Performance Enhancement of Power Amplifier Class AB Push-Pull Using Component Balun and Invert Doherty Combined with Negative Feedback

Sutthiphong Kophon, Peerapong Uthansakul, Monthippa Uthansakul, and Sampart Cheedket

***Abstract*—The System of storage ring in Synchrotron Light Research Institute (SLRI) is designed to compensate electron energy in storage ring using a cavity tuner. The cavity acquires a power from vacuum tube amplifier around 30-35 KW at the operating frequency of 118 MHz. To maintain such a high power, the system requires Power Amplifier (PA) having a high efficiency by solid state technology. This amplifier is a class AB push-pull type which has three important parts including Balun, matching circuit and DC bias. In this paper, we use Invert Doherty combined with Negative feedback to improve the PA performance. Invert Doherty technique can improve the efficiency of PA but the circuit is non-linear so it causes non-linear performance. Hence, in this paper, the authors propose a negative feedback in conjunction with invert Doherty for increasing linearity and power efficiency of PA. Also the use of lumped element instead of microstrip line in balun circuit is proposed to obtain the best efficiency. The performance measurement of Invert Doherty power amplifier combined with negative feedback (IDPA-NF) is presented and it is compared to the conventional PA with the same matching circuit. The results show that the proposed system can significantly improve the efficiency of class-AB amplifier.**

***Index Terms*—Power amplifier, balun, Invert doherty, negative feedback, class AB push-pull amplifier**

I. Introduction

The Class AB amplifier is a compromise between Class-A and Class-B in terms of efficiency and linearity. Typically the transistor is biasing to a quiescent point, which is somewhere in the region between the cutoff point and the Class A bias point. In this case, the transistor will be ON for more than half a cycle (like class B), but less than a full cycle (like class A) of the input signal [1]. Conduction angle in Class-AB is between 180^o and 360^o and efficiency is between 50% and 75%. The principle of PA push-pull is to use two identical transistors and each transistor amplifier works on a half periods. This process makes system both high gain and high efficiency.

In general, there are three important parts of PA push-pull including with Balun circuit (BALance / UNbalance circuit), DC bias, and Matching circuit. The Balun circuit separate one input signal into two output signals with 180^o phase difference. Also the circuit can work as a reversible operation to combine two signals into one [2]. There are two necessary Balun circuits for push-pull PA type for input and output sides. Normally, the input side has 50Ω impedance. It means that the input Balun has to be matched with 50Ω and both outputs are 25Ω [3]. As a result, the input signal of two identical transistors has the same equal impedance with 180^o phase difference. Consequently, both transistors are able to perfectly amplify their half period. One transistor is in a positive amplifier side and the other is in a negative amplifier side [4]-[5]. Then, at the output side, the other Balun circuit combines two output signals from transistors. It is obvious that the performance of power amplifier will be degraded if both sides of Balun circuit are not perfectly matched. Next part is a DC Bias. DC bias is a source power of PA. In this paper, we use DC bias 48Vdc at drain source and 2.5Vdc at gate source. The last important part is a matching circuit. Matching circuit is a circuit for matching impedance between balun and transistor. The matching network is very important to PA because, if PA has a mismatch between transistor and balun then the power efficiency and gain are poor [3].

Improving the performance of PA can be performed in part of Balun and Matching circuit. If we design two parts properly, then the power amplifier efficiency (PAE) and gain of PA can be enhanced. In this paper, the authors present the concept of using lumped elements such as capacitors instead of microstrip line for Balun matching and two interesting techniques for increase PAE performance. Two techniques are invert Doherty and negative feedback. The Doherty amplifier is a technique for improving the PAE. However, the drawback of using invert Doherty is the non-linear performance. In order to improve the linearity, the combining of negative feedback is proposed to solve the problem of non-linearity. This is very important to the project of SLRI because the non-linearity can cause the unexpected signal spurring in the cavity tuner. Hence, the authors focus on both efficiency improvement and linearity control

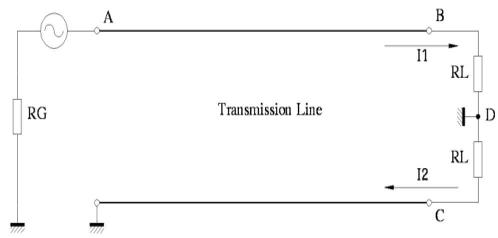

Fig. 1. Balun operation

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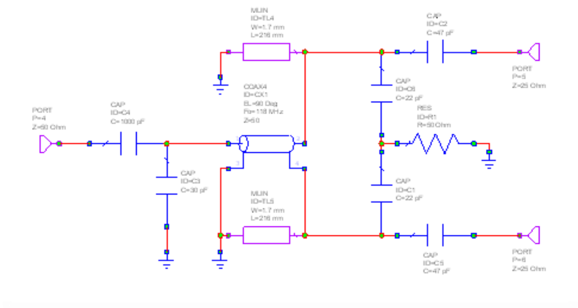

Fig. 2. Balun design with microstrip line

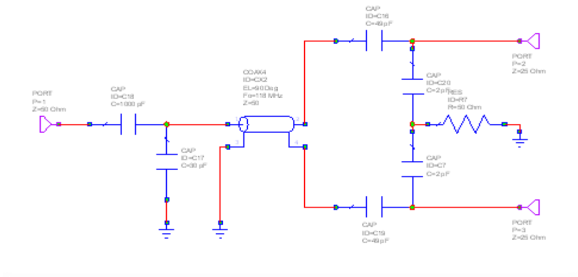

Fig. 3. Balun design with lumped element

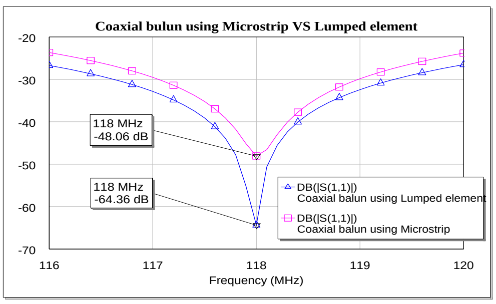

Fig. 4. Return loss of coaxial balun using microstrip and lumped element

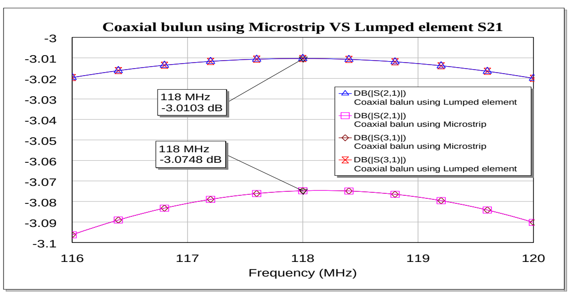

Fig. 5. Transition coefficient of coaxial balun using microstrip and lumped element

II. Balun Performance

There are two Balun circuits required for a push-pull PA type. When the input signal is separated into two output signals with 180^{o} phase difference, the operating circuit is called as input Balun. In turn, the combination of two output signals from transistors is called as output Balun. Both Balun circuits can be similarly designed. In general, the Balun designs are classified into 3 types. There are conventional coil transformer, transmission line transformer and microstrip structures (Wikinson Divider ; Line and Hybrid Ring) [4]. The usability depends on frequency and power. In case of frequency less than 1GHz, it should be either transmission line or conventional coil transformers. On the other hand, the microstrip structure is used for frequency more than 1 GHz. In this paper, the operating frequency is 118 MHz with 1KW power so the choice of transmission line transformer is appropriated.

The theoretical circuit of transmission line transformer is shown in fig. 1. The operation of separated signals of Balun circuit is explained by considering a movement of current in transmission line (coaxial). In fig. 1, the current flows into load RL at point B and it flows out from load at point C with equal quantity but the opposite direction in comparing with ground at point D. If we consider signals at point B and C, the phases of signals at point B and C are different by 180^{o}. Generally, the length of transmission line (coaxial) is $\lambda/4$ or $\lambda/2$.

In general, the matching design of Balun circuit for class AB push-pull PA type use a microstrip line and shunt capacitor between coaxial line of Balun with shown in figure 2. This circuit can optimize a return loss by adding or reducing either width or length of microstrip line. With many drawbacks mentioned in the introduction, the paper present the use of lumped element instead of microstrip line. The new circuit using adjustable capacitor is shown in figure 3. It can be obviously seen that the new circuit is less complexity and easy to be implemented. Fig. 4 shows a comparison of return loss, S(1,1), between using microstrip line and lump elements. The results in this figure show that Balun with lumped element has return loss 16.3dB better than microstrip line at 118 MHz.

III. Inverse Doherty Power Amplifier (IDPA)

Invert Doherty Power Amplifier is a technique for improving the PAE. In a Doherty amplifier, the output powers of two amplifiers operating at a proper phase alignment and bias level are combined using a quarter-wave transmission line without the use of any additional components [6]. The classical Doherty amplifier configuration is illustrated in Fig. 6.

In general, the IDPA is used for aligning signals before sending them into transistor and before combining output signals. However, for the part of input transistor, the length is very short. Then, in this paper, the PA has ID only on output side. The calculated transmission line for ID technique is approximate at 25 ohm. The result of PA when adding ID technique will cause the power efficiency more non-linear. This is because ID technique provides the best performance based on transmission line matching in which its response is non-linear function to output signal. In this paper, the authors propose the combining of negative feedback technique with ID technique to solve the non-linear problem.

IV. Negative Feedback (NF)

Negative Feedback is a technique to feedback signal from output of transistor (Drain) to input of transistor (Gate). That feedback process will perform a subtraction between input signals with feedback signal. In this paper, the authors choose the component circuits such as capacitors and resistors to perform the feedback signal. The negative feedback technique can greatly improve the PA performance including with a non-linear distortion, log-gain stability and band pass width [7].

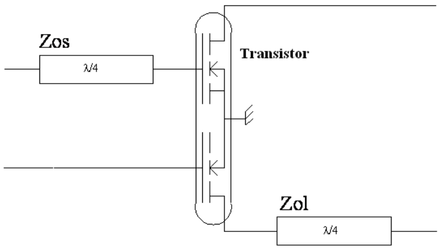

Fig. 6. Schematic diagram of the classical Doherty amplifier.

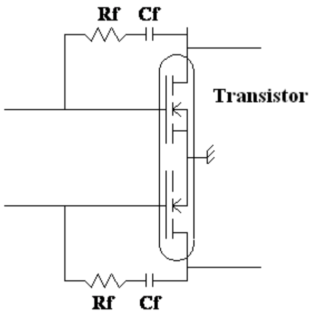

Fig. 7. Schematic diagram of Negative feedback amplifier.

Although the PA performance is more linear when using a negative feedback but its drawback is on the matching input. The matching unit of feedback technique degrades S11 performance but in a little. Hence, it is a perfect choice for applying feedback technique with IDPA in order to solve a linearity problem. Then, the proposed technique offers the higher efficiency as well as a good linear performance.

V. Power Amplifier Performance

The selected PA type in this paper is aimed to practically implement for the project of SLRI at 118MHz. It is used for cavity driving in storage ring of SLRI. The authors design power amplifier in Class AB push - pull type. For this type, there are three important parts including Balun circuit, matching circuit and DC bias. The design of each part will affect to operation, efficiency and stability of PA. The first key factors on designing PA for a task of SLRI are power efficiency and return loss. If the value of return loss is too high, it means that the risk of generator breakdown is very high. In this paper, the design of PA neglects a harmonic problem because the cavity has a reliable low-pass filter [8].

For SLRI project, the transistor chip BLF578 is selected for purpose of power amplifier because it provides an excellent ruggedness, a good thermal stability and high power efficiency [9]. This device is a product of NXP semiconductor. It can operate in a frequency band of 10 - 500 MHz with a supply voltage of 50 V. For typical use at 225 MHz, the load power is 1200W and power Gain is 24dB with 71% power efficiency [10], [11]. This device is sensitive to Electro Static Discharge (ESD) and a storage temperature is limited to 150°C. However, the low level system of SLRI project operates at 118 MHz. Therefore, the designs in this paper focus on this frequency operation and try it best to fit the highest performance at 118 MHz.

VI. Simulation

The simulations of PA class AB push-pull are performed via Microwave office (AWR). The input power of 0.8-2 watt (29-33 dBm) is set.

The results of return loss S(1,1), are shown in Fig. 8. The return loss of PA using Balun with lumped element is 14 dB better than microstrip line. To consider the power efficiency of PA, the results are shown in Fig. 9. The efficiency of PA is 79% and 76% at typical 36 dBm when using lumped element and microstrip line, respectively. The power gain are also measured and shown in Figure 10, respectively. However, there is no significant difference in power gain.

Fig. 11 presents S-parameters of the best fit design at 118 MHz. As seen in this figure, the invert Doherty technique can decrease the value of S11 which it means that the reflected power also decreases. Consider a negative feedback technique; the S11 performance is slightly increased. It means that the feedback slightly destroys a PA matching. Also in this figure, the proposed technique that combines invert Doherty and negative feedback can improve the S11 performance.In fig. 12, the PAE performance of PA is presented. For a normal PA, it has PEA 76.3% at input 30 dBm. When applying an invert Doherty, the PAE increases to 76.75%. However, the effects of IDPA cause the non-linear results of PAE performance. After taking a negative feedback to PA, there is no change to PAE performance. For the case of IDPA combined with negative feedback, the PAE performance is obviously improved to 78% as shown in fig. 12.

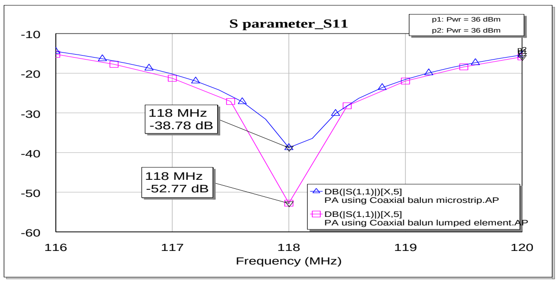

Fig. 8. Return Loss of PA using Balun with lumped element and PA using Balun with microstrip line

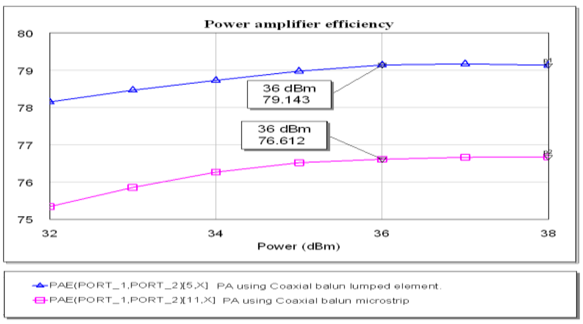

Fig. 9. Power amplifier efficiency of PA using Balun with lumped element and PA using Balun with microstrip line

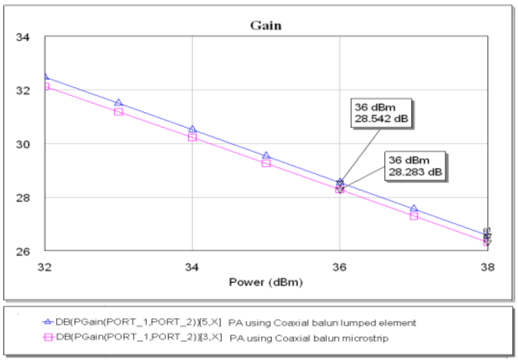

Fig. 10. Power amplifier Gain of PA using Balun with lumped element and PA using Balun with microstrip line

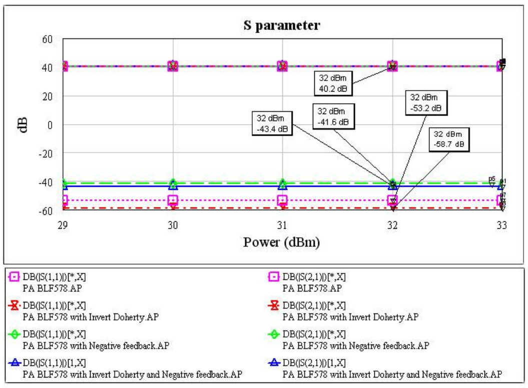

Fig. 11. Simulation of PA in S-parameter

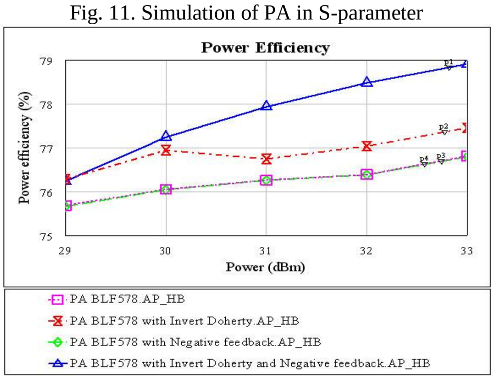

Fig. 13. Simulation of PA in power gain.

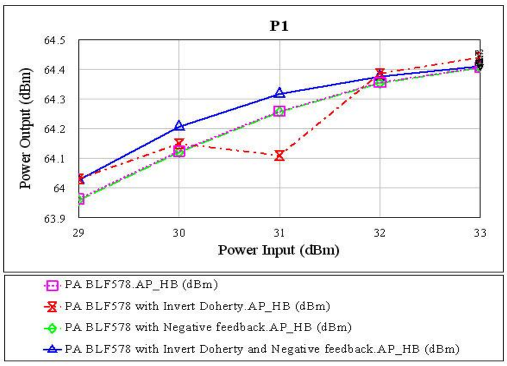

Fig. 14. Simulation of PA in P_{1dB}

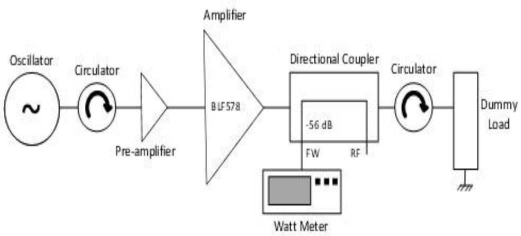

Fig. 15. Block diagram of power efficiency measurement

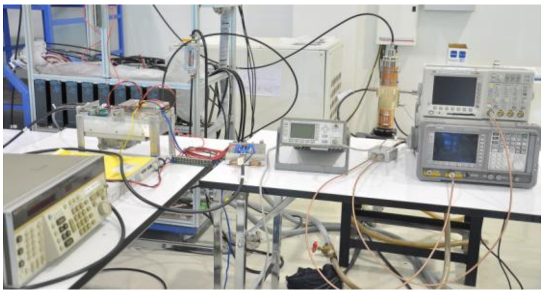

Fig. 16. Measurement setup

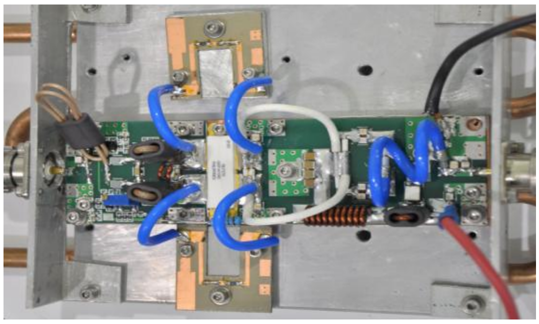

Fig. 17. The prototype of IDPA combined with a negative feedback.

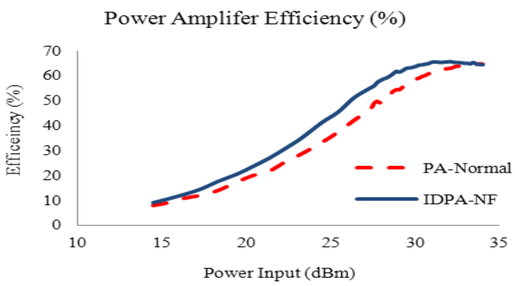

Fig. 18. Measurement of PA in power efficiency

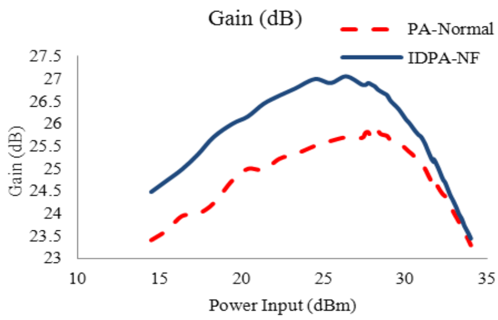

Fig. 19. Measurement of PA in power gain

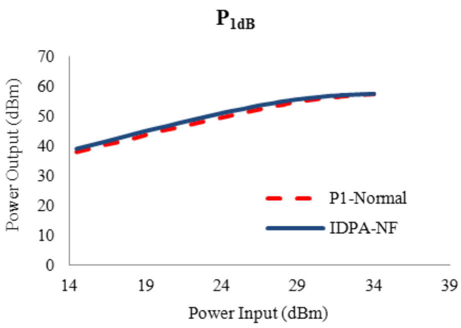

Fig. 20. Measurement of PA in $P1_{dB}$

The power gain of PA is also tested and shown in fig. 13. It is noticed that the power gain of PA when an invert Doherty technique is used can increase gain but the non-linear problem is a tradeoff. As expected, the use of IDPA combined with negative feedback increases the power gain along with linear property.

Fig. 14 shows the performance of power input comparing with power output (P_{1dB}) in a dBm scale. The results confirm the same trends as described in fig. 12 and fig. 13.

VII. Measurement

For measurements, the block diagram of power efficiency measurement is shown in figure 15 and the real equipment setup is shown in figure 16. The real prototype of IDPA combined with a negative feedback is shown in figure 17. In our measurement, the directional coupler is used to tap a small output signal and then it is measured by power meter. The limitation of tested output power is around 800W because the circulator has a power limit at 800W.

The measured results of power efficiency are shown in figure 18. It is obviously seen that the trends of measurement are the same as simulation. However, the measured values are less than the ones in simulation because the unexpected loss occurred within the real prototype.

In figure 19, the measured results of power gain are presented. It is interesting to observe that the trends are different from simulation. In measurements, the proposed technique can improve power gain with a significant.

The results of P1dB are also measured and shown in figure 20. The results confirm that the proposed technique can improve the system performance in both simulations and measurements.

VIII. Conclusion

This paper presents the concept of using lumped element instead of microstrip line for better matching impedance of Balun circuit which is a main part of push-pull PA type. The performance of PA class AB push-pull can be enhanced by improving balun circuit and adding invert Doherty technique but the non-linear property is its drawback. Thus, this paper proposes the negative feedback to combine with invert Doherty power amplifier to fix the drawback. Three system performances including with power efficiency, power gain and power input/output ratio are investigated. Both simulation and measurement results confirm that the proposed system can improve performance of PA class AB push-pull.

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