Power Amplifiers in Cable Access Network

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***Abstract* — Cable access network as a kind of wireline communication is very different from ubiquitous wireless counterparts. In the newest standard i.e., Data-Over-Cable System Interface Specification (DOCSIS) version 3.1, large bandwidth (5*192MHz), orthogonal frequency division multiplexing (OFDM) and higher-order QAM modulation (4096-QAM) are simultaneously used for >10 Gbps downstream (DS) data rate, which poses significant challenges in the design of power amplifiers (PAs) in Cable network, especially high-efficiency requirement. This paper reviews the PA realization in Cable industry and the possibility of two common efficiency techniques including load- and supply- modulations to be used in Cable DS PA. Digital pre-distortion (DPD) as a famous linearization technique can be applied to Cable PA with the availability of advanced ADC & DAC, which is proven in this paper.**

***Index Terms* — GaN, cable television (CATV), data over cable service interface specification (DOCSIS), power amplifiers (PAs).**

I. INTRODUCTION

To meet the increasing requirements of data rate, same as wireless access (WiFi, LTE, Bluetooth, and etc.), spectrum extending is also along with the evolution of Data-Over-Cable System Interface Specification (DOCSIS) standard, such as downstream (DS) frequency bands extending from 870 MHz of DOCSIS 1.0 to 1.2/1.8 GHz of DOCSIS 3.1 and upstream (US) frequency bands extending from 42 MHz of DOCSIS 1.0 to 204 MHz of DOCSIS 3.1 [1]. For higher spectrum efficiency, orthogonal frequency division multiplexing (OFDM) and higher order QAM modulation (>256-QAM) are used in DOCSIS 3.1, which resulting in larger peak-to-average-power ratio (PAPR) [2]. Therefore, the design of power amplifier (PA) used in Cable access network is very challenging, needing to meet the wide bandwidth, strict linearity, good robustness requirements, simultaneously. Pull-push architecture is widely used in Cable PAs for the intrinsic wide bandwidth and lower even harmonic distortions, furthermore, Class-A bias condition is mainly adopted for the best linearity performance, but leads to very low efficiency, which is a big problem in distributed Cable access network.

In section II-III of this paper, we will introduce the distributed Cable network and then summarize the newest Cable PAs in industry. Secondly, we discuss the possibility of efficiency enhancement techniques in Cable PA. Thirdly, digital pre-distortion (DPD) is described, which is being researched in Cable PA for better linearity and lower power consumption. Finally, we make a conclusion.

II. CABLE ACCESS NETWORK

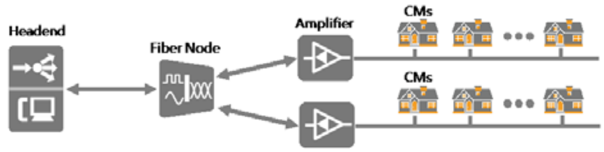

Fig. 1. Typical distributed access cable network.

Typical distributed access architecture (DAA) is shown in Fig. 1, which consists of headend, fiber node, taps, trunk amplifier in the distribution cable lines, and Cable Modems (CMs) in home. As fiber deeper evolves, cable operators also change their existing hybrid fiber-coaxial (HFC) networks from centralized access architecture (CAA) to DAA to save the power and space in headend, but sacrificing the power consumption in fiber node. Fiber node typically serves hundreds of CMs, which is similar with the Base Station (BS) in handset communication systems, leading to high output power and efficiency requirements of PAs in fiber node. Furthermore, the larger bandwidth of Cable signal poses more challenges on PAs than the wireless BS ones.

III. PAS IN CABLE INDUSTRY

In DOCSIS 3.1 era, there are three famous players of Cable PA in industry, i.e., Qorvo, Skyworks (acquiring Anadigics), ADI (acquiring Onetree). In order to output high power with ~1GHz signal bandwidth, GaN technology is mainly used in the final stage PA of the fiber node DS link by the above mentioned three companies. GaAs is used in low output power condition, such as driver stage PAs and Si used in the US link PA.

Take RFPD3580 as a final stage DS PA from Qorvo as an example and the functional block diagram and package (SOT-115J) of RFPD3580 [3] are shown in Fig.2. RFPD3580 consists of input & output balun, two-path power transistors to composite pull-push architecture. The power transistors are cascaded with GaAs pHEMT die and GaN HEMT die, i.e. a hybrid solution. SOT-115J package with thermal sink is very suitable for high power PA module.

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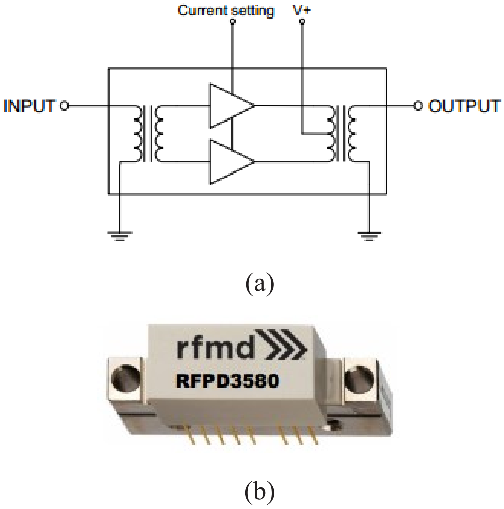

(a)

(b)

Fig. 2. (a) Functional block diagram of RFPD3580, (b) SOT-115J package of RFPD3580.

IV. EFFICIENCY ENHANCEMENT

In the US link of fiber node, the signal bandwidth is just 200MHz and signal power to be handled is low, so the power consumption in US PA is not a big problem. On the contrary, the peak output power of the final stage PA in the DS link usually requires above 10W, because of >14dB PAPR, so the average efficiency of DS PA is extremely low, less than 4% [2]. In this section, we will discuss two kinds of efficiency enhancement techniques, i.e., load modulation & supply modulation, to be used in Cable DS PA for greener communications.

A. Load-Modulation

Doherty is the most famous load-modulation technique to improve the power back-off efficiency, widely used in handset base stations, microwave link, digital TV broadcast (e.g. DVB-T1/T2). Traditional Doherty PA is inherently narrow band, mainly limited by the λ/4 transmission line and offset lines. Although a number of bandwidth extension techniques for Doherty PA are proposed [4], but to meet >130% fractional bandwidth of Cable DS PA is almost impossible.

Chireix Outphasing is another kind of load modulation technique, also with narrow band characteristic, limited by reactive compensation components in the output combiner network. The bandwidth expansion in the traditional Outphasing system further constrains the application of this technique in wideband signal communication. Although mixed-mode Outphaisng can reduce the bandwidth expansion [5], it’s still unforeseeable to support Cable DS signal.

In theory, Load Modulated Balanced Amplifier (LMBA) [6] as a new technique proposed by S. C. Cripps can easily support large RF wideband, making >130% fractional bandwidth possible by deeper research work, whereas how to use a proper control signal to modulate such wideband signal is still a challenging problem.

In conclusion, although above three kinds of load modulation techniques could be wideband to support Cable DS frequency bands, ~1GHz signal bandwidth requiring high linearity would make these techniques very challenging.

B. Supply-Modulation

Envelope tracking (ET) is already widely used in 4G handsets to decrease power consumption of PA for longer battery time. The major problem in ET system is the bandwidth expansion in envelope amplifier path, leading to faster switching converter, which is even worse in large bandwidth system, such as 200MHz in 5G, ~1GHz in DOCSIS 3.1. Therefore, in the algorithm level, reduced bandwidth power supply waveforms or slow-envelope is used to restrict the expansion effect [7]. In the hardware level, various wideband supply modulator architectures are presented recently [8-9], including new circuit techniques and advanced semiconductor processes (e.g. GaN). For example, [8] proposed a novel high-speed current-mode instantaneous supply switching (ISS) technique to follow the instantaneous amplitude of a broadband signal, proven to be applied to Cable DS/US PA, but higher output power should be reached in Cable DS link.

V. DPD IN CABLE

As described above, more new solutions on load-modulation and supply-modulation should be proposed to support the ~1GHz signal bandwidth in DOCSIS 3.1. Nowadays, one more practical way is to change the bias condition of Cable PA from Class-A to Class-AB for high efficiency, and then use DPD to compensate the non-linearity induced by the reduced conduction angle. Thanks to the availability of very high sample rate DACs (e.g. AD916x & AD917x from ADI) and ADCs (e.g. AD9208 from ADI, ADC32RF4x from TI), ultra-wideband DPD becomes possible for Cable PA [2].

Very different from the wireless communication where the RF carrier frequency is much higher than the signal bandwidth, such as 3.84MHz bandwidth at 1.98GHz carrier in WCDMA, 160MHz at 5GHz in 802.11ac, i.e., small fractional bandwidth, the RF carrier frequency is same as signal bandwidth resulting in >130% fractional bandwidth in Cable DOCSIS 3.1 DS link. Therefore, except the odd harmonics and inter-modulation distortions (IMDs), the even harmonics and IMDs are also located inner the signal bands, leading to more complex DPD algorithm than wireless counterparts.

Memory effects are inherent in PA and become worse under wideband signal condition, which can be indicated by the asymmetry of IMD3s. Fig.3 shows the two-tone signal measurement results of RFPD3580 biased at 34V & 530mA, with 31 dBm power per tone. Obvious asymmetry between IMD3_H and IMD3_L can be seen and become larger as two-tone spacing increases. Consequently, DPD with short- and medium- term memory effects is necessary to linearize Cable PA and long-term memory effects are also considered to be included [10].

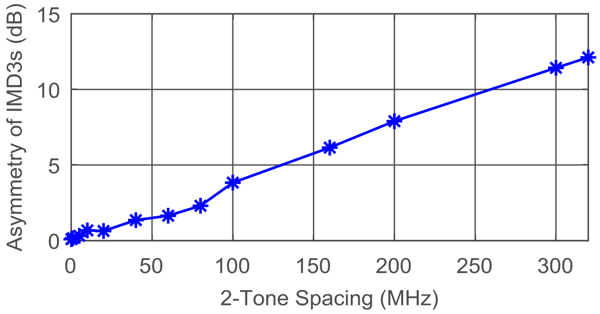

Fig. 3. Two-tone measurement results of RFPD3580.

We design a proper DPD algorithm to compensate the non-linearity of RFPD3580 with ~0.8GHz wideband Cable input signal. The average output channel power of RFPD3580 is set to 29dBm. The measured AM-AM and spectrum curves with and without DPD are shown in Fig.4 and Fig.5, respectively. We can see that memory effects are obviously reduced and in-band distortions are lower after DPD. Calculated normalized mean square error (NMSE) is improved from -40.5dB to -46dB.

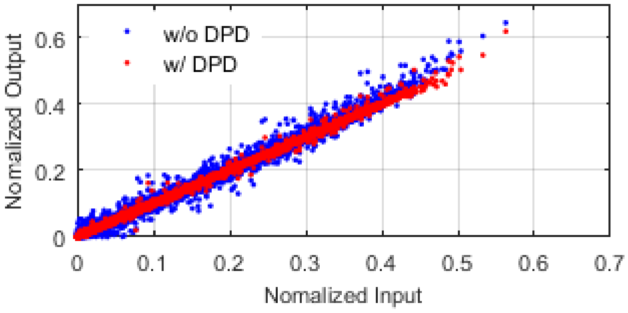

Fig. 4. Measured AM-AM curves with and without DPD.

VI. CONCLUSION

In Cable access network, low efficiency of PA is very troublesome for high output power requirement, even worse in the case of ultra wideband signal standardized in DOCSIS 3.1. DPD is proven to be used to improve the linearity of Cable PA with more margin for higher efficiency.

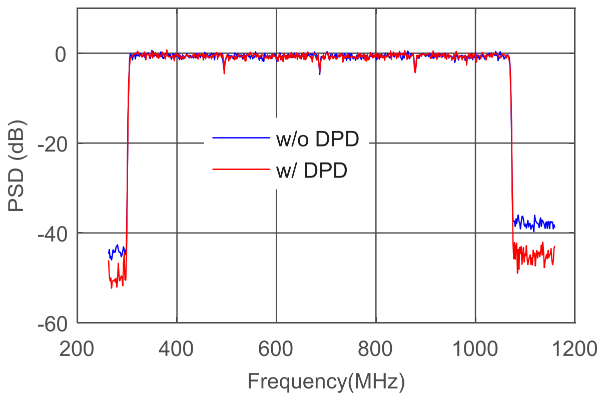

Fig. 5. DPD measured results using wideband Cable signal.

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