High Efficiency S-band Class AB Push-Pull Power Amplifier with Wide Band Harmonic Suppression

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***Abstract* — In this paper, a high efficiency class-AB push-pull power amplifier is designed utilizing a novel photonic band-gap (PBG) ground plane. This design allows simultaneous tuning of both second and the third harmonics, thus, results in a high efficient power amplifier design. The measured PAE is 63.8% at an output power of 28.2dBm. In addition, the measured IP3 is 45 dBm, about 17 dB above the P_{1dB} point. .**

I. Introduction

Power amplifier is the main power consumption block in any advanced wireless communications system. When the DC power is limited, it is crucial to design power amplifiers with high power-added efficiency (PAE). To do so, PA designers often bias the circuit in Class AB operation to compromise between linearity and PAE. This will increase the lifetime of the battery cell, and reduce the size and weight of the heat sink. In addition, Class AB operation is often used in a push-pull PA design to eliminate the crossover distortion that can be introduced if biased at Class B. As seen in all PA designs, power amplifiers require substantial variation in the bias currents of the transistors in order to achieve the maximum power added efficiency; therefore, the linearity of the system is severely distorted. A high-Q resonator is absolutely mandatory in order to obtain a sinusoidal output voltage. Unfortunately, it is extremely hard to find a high-Q resonator at higher frequency due to the losses of the inductor. Additionally, when a push-pull PA is biased at Class AB, it is necessary to tune both the second and third harmonics in order to achieve higher PAE. Traditionally, harmonic tuning can be done by adding open or short-circuit stubs at the output [1]-[2]. Alternative methods include the use of the periodic structures at the output [3]. Unfortunately, these methods usually tune only the even or odd harmonic, and typically give narrow band performance.

Recently, we proposed and demonstrated a radically new approach for broadband tuning of both second and third harmonics in the microwave power amplifiers based on a novel photonic band-gap (PBG) structure [4]. The proposed PBG ground plane for microstrip line provides low-loss, slow-wave propagation at lower frequencies, and a wide, distinctive stop-band as the frequency increases [5]-[6]. In this paper, this idea is extended to an S-band push-pull class AB power amplifier architecture. Fig. 1 shows the photograph of the fabricated push-pull PA with PBG ground plane. Both the simulation and measurement results indicate that the new design concept promises to provide high efficiency with good linearity.

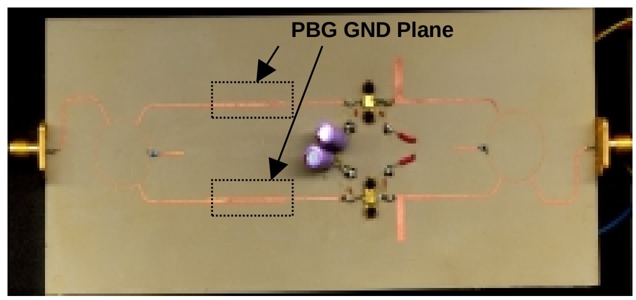
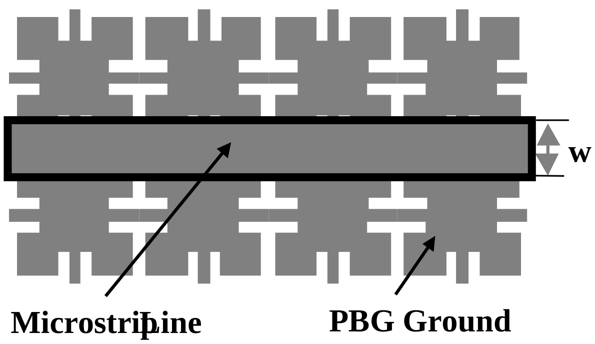


Fig.1. Fabricated Class AB push-pull PA with PBG ground plane.

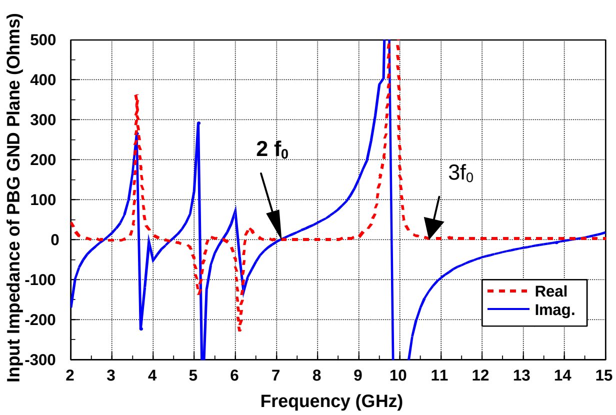
II. Photonic Band-Gap Ground Plane For Harmonic Tuning

PBG ground plane is a periodic structure where each single element consists of a square pad with four connecting branches. The narrow branch is used to create an inductive effect. The gap between adjacent pads provides capacitive coupling and increases the shunt capacitance seen by the microstrip. The resultant distributed LC network in the ground plane changes the properties of microstrip line, and is responsible for both the slow wave and stop-band effects. The deep and broad stop-band indicates that this structure can be used as a broadband harmonic tuning load for Class AB push-pull PA.

The PBG structure in this design consists of 2×4 elements, as shown in Fig. 2(a). RT/Duroid 6010 with dielectric constant of 10.2 and thickness of 25 mil is used. The width of the inductive branch and gap between adjacent pads are both 10 mil. The period of the lattice is 180 mil. The microstrip line width is 40mil, and its length is 720 mil. Fig. 2 (b) shows the measured input impedance of the PBG ground plane with microstrip line. We observe that the real part of the input impedance is kept around zero from 6.8 to 9 GHz and from 10.5 to 15 GHz. Clearly, this structure is reactive over a wider bandwidth than a single stub. When it is used as a harmonic tuner at the output of a power amplifier, the signal will be distortion free over a broad frequency range. In this paper, the PBG ground plane is implemented into an S-band push-pull power amplifier. The operating frequency is 3.55 GHz, which is slightly off the first resonance to allow easier power match. Since both the second and third harmonics are reactively terminated, the harmonics of the drain current waveform are intrinsically filtered out, leaving a clean sinusoidal drain output voltage. Fig. 3 shows simulated (a) drain current before PBG, and (b) output voltage after PBG ground plane at 3.55 GHz with 18dBm input power.



(a)

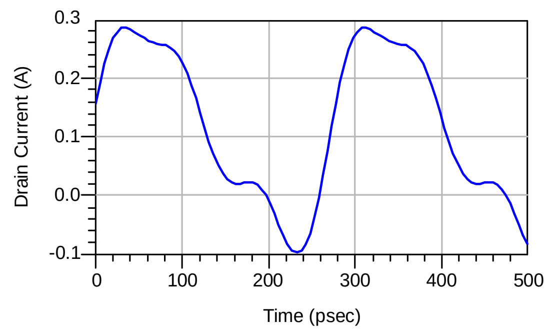


(b)

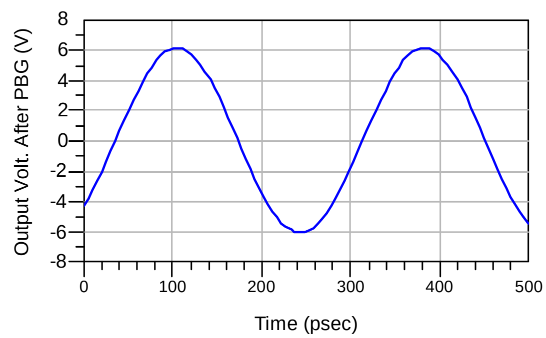
Fig. 2. (a) Schematic, and (b) Input impedance of the PBG ground plane with microstrip line.

III. Power Amplifier Design

A Class AB push-pull amplifier was designed using Agilent's Series IV simulator. The microstrip line with the PBG ground plane was incorporated into Series IV as a two-port network with measured S-parameters data from 0.13 to 20 GHz. The device used was the MicroWave Technology MWT-8HP power GaAs FET. The large-signal model of this device and harmonic balance simulation including the first three harmonics were used in the design. The circuit was biased at 10% of Idss with 5 V drain voltage.



(a)



(b)

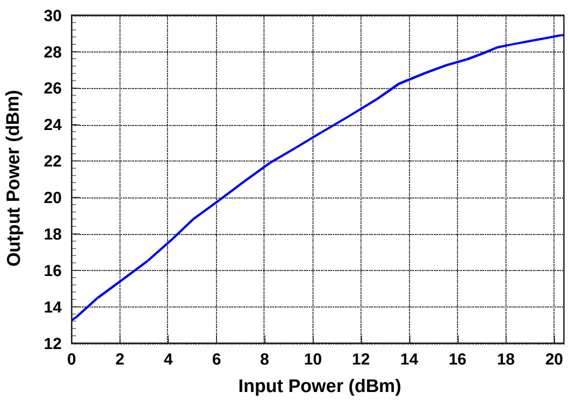
Fig.3. (a) Simulated drain current before PBG, and (b) Output voltage after PBG ground plane.

IV. Measured Results

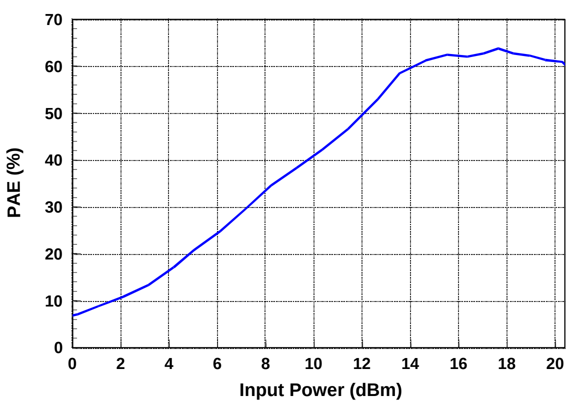
The measured output power and PAE versus input power at 3.55 GHz are shown in Fig. 4 (a) and (b), respectively. The maximum measured PAE is 63.8% at an output power of 28.2 dBm. Fig. 5 shows (a) the measured output power, and (b) PAE versus frequency. It is observed that the measured PAE is better than 50% from 3.47 GHz to 3.67 GHz.

As mentioned in the introduction section, the Class-AB power amplifier can generate substantial harmonics when it is driven with large input power. These undesired harmonics can significantly degrade the overall system performance.

We observe significantly low harmonic power levels over a broad frequency range due to the filtering effects of the PBG ground plane. Table 1 shows the measured second and third harmonics level from 3.5GHz to 3.6 GHz. At 3.55 GHz, the measured second harmonic and third harmonic levels are 70 and 63 dB below the power level at the fundamental, respectively.



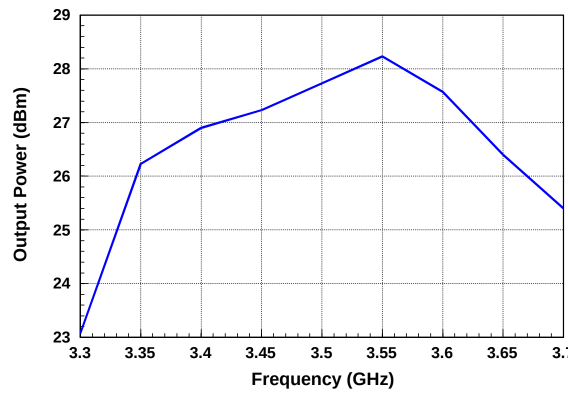
(a)



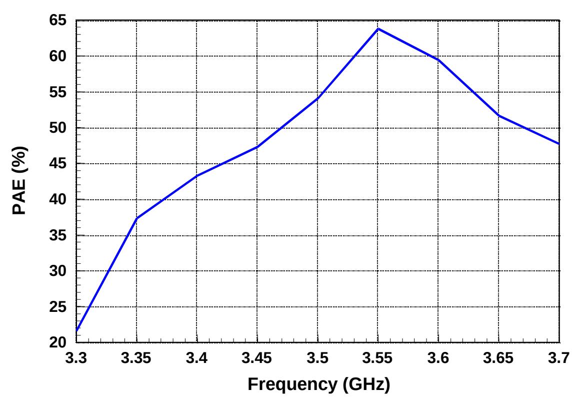
(b)

Fig.4. (a)Measured output power, and (b) PAE Vs. input power at 3.55 GHz.

In addition, a two-tone test was performed. It is the simplest testing method that can provide a rough measurement of power amplifier linearity. Fig. 6 shows the measured two-tone test results of the push-pull power amplifier with PBG ground plane for harmonic tuning. The measurement was done by simultaneously injecting the fundamental signal at 3.55 GHz and the second signal with the same input power level but at the frequency shifted by 10-MHz into the push-pull power amplifier. The third order intercepted point, IP3, is obtained as the interception of the extrapolated 3-dB in-band intermodulation distortion slope line and the 1-dB linear output power line intercept. As shown in Fig. 6, the intercept point is 45dBm, which is about 17 dB above the P_{1dB} point.



(a)



(b)

Fig.5. (a) Measured output power, and (b) PAE Vs. frequency at Pin = 17.6 dBm.

V. Conclusion

In this paper, a Class AB push-pull power amplifier is designed utilizing a novel PBG ground plane for both the second and third harmonic tuning. A peak PAE of 63.8% at the output power of 28.2 dBm has been achieved at 3.55GHz. The PAE is kept above 50% over a 200 MHz bandwidth. Additionally, at the operating frequency of 3.55 GHz, the second and the third harmonic levels are 70 dB and 63 dB below the output power level at the fundamental. A two-tone test has shown that the

TABLE I
POWER LEVEL AT THE 2ND AND 3RD HARMONICS FROM 3.5 GHZ TO 3.6 GHZ AT Pout=28 dBm

Frequency (GHz)	Second Harmonic (dBc)	Third Harmonic (dBc)
3.5	-50	-60
3.55	-70	-63
3.6	-50	-80

measured IP3 point is about 17 dB above the P_{1dB} point. These results indicate that this compact push-pull power amplifier with PBG ground plane can simultaneously achieve excellent performance in terms of linearity as well as efficiency.

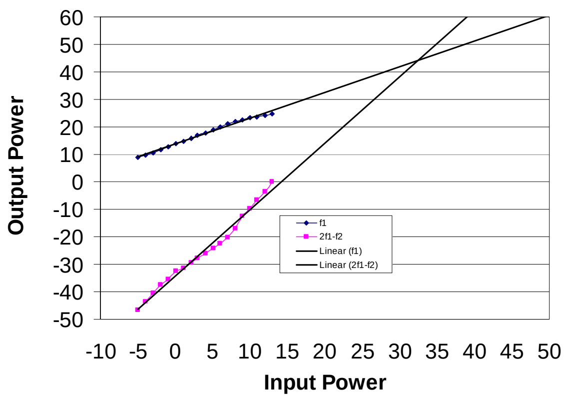


Fig.6. Two-Tone test of push-pull PA with PBG ground plane (f1=3.55 GHz, and f2=3.56 GHz).

ACKNOWLEDGEMENT

This work was supported by ARO MURI under contract DAAH04-96-0005.

REFERENCES

[1] J.R. lane, R.G. Freitag, H.-K Hahn, J.E. Degenford, and M. Cohn, "High-efficiency 1-,2-, and 4-W class B FET power amplifiers," *IEEE Trans. Microwave Theory Tech*., vol. 34, pp. 1318-1325, Dec. 1986.

[2] C. Duvanaud, S. Dietsche, G. Pataut, and J. Obregon, "High-efficiency class F GaAs FET amplifier operating with very low bias voltage for use in mobile telephone at 1.75 GHz," *IEEE Microwave Guided Wave Lett*., vol. 3, pp.268-270, Aug. 1993.

[3] V. Radisic, Y. Qian, and T. Itoh, "Novel architectures for high efficiency amplifiers for wireless applications," *IEEE Trans. on Microwave Theory and Tech*., vol. 46, no. 11, pp. 1901-1909, Nov. 1998.

[4] C.Y. Hang, V. Radisic, Y. Qian, and T. Itoh, "High Efficiency Power Amplifier with novel PBG ground plane for harmonic tuning," 1998 *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, pp. 807-810, June 1998.

[5] F. R. Yang, Y. Qian, R. Coccioli and T. Itoh, "A novel low loss slow-wave microstrip structure, " *IEEE Microwave and Guided Wave Lett*., vol.11, pp.372-374, Nov. 1998.

[6] Y. Qian, F. R. Yang, and T. Itoh, "Characteristics of microstrip lines on a uniplanar compact PBG ground plane,"1998 *Asia-Pacific Microwave Conf. Dig.*, pp. 589-592, Dec. 1998.