Adaptive Linearization of Frequency Doubler Using DGS

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Abstract — **This paper presents adaptive digital predistortion linearization for the frequency doubler of dual band transmitter designed with DGS. The proposed dual band module operates either as an power amplifier for 2.4GHz band, or as a frequency doubler for 5.8GHz band according to signal frequency and bias control. The linearized frequency doubler shows significant enhancement in terms of output power, ACPR and EVM. Measured result shows that the frequency doubler has more than 26dB ACPR improvement at 11MHz offset from center frequency by the proposed adaptive predistotion. The EVM of the frequency doubler is 4.4% with adaptive predistortion, whereas it is 15.4% with non-adaptive predistortion. The required power back-off has decreased 7dB to meet the IEEE 802.11a EVM requirements with 54Mbps data rate.**

Index Terms—**Frequency doubler, adaptive predistortion, ACPR, DGS, error vector magnitude, wireless LAN.**

I. Introduction

There has been explosive adoption of wireless LAN technology in the corporate environment and hot-spot areas since the finalization of IEEE 802.11a/b/g standards. The widely deployed 802.11g network, operating in the 2.4GHz ISM band, provides a maximum data rate of 54Mbps, whereas the 802.11a, operating in the 5GHz band, can support up to similar data rate. Recently, the IEEE has worked to extend the 802.11g standard to higher data rates up to several hundred Mbps by using the MIMO-OFDM modulation in the 2.4GHz band, resulting in the new standard 802.11n [1].

Dual band (2.4/5GHz) triple mode wireless LAN systems with IEEE 802.11a/g/n standards have recently become popular because they provide users with flexibility in various wireless environments. Thus, dual band capability of wireless LAN transmitter is necessary for compatibility and covering multiple wireless standards. In RF front-end for wireless LAN, especially the power amplifier is a key component, occupying relatively large portion of assembly area and cost. To achieve practical implementation of IEEE 802.11a/g/n RF front-end solution in a dual band environments, the PA modules not only need to meet the required system performance, but they also need to be low cost and small compact size. There have been some presentations of the dual band transmitter and they have used two separate RF chain for 2.4GHz and 5GHz bands which require additional material cost and physical space[2],[3].

The frequency multiplier can be used to avoid the separate upconverter and PA chain for the dual band transmitter. Ref.[4] and [5] showed the possibility of transmitting digitally modulated signals through frequency multiplier and the feasibility of dual mode transmitter by introducing CDMA and PCS band reconfigurable transmitter architectures. Ref.[6] demonstrated the dual band transmitter using frequency doubler for wireless LAN application. Ref.[7] presented dual band transmitter using digitally predistorted frequency doubler.

In this paper, we expand dramatically on our presentations in references[6]-[7] by proposing adaptive digital predistortion linearization techniques for the frequency doubler of a novel dual band transmitter designed with DGS. The use of adaptive predistortion linearization technique for frequency doubler can lead to the substantial improvement in the output power of the dual band transmitter while meeting the IEEE 802.11a standard Tx EVM requirements.

II. Dual Band WLAN Transmitter Architecture

The conventional dual band transmitter architecture includes two parallel single band transmitter at 2.4 and 5GHz, respectively. This implementation wastes circuit area since no component is reused or shared. This structure requires power

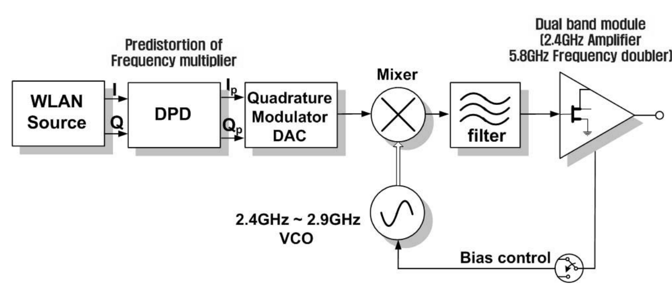

Fig.1. Block diagram of the proposed dual band transmitter with digital predistorter.

amplifier at each band and different voltage controlled oscillator(VCO) for each band, and high integration complexity. We have presented a novel dual band transmitter in order to cover 2.4 and 5.8GHz wireless LAN applications. The proposed dual band transmitter operates either as the power amplifier for 2.4GHz, or frequency doubler for 5.8GHz as in Fig.1. It consist of a VCO operating from 2.4 to 2.9GHz, and the Tx amplifier/ frequency doubler circuit with microstrip

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DGS to optimize stop band characteristics between 2.9GHz and 4.8GHz for the dual band transmitter. The predistortion linearization technique has been proposed to get the proper 5.8GHz band wireless LAN signal.

III. ADAPTIVE PREDISTORTION OF FREQUENCY DOUBLER

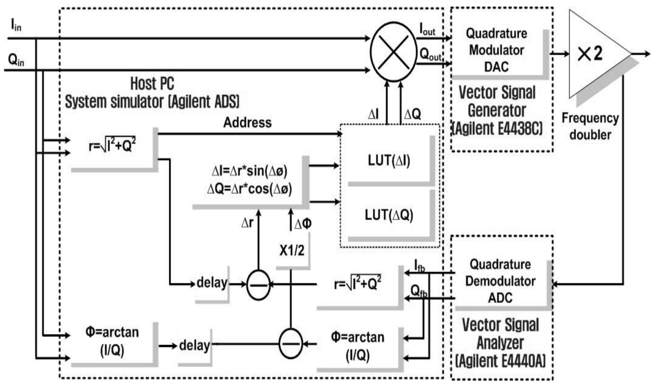


Fig.2. Block diagram of the proposed adaptive digital predistortion

A digital predistortion technique consisting of pre-processing of the I and Q input streams according to the complement of the transmitter response is used to compensate for its nonlinearity effects. To achieve this correction, a complex function of the predistorter is determined while satisfying the following condition:

$$f(V_{in}(t))g(V_{in}(t)|f(V_{in}(t))|) = G \quad (1)$$

$$f(\phi_{in}(t)) = -g(\phi_{in}(t)) \quad (2)$$

where *f* and *g* represent the complex nonlinear functions of the predistorter and transmitter, respectively. Both *f* and *g* are determined using I and Q values at the input and output of the transmitter. In order to accomplish improvable compensation for transmitter characteristic variation, adaptive digital predistortion system is more desirable. To achieve improvable correction, the feedback signal is downconverted, digitized, and analyzed in the baseband signal processing. Finally, a LUT based digital predistorter updates its coefficients and is applied to cancel out the nonlinearity. The new correction values of the predistorter is determined as following equation:

$$f'(V_{in}(t)) = f(V_{in}(t) \cdot (\Delta f(v_{in}(t)))^m \quad (3)$$

$$\phi'(V_{in}(t)) = \phi(V_{in}(t) - k\Delta\phi(V_{in}(t)) \quad (4)$$

where Δf and $\Delta \varnothing$ represent amplitude and phase error, respectively. And *m* and *k* represent amplitude control loop gain and phase control value, respectively.

In order to accomplish the full compensation for the frequency doubler nonlinearities, the fully digital complex predistorter using the adaptive look-up table (LUT) implementation is more desirable. The Fig. 2 shows the detailed block diagram of the adaptive LUT based predistortion system. Phase division of the input signal is applied for the compensation of PM-PM distortion.

The quality and performance of the digitally predistorted frequency doubler greatly depends on the accuracy of the frequency doubler characterization to be used in synthesizing the predistortion function. Thus, the frequency doubler is

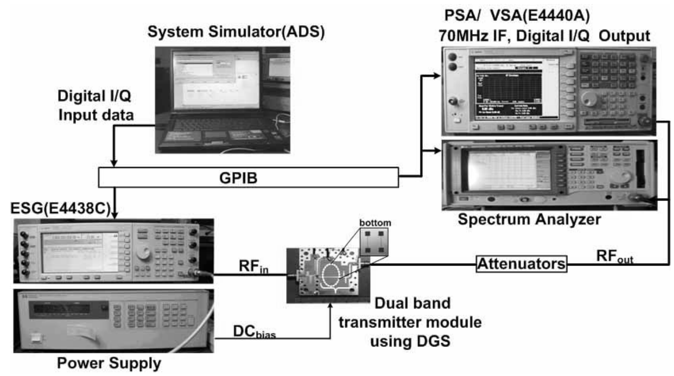
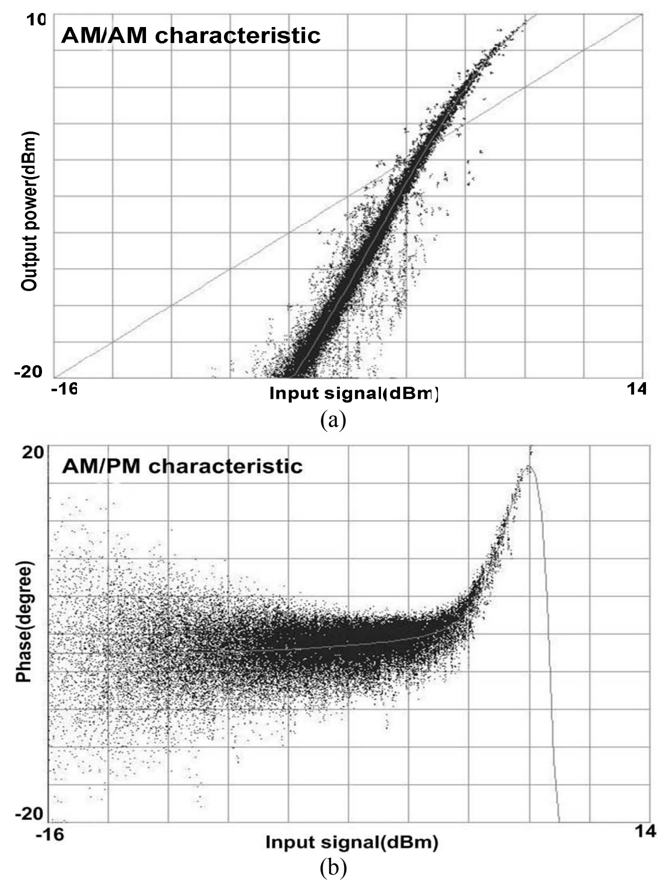


Fig.3. Experimental set-up for linearization of dual band module.



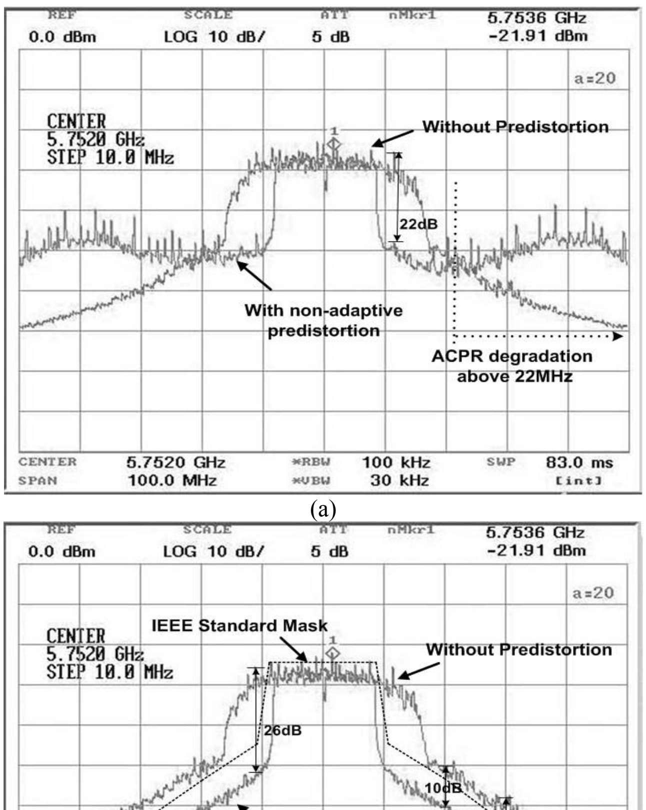
(a)

(b)

Fig.4. Measured results of the frequency doubelr. (a) AM/AM characteristic (b) AM-PM characteristic

characterized under wireless LAN signal excitation. Fig. 3 presents the measurement set-up. The signal is generated using system simulator software. The baseband waveforms are then downloaded into the signal generator(ESG E4438C). The ESG generated the corresponding IEEE 802.11a signal, around 2.9GHz, that is fed to the frequency doubler. A spectrum analyzer(PSA E4440A) is used for down-conversion and signal analysis. Fig. 4 shows the measured AM/AM and AM/PM distortion characteristics with polynomial curve fitting. These AM/AM and AM/PM characteristics are used to synthesize the predistortion function.

IV. MEASUREMET RESULTS



(a)

(b)

Fig.5. Measured output spectrum of IEEE 802.11a 5.8GHz frequency doubler with and without predistortion (a) with non-adaptive predistortion (d) with adaptive predistortion.

For the frequency doubler measurement, the output signal was taken at 5.8GHz band with IEEE 802.11a signal. Fig. 5 shows frequency doubler output spectrum with and without predistortion. The frequency doubler output spectrum without

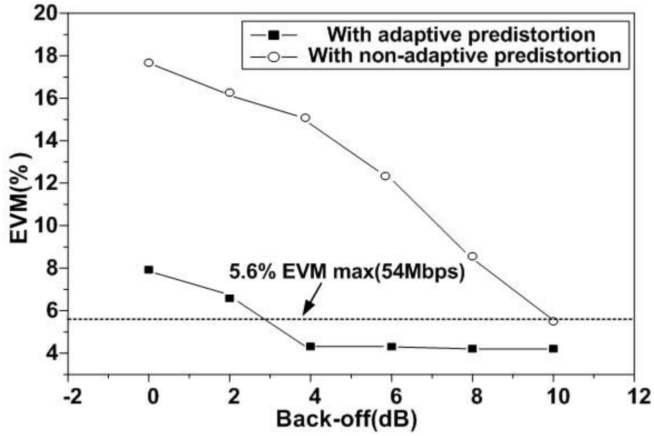


Fig.6. EVM variation versus back-off with and without adaptive predistortion.

TABLE I
MEASUREMENT RESULTS OF DESIGNED DUAL BAND WLAN TRANSMITTER

5.8GHz IEEE 802.11a (OFDM-64QAM 54Mbps)		
Item	With non-adaptive Predistortion	With adaptive Predistortion
EVM@ 6dBm	15.4%	4.4%
Pout for EVM= 5.6%	0dBm	7dBm
Back-off for EVM=5.6%	10dB	3dB

predistortion is widely spread, resulting in the adjacent-channel power ratio(ACPR) of about 3dBc at 11MHz offset from center frequency. This is mainly due to the frequency and phase multiplication of the modulated signal through the frequency doubler. In Fig. 5(a), the predistorted output spectrum has improved the ACPR by 22dB at 11MHz offset from the center frequency. However, the ACPR becomes worse as the offset frequency increases. This degradation seems to be due to the out-band distortion of the 4th IMD terms ($3f_1$-f_2, $3f_2$-f_1) through the phase division. The phase dividing in the digital predistortion system compensate for PM-PM distortion however, it generates out-band distortion of 4th IMD. This distortion should be compensated to meet the IEEE 802.11a standard Tx mask. Thus, the sophisticated algorithm, adaptive digital predistortion system could be employed to compensate for out-band distortion. The least mean square(LMS) algorithm of an adaptive predistortion system is used to compensate for the out-band distortion of the frequency doubler. The adaptive predistorted frequency doubler of Fig. 5(b) shows 26dB, 10dB, and 9dB ACPR improvement at 11MHz, 20MHz, and 30MHz offset from center frequency, respectively. And, the frequency doubler output spectrum with adaptive prdistortion does meet the IEEE 802.11a standard Tx mask.

The back-off value from maximum output power of 10dBm to satisfy the required IEEE 802.11a standard Tx EVM has been compared with and without adaptive predistortion. For non-adaptive predistortion, the measured EVM of 5.6% is

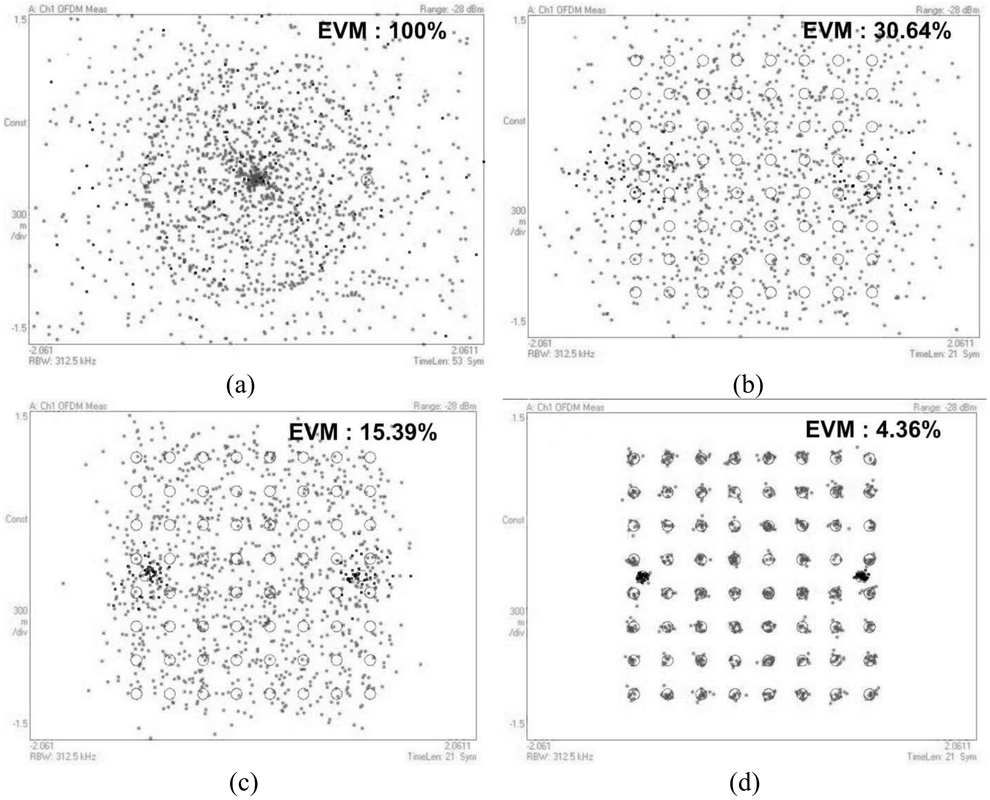


Fig.7. Measured EVM and I/Q constellation of frequency doubler. (a) without predistortion (b) with predistortion of only PM-PM compensation (c) with non-adaptive predistortion (d) with adaptive predistortion

obtained for a back-off value equal to 10dB whereas it is obtained for 3dB back-off value with adaptive predistortion. Measured EVM and I/Q constellation of frequency doubler with 64-quadrature amplitude modulation (QAM) are shown in Fig. 7. The EVM of frequency doubler was 4.4% with adaptive predistortion, whereas it was 15.4% with non-adaptive predistortion. Note that the symbol detection is completely impossible without adaptive predistortion linearization. The measured results are summarized in Table I.

V. CONCLUSIONS

This paper has presented the adaptive digital predistortion technique of frequency doubler for dual band wireless LAN transmitter. The adaptive predistortion technique of frequency doubler has been used to get the proper 5.8GHz band wireless LAN signal. The frequency doubler output with adaptive predistortion does meet the IEEE 802.11a standard Tx mask and EVM requirement. Also, a significant reduction of power back-off level of approximately 7dB was achieved while meeting the IEEE 802.11a standard Tx EVM requirements. The results show that it is feasible to use adaptive predistorted frequency doubler to realize dual band wireless LAN transmitter.

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