A 28 GHz Linear Envelope Tracking-Power Amplifier for LMDS Applications

Parisa Momen Roodaki, Fatemeh Taghian, Abbas Mohammadi, Abdolali Abdipour
Microwave/mmw and Wireless Communications research Lab. Electrical Engineering dept.
Amirkabir University of Technology Tehran, Iran
parisa.roodaki@yahoo.com, f.taghian@aut.ac.ir, abm125@aut.ac.ir, and abdipour@aut.ac.ir

***Abstract*-This paper presents the design and simulation of an envelope tracking power amplifier (ET-PA) for 28 GHz LMDS applications. A linearization algorithm is also employed in digital domain in order to reduce the distortion of the system. Simulation shows that the proposed ET-PA delivers 19dBm output power with 21dB linear gain. Power added efficiency of this amplifier is more than 41% which shows about 15 percent efficiency enhancement compared to conventional LMDS PAs.**

Keywords-envelope tracking; power amplifier; millimeter wave; LMDS; linearization; digital predistortion

I. INTRODUCTION

The Local Multi-point Distribution Service (LMDS) system is a broadband wireless point to multipoint communication system that commonly operates on microwave frequencies across the 26 GHz and 29 GHz bands. This is an interesting band for providing two-way voice, data, Internet and video services.

Power amplifier (PA) is the most power consuming element in transmitter. High efficient PA design plays a significant role in determining the overall system power consumption, size, and battery lifetime. Several efficiency enhancement techniques such as envelope elimination and restoration (EER), envelope tracking (ET) and Doherty have been developed in lower microwave frequency bands [1-3] but this subject has not paid much attention in mmw frequencies. The efficiency of conventional mmw power amplifiers is less than 35 percent in the best case [4-7]. There is therefore a need to investigate some design methods to improve efficiency for mmw PAs.

In contrast to Doherty technique which uses two separated PAs, envelope tracking technique uses only one PA with a low cost envelope amplifier. This paper details the design of highly efficient single stage PA using an ET technique to meet the efficiency requirement for LMDS signals. Efficiency enhancement techniques usually introduce a new source of distortion to the system so they need a linearization algorithm to reduce nonlinearity effects of PA. As a result we employed a digital predistiortion algorithm to the overall envelope tracking system. Simulation results of ET-PA after employing linearization algorithm show that this system can work correctly as a high efficient and linear PA.

This paper presents as follows; in section II designing of a 28GHz envelope tracking power amplifier is completely described along with simulation results. In section III algorithm is discussed and linear characteristic of final envelope tracking PA is shown. At the end, in section IV we set the conclusion.

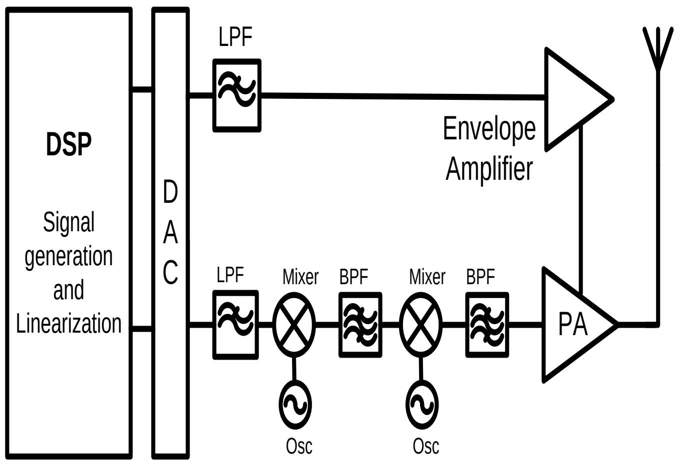

Figure 1 block diagram of lmds envelope tracking transmitter

II. ENVELOP TRACKING POWER AMPLIFER DESIGN

In the envelope tracking technique, the supply voltage of the PA is dynamically changed by the amplified envelope signal through an envelope amplifier. As a consequence, PA works near saturation region for all instantaneous input powers. Since PA releases the best efficiency in the saturation region, the efficiency of PA increases. Traditional ET amplifiers used a switch mode PA and a supply modulation circuit where the supply voltage tracked the input envelope. In current ET systems, the amplitude and phase signals are generated directly in the baseband domain and up-converted to RF [8-11].

Fig. 1 shows the block diagram of LMDS envelope tracking transmitter. Envelope of base-band signal which is generated in the digital domain is fed into the envelope amplifier after passing a digital to analog converter (DAC). In this paper the envelope of a 10 MHz QPSK waveform is used. The complex RF signal is applied to the PA after two stages of up-conversion. These two steps are used for providing adequate power levels into the millimeter wave mixers to drive the PA [12].

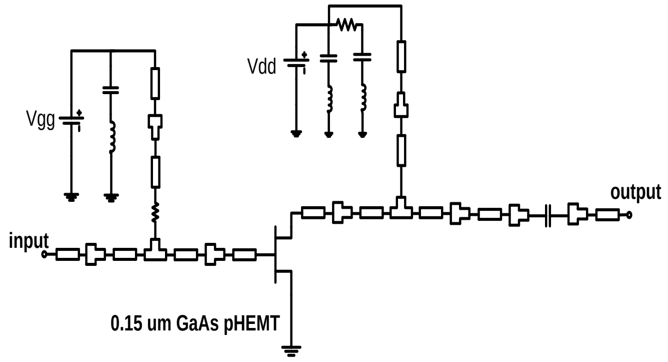

Figure 2 shematic of single stage GaAs pHEMT PA at 28 GHz

A. 28 GHz Power Amplifier Design

A 100 mW class AB PA was designed using 0.15 µm GaAs pHEMT process technology. The HEMT device was used because it exhibits excellent power performance, which together with good linearity and efficiency makes it suitable for power applications. The designed amplifier is shown in Fig. 2. Since the gain of this amplifier was adequate, a single stage structure was used rather than multi stage arrangements which decrease the overall efficiency and enhance complexity.

Simulation results of this amplifier under continues wave 28 GHz input signal and fixed drain bias of 6 V show maximum power added efficiency (PAE) of 30% and maximum output power (Pout) about 20 dBm with about 20 dB gain. Fig. 3 shows the simulated PAE, Gain and Pout as a function of input power. This amplifier shows quasi-linear gain until the transistor saturates.

B. Envelope Amplifier Design

ET system efficiency is roughly defined as product of PA and Envelope amplifier efficiencies. So efficiency of envelope amplifier should be as high as possible.

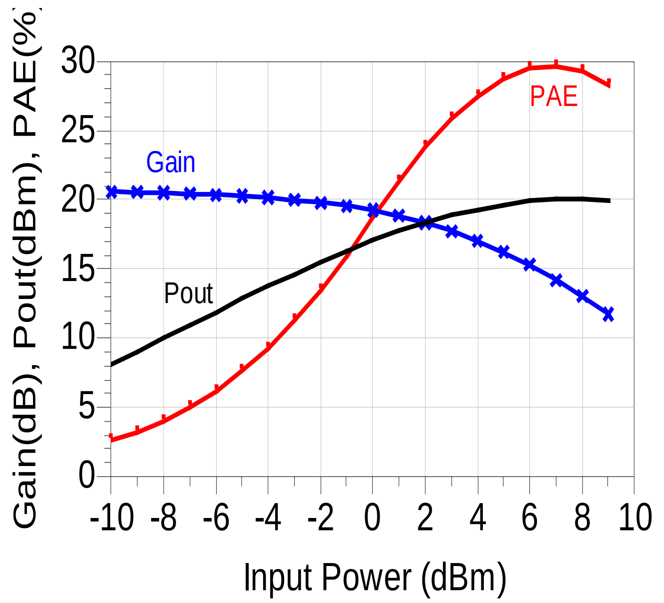

Figure 3 simulation results of 28 GHz PA gain, pout and PAE versus input power

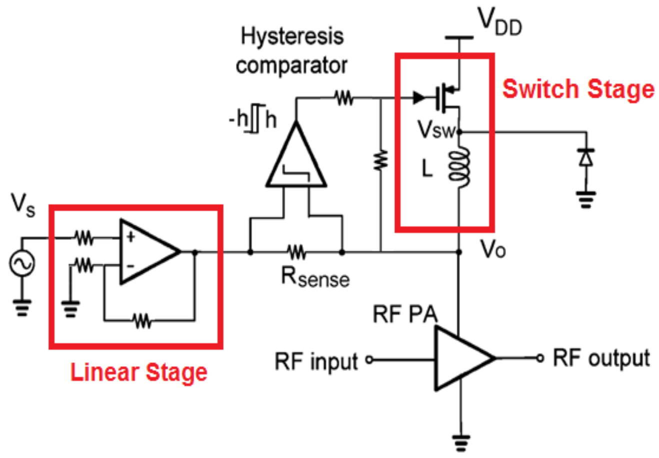

Figure 4 high efficient envelope amplifier [13]

To meet the stringent requirements for high efficiency, bandwidth, and slew rate we used an envelope amplifier which was detailed in [13]. Fig. 4 shows a picture of this amplifier. The input envelope signal is applied to the linear opamp. The output voltage of opamp is compared with Vout through a sensor resistance. This resistance senses the voltage across it and turns the switch on when the difference between voltages is high, adapt Vout with opamp output voltage. When the switch is on, Vout will increase and when it is off, the diode will turn on and Vout will decrease. The PA is replaced by a resistor in this simulation. The inductor value in the switching stage is tuned for obtaining best efficiency performance.

Simulation result of ET amplifier with a 10 MHz QPSK envelope signal is shown in Fig. 5. Output voltage of the envelope amplifier (Vout), which is the same as drain voltage of the PA, correctly amplifies the input envelope. Efficiency of envelope amplifier was as high as 61% with peak output voltage of 5.75 V.

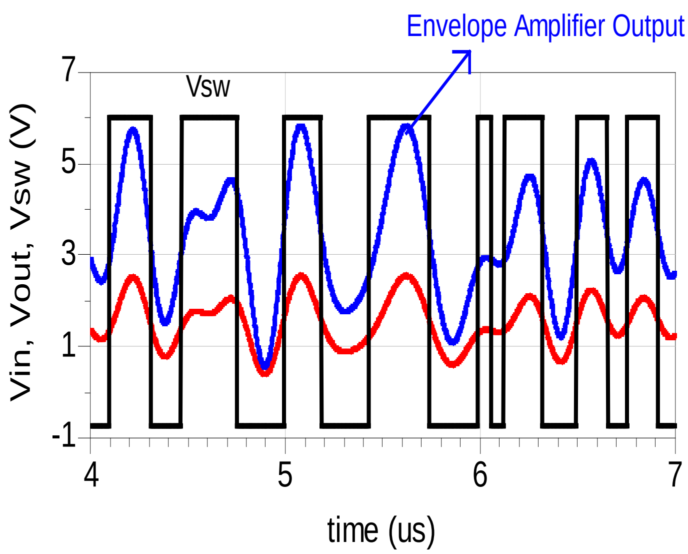

Figure 5 simulation of input and output voltages of envelope amplifier along with switching voltage.

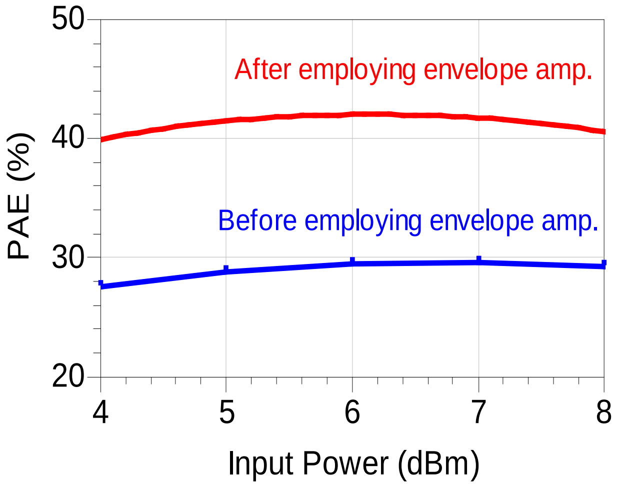

Figure 6 simulation of PA efficiency before and after employing envelope amplifier

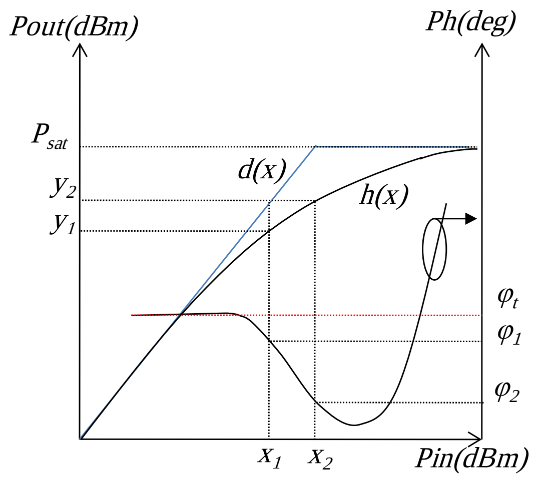

Figure 7 an example of AM/AM and AM/PM characteristics before and after linearization.(d(x) and φt are characteristics of a linear PA)

C. Employing Envelope Amplifier to the PA

Simulations were done under both constant drain and modulated drain biasing. Drain bias was varied according to behavior of designed envelope amplifier. Fig. 6 shows the simulation results before and after utilizing this amplifier. When operated under a fixed drain bias of 6 V, the PA achieved 30% PAE at an output power of 20 dBm. Under ET, the PA achieved 41% PAE over wider range of input power. This increase in efficiency can be attributed to the operation of the PA near saturation at most times.

In order to verify the correct operation of ET technique in LMDS frequency band, we have summarized simulation results of published PAs for LMDS applications and proposed PA in table I. As it seen, most of the PAs in this band use 0.15 um GaAs technology and their PAE are about 25% in average. In this paper we have reached 41% PAE which shows a significant improvement in PAE.

III. LINEARIZATION

The dynamic biasing of the PA will introduce a new source of distortion to the circuit. Usually a gain compression is occurred in the low input powers. Since DSP is a necessary part of all modern transmitters, using a digital linearization technique will improve this nonlinearity without increasing the cost of the system.

TABLE I COMPARISION BETWEEN PUBLISHED PAS FOR LMDS APPLICATION AND PROPOSED PA

Freq. Band (GHz)	***Process Technology***	***Gain (dB)***	***P1dB (dBm)***	***PAE***	***Ref***
27.5 – 29.5	0.15 µm GaAs pHEMT	16	32	35%	[4]
24 -28	0.15 µm GaAs pHEMT	17.5	17.5	19.8%	[5]
27.5 – 28.4	0.15 µm GaAs pHEMT	23	33	N/A	[6]
23 – 26	0.25 µm GaAs pHEMT	29	33	16%	[7]
27.5 – 28.5	0.15 µm GaAs pHEMT	21	19	41%	This work

Linearization of PAs usually is based on AM-AM and AM-PA characteristic of PA. Next step after obtaining characteristics of PA is LUT coefficient calculation [10]. Fig. 7 gives an overview on linearization of PA. It shows nonlinear AM/AM characteristics given as h(x) where the target linear AM/AM is d(x). Two points y_1 and y_2 have been selected from the figure such that

$$y_1 = h(x_1) \tag{1}$$

$$y_2 = h(x_2) \tag{2}$$

where x_i and y_i are the magnitude of the PA input and output respectively. The desired function having a linear response as:

$$y_2 = d(x_1) \tag{3}$$

If we define the coefficient c_x as

$$c_{x_1} = \frac{x_2}{x_1} \tag{4}$$

By multiplying it with x_1 and apply to the function h, then it is possible to obtain the linear function d as shown in the equation below.

$$y_2 = h(x_2) = h\left(c_{x_1} x_1\right) = d(x_1) \tag{5}$$

The phase of LUT coefficients y can be obtained by subtracting the input dependent phase values from a constant target phase φ_t as shown in Fig. 7. For each input value, x_i, the algorithm search through the table to find the best matched value, x_d. Hence ith input sample value $x_i=r_i e^{j\theta i}$ is converted to predistorted value $y_i=R_i e^{j(\theta i+\theta di)}$. Note the peak value of |xi| must be scaled equal to the address size of the table. The algorithm should be able to identify the amplifier characteristics and update the table to adapt with the variation of PA characteristics [14-15]. In this work, a MATLAB code is used for the linearization purpose. The table is updated based on minimizing the error, defined as the difference between real and expected output.

Fig. 8 shows the simulation results of Normalized AM/AM characterization of ET-PA before and after digital predistortion. As it seen, the proposed algorithm completely linearizes the overall envelope tracking power amplifier.

IV. CONCLUSION

In this paper, we show that ET technique can be used for efficiency enhancement of PAs for LMDS applications. More than 10 percent enhancement in PA efficiency was earned under ET, when compared to a fixed drain bias. A linearization algorithm was also investigated and used for linearization of overall ET-PA and show a linear performance for proposed ET-PA.

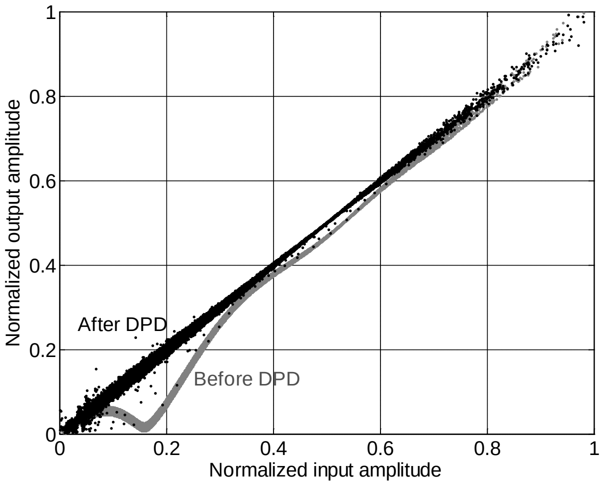

Figure 8 normalized AM/AM characterization of ET-PA before and after digital predistortion

REFERENCES

[1] S. C. Cripps, RF Power Amplifiers for Wireless Communications, Norwood, MA: Artech House, 1999.

[2] S. C. Cripps, Advanced Techniques in RF Power Amplifier Design, Artech House, 2002.

[3] P. B. Kennington, High Linearity RF Amplifiers Design. Norwood, MA: Artech House, 2000.

[4] Mansoor K. Siddiqui, Arvind K. Sharma, "A High-Power and High-Effciency Monolithic Power Amplifer at 28 GHz for LMDS applications", IEEE Transactions on Microw. Theory Tech, Vol. 46, No. 12, pp. 2226- 2232, Dec. 1998

[5] Young-Gi Kim, Sung-Jae Maeng, "A PHEMT MMIC Broad-Band Power Amplifer for LMDS", IEEE Radio and Wireless Conference, pp. 121-124, Aug. 1998

[6] J. Shu, T. Hwang, "Ka-Band 2 Watt Power SSPA for LMDS Application," IEEE Trans. Microw. Theory Tech, pp.573-576, June 1998.

[7] T. Satoh, T. Shimura, "A compact PA MMIC module for K-band high-speed wireless systems", 2000 IEEE MTT-S Digest, pp. 1333-1336, June 2000.

[8] Jinseong Jeong, Donald F. Kimball,, Myoungbo Kwak, Chin Hsia, Paul Draxler and Peter M. Asbeck "Wideband Envelope Tracking Power Amplifiers with Reduced Bandwidth Power Supply Waveforms and Adaptive Digital Predistortion Techniques" IEEE Transactions On Microwave Theory And Techniques, Vol. 57, No. 12, December 2009.

[9] B. Kim, J. Moon, and I. Kim "Efficiently amplified" IEEE Microw. Magazine, Aug. 2010.

[10] D. F. Kimball, J. Jeong, C. Hsia, P. Draxler, S. Lanfranco, W. Nagy, K. Linthicum, L. E. Larson, and P. M. Asbeck, "High-efficiency envelope tracking W-CDMA base-station amplifier using GaN HFETs," IEEE Trans. Microw. Theory Tech., vol. 54, no. 11, pp. 3848–3856, Nov. 2006.

[11] P. M. Roodaki, A. Mohammadi, A. Abdipour, "Utilizing Five-Port Down-Converter in Adaptive Linearization of Base Station Envelope Tracking Power Amplifiers", unpublished.

[12] J. Yan, C. D. Presti, D. F. Kimball, Y. Hong, Ch. Hsia, P. M. Asbeck, and J. Schellenberg, "Eficiency Enhancement of mm-Wave Power Amplifiers Using Envelope Tracking" IEEE Microw. Wireless Components Letters, Vol. 21, No. 3, March 2011.

[13] F. Wang, D. F. Kimball, J. D. Popp, A. H. Yang, D. Y. Lie, P. M. Asbeck, L. E. Larson., "An improved power-added efficiency 19-dbm hybrid envelope elimination and restoration power amplifier for 802.11 g WLAN applications," IEEE Trans. Microw. Theory Tech., vol. 54, no. 12, pp. 4086–4099, Dec. 2006.

[14] O. Hammi, F. M. Ghannouchi and B. Vassilakis, "A Compact Envelope-Memory Polynomial for RF Transmitters Modeling with Application to Baseband and Rf-Digital Predistortion," IEEE Microw. and Wireless Components Letters, vol. 18, pp. 359-361, May 2008.

[15] M. Dashti, A. Mohammadi, and Jun-ichi Takada, "Adaptive Digital Predistortion linearizer for high power amplifiers", the institude of electronic, Information and Communication Engineers, 2007.