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Simulation of 2.4 GHz Low Power RF Front End Design for Radio over Fiber Technology

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ABSTRACT

This paper presents the simulation low power RF front end design of radio access point (RAP) for Radio over Fiber (RoF) technology at 2.4 GHz. Wireless network based on radio over fiber (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. Pico cell has a coverage range up to 100 m. To achieve this distance, RAP needs to operate in active mode, by inserting RF power amplifier and Bandpass Filter (BPF) between EAM and the antenna for the downlink path. BPF is needed remove out of band interference after EAM while the power amplifier is used to improve the dynamic range of RAP. The implementation of the design is based on microstrip technology and Advanced Design System (ADS) software used to perform the simulation. In the simulation, the analyses of scattering parameters are concerned which presents the gain and return loss of the front end. At the end of design, the combination between parallel couple BPF and power amplifier is purposed as a RF front end of RAP for RoF technology.

Key words: Radio over Fiber, Radio Access Point, Power Amplifier, Bandpass Filter.

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INTRODUCTION

Wireless network based on RoF technology has been proposed as a promising cost effective solution to meet ever increasing user bandwidth and wireless demands. RoF is well established technology that used intensively worldwide for delivering radio signal from a central station to RAPs via an optical fiber [1]. 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 [2]. 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) [2]. 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 [3]-[4].

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 central station (CS). Consequently, the RAP becomes a small module that only consists of an EAM, filter, amplifier and an antenna. Figure 1 describes the basic diagram of RoF. 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 a wireless system, the operating range associated with the downlink is often different from that of the uplink. This is because the RAP and mobile terminal can operate with different transmitter power, antenna gains and also receiver sensitivities. For the passive mode of RAP, there are practical limitations on the amount of RF power that can be produced 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. A power amplifier is placed between the EAM and the antenna in order to improve the dynamic range of passive pico cell (RAP).

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.

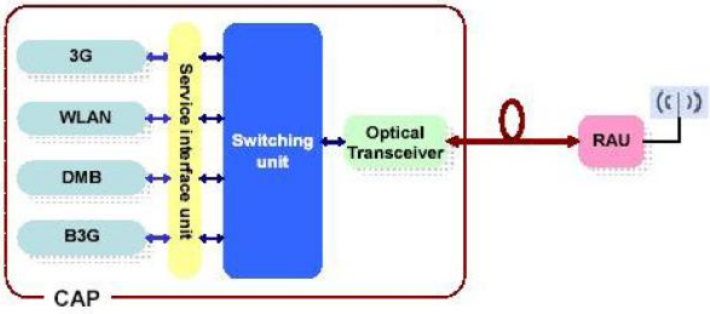

Fig. 1: RoF system block diagram [5]

Figure 2 shows the simple diagram representation of an active optical RAP [1]. 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. An advantage of using electrical amplification is that lower tolerance EAM can be used because their lower output signals can be offset by increasing the electrical gain. This is important for WLAN applications where the cost is an important consideration.

In this paper, the major goal is to design and simulate a power amplifier and BPF which at the front end of RAP for the downlink path using ADS software. The performance of front end design can be examined in terms of gain, input and output return loss.

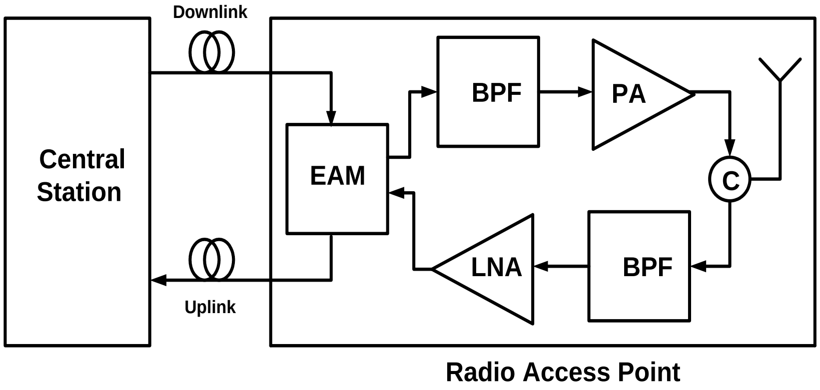

Fig. 2: Active optical radio access point

BANDPASS FILTER DESIGN

Basically, the design of BPF filter is based on the insertion loss method. The perfect filter would have a zero insertion loss in the passband, infinite attenuation in the stopband and a linear phase response to avoid signal distortion in the passband [6]. This method allows filter performance to be improved in a straightforward manner, at the expense of a higher order filter. There's four main steps of BPF design which including a design specification, low pass prototype design, scaling and conversion and implementation. The filter specification is shown in Table 1.

The performances of bandpass filter using lumped element, parallel couple and hairpin line are compared. The comparison is based on the response of insertion loss (S_{21}) and input return loss (S_{11}). The lumped element BPF is used as reference for the ideal case. From the simulation, S_{21} of parallel couple BPF is less compared to the hairpin line BPF at the passband. However, the response of hairpin line have a sharper cutoff compared to parallel couple BPF in the stop band. Figure 3 shows the comparison of S_{21} for lumped element, hairpin line and parallel couple. According the Figure 4, the S_{11} of parallel couple is less than hairpin line at the center of frequency. Therefore, the performance of parallel couple is better than hairpin line because it more power reflected for the hairpin line. It can be concluded that the parallel couple performed better at the passband while at the stop band, the performance of hairpin line is better compare to parallel couple. In terms of the fabrication process, the hairpin line is complex because the filter is compact structures. There are more parameters are needed to consider for the hairpin line filter compared to parallel couple such as coupling coefficient.

Table 1**:** Band Pass Filter Specifications

Filter Specifications	Values
Center Frequency, f_c	2.442 GHz
Upper cutoff frequency, f_2	2.4835 GHz
Lower cutoff frequency, f_1	2.4 GHz
Bandwidth	0.0835 GHz (3.42 %)
Response	Chebyshev (0.2 ripple)
Min. Stopband Attenuation	At least -25 dB at 2.5 GHz
Implementation	Parallel coupled and Hairpin Line
Input / Output Impedance	50 Ω
Substrate	Roger 4003C

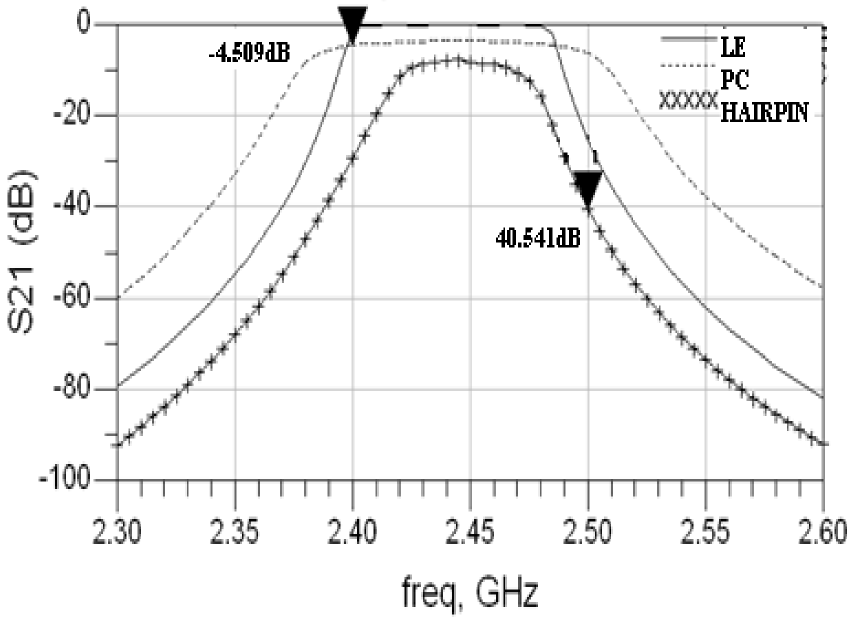

Fig. 3: Comparison of S_{21} for lumped element, hairpin line and parallel couple.

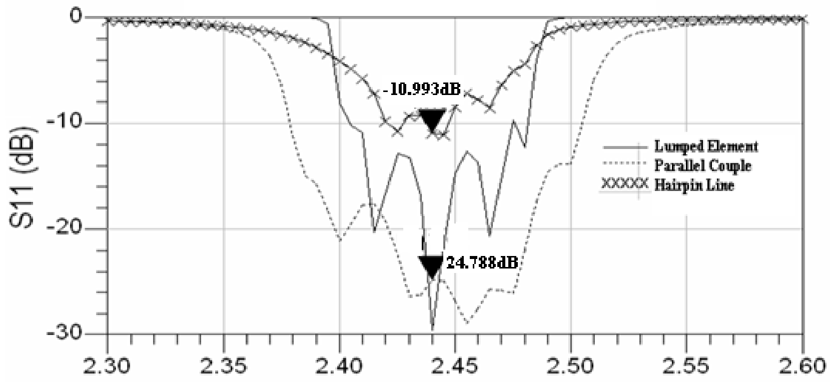

Fig. 4: Comparison of S_{11} for lumped element, hairpin line and parallel couple.

POWER AMPLIFIER DESIGN

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. 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.

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. Designing a power amplifier consist on different steps. First of all a DC simulation must be done to find the optimal bias and bias network for the system. Then S-parameter simulations is done to find exact value of the S-parameters and to evaluate the stability of the model at the operating point. After that 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 [6]. Finally the whole system is optimized to achieve the better output power, efficiency and gain.

The performance of transistor at the optimal bias value is based on class A amplifier design. The maximum output power of this transistor is 16.22 dBm which the transistor can be used for picocell application (less than 20 dBm). Transistor I-V curves with the optimal load line for the class A operation is shown in Figure 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.

Figure 6 shows the simulation of stability factor of amplifier. The system is the unconditional stability due to |Δ| < 1 and K > 1 which mean that amplifier is stable for all passive source and load impedance. After the stability of the transistor have been determined, and the stable regions for 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.

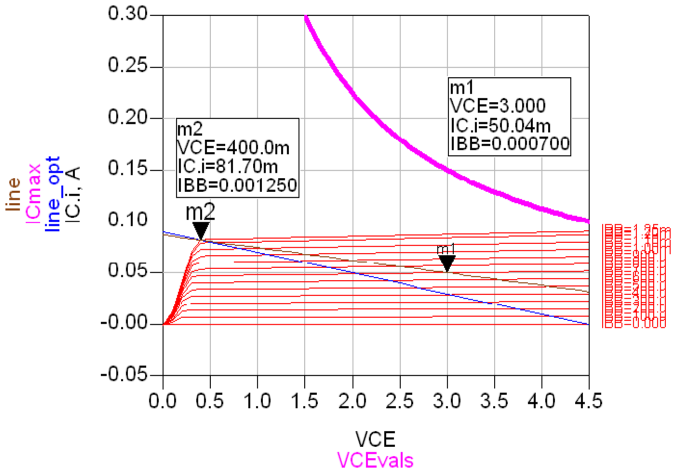

Fig. 5: I-V curves.

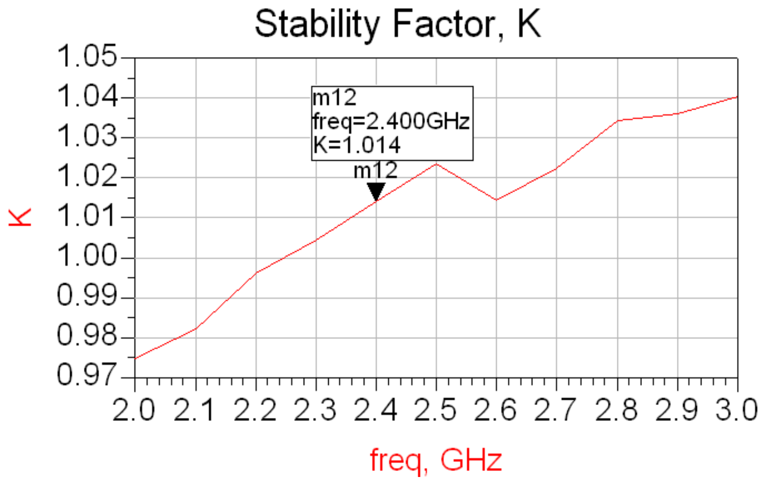

Fig. 6: Simulation of stability factor, K .

Simulation maximum gain will be realized when matching sections provide a conjugate match between the amplifier source or load impedance and the transistor. Figure 7 shows the simulation of effective gain. The important factors in the selection of a particular matching network include complexity, bandwidth, implementation and adjustability. The single stub matching technique is used to obtain the input and output matching. From this matching technique, the distance and length of stub, are acquired which open circuit shunt stub is used to find the length of stub. The transformations from Smith chart to microstrip lines (MLIN and MLOC) are obtained by using ADS Line calculator, LineCalc. The optimization of input and output matching is needed to improve the performance of amplifier. The width and length of microstrip 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 is referred to the reflection coefficient, Γ at the input and output. 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.

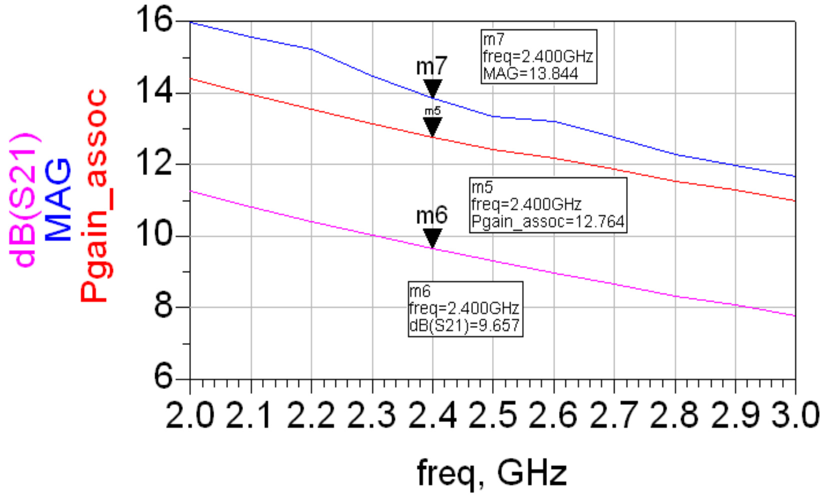

Figure 7: Simulation of effective gain.

FRONT END DESIGN

The simulations of the front end are based on the combination between bandpass filter and power amplifier. The analysis only based on the gain (S_{21}), input return loss (S_{11}) and output return loss (S_{22}). Figure 8 shows the comparison between power amplifier and bandpass filter (lumped element, hairpin line and parallel cable) for a gain of the front end. The maximum gain is at 11. 929 dB for the front end (using lumped element) and followed by using parallel couple (8.494 dB) and hairpin line (-15.473 dB). The gain is depending on the transducer power gain from the amplifier and also the insertion loss of the filter in the passband. The hairpin line filter has a large insertion loss compared parallel couple. Therefore, the gain of front end using hairpin line presented the worse the performance. The gain of the front end will affect the overall performance of RAP especially the dynamic range.

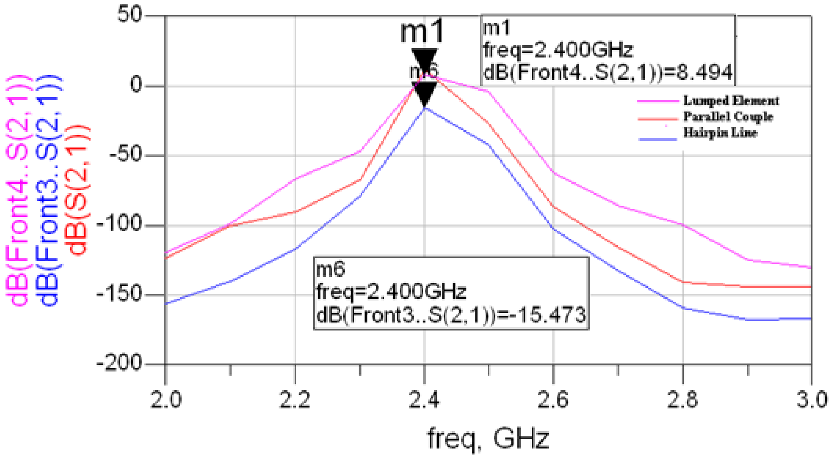

Fig. 8: Comparison of gain for front end

Figure 9 shows the input return loss of the front end. The return loss presented the amount of reflected incident power to the source or load. Hence, with increases of return loss but the total reflected power will decrease. The front end using parallel couple filter gives a better performance compared to using hairpin line and lumped element. The response of output return loss also presented the same characteristic with the input return loss. However, there are having small differences value of return loss of input and output. For example the input return loss front end using parallel couple filter is about - 17.044 dB, while the output return of that front end is about - 17.211 dB.

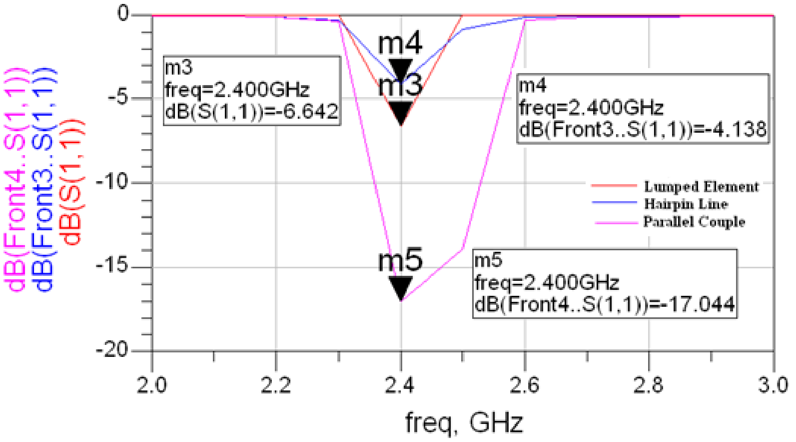

Fig. 9: Comparison of input return loss for front end

OVERALL RESULT ANALYSIS AND DISCUSSIONS

The RF front end design of RAP was successfully simulated using ADS software. The front end consists of BPF and PA which used for the RoF technology. Both of components are placed after the EAM in the RAP. The BPF is used for remove out the band interference of operating frequency at WLAN 2.4 GHz band. While PA can be used for increases the power level of the signal which satisfied for the picocell application.

There has three important procedures in BPF design. The procedures are determined the LPF prototype from bandpass filter specifications, transformation to BPF and implementation of the filter. The implementation of the BPF is based on microstrip line where using the parallel couple and hairpin line. The lumped element BPF also is used as reference to the ideal case. Hence, the performance of BPF is depending on insertion loss and return loss which the insertion loss of parallel couple BPF is less compared to the hairpin line BPF at the passband. However, the response of hairpin line have a sharper cutoff compared to parallel couple BPF in the stopband. The perfect filter would have a zero insertion loss in the passband and infinite attenuation in the stopband.

Subsequently, 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 final stage of simulation is to perform the front end which combination between PA and BPF. The most important parameter considered in the front design is the gain (S_{21}) Based on the simulation, front end using lumped element BPF give the maximum gain at 11.172 dB and the gain produced from the front end using parallel couple BPF is about 8.494 dB. The gain is controlled by the gain from the power amplifier and also the insertion loss of BPF in the passband. Therefore, the maximum gain from power amplifier design and less insertion loss of BPF is concerned. The maximum gain can decrease the nonlinearity effect of fiber. The effect will cause the much loss for the system. In the RAP, the gain of the front end will increase the dynamic range of the overall system. However, in the RoF technology, the other factors would be considered for RAP design are costs, length of optical fiber link, properties of laser and operating frequency.

CONCLUSION

In this paper, the combination between parallel couple BPF and low power amplifier is purposed as RF front end of RAP for RoF technology at 2.4 GHz. So an interesting future work would be to improve the performance of the system and achieve a higher gain. The simulation of BPF can be enhanced by simulating that filter using electromagnetic structure or called momentum in ADS software. Implementation of BPF also can be done by using the other type such as comb line and interdigital. While for PA design, 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.

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