of AM/AM and AM/PM distortion in desired signal. PAPR need to compromise antenna performance with respect to in band distortion and out of band emission. The sidelobe level of antenna can be reduced with CFR in pulse waveform. In this paper, we used a linear frequency modulation (LFM) waveform and a NLFM with DPD and CFR technique. Spectral regrowth is a significant part in PA design. It can be attributed to neighbor channel and FCC regulation. Inside phased array antenna system, array factor, directivity, half power beamwidth, sidelobe level and data quality would be degraded. Poorer nonlinearity results in lower range of spurious free dynamic range (SFDR) and minimum detectable sensitivity (MDS). Extended linearity and reducing out of band emission is important characteristics in phased array antenna system. CFR technique can be a good option to linearize PA and reduce out of band emission.

Measured PA Output with DPD and CFR

The DPD and CFR are available on the AD9375. Memory polynomial (MP) model for DPD on this chipset is enabled to achieve high efficiency and high adjacent channel leakage ratio within frequency band. This model has a feedback signal from transmitter output and predistorts baseband signal from it to linearize RF signal. Finally DPD engine generates and updates LUT and react to quick changes in transmitter waveform. For the measurement, both LFM and NLFM pulse waveforms are used per frequency band. Frequency bandwidth is 5 MHz. Pulse width is 50 micro second. The SKY66297 PA is used for 2.8 GHz and HMC415 PA is used for 5.4 GHz. They are directly derived by transceiver which is direct conversion. Direct conversion does not need intermediate frequency stage in the chain. Once PA is operated in saturated region, the intermodulated products are shown on frequency spectrum then DPD is activated. Immediately AM/AM and AM/PM were extended in Fig.1.

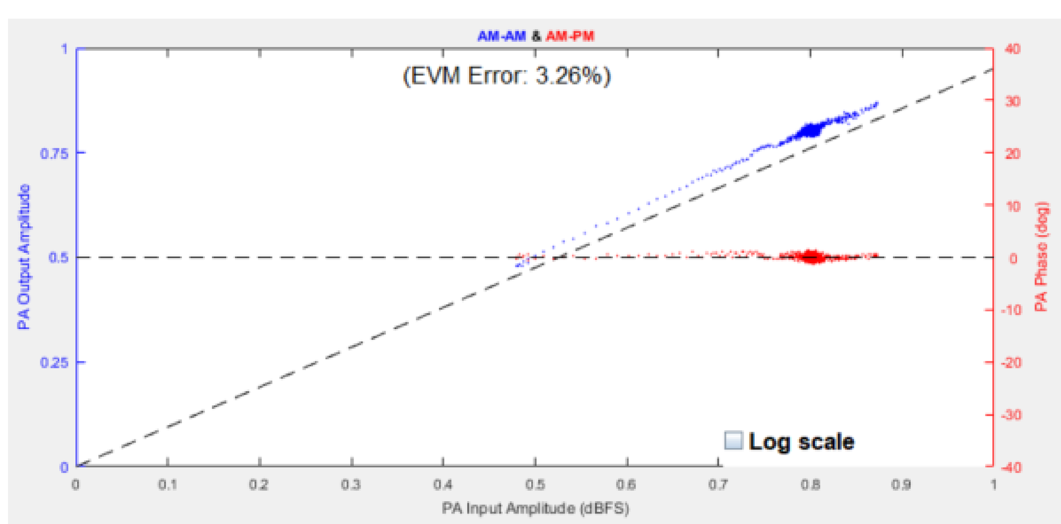
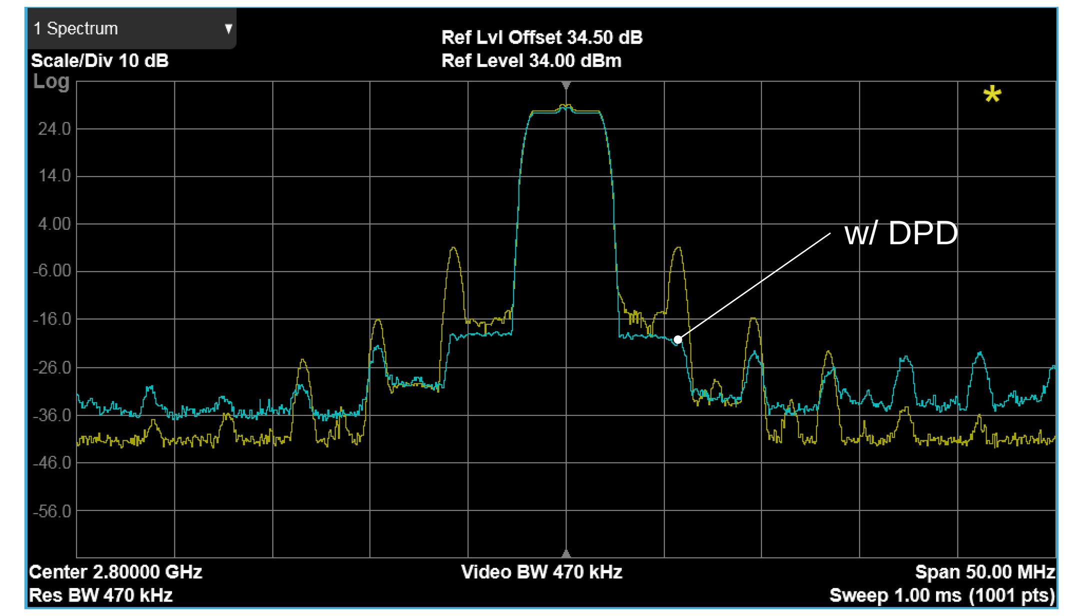


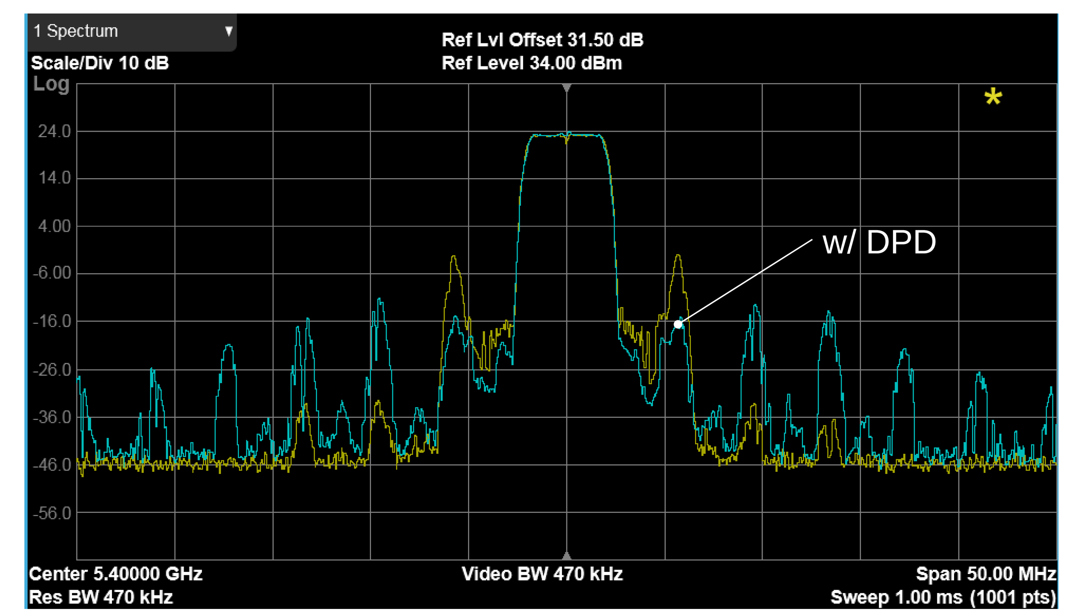
Fig.1. AM/AM and AM/PM response of 2.8GHz PA output for LFM waveform

In Fig. 2, side band frequency is reduced than original transmitter output with same output power. However, signal out of frequency band is worse than original because DPD can work for only dedicated frequency band that is 2 or 3 times of frequency band of waveform. In this case, we had 19 dB reduction for 2.8 GHz and 14 dB reduction for 5.4 GHz for first product of sidelobe. Broadband matching network of transceiver is better for low frequency band.

During DPD and CFR adaptation to LFM and NLFM waveform, DPD did not provide a linearization benefit to NLFM. NLFM already reduces sidelobe level with continuous modulation waveform and NLFM gives an amplitude tapering to the transmitted signal. In Fig. 2, CFR was changed with different level to verify sidelobe level and measured power spectrum on the frequency band. In Fig. 3(a), PA output of 2.8GHz was measured with 5, 6.5, and 7.5dB CFR. CFR with 7.5dB was shown reduced sidelobe level. The operation area of average power was back off from compression point. In this case, power efficiency may be a concern. In Fig. 3(b), sidelobe level was not reduced dramatically. But it was still reduced sidelobe level in 5.4GHz. Both test results are used NLFM waveform to see linearity impacts.

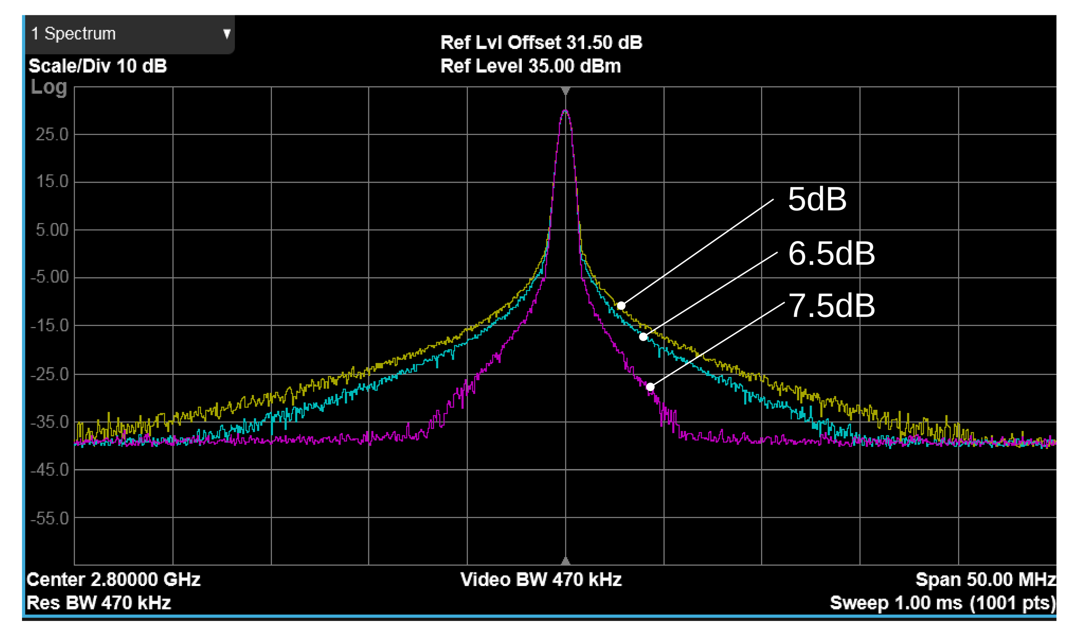


(a)

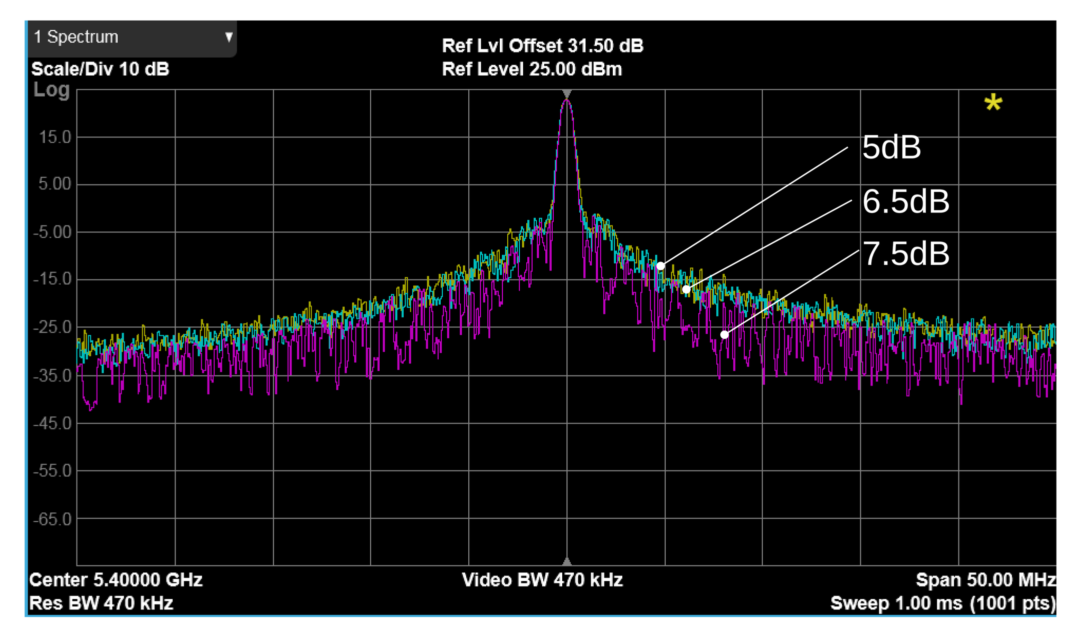


(b)

Fig.2. Linear Frequency Modulated waveform (a) PA output of 2.8GHz with DPD, (b) PA output of 5.4GHz with DPD



(a)

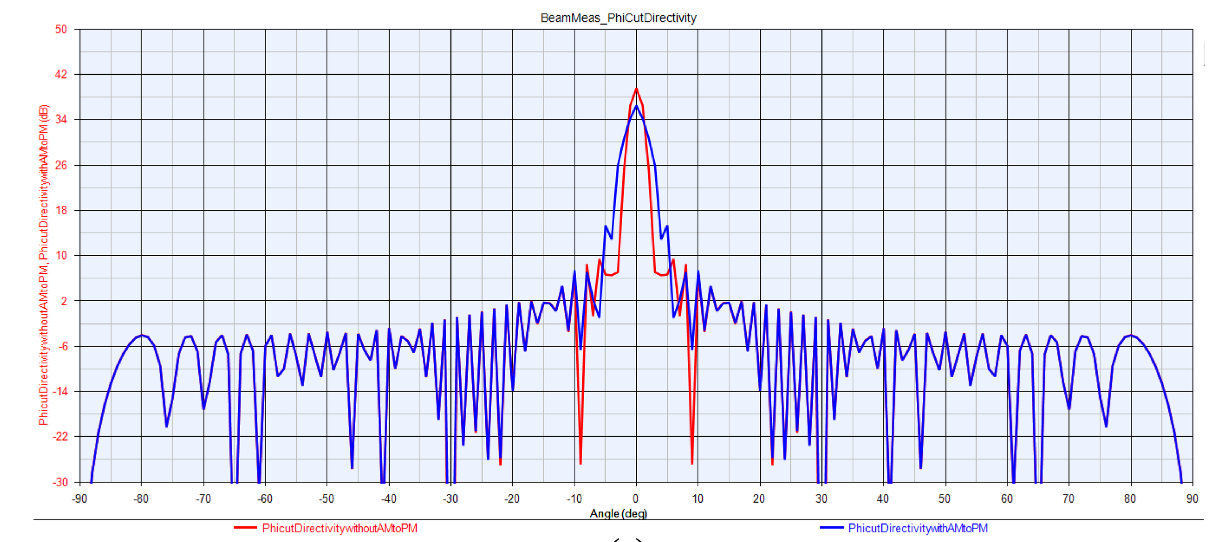


(b)

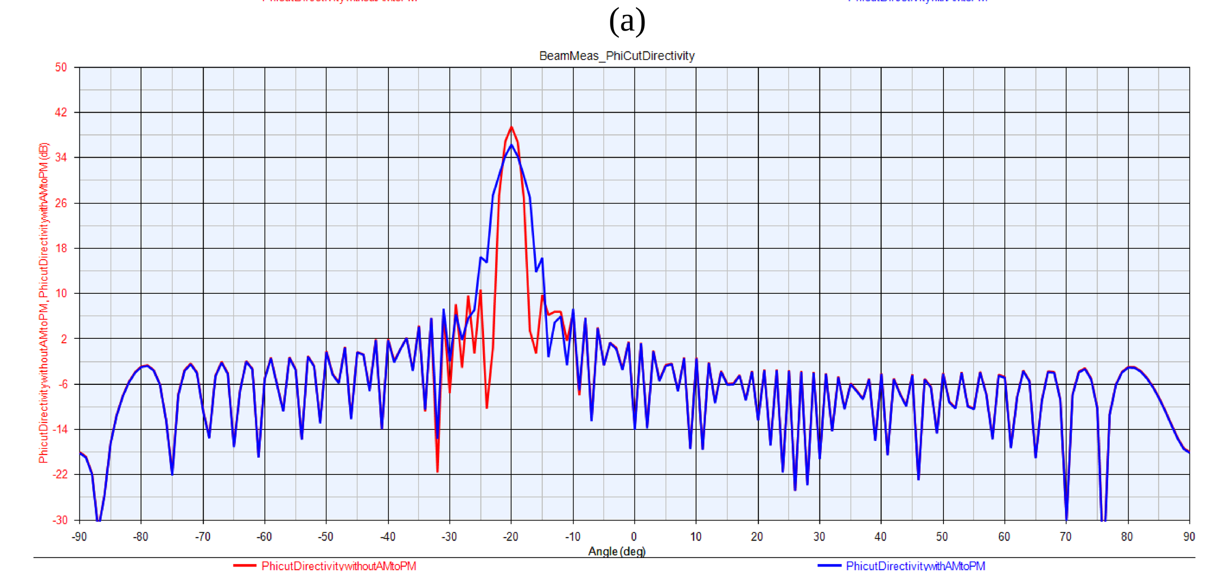
Fig.3. Non-Linear Frequency Modulated waveform (a) PA output of 2.8GHz with CFR (b) PA output of 5.4GHz with CFR

Antenna Beamforming Simulation

In simulation, AM/PM effects was investigated in phased array antenna system. Hybrid architecture with phase shifter and digital controlled attenuator is used for simulation. 64 x 64 rectangular antenna array pattern is used with Taylor window. Each antenna spaced half wavelength. In Fig 4(a), antenna directivity without AM/PM distortion is 3dB higher than with AM/PM distortion. First null is deeper and beamwidth is narrower than with distortion. In Fig 4(b), antenna directivity is more degraded at this angle. Although antenna beam angle is changed, HPBW is maintained well without beam widening. AM/PM distortion results in beam degradation over all angles. Increased sidelobe level and wider beam are critical to weather radar. It will return ZDR and LDR bias for dual polarization antenna.



(a)



(b)

Fig.4. Directivity of Phased Array Antenna is shown with AM/PM distortion at (a) 0 deg and (b) 20 deg.

Conclusion and Future Work

In this research, we adopted DPD and CFR technique to the radar pulse waveforms. Each waveform does work with different technology. With DPD and CFR represented good sidelobe level reduction and out of band emission. According to the simulation results, linearization technique such as DPD and CFR gives a benefit to the phased array antenna system to keep beam pattern in radar. It brings a conclusion that distorted signal makes poor radar performance. We will develop high isolation dual polarization antenna and adopt DPD and CFR. 300kW power level solid state power amplifier for S-band and 30kW for C-band are considering in transmitter. Longer pulse is available in this solution. This development can be a common platform for L to C band phased array radar system.

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