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Design the High Gain and Low Power Amplifier for Radio over Fiber Technology at 2.4 GHz

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Abstract:- This paper describes the high performance design a power amplifier for Radio over Fiber (RoF) Technology at 2.4 GHz using Agilents HBFP-0450 transistor. Based on wireless network RoF technology has been proposed as a promising cost effective solution to meet ever increasing user bandwidth and wireless demands. In this network, a central station (CS) is connected to numerous functionally simple Radio Access Point (RAP) via an optical fiber. The only components required at the passive RAP are Electro Absorption Modulator (EAM) and antenna where EAM is used as a remote transceiver. There are practical limitations on the power that can produce by the passive RAP which can affect the dynamic range. In order to improve the dynamic range of passive pico cell RAP power amplifier is placed at the front end of RAP for the downlink transmission which operate in active mode. The central station (CS) is connected to numerous functionally simple RAP via an optical fiber in the RoF network. The design is based on the conjugate matching method which able to achieve the maximum gain. The performance of the design simulation done using Agilent Advanced Design System (ADS) software . The design has shown an acceptable behavior with gain of 13.172 dB. At the 1-dB compression point the output power is approximately 16.108 dB and the Power Added Efficiency (PAE) is 24.915 %.

Keywords: **-** *Power Amplifier, Radio Access Point, Radio over Fiber, Advanced Design System (ADS), Gain*

I. INTRODUCTION

RoF is refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access [1]. RoF is a well established technology that used intensively worldwide for delivering radio signal from a CS to RAPs via an optical fiber [2]. Recently, wireless communication is becoming an integral part of today's society. The proliferation of mobile and other wireless devices coupled with increased demand for broadband services are putting pressure on wireless systems to increase capacity. To achieve this, wireless systems must have increased feeder network capacity, operate at higher carrier frequencies, and cope with increased user population densities. However, raising the carrier frequency and thus reducing the radio cell size leads to costly radio systems while the high installation and maintenance costs associated with high-bandwidth silica fiber render it economically impractical for in-home and office environments [3]. With such advantages of optical fiber as low loss, large bandwidth and transparent characteristics, RoFs system can simultaneously support multi-standard applications including cellular services and Wireless Local Area Networks (WLANs) [4]. 2.4 GHz frequency is one most commonly used license free frequencies which based on IEEE802.11 standard for WLAN. RoF systems are expected to play an important role in future wireless communication and phased array antenna sensor systems [5-8].

In the new concept of wireless architecture using this technology, all the signal processing associated with the base station, usually found in the RAP or remote antenna unit (RAU), can now be moved to the CS. Consequently, the RAP becomes a small module that only consists of an electroabsorption modulator (EAM), filter, amplifier and an antenna. Fig. 1 shows the basic diagram of RoF [9]. In practice, some loss of simplicity may need to be traded for increased range. The benefits of such a system result directly from the shift of complexity away from the antenna unit to the CS. In other words, centralization can be used to aid simplification. In the passive RAP, EAM is used as a remote transceiver. The only components required at the RAP are the EAM and an antenna.

There are practical limitations on the amount of power that can produce by the RAP which can affect the dynamic range. Firstly, there are limits to the amount of RF modulated optical power that can be produced economically when linearly modulating a semiconductor laser which this is the source of power ultimately used by the RAP. Secondly, there is a threshold power beyond which the EAM optical waveguide saturates (typically less than 10 mW) [1]. Other limitations arise from the coupling efficiency between the input or output fibers and the EAM waveguide. Apart from the limiter radio range, another potential problem with passive optical link is intermodulation distortion, especially since the EAM is operated without bias. However, analogue optical links are noted for their broadband capability, which allows several radio systems to be supported simultaneously. Inter-system interference is therefore an important issue if there is overlap between signals from one system and the harmonics of another. Such a situation arises for example between GSM900 and DCS1800. Second order distortion is therefore the main limitation of dynamic range in this situation [1]. A power amplifier is placed between the EAM and the antenna in order to improve the dynamic range of passive pico cell (RAP). Pico cells use low power and low capacity base stations that are small, light, relatively low cost and easy to install [2]. Pico cell has a coverage range up to 100 m. To achieve this distance, the RAP needs to operate in active mode, by inserting RF amplifier between optoelectronic photo detector and antenna for downlink path, and inserting LNA between the antenna and optoelectronic modulator [9]. Fig. 2 shows the simple diagram representation of an active optical RAP. Due to a bi-directional amplifier is needed to provide amplification in both transmit and receive directions, the microwave circulators or similar devices will be needed to provide separate uplink and downlink signal paths between the EAM and the antenna. Likely the power amplifier of general RF system, amplifier design for RoF involves many tradeoffs between noise figure, gain, linearity, impedance and matching network [10].

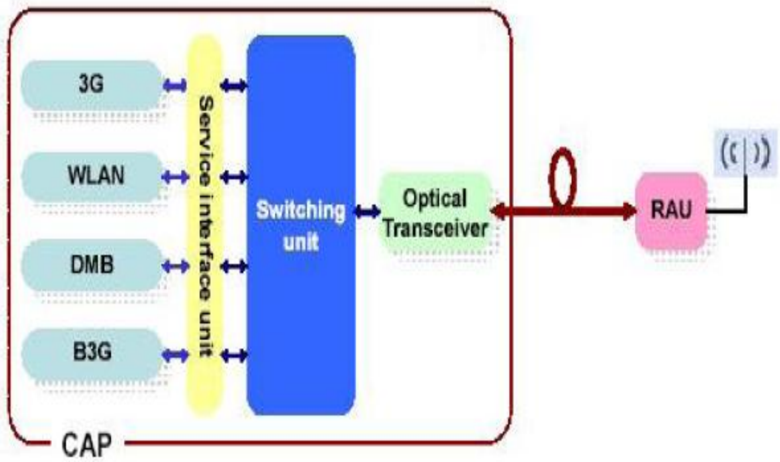

Figure 1: RoF system block diagram

The power amplifier is the critical element in transmitter units of communication systems, is expected to provide a suitable output power at a very good gain with high efficiency and linearity [11]. The output power from a power amplifier must be sufficient for reliable transmission. High gain reduces the number of amplifier stages required to deliver the desired output power and hence reduces the size and manufacturing cost. High efficiency improves thermal management, battery lifetime and operational costs. Good linearity is necessary for bandwidth efficient modulation. However these are contrasting requirements and a typical power amplifier design would require a certain level of compromise. There are several types of power amplifiers which differ from each other in terms of linearity, output power or efficiency. Parameters which quantify the various aspects of amplifier performance such as output power, gain, 1-dB compression point, intermodulation distortion, efficiency and are discussed in the next section. In this paper, the major goal is to design and simulate a power amplifier using the ADS software at 2.4 GHz based on RoF requirements. The analysis is based on S-parameters which are used to determine stability, maximum gain and matching network.

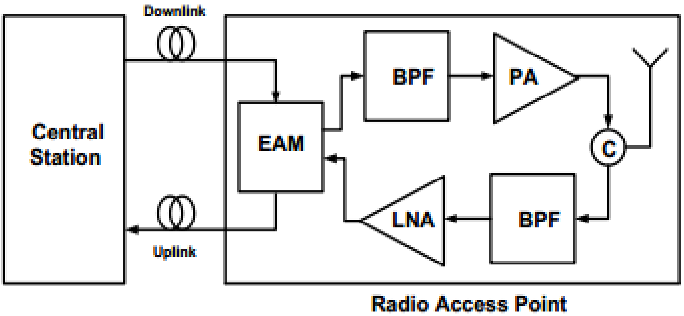

Figure 2. Active Optical Radio Access Point

II. DESIGN METHODOLOGY

Designing a power amplifier consist of different steps which based on conjugate matching method. The maximum gain or conjugate matching method is in the single stage amplifier design. This method will be realized when the overall gain given by a transistor, G_o provide a conjugate match between the amplifier source or load impedance and the transistor as shown in Fig. 3. A critical step in any power amplifier design is the selection of transistor. The transistor used in the current design is Agilent HBFB-0450. This product is based on a 25 GHz transition frequency fabrication process, which enables the products to be used for high performance, medium power, and low noise applications up to 6 GHz. The microwave bipolar transistor is usually of the non type and are often preferred over GaAs field effect transistor (FET) at frequencies below 2 to 4 GHz because of the higher gain and lower cost [12]. Table 1 shows the specifications of the power amplifier (PA) design. The operating frequency of the amplifier is at 2.4 GHz. The target of this project is that design the low power of PA which for short range application (pico cell). The output power of pico cell is less than 1 Watt (30 dBm) and the maximum output power produced at WLAN 2.4 GHz is 20 dBm [13].

First of all a DC simulation must be done to find the optimal bias and bias network for the system. From the transistor datasheet, it concern to choose the biasing point which produced the best performance in term of gain. The gain of the transistor is depending on the S parameter at the operating frequency. Biasing is a process to obtain the transistor static IV curves for desired operation such as class A, class B, class C, or class AB. The biasing point at V_{CE}= 3 V and I_C = 50 mA is selected because have higher gain compare to the others biasing point. The higher value of S_{21} (dB) can give a higher gain. Next, S-parameter simulations is done to find the exact value of the S-parameters and evaluate the stability of the model at the operating point. When embarking on any amplifier design it is very important to spend time checking on the stability of the device chosen, otherwise the amplifier may well turn into an oscillator. The main way of determining the stability of a device is to calculate the Rollett's stability factor (K) based on a set of S-parameters for the device at the frequency of operation [12]. There are two stability parameters K and $|\Delta|$ is used to indicate that whether a device is likely to oscillate or not or whether it is conditionally or unconditionally stable.

The input and output matching network are designed to make sure that maximum power is delivered when the load is matched to the line and power loss in fed is minimized. The single stub method is used for matching network. In the single stub matching that uses a single open circuited or short circuited of transmission line (stub), connected either in parallel or in series with the transmission feed line at the certain distance from the load as shown in Fig. 4. The important factors in the selection of a particular matching network include complexity, bandwidth, implementation and adjustability. Finally the whole system is optimized to achieve the better output power, efficiency and gain.

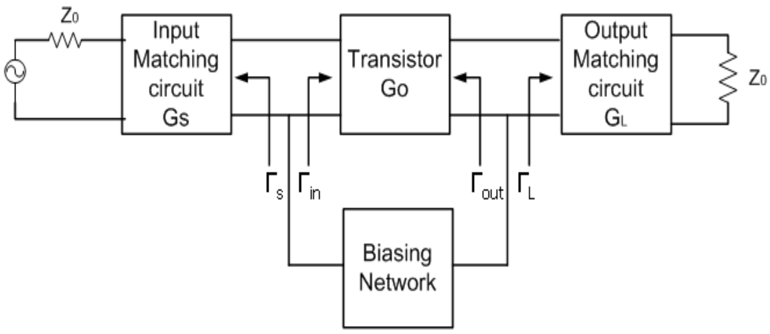

Figure 3. Model of single stage microwave power amplifier

Table I: Power Amplifier Specifications

Parameters	Values
Operating	2.4 GHz
Output Power, P_{out}	< 30 dBm
Gain, G	> 10 dB
Transistor	Agilent HBFB-0450
Matching Network	Single Stub

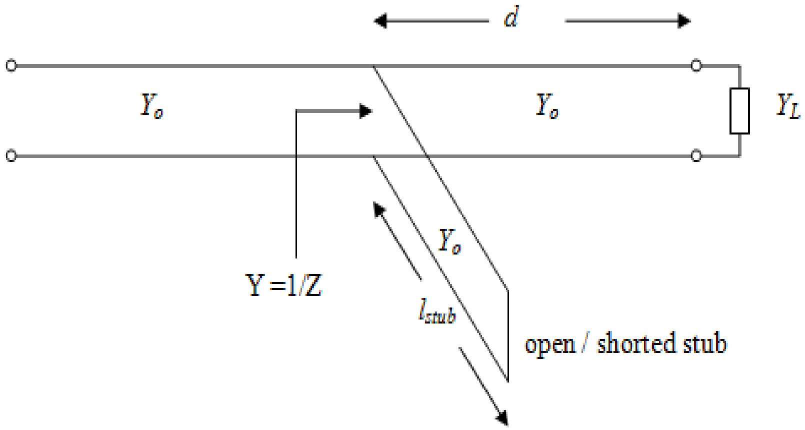

Figure. 4. Single Stub Tuning

III. RESULT AND ANALYSIS

The first step towards designing the class A power amplifier was to select a suitable bias point for the operation. The transistor should be biased for class A operation and maintained comfortably inside the rectangle limited by the nonlinearity borders which are the collector-emitter voltage, Knee voltage, V_k, and collector-base breakdown, V_{BR}. Transistor I-V curves with the optimal load line for the class A operation is shown in Fig. 5. The bias point at the optimal condition is V_{ce} = 2.45 V and I_c = 40.35 mA. The I-V curves also help to see a safety region which condition that the device can be expected to operate without self-damage due to thermal heating. The performance of transistor at the optimal bias value is summarized in Table 2. The maximum output power of this transistor is 16.22 dBm which the transistor can be used for pico cell application (less than 20 dBm).

The main way of determining the stability of a device is to calculate the Rollett's stability factor (K), which is calculated using a set of S-parameters for the device at the frequency of operation.. The stability can be determined from the value of K and Δ. The simulation of stability is shown in Fig. 6. The system is the unconditional stability due to |Δ| < 1 and K > 1 which mean that the amplifier is stable for all passive sources and load impedance. After the stability of the transistor have been determined, and the stable regions for the reflection coefficient for source and load (Γ_S and Γ_L) have been located on the Smith chart, the input and output matching section can be designed. Simulation maximum gain will be realized when matching sections provide a conjugate match between the amplifier source or load impedance and the transistor. Fig. 7 shows the simulation of effective gain. The results of effective gain between calculation and simulation almost the same. Available gain is a ratio between the power available from the output of the transistor and the power available from the source. The maximum value is occurring when the input of the power amplifier is conjugate-matched to the source. The Maximum Available Gain (MAG) is the highest possible value of transducer gain in case when both the input and output ports are conjugate-matched. MAG can be defined only if the transistor unconditionally stable.

$$K = \frac{1-|S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}.S_{21}|} = 1.014 \text{ where } |\Delta| = S_{11}.S_{22} - S_{12}.S_{21} = 0.543\angle -77.35^\circ$$

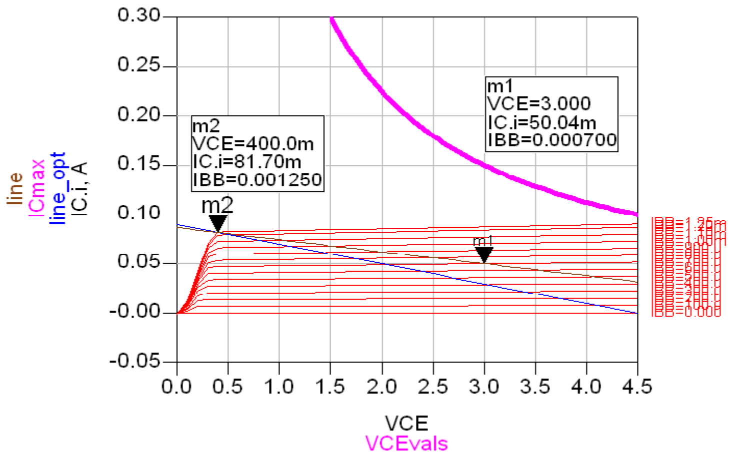

Figure. 5 I-V curves.

Table 2: Performance of Transistor at Optimum Bias Point.

Parameter	Values
Output Power, P_{out}	16.22 dBm
Efficiency, η	41.84%
DC Power, P_{dc}	100.1 mW
V_{ce}	2.45 V
I_c	40.85 mA
R_L	50.183 Ω

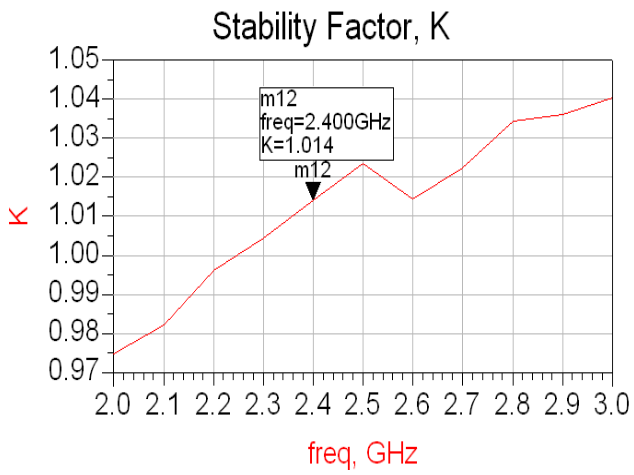

Fig. 6. Simulation of stability factor, K .

The single stub matching technique is used to obtain the input and output matching. From this matching technique, the distance, d and length of stub, ℓ are acquired which open circuit shunt stub is used to find the length of stub. Fig 7 shows the schematic of the input and output matching. The distance and length of stub which obtained from the Smith chart are converted to micro-strip line. The transformation to the micro-strip lines (MLIN and MLOC) are obtained by using an ADS Line calculator, LineCalc. The shunt tuning is especially easy to fabricate in microstrip or stripline form. The matching network can easily be determined using the Smith chart. For the shunt- stub case, the basic idea is to select the distance, d so that admittance, Y, seen looking into the line at d from the load is of the form Y_0 + jB. Then the stub susceptance is chosen as –jB, resulting in the matching condition.

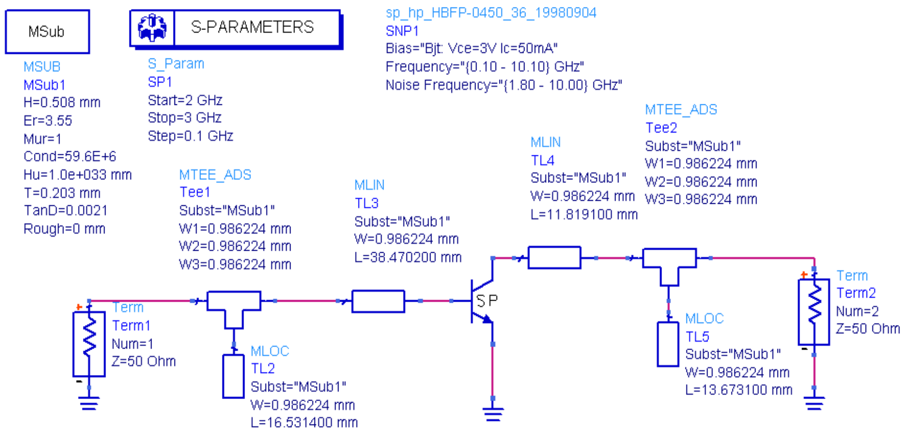

Figure. 7. Schematic of Input and Output Matching

The optimization of input and output matching is needed to improve the performance of the amplifier. The width and length of micro-strip line are tuned until the magnitude of S_{11} and S_{22} approximately to zero which for the perfect matching. The magnitude of both S-parameters are referred to the reflection coefficient, Γ at the input and output. Fig. 8 shows the comparison of gain before and after optimization. From the observation, all the parameter presented the improvement. For example, the gain of amplifier was increased from 12.89 dB to 13.172 dB. The aim of optimization is to improve the performance of an amplifier such as the gain, input and output return loss. For example, in the simulation using ADS software, tune parameter is used to tune the input (magnitude of S_{11}) and output matching (magnitude of S_{22}). Both of magnitudes are referred to the reflection coefficient, Γ which for the perfect matching, the value of Γ should be equal to zero.

The single tone harmonic balance simulation was done to plot the transducer power gain, the PAE, input power, P_{in}, and output power, P_{out}. Fig. 9 shows the transducer power gain versus frequency. The gain increases a frequency increases until 2.6 GHz. Then, after that frequency, the gain decreases as a frequency increases. At a 1-dB compression point, the gain is 9.012 dB at 2.4 GHz. The input 1-dB compression point is defined as the power level for which the input signal is amplified 1 dB less than the linear gain. When a power amplifier has operated in its linear region, the gain is a constant for a given frequency. However when the input signal power is increased, there is a certain point beyond which the gain is seen to decrease. Fig. 10 shows the relationship between PAE and frequency. PAE is directly proportional to output power, it takes a maximum value of 32.132 at 11 dBm input power and it takes a value of 24.951 at the 1-dB compression point. Fig. 11 shows the P_{out} vs. frequency which the response has same characteristic with the Fig 10. The output power is about 16.108 at 1-dB compression point.

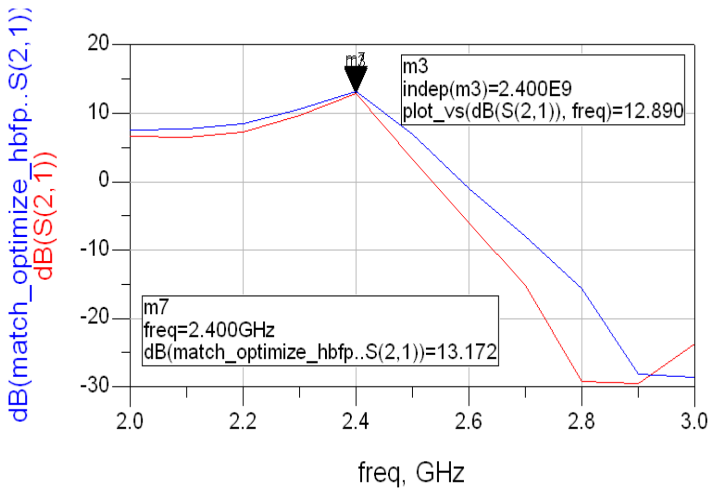

Figure. 8. Comparison of gain before and after optimization.

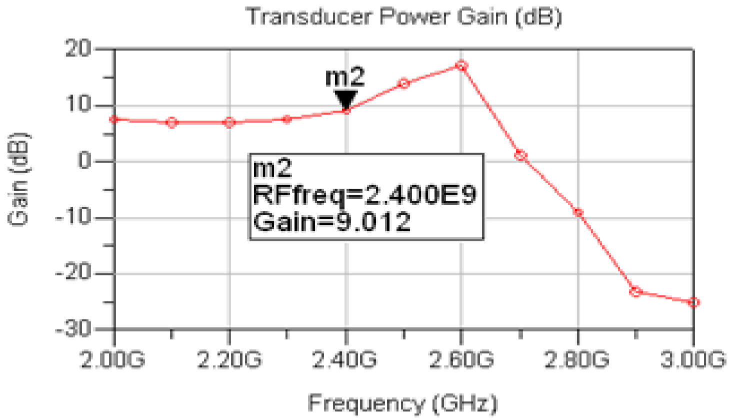

Figure. 9. Transducer power gain versus frequency

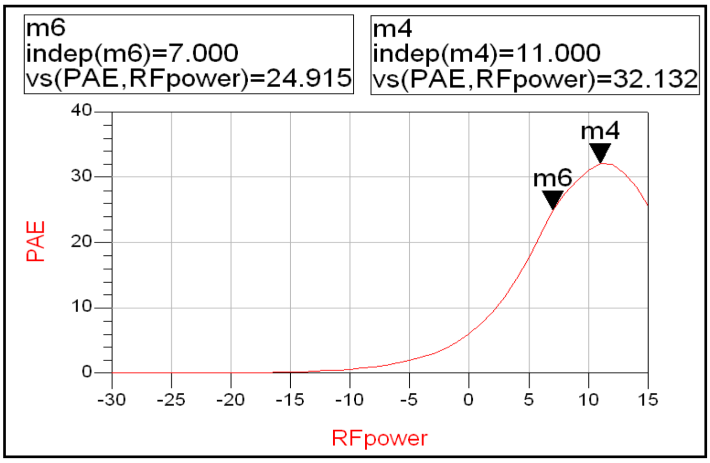

Figure. 10. Power Added Efficiency Vs. Input Power

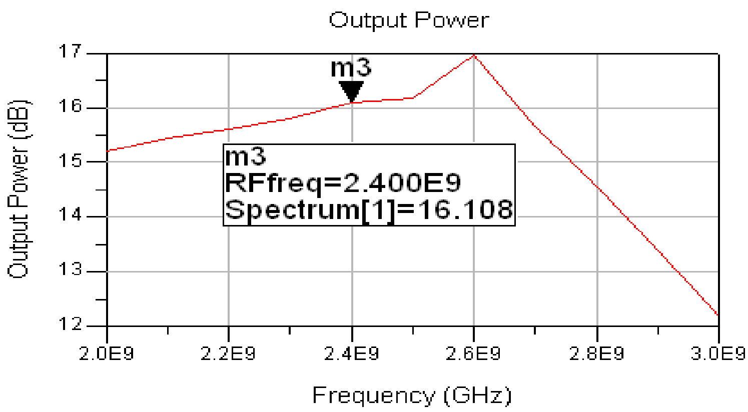

Figure. 11. Output power vs. frequency

IV. CONCLUSION

In this paper proposed designs and analysis power amplifier in the RAP at 2.4 GHz for RoF. In order to achieve that, an ADS model for the transistor, given from freescale, has been used in the designing process. The selection of transistor is the most critical part in the power amplifier design. From that, S-parameter at the operating frequency (2.4 GHz) is used to determine stability, maximum gain and matching network. Many aspects of the PA were considered when presenting the final results, as the power gain, output power, linearity, efficiency, PAE. At the optimal bias point for class A operation, the maximum output power is about 16.22 dBm and the PAE is approximately 41.84 %. Then, the power transducer gain after optimization of matching network is about 13.172 dB. The performance final implementation of power amplifier was examined using one tone and two tone simulations. At the 1-dB compression point the output power is found approximately 16.108 dB, the PAE is 24.915 %, and transducer power gain is 9.019 dB. All the results are meeting the requirement for a low power amplifier with operating in Class A and can be used for short range application (pico cell). So an interesting future work would be to improve the performance of the system and achieve a higher gain. The load pull technique can be used to determine the load impedance required for maximizing efficiency. From the two tone simulation, the other parameters also can be computes such as the intercept point and intermodulation.

V. ACKNOWLEDGEMENTS

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