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New Techniques for High Efficiency Microwave Amplifiers

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ABSTRACT
High efficiency is essential in microwave amplifier technology to optimize its capability and usage. With the variety of usage of the microwave amplifier especially in this changing and innovative technological era, it is imperative that new techniques will be determined or developed to come up with the possible highest efficient amplifiers. Digging deep into different related literatures or research studies regarding the topic, this paper was able to collect and identify the different techniques for high efficiency microwave amplifier. This techniques include the **a**pplication of Dynamic Adaptive Buck-Boost Supply, Envelop Tracking Technique, Envelop Elimination and Restoration or Kahn's Technique, and some strategies under hardware implementation techniques such as the directional coupler and power detector, non-inverting buck-boost converter, and the dynamic gate bias generation circuit. This study is expected to impart these collected techniques available for future researches, possible modifications and further enhancement in terms of microwave amplifier technology efficiencies.

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I. INTRODUCTION

The world of telecommunications has evolved throughout the years and gave way to advance innovations especially when it comes to producing high efficiency products. These innovations are results of continued search for better techniques or designs to enhance the efficacy of existing products or materials. This innovation is also true to the world of microwave amplifier technology.

What is Microwave Amplifier?

Microwave amplifier is defined as a device being used to enhance the output power signal of a microwave device through increasing the amplitude or height of the wave that is relative to its power level. This is being done through channeling added input power to the device in order for the microwave radiation to carry more energy (Wise Geek). Microwave amplifier is commonly used in a wide variety of application which includes wireless communication, jamming, imaging, radar, and radio frequency (RF) heating (Raab, Asbeck, Cripps, Kennington, Popovic, Pothecary, Sevic & Sokal).

There are different classifications of microwave amplifier, and these include the low noise amplifier or the LNA, which is considered as the most straightforward microwave amplifier due to its relative insignificance of nonlinear effects and low input power. This amplifier is usually designed to take very low signal level and amplify it without the presence of so much noise. This type of amplifier however are narrowband as it optimizes the noise figure of its transistor ("An Introduction to Microwave Amplifiers Part 1: Microwave Amplifier Applications"). Another type is the power amplifier, which is the exact opposite of low noise amplifier. It usually takes signals that are already at a high level and boost it for transmission over lossy medium. Among its important parameter is the saturated output power. Aside from power amplifier, the linear signal amplifier is also another type of microwave amplifier, which is also called as generic amplifiers. Among its main application is to offset system losses. It provides signal gain within a system and has a higher power levels compare to the low noise amplifier and has a lower power level compared to the power amplifier. The other type of microwave amplifier is the driver amplifier, which is used for single frequency operation. Its main role is to integrate into the transceiver chip as a CMOS circuit and amplify CW signal.

There are different classes of microwave/RF amplifiers. These classes include the following:
Class A Amplifiers – This is the most common type of amplifier due to its simple design. It is regarded as the best class due to some specifications such as low signal distortion level and has the best sounding quality. It also has the highest linearity compare to other microwave amplifiers. This class utilize single transistor which is connected in a common emitter configuration. However, class A amplifiers has some disadvantages such as the continues loss of power in the amplifier due to its always "ON" specifications in the output device. This creates a high amount of heat which lead to the reduction of its efficiency at around 30% (Electronics Tutorials).

Class B Amplifiers – Class B Amplifier was developed as an innovation to the inefficiencies or heating problems associated with the Class A amplifier. This type of amplifier utilizes two complimentary transistors. There is no DC base bias current, making it more efficient as compared to class A amplifier since the DC power is usually small. Its efficiency is almost 50% compared to the Class A. One of the downside of the Class B Amplifier is that the output transistor is nor biased to an "ON" state of operation until voltage exceeded, making it unsuitable for precision audio amplifier applications (Electronics Tutorials).

Class AB Amplifier – It is a combination of class AB amplifier. It has two transistors with relatively small bias voltage. Its conducting device is "ON" for more than one half cycles but less than one full cycle of the input signal. One of the advantages of the class AB amplifier is the small bias voltage which overcomes the crossover distortion created by class B amplifier and the inefficiencies of class A amplifier design (Electronics Tutorials).

Class C Amplifier – this class is considered to be of greatest efficiency, however, it also has the poorest linearity of all the amplifier classes. Its transistor bias gives a more improved efficiency of about 80% , but it also produces a relatively heavy distortion of the output signal, making it unsuitable to be used as audio amplifiers. It is commonly used in the high frequency sine wave oscillators and other functions where the produced pulses of current can be converted to complete sine waves (Electronic Tutorials).

Other Classes – Aside from the Class A, AB, B and C amplifier classes, there are other types of amplifiers in the market and these include the Class D amplifier, which is also non-linear and can reach 100% efficiency; the Class F Amplifier, which could boost efficiency and output through the use of harmonic resonators. It has 90% or more efficiency. Another class is the Class G Amplifier, which is the enhanced version of class AB design. It uses multiple power supply with various voltages. Also, there is the Class I Amplifier, which has two sets of output switching- which switches the positive and the negative half of the waveform. The class S Amplifier, on the other hand is a non-linear switching amplifier which operates almost the same as the class D amplifier. It could reach an efficiency of about 100% due to its zero power dissipation. Another class is the Class T Amplifier, which uses a digital switch design. It is most commonly used as audio amplifier considering its digital signal processing chips. It has a combination of low distortion signal levels of class AB amplifier and the efficiency in power of the class D (Electronics Tutorials). .

High Efficiency Microwave Amplifiers

Like any other amplifying systems, there is a need for a highly efficient microwave amplifier. It is important in the reduction of the size, weight while increasing the output power, battery life, and reliability of the transmitters. Through increasing the efficiency of the microwave amplifier somewhere between 50 to 90% the dissipated heat power is reduced (Mader, Bryerton, Markovic, Forman, Popovic).

Power amplifier efficiency is usually measured using the following formula:

$$PAE = \frac{RF_{out} - RF_{in}}{RF_{DC}}$$

Where,

PAE = Power-added Efficiency of the Amplifier

RFin = Amplifier Input Power

RFout = Amplifier Output Power

RFDC = Amplifier DC Power Input

There are different definitions of efficiency when it comes to microwave amplifier and these include the drain efficiency, which refer to the ratio of RF output power to DC input power; power added efficiency is the incorporation of RF drive power by subtracting it to the output power; and the over-all efficiency can be used in all situations, and can include driver DC input power, power consumed by supporting circuits, and others (Raab, et al.).

There is also a so called average efficiency or the instantaneous efficiency, which refers to the one specific output level and is the highest at the peak output power and decreases as the output deceases. Average efficiency is also defined as the ratio of the average output power and the average input power of the DC (Raab et al.).

Through the years, as the electronic technology continue to progress, several innovations were make to enhance the efficiency of microwave amplifier technology. This paper will discuss new available techniques to increase the efficiency of microwave amplifier.

Objective

This research study aims to discover new techniques to make microwave amplifiers more efficient. Through an integrated review of relevant literatures, this study aims to pinpoint ways or designs for highly efficient microwave amplifier to aid amplifier developers as well as users on which design would enable them to save costs, energy and effort when it comes to such topic. This study will also help to determine available technology and designs, which will be of help in future researches and modifications for a more or highly efficient microwave amplifiers.

Content
This section will discuss the methodology used in this research study, the results, and also it will discuss the new techniques available in improving the efficiency of microwave amplifier technology in the market today.

Methods

This study uses an integrated review of different available literatures regarding microwave amplifiers and looked for new techniques discovered for highly efficient microwave amplifier. Using sources from electrical engineering journals and other reliable sources, this writer compiled relevant researches and studies leading to the topic, and make a meta-analysis to come up with what is the newest and best technique to make microwave amplifiers more efficient.

II. RESULTS

Characteristic of Highly Efficient Microwave Amplifier

In order to understand how microwave amplifier efficiency is achieved, it is important to know or define the characteristics of a highly efficient microwave amplifier. The following are some of the parameters which comprise or affect an effective microwave amplifier technology:

- Proper Impedance Matching – impedance matching is important in power amplifier design particular in terms of power output, gain and efficiency. Improper matching of impedance degrades stability and reduce the efficiency of the circuit. The resonated impedance is somewhere less than 50 **Ω** to much higher to avoid problem (DeBloois).
- Thermal Management – Thermal management in a microwave amplifier technology refers to the removal of heat from sensitive areas of the amplifier to avoid damage or degradation of performance. It is being done through providing the proper mix of thermally conductive materials so that heat is extracted from the source such as transistors or thermal pathways. Thermal management must be among the highest priority in any microwave amplifier design for long-term reliability especially if the amplifier has to operate o a high power levels (Browne).
- Bandwidth – In modern wireless communication, bandwidth is highly important in achieving high efficiency. In realizing a highly efficient power amplifier within a wider bandwidth is very critical since the increase of bandwidth most often reduces the efficiency of power amplifier. In this regard, a proper design is needed to optimize both the bandwidth and amplifier efficiency (Chen).
- Linearity – Linearity is the measure of output current and the clarity of voltage waveforms. Many amplifying technology such as the microwave amplifier demand strict requirements when it comes to linearity. Problems in linearity could posed problems within the system such as harmonic distortion and reduce the efficiency of the power amplifier (Altanany).

New Techniques/Designs for Highly Efficient Microwave Amplifier

The future of wireless communication is innovating and is required to operate at different standards and applications. This calls for the continuous upgrade of power amplifiers especially when it comes to efficiency and be able to operate over broad frequency range. Through the years, there have been several techniques tried and implemented to optimize the efficiency of microwave power amplifier. Among these techniques include the harmonic phase tuning which enables to reflect power back to the device and optimize the power supply voltage to maximize the power-added efficiency. There were also the Doherty amplifier technique and the linear amplification control, which further improved the efficiency of power amplifiers. But due to the complexity of both techniques, these became less attractive for system-on-chip solutions (Sahu & Rincon-Mora).

Recently, there were different research studies aimed to look for techniques in maximizing the efficiency of the microwave amplifiers. There are different techniques with varying level of efficiency and complexity that were discovered and some of these include the following:

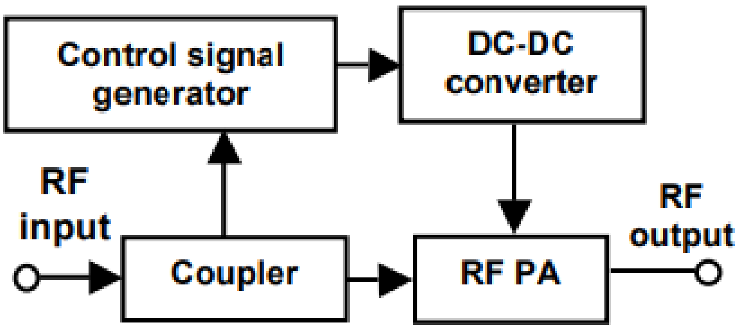
1. Application of Dynamic Adaptive Buck-Boost Supply – Sahu and Rincon-Mora tested a dynamic adaptive buck-boost converter supply to increase the efficiency of RF/microwave amplifier. The schemes used for this technique aim to improve the efficiency of microwave amplifier using dynamic supplies that are classified into non-linear PA with a linearization circuit and linear PA with an efficiency-enhancement circuit. The control signal is generated from the input signal through a directional coupler and detector circuit or a base-band processor (Sahu & Ricon-Mora).

The experiment resulted to 88% efficiency in terms of battery life compared to a fixed power supply, while at the same time maintaining the other needed requirement such as the linearity of CDMA IS-95 specifications. This led to their conclusion that dynamic adaptive buck-boost converter supplied power amplifier has a significant impact the optimizing the performance of an amplifier regardless if the battery is near empty (Sahu & Rincon-Mora).

2. Envelop Tracking Technique - The envelop tracking technique is an innovative strategy which improve the efficiency of RF/microwave power amplifier. This is commonly used in smartphones and other kinds of applications where amplifier efficiency is needed. This technique is also being utilized in broadcast transmitter systems and cellular communications as it provides significant advantages when it comes to minimizing the power used and significantly helps in saving battery life of the amplifier. This technique clearly reduces the dissipation of power since the system supplies the needed supply voltage instead of the power amplifier (Electronic Notes).

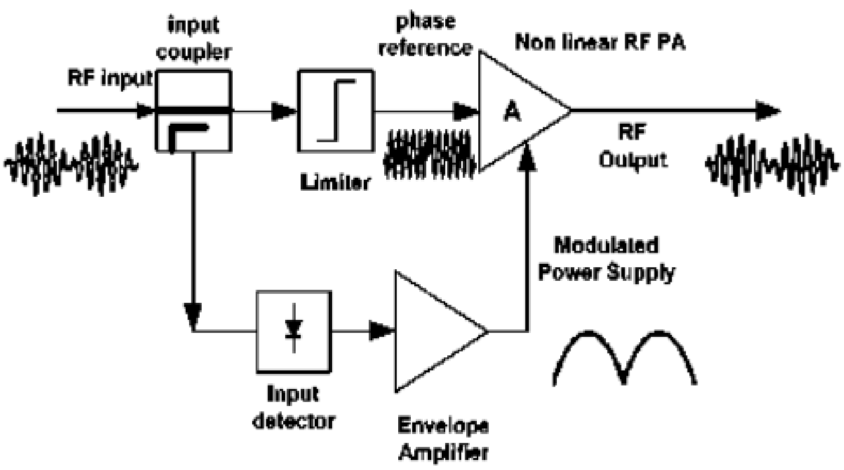
Envelop tracking technique works by employing a system where the amplitude envelop of the signal is tracked and used by the amplifier to constantly adjust the power supply voltage and ensure that the amplifier is operating at the optimized efficiency level (Electronic Notes).

The envelop tracking method provides different advantages such as maximized performance at all power levels, allows broadband operation, provides benefits in terms of mismatched loads and other problems. On the downside, it requires very fast and high-bandwidth power supply and accurate envelop signal for power supply in order for it to work at its optimum level (Electronic Notes). Below is a block diagram of envelop tracking linear power amplifier (Sahu &Ricon-Mora).

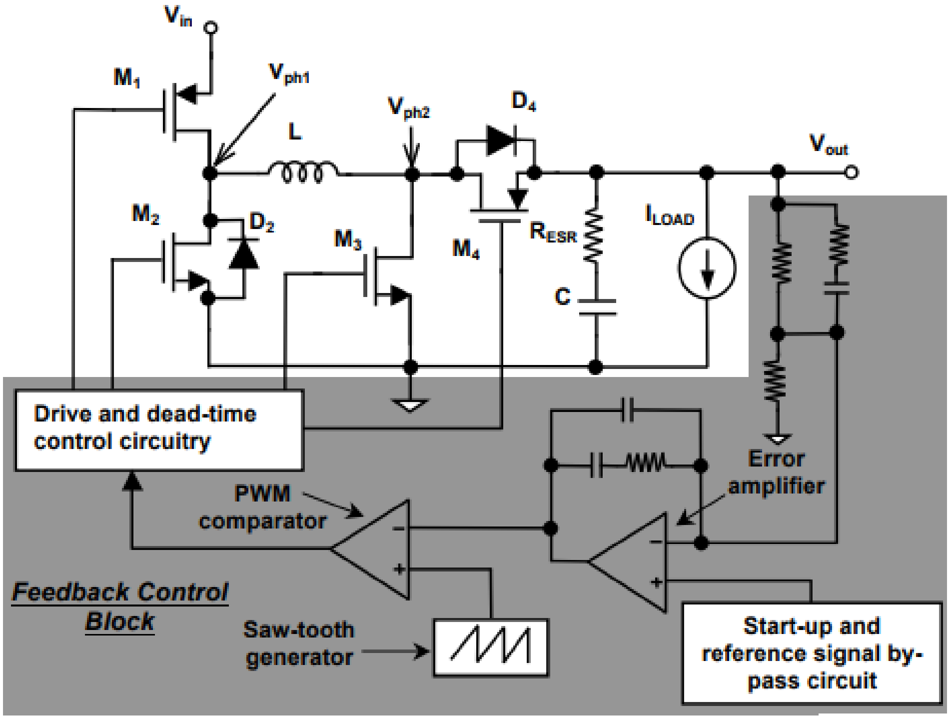


3. Envelop Elimination and Restoration – Another technique for a highly efficient microwave amplifier is the envelop elimination and restoration technique, or also called the Kahn's technique. This is a non-linear power amplifier where the microwave power amplifier works as a time domain multiplier where in the envelop modulation is incorporated into the non-linear PA. The efficacy of Kahn's technique lies within class E, D and F amplifiers which have high efficiencies and also on its high efficiency power supply. The Kahn's technique offers an average efficiency of about three to five time compared to the linear amplifiers (Vasic, Garcia, Alou, Oliver, Diaz, Cobos, Pardo, Benavente & Ortega).

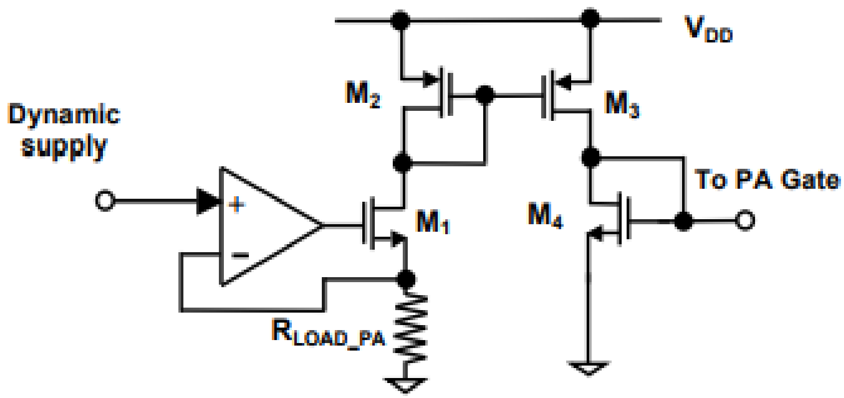
Below is the block diagram of Kahn's technique on a microwave amplifier based fromVasic et al. research study.



4. Hardware Implementation Technique – Another technique in optimizing the frequency of microwave amplifier is the hardware implementation technique which covers different strategies. Among these strategies include the directional coupler and power detector, wherein a micro-strip, a directional coupler are designed on a printed circuit board with corresponding requirements. A power detector is then used to detect the RF power that generates DC voltage which is proportional to the input power (Sahu & Rincon-Mora). Also, there is the non-inverting buck-boost converter, which also maximizes the efficiency of power amplifiers. This technique reduces the possibility of damaged transistors and prevents failures, resulting to a highly efficient PA performance due to the incorporation of slow-start circuit in prototype used. Below is the block diagram of buck-boost converter (Source: Sahu & Rincon-Mora):



Another technique under hardware implementation is the Dynamic Gate Bias Generation Circuit. Ye et al., proposed the use of dynamic gate bias circuit using two NMOS transistors, a capacitor for coupling RF input signal and resistors for bias. It was implemented through bias control using two-stage power amplifier to be able to general power added efficiency and be able to deliver about 22dBm output power. The result of this study found out that the efficiency of the amplifier is improved to more than 100% efficiency as compared to amplifier without dynamic bias circuit (Ye et al.).
Below is a block diagram of a Dynamic Gate Bias Generation Circuit (Source: Sahu & Rincon-Mora).



III. DISCUSSION AND RECOMMENDATION

The availability of various techniques in achieving the highest possible efficiency of microwave amplifier offers significant help especially in the ever growing wireless communication industries and other possible platform where microwave amplifier applies. The evolution of these industries, which pave way for innovative technologies such as the WCDMA, LTE, WiMAX and others brought a need for highly efficient microwave amplifiers since they utilize high power ratio due to its complex modulation schemes, which in turn requires power amplifiers to operate at a maximum requirement, which sometimes affect its performance in terms of efficiency.

In boosting the efficiency of the microwave amplifiers, there are a lot of considerations to make, not just the hardware, the circuit designs, and the incorporation of different techniques to attain the highest efficiency possible, which is at most between 50 to 90 percent, although, in some cases, it could reach up to 100% efficiency level, such as in the case of dynamic gate bias generation circuit tested by Yen et al. One of these consideration include the full understanding of the amplifier behaviors before choosing the possible optimal design to ensure that the needed result correspond to the projected output of the application and the amplifier performance. It is also important to determine the class of amplifier to be used whether they are non-linear or linear to be able to properly integrate the best possible hardware and circuits needed for optimum amplifier efficiency.

The aforementioned techniques have their share of advantages and disadvantages, which give more room for improvements and innovations on how to address particularly the downside. The continues innovation and emergence of new technologies and strategies also provide the amplifying technology ample space for more innovative style to achieve highly efficiency that meets the different performance parameters such as battery life, drain efficiency, heat dissipation level, energy conversion and others.

IV. CONCLUSION

In this paper, the different parameters in achieving high efficiency microwave amplifier was discussed, from the definition of the microwave amplifier the meaning of efficiency in amplifying technology, classes of power amplifiers, and particularly the different techniques available to improve the performance or efficiency levels of microwave amplifiers. These techniques mentioned include the **a**pplication of Dynamic Adaptive Buck-Boost Supply, Envelop Tracking Technique, Envelop Elimination and Restoration or Kahn's Technique, and some strategies under hardware implementation techniques such as the directional coupler and power detector, non-inverting buck-boost converter, and the dynamic gate bias generation circuit. All of these techniques contribute to optimizing efficiency level of microwave amplifiers—from reducing dissipation, extending battery life, and other forms of efficiencies.

While there are certain limitations involved in this research such as absence of actual testing of these techniques, the collected strategies from various literatures offer significant insight about microwave amplifier efficiency, which could also be use as a headstart for future researches and studies.

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