Digital Predistortion for THz RF Power Amplifier with 16-APSK Modulation in Non-Terrestrial-Networks

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SUMMARY The ultra-high-speed feeder link system in Non-Terrestrial Network (NTN) being considered as a critical challenge for Beyond 5G. In this paper, firstly the transmission path is developed for feeder link systems that connected NTN to the ground. Gray coded 16-ary Amplitude-Phase-Shift keying (16-APSKgc3) modulation scheme is proposed for a triple-multiplier power amplifier (TMPA). The nonlinearity impact and characteristics of radio frequency (RF) power amplifiers are explored in high frequency the terahertz (THz) band (100 GHz band). Digital predistortion (DPD) methodology is deployed in the proposed TMPA model for compensation of the nonlinear distortion. The DPD coefficients of the power amplifier model have been extracted based on the nonlinear characteristics of amplifier and those of DPD have been identified by applying an indirect learning structure. Finally, the performance evaluation of proposed transmission model has been conducted by constellation of compensated signals and error vector magnitude (EVM) simulation.
keywords: *digital predistortion, non-terrestrial-networks, terahertz, 5G system and beyond.*

1. Introduction

One of the main goals of beyond 5G is non-terrestrial wireless communication technology applying terahertz band frequency [1]. The transmission scheme using the THz band (100 GHz band) was proposed as a new feeder link system in relatively bad weather conditions and achieving high speed and high capacity in [2]. NTN intends to support high data rate communications among aerial platforms, such as such as Low Earth Orbit (LEO) satellites and High-Altitude Platform System (HAPS), for seamless connectivity [3,4]. Unfortunately, the great impact of atmospheric attenuation because of weather effects and disaster effects makes degradation of signal qualities in NTN communication. On the other hands, the imperfect on board devices, such as power amplifier (PA) non-linearity and non-linear phase noise, degrade communication quality of NTN. In beyond 5G, the nonlinearity impact of power amplifier has remained as a critical issue. The trade-off between the nonlinearity and efficiency-enhancement of RF power amplifiers (PAs) has been a critical challenge in the latest generations of communication systems, such as NTN in beyond 5G. DPD is one of the most suitable compensation techniques for nonlinearity distortion at the transmitter [4].
In this work, DPD are consider as one of key solutions to deploy in feeder link NTN for impairment of nonlinearity and signal quality. The NTN is considered in stratosphere that we proposed in the previous work [5]. HAPS, low earth orbit satellites, and aircraft utilized NTN as communication platforms. The proposed system deployed 100 GHz band and 2 GHz bandwidth due to the system requirements. We assumed that low earth orbit satellites have an altitude of about 20km with a ground station.
In this paper, NTN feeder link transmission model based on the combination of DPD and 16-APSKgc3 with a triple-multiplier power amplifier (TMPA) is proposed. A DPD is designed as a memoryless compensation method for improving linearity of TMPA using gray coded modulation scheme. The DPD coefficient estimation model is designed by observing the characteristics of TMPA. The characteristics of PA input, PA output and phase in degree, [PA_{in}, PA_{out}, $\Delta\Phi$], are specified by the Table property [6]. The PA's nonlinearities are usually modeled as the AM/AM and AM/PM distortions. On the other hand, the evaluation results of DPD based proposed transmission system are approved by signal constellation. The simulation results indicated that the performance of proposed 16-APSKgc3 based TMPA model in the form of improving error vector magnitude (EVM).

2. Proposed Transmission System

In this section, the proposed transmission system is described in Fig.1.

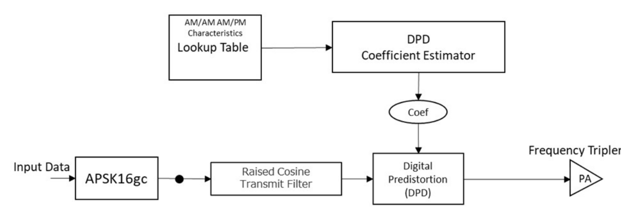

Fig.1 Proposed Transmission System for the DPD compensation with 16-APSKgc3 and TMPA

The proposed system is considered for 100 GHz band feeder link system in NTN by applying DPD. Baseband part focus on 16-APSKgc3 modulation, raised cosine filter (RCF) and DPD. In analog part, TMPA are implemented. Since 16-APSK can effectively reduce the peak-to-average power ratio (PAPR) than 16QAM resulting in improved BER, 16-APSK is chosen to apply in this system by designing the constellation and bit allocation. To maintain the desired shape of pulse, the pulse shaping is applied to the modulated signals by filtering the modulated signal using RCF. And the signals are up-sample for oversampling factor by applying the RCF. Based on the memory polynomial model, DPD has performed by observing the nonlinear characteristic of PA based on the lookup table. The indirect learning DPD model

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is applied to pre-distort the filtered signals. The coefficient of PA is estimated by using least square algorithm. To get the high-power amplification, the PA has designed as memoryless nonlinear amplifier model by applying the pre-defined [Pin(dBm), Pout(dBm), ΔΦ], of PA.
In RF device, the proposed TMPA is implemented as a 3rd order harmonic band pass filter and a linear amplifier, and the amplified signals are produced to radiate from the transmission antenna. Finally, the compensated amplified signals are compared with modulated signals to evaluate the system performance in term of EVM.

3. Designing Proposed 16APSkgc3 for Tripler Multiplier Power Amplifier Model

In this section, the proposed 16-APSKgc3 modulation and a TMPA are described. The proposed 16-APSKgc3 modulation scheme is designed by using gray-coding technique based on 16-APSK multilevel modulation scheme. The phase shift is 1/3 of normal 16-APSK. In a Tripler-Multiplier, the output amplitude is produced by cube root of normal power amplifier. The mathematical formulation of 16-APSKgc3 modulation [5] is expressed in (1).

$$x = \sqrt[3]{A} e^{-j\frac{\emptyset}{36}\pi} \quad (1)$$

Where x is modulation output, A=0.5 and ϕ=±3,8 or A=3,9 and ϕ=±1,3,5,7,9,11. The gray coded mapping of 16-APSKgc3 and TMPA are described in both the amplitude and phase dimensions in Fig.2.

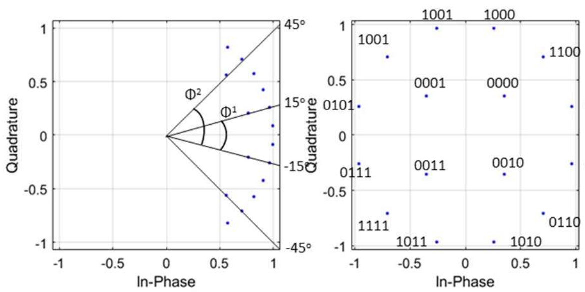


Fig.2 Constellation of (a)16-APSKgc and (b)16-APSK

4. Designing Digital Predistortion (DPD) model and DPD coefficient Estimation

The DPD is applied to compensate the nonlinearity output signal of PA by predistortion of the input signals of PA [7]. The basic predistortion model [8] is shown in Fig.3.

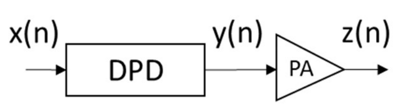


Fig.3 Basic Predistortion Model

DPD distorts the input signal x(n) to output distorted signal y(n) to compensate for nonlinearity of PA. $F_{dpd}(x(n))$ is defined as nonlinear distortion function. The formulation of output distorted signal y(n) is expressed in (2) and (3).

$$y(n) = F_{dpd}(x(n)) \quad (2)$$

$$y(n) = \sum_{n=0}^{N-1} \sum_{m=1}^{M} coef_{nm} * x(n) * |x(n)|^N \quad (3)$$

where $coef_{mn}$(n = 0, 1, . . ., N) is the complex coefficient of n^{th} nonlinearity, N is the order of nonlinearity and (m = 0, 1, . . ., M) is the complex coefficient of m^{th} memory effect, M is memory depth.
To find the predistortion function F_{dpd}, indirect learning methodology is used for estimating coefficient of PA to fine the nonlinear function by observing the characteristics of amplitude (AM/AM distortion) and twist phase (AM/PM distortion). The coefficient of PA can be identified by observing input and output of PA as follow in (4).

$$coef = F_{coef} (PA_{in}, PA_{out}) \quad (4)$$

Where F_{coef} is the coefficient estimation function. To provide the estimation of $coef$, inverse mapping of the PA is conducted by normalizing the amplified signal z(n) with desired amplitude gain, G [9] as shown in (5).

$$z(n)^{-1} = z(n)/G \quad (5)$$

Least square fit algorithm estimates the required coefficient by applying the DPD to distort x(n) to produce z(n).

4.1 Raised Cosine Filtering (RCF)

Nonlinearity cause the intersymbol interference (ISI) and memory effects leads to transients in the signal amplitude of the PA output. For rejection of the ISI, RCF support to maintain the desired shape of pulse and each pulse within a coherent processing interval (CPI) achieves the same amplitude [9]. Therefore, DPD can fetch the desired shape of the input signal to produce the distorted output signal to input to PA. In this work, the modulated data stream is upsampled and filtered at the transmitter using the RCF to reduce ISI.

5. Simulation and Analysis

5.1 Simulation Conditions

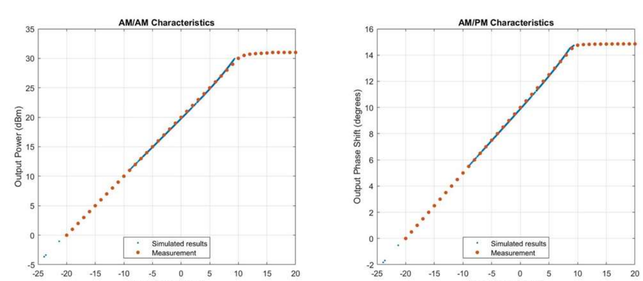


Fig.4 (a)AM/AM and (b)AM/PM Distortion Characteristics of TMPA

The constellation analysis of transmission DPD compensation have performed by simulation. The roll-off factor is considered for pulse shaping. The TMPA outputs the cubit characteristics without using a band pass filter. Therefore, table-based PA is setup based on AM/AM and

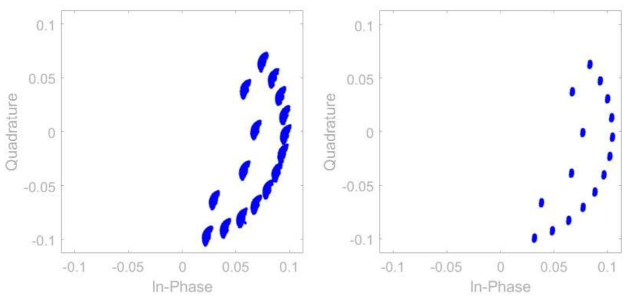
AM/PM distortion for DPD coefficient estimation. The PA characteristics are measured by the ideal PA characteristics as shown in Fig.4. Pin is [0～+30] dBm and Pout is [-5～+30] dBm. The input backoff is setup to 8 dB to scale up the input signal to the required output power of PA. The output phase shift is [-2～+15] degree. The use case of deployment of coefficient complex values in DPD is described in Table 1. The length of memory depth, M, is 1 and the length of liner order, N, is 3.

Table 1. The Explanation of Deployment of coefficient in DPD

	N, Linear Order		
M, Memory Depth	1.08663163855306-9.34801632682491e-18i	-1.09385542607380 + 3.69693386760300e-17i	4.26394503560232 - 5.86233174713736e-17i

5.2 EVM Evaluation Results

In this section, the evaluation of EVM and signal constellation of DPD simulation in transmission process are described. We expressed the constellation of before DPD and after DPD in Fig.5 with roll-off factor 0.25. As shown in figure, the signal constellation was improved in distortion after compensation of DPD.



(a) (b)

Fig.5 Constellation of Filter Output and DPD Output, (a)Input Signal of DPD, x(n) and (B) Output signal of DPD, y(n)

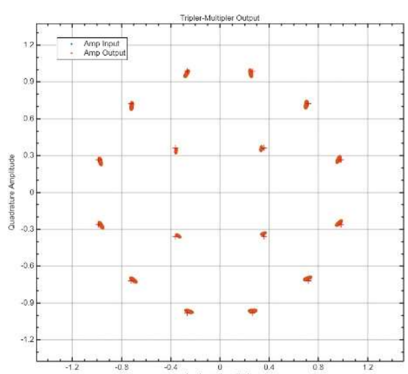


Fig.6 Constellation and EVM Evaluation, z(n)

Evaluation of EVM is described with EVM root mean square error values in the Fig.6. The proposed model can reduce RMS EVM from 4.38% to 2.20% with DPD compensations compared with Non-DPD model.

6. Conclusion

In this work, firstly 16-APSKgc modulation and TMPA are proposed. Furthermore, DPD compensation model was designed for nonlinearity of TMPA and estimated the DPD coefficient. The DPD was implemented in the proposed NTN feeder link transmission model. The performance of DPD compensations for the proposed transmission model is evaluated with constellation and EVM results. Finally, we validated the best performance of 16-APSKgc3 modulation and TMPA effectively improved the signal constellation by DPD compensation. The evaluated results approved that the proposed system could support a good transmission model with DPD compensation for the nonlinearity of PA in feeder link NTN.

Acknowledgments

This paper contains the results of a research project commissioned by the National Institute of Information and Communications Technology (NICT), "Beyond 5G Research and Development Promotion Project", which is a research and development of wireless communication technology for realizing Beyond 5G ultra-high-speed and large-capacity communication using the terahertz band (task number 003).

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