

TWO STAGE ON OFF KEYING CLASS A RF POWER AMPLIFIER IN 0.18 μ m CMOS TECHNOLOGY



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ABSTRACT

A novel architecture for the On Off Keying (OOK) modulator with high gain and high data rate power amplifier (PA) operating at 11.6 GHz IBM 0.18- μ m RF CMOS technology is presented for a X-band passive RFID tag. Currently used low frequency switching techniques such as multiplexers were not functioning in the high frequency X-band architectures. In this novel approach OOK modulator with power amplifier, a CMOS switch was used to transmit '1' and '0' coming from the digital signal unlike in the existing low frequency architectures. Both the load and driver in this proposed PA were class A operation supplied by a single ended 1.83V source. The important design considerations include output power, 1 dB compression point and linearity. The fabricated results of the amplifier have a 1 dB compression point of 1.2 dBm and input power of 5.19 dBm at 9.2 GHz.

1. INTRODUCTION

Currently used low frequency switching techniques such as multiplexers were not functioning in high frequency X-band architectures. Therefore, high efficient X-band Power Amplifier (PA) was designed for the novel passive RFID tag. The bits were transmitted using OOK.

PA was a two-stage amplifier with both driver and output stages have class A operation. The basic CMOS class A PA was shown in Fig.1. The transistor (M1) was connected with large inductor (L1) which acted as an ideal current source. Capacitors were used to block DC and pass AC (V_{in}).

It was designed to resonate at the X-band frequency (11.6 GHz). The power amplifier was used to drive the 50 Ω antenna. In this novel approach On Off keying (OOK) modulator with power amplifier was used to transmit the bits [1]. The CMOS switch was used to transmit '1' and '0' of the digital signal unlike in the existing architectures. Special consideration was made to minimize the delay between low to high and high to low switching of the PA to increase the high data rate operating at the X-band frequency.

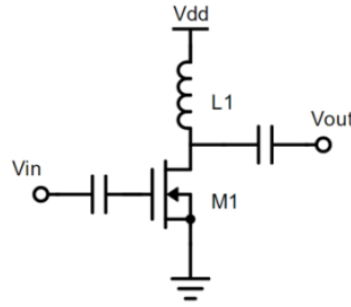


Figure 1: Class A power Amplifier

In this circuit (Figure 1.) a single MOS transistor was used and loaded with RF choke [2], [3]. The widths of M1 and M3 were computed from CMOS saturation drain current equation [4]. The inductors were designed to have a large enough inductance to pass through a fairly constant current. The driver stage was designed because the single PA cannot reach the requirements of high gain and high data rate.

A single CMOS transistor was used and loaded with a RF choke, which acted like an ideal current source. Constant g_m bias generator circuit was used to generate the bias voltages of the first and second stages of the power amplifier. The isolation of AC to DC of each stage of the power amplifier was carried out through resistors. During the charging cycle the PA will go into standby mode with the rest of the system. Constant bias voltages for the PA were provided by the constant g_m bias circuit. The PA was changed to active mode when the enable signal of the mode selector was high. The block diagram of the RFID tag was shown in Figure 2.

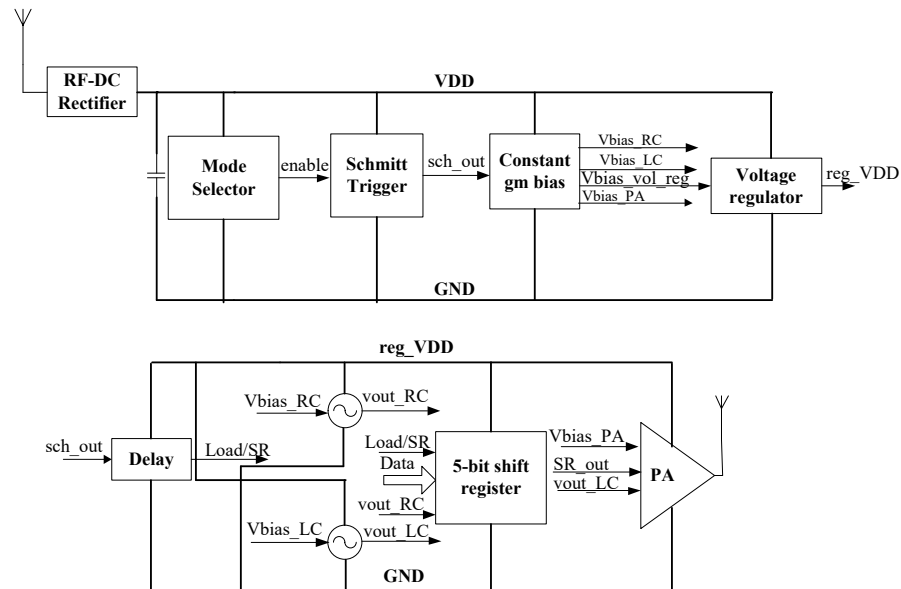
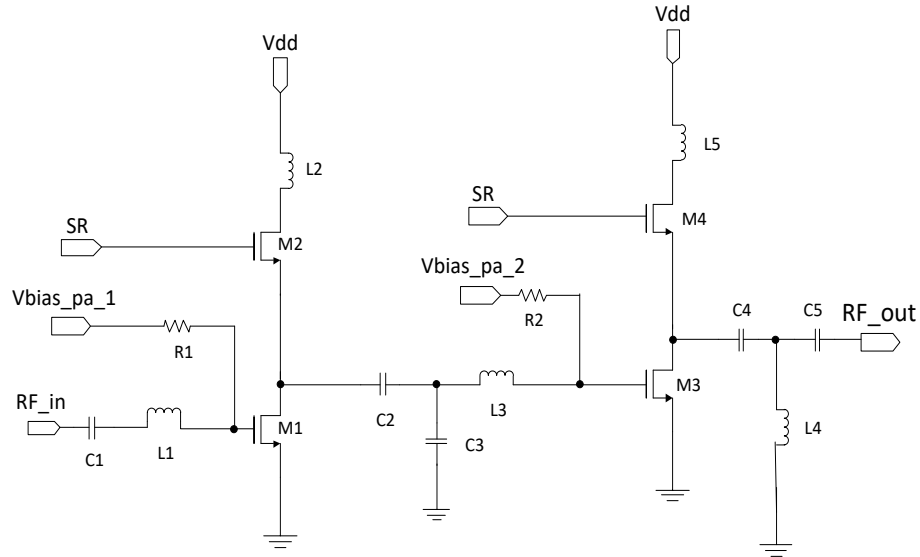


Figure 2: Block diagram of the RFID tag

2. MATERIALS AND METHODS

The proposed X-band two stage class A PA circuit is shown in Figure 3. In the proposed passive RFID tag design, the PA amplifies the signal received from the LC oscillator and matches the load to a 50 Ω antenna. The 11.6 GHz sinusoidal signal from the injection lock LC oscillator was fed into the gate of the lower transistor.

The pulsed digital data was fed into the gate of the other transistor. The modulation depends on both the bias condition of the two gates and the device dimensions. The OOK modulation happens when the device operates in the saturation or in the cut-off region when there is '1' or '0' coming from the digital data [5], [6], [7], [8]. The top transistors (M2 & M4) act as switches and are turned on the high state of the digital data and remains off at the low state, resemble the OOK modulation scheme. PA transistor sizes are given in Table 1.

**Figure 3:** Proposed X-band two stage class A PA circuit**Table 1:** X- band PA Transistor sizes

Transistor Name	Sizes (μm)
M1	50/0.18
M2	30/0.18
M3	60/0.18
M4	90/0.18
L1	1.323nH
L2	1.621nH
L3	411pH
L4	1.303nH
L5	1.284nH
C1	200fF
C2	200fF
C3	10.3fF
C4	120fF
C5	400fF
R1	10K Ω
R2	5K Ω

Transistor sizes have been optimized to obtain the maximum RF_out voltage from the power amplifier. More RF_out voltage improves the voltage gain of the power amplifier. When the transistor sizes were optimized, consideration was made that the power amplifier frequency was still at the X-band frequency, and the delay between RF_out and SR signal was minimum. Less delay between the RF_out and SR signal improves the switching of the power amplifier. The delay between RF_out and SR signal is important for the On-off_keying amplitude modulation (Figure 4.) performance of the power amplifier.

2.1. DRIVER STAGE

A driver stage was designed because the amplifier cannot reach the requirements for its operation. The input impedance of the proposed PA is calculated and consequently matched closed to 50 Ω . The block diagram of the PA with driver stage is given in Figure 5.

2.2. OUTPUT POWER

The output power (P_{out}) is the active power delivered in the load antenna at the fundamental frequency, $V_{out(max)}$ as the sinusoidal amplitude (A) of the signal at the fundamental frequency and $V_{out(rms)}$ as the corresponding rms value. The power generated at the fundamental frequency is called P_{out} .

$$P_{out} = A^2/2R_L = V_{out,max}^2/2R_L = V_{out,rms}^2/R_L \quad (1)$$

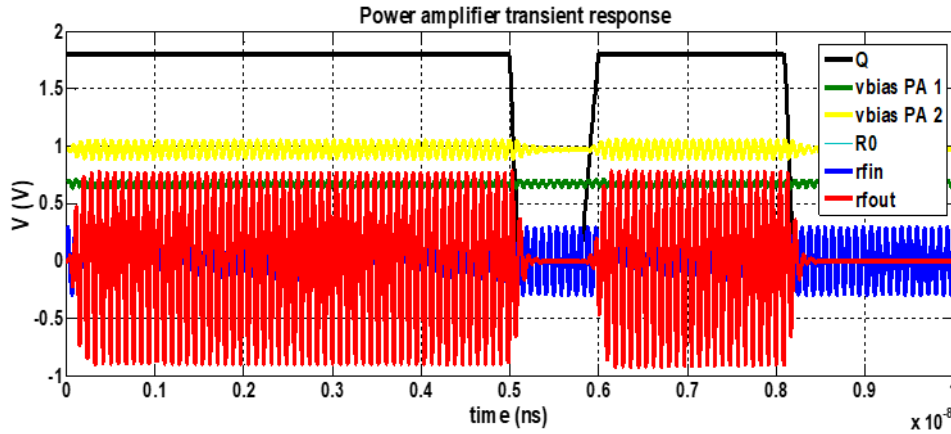


Figure 4: Power amplifier on-off keying transient response

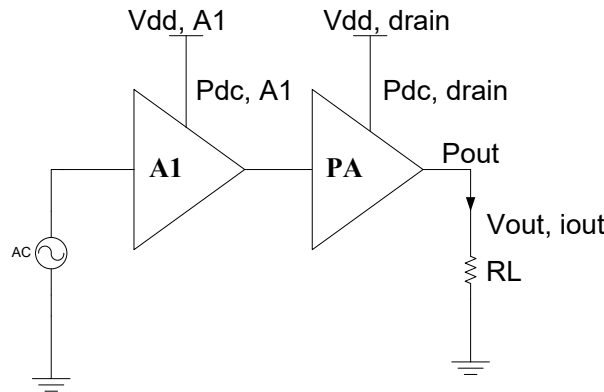


Figure 5: Power amplifier with the driver stage

2.3. GAIN AND EFFICIENCY

Gain (G) of the PA can be defined as the ratio of the output power (P_{out}) and the input power (P_{in}) which is expressed in dB. Power Added Efficiency (PAE) of the PA is defined as

$$G_{dB} = 10\log_{10}(P_{out}/P_{in}) \quad (2)$$

$$PAE = (P_{out} - P_{in})/P_{dc,tot} \quad (3)$$

3. RESULTS AND DISCUSSIONS

The RF signal was generated by Agilent 8341A vector signal generator. RF signal was connected to PA is shown in Figure 6. The output of the PA was connected to Agilent E4440A spectrum analyzer. X- band PA probe setup is shown in Figure 6. When the modulation was “on” and “off” the output spectrums of the PA are shown in Figure 7 and Figure 8.

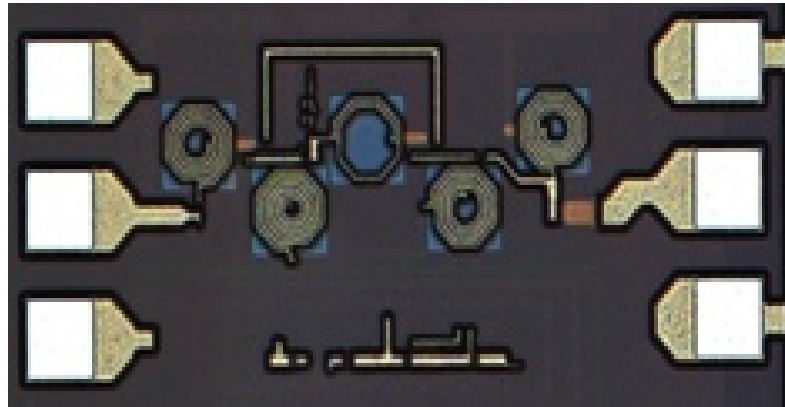


Figure 6: Microphotograph of the X-band PA test structure

When the modulation of the PA was “on” the output power magnitude at 11.58GHz is -29.21dBm (Figure 7). Similarly, when the modulation of the PA was “off” the output power magnitude is -60.46dBm (Fig.8). This magnitude was shown in Spectrum Analyzer after 20dB attenuator and a 6.41dBm cable loss.

The test condition for the X band PA for output power vs frequency is given in Fig.7 & Fig.8 (vdd = 1.83 V, current = 9mA, vbias_pa_1 = 0.84 V, vbias_pa_2 = 0.82 V, input power = -1 dBm)

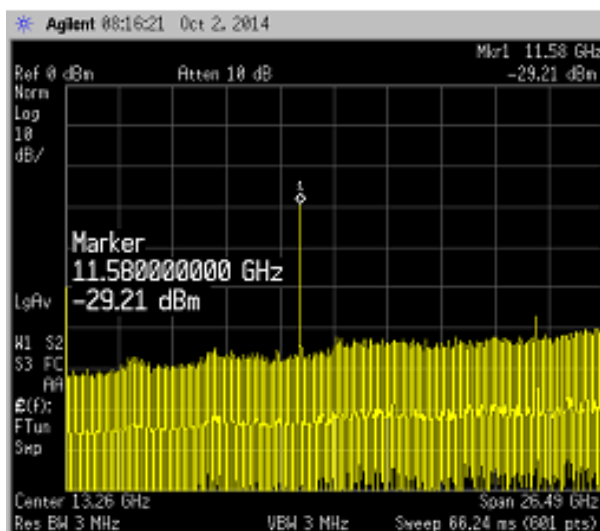


Figure 7: X-band PA output power spectrum when the modulator is on

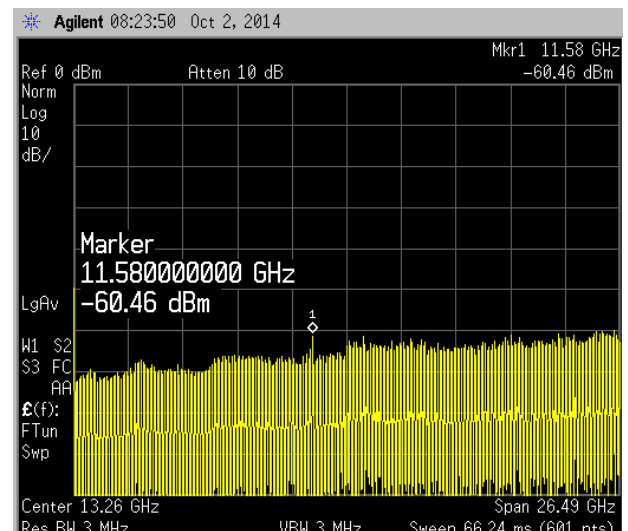


Figure 8: X-band PA output power spectrum when the modulator is off

The test condition for the X band PA for output power vs frequency is given below. (vdd = 1.83 V, current = 9mA, vbias_pa_1 = 0.84 V, vbias_pa_2 = 0.82 V, input power = -1 dBm)

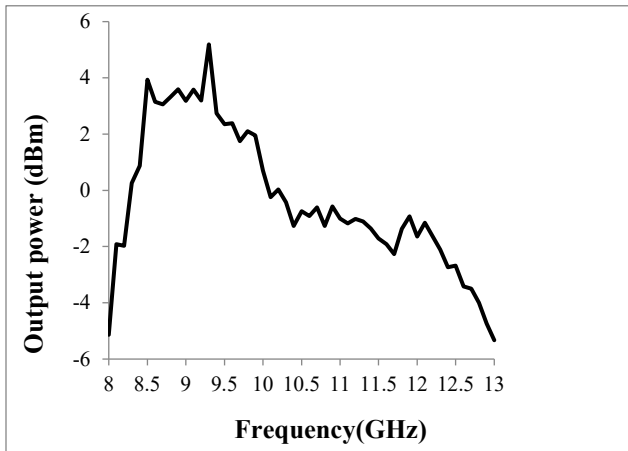


Figure 9: X-Band PA output vs. frequency

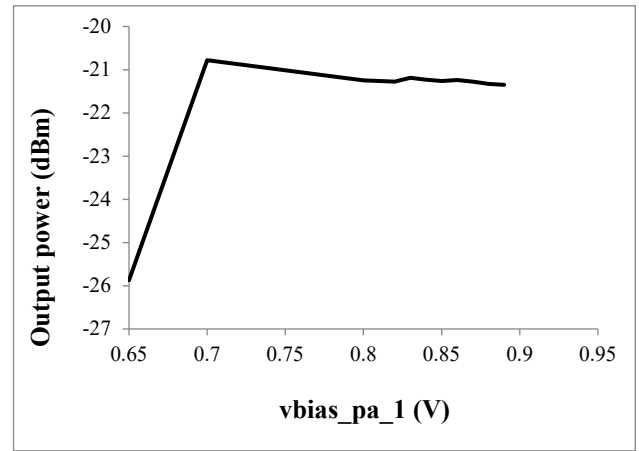


Figure 10: X-Band output power vs. bias voltage of the PA

The output power reached the maximum value of 5.19dBm at 9.4GHz frequency as shown in Fig.9. In addition, the output power of the PA reached the maximum value when the bias voltage was about 0.82 V(Fig.10). The bias voltages were swept to check whether it agreed with simulation results. The correct bias voltages were required for the PA to function at its optimum efficiency and to provide the maximum output power.

4. CONCLUSIONS AND RECOMMENDATIONS

Currently used low frequency switching techniques such as multiplexers were not functioning in high frequency X-band architectures. Therefore high efficient X-band Power Amplifier (PA) was designed for the novel passive RFID tag. The fully integrated X-band PA with OOK modulator was developed, fabricated and implemented in IBM 0.18 μ m RF CMOS technology. The design of the PA relied heavily on hand computations for biasing and parametric analysis to ensure the optimum values for the matching network. The fundamental frequency of the PA can be increased to the desired frequency by using the Cadence spectre post layout simulation.

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CONFLICT OF INTEREST

The author have declared that no competing interests exist.

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