High-efficiency power amplifier using injection-locked pulsed oscillator with non-deterministic pulse technique

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A non-deterministic pulse technique for pulsed oscillating amplifiers is presented. Using random pulse width modulation (RPWM) for switching the injection-locked oscillator, its discrete harmonics are spread. Measured results show that discrete harmonics are reduced by 60 dB, which greatly reduces the filtering required for these harmonics.

Introduction: Modern digital communication systems widely use modulation formats where signal envelopes are not constant. Therefore, linear RF power amplifiers are required for those applications. Unfortunately, conventional linear power amplifiers such as classes A and AB have poor efficiency. Various techniques have been proposed for improving the efficiency of linear power amplifiers [1]. The present author suggested a pulsed oscillating amplifier (also known as a pulsed 'injection-locked' amplifier) [2]. The pulsed oscillating amplifier amplifies the input signal using a class-F injection-locked oscillator. The efficiency of the pulsed oscillating amplifier is high owing to the class-F oscillator. It has good linearity because its output is determined only by the on-time duration of the injection-locked oscillator. Therefore, unlike conventional amplifiers, good linearity can be maintained even at maximum output power. The amplifier, however, requires a high-Q bandpass filter (BPF) to restore the input signal.

In this Letter, a randomised switching scheme for pulsed oscillating amplifiers is suggested. Instead of using deterministic pulses to switch the injection-locked oscillator, a non-deterministic pulse is introduced to spread the discrete harmonics of the pulsed oscillating output. Since the random switching technique spreads the unwanted harmonics over a wide range of frequencies, it has the advantage of reducing the filtering required for these harmonics [3].

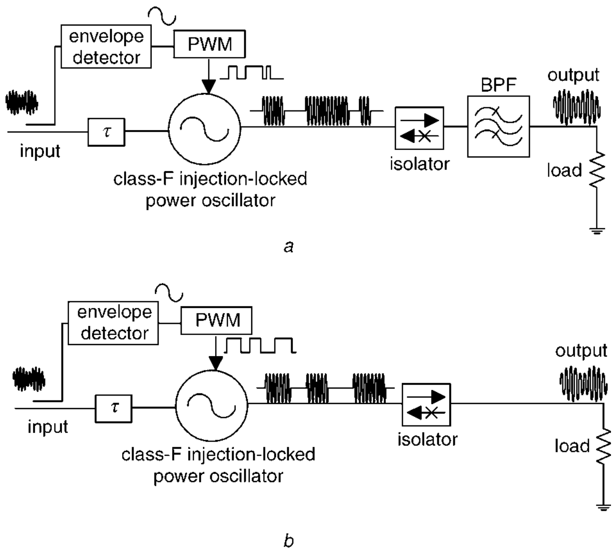

Fig. 1 *Block diagram of pulsed oscillating amplifier and proposed pulsed oscillating amplifier using RPWM technique*

a Pulsed oscillating amplifier
b Proposed pulsed oscillating amplifier using RPWM

RPWM scheme for pulsed oscillating amplifier: Figs. 1*a* and *b* show block diagrams of a pulsed oscillating amplifier and the proposed pulsed oscillating amplifier using an RPWM technique. As shown in Fig. 1*a*, a part of the RF input is coupled, and it is detected by an envelope detector for the pulsed oscillating amplification system. The detected low-frequency envelope is modulated by pulse width modulation (PWM). On the other hand, the RF signal connected to the through port of the coupler is delayed, and then locks the class-F power oscillator. The signal of the pulse width modulated envelope is applied to the gate of the class-F power oscillator, switching it on and off. After the RF pulse train is filtered by a BPF, the amplified RF input is restored. The isolator is for stability.

A high-Q BPF is required to eliminate the unwanted harmonics in the pulsed oscillating amplifier. This type of BPF, however, has a large insertion loss, resulting in a decrease in the overall efficiency of the pulsed oscillating amplifier. Furthermore, the high-Q BPF is difficult to implement in a planar structure such as a microstrip line.

Fig. 1*b* shows the proposed RPWM schemes for the pulsed oscillating amplifier. The low-frequency envelope is modulated by RPWM instead of PWM. It allows the switching period to vary, but the average pulse width is equal to the required duty ratio. Therefore, the unwanted discrete harmonics are spread without changing the wanted fundamental power. Consequently, the random switching technique can reduce the filtering efforts, or even eliminate the BPF. This results in improving the overall efficiency of the pulsed oscillating amplifier by reducing insertion loss from the BPF.

Results: A class-F injection-locked power oscillator was designed for fundamental locking. A GaAs FET device from Excelics (EFA 240D-SOT89) was selected to implement the power oscillator. The measured output power of the F injection-locked oscillator was about 26.3 dBm at 1.857 GHz. Its measured efficiency was about 64% when the duty ratio was 100%. On the other hand, the non-deterministic pulse for the RPWM was generated by a VCO the frequency of which was modulated by a pseudorandom noise signal. The amount of frequency spreading is determined by the pseudorandom noise. In this experiment, the pseudorandom signal was generated by a linear feedback shift register 9 bits long.

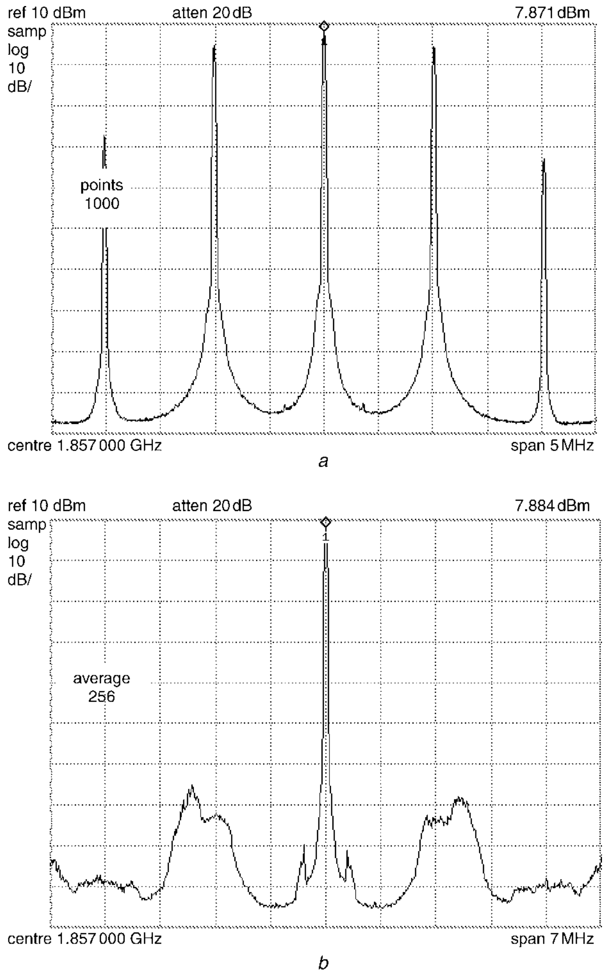

Fig. 2 *Measured output spectra of pulsed injection-locked oscillator before and after RPWM technique applied*

a Before RPWM
b After RPWM

The measured output spectrums of the pulsed injection-locked oscillator, before and after the RPWM technique is applied, are shown in Figs. 2*a* and *b*, respectively. Duty ratios in both cases are 50%. In the RPWM case, the duty ratio is the average value. The result verifies that the RPWM technique in the pulsed oscillator enables the unwanted deterministic harmonics to be spread over a wide frequency band without changing the wanted fundamental component. The discrete harmonics were reduced by 60 dB owing to the RPWM technique. More than 60 dB harmonic suppression is possible if a shift register, which is longer than 9 bits, is used for the pseudorandom signal.

Fig. 3 shows the measured performances of the proposed pulsed oscillating amplifier using the RPWM technique compared to the pulsed oscillating amplifier shown in Figs. 1*a* and *b*. The output power and the overall efficiency of the proposed pulsed oscillating amplifier with the RPWM are larger than those of the pulsed oscillating amplifier. Because the high-Q BPF is not required in the proposed amplifier, there is no insertion loss from it. The measured insertion loss of the high-Q BPF of the pulsed oscillating amplifier in Fig. 1*a* is about 0.5 dB. Therefore, the output power and the overall efficiency can be improved by 0.5 dB and 11%, respectively, by the RPWM technique.

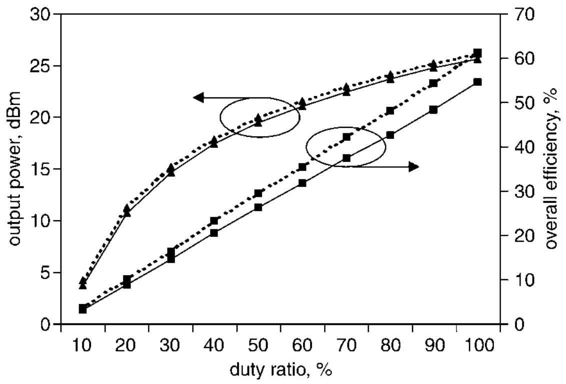

Fig. 3 *Measured performances of proposed pulsed oscillating amplifier using RPWM technique compared to pulsed oscillating amplifier*

—■— measured output power of pulsed oscillating amplifier
- - □ - - measured output power of proposed pulsed oscillating amplifier using RPWM technique
—▲— measured efficiency of pulsed oscillating amplifier
- - △ - - measured efficiency of proposed pulsed oscillating amplifier using RPWM technique

Conclusion: An RPWM technique for pulsed oscillating amplifiers is presented. Instead of using a deterministic pulse for switching the injection-locked oscillator, a non-deterministic pulse is introduced to spread unwanted discrete harmonics over a wide range of frequencies. This technique promises to reduce the filtering required for the unwanted harmonics and to improve the output power and efficiency of the pulsed oscillating amplifier.

3 December 2005
Electronics Letters online no: 20064224
doi: 10.1049/el:20064224

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