

Design of concurrent multiband biasing networks for multiband RF power amplifiers

Anh Nghiem Xuan and Renato Negra

Mixed-Signal CMOS Circuits, UMIC Research Centre
 RWTH Aachen University, 52056 Aachen, Germany
 Telephone: +49-241-8027757, Fax: +49-241-8022199
 Email: nghiem@umic.rwth-aachen.de

Abstract—In this paper, a new technique for designing concurrent multiband biasing networks for multiband RF power amplifiers is presented. The proposed design technique can theoretically be applied for a large number of frequency bands. The biasing network (BN) is composed of a transmission line and high impedance quarterwave open stubs (QWOS) that are located at appropriate positions along the transmission line. Two tri-band BNs for 1.49 GHz, 2.15 GHz and 2.65 GHz frequencies were designed, fabricated and display very good performance with regard to the input impedance seen looking toward the BNs from the active devices, such as FETs, are approximately open for all three bands. For demonstration, a 10 W Class-AB tri-band power amplifier (PA) using the proposed technique was implemented, characterized and exhibits high output power of more than 40 dBm and maximum power added efficiency (PAE) of over 50 % in all the three bands.

I. INTRODUCTION

With the rapid growth of wireless communication systems and standards [1] from GSM, UMTS to LTE which exist in different frequency ranges (900 MHz, 1800 MHz, 2100 MHz, 2600 MHz, etc.) [2], the requirement for RF transmitters that are able to operate in multiband/multistandard modes is increasing accordingly for a reconfigurable, low-cost and highly integrated solution. RF power amplifier (PA) module located in the RF front-end of a transmitter is one of the most challenging and expensive components of a base station (BTS) in terms of compactness, high output power, high linearity and high efficiency. Especially, for mobile systems that use modern digital modulation schemes like W-CDMA, power amplifiers with high linearity and high efficiency for a large power backoff are necessarily demanded. Although the concurrent operation of power amplifiers in multiple frequency bands may not allow the best performance to be achieved, multiband PAs are among the best choices if a broadband solution cannot be realised. Among other semiconductor technologies like LDMOS and GaAs that have been used widely and successfully in the deployed base stations, wide-bandgap GaN HEMT has been emerging as a very promising technology for RF power amplifier for base stations as it can provide higher power density, greater breakdown voltage and thus higher output power compared to the former technologies. Therefore, in this work GaN HEMT transistors were selected for the demonstration.

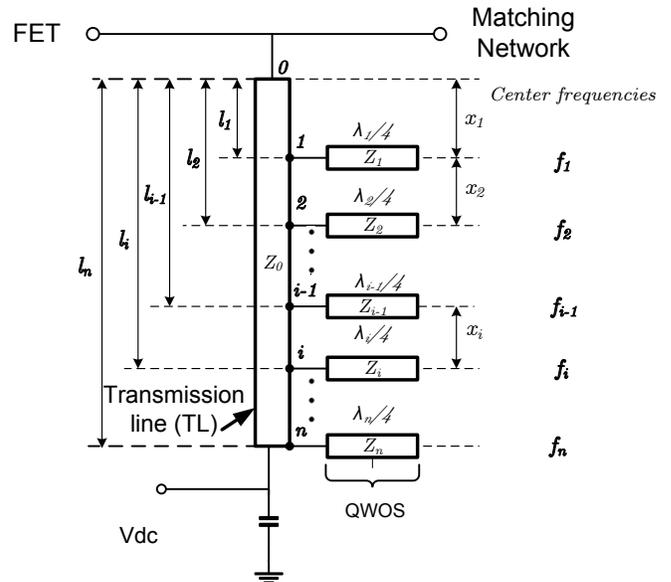


Fig. 1: Schematic of the proposed concurrent multi-band biasing network.

There have been a number of works on multiband RF power amplifiers reported recently, some of them are concurrent [3]–[5] and some are reconfigurable using Micro-Electro-Mechanical Switches (MEMS) [6], [7]. However, the design of multiband biasing network required to supply DC bias to the amplification devices *e.g.* FETs has not been introduced in a systematical way except for the reconfigurable biasing network using MEMS in [7].

This work presents a novel technique for designing concurrent multiband switchless biasing networks that utilises purely transmission line and open stubs. Two BNs were designed and fabricated for the demonstration of the technique. The measured results are in good agreement with simulation and exhibit better performance or at least comparable with the technique using MEMS presented in [7]. The input impedances seen looking toward the BNs from the amplifying device are close to open and the insertion losses from the device to the matching network are 0.143 dB, 0.239 dB and 0.189 dB at the

designed frequencies of 1.49 GHz, 2.15 GHz and 2.65 GHz respectively. In addition, the application of the designed BN for a 10 W Class-AB tri-band PA is presented as an example. The measured results of the PA showed a good agreement with simulation and achieve high power of over 40 dBm and maximum power added efficiency of over 50 % for an input power ≤ 30 dBm in all frequency bands.

II. MULTIBAND BIASING NETWORK DESIGN TECHNIQUE

Fig. 1 illustrates the novel concurrent multi-band biasing network. For consistency and convenience, from now on the term FET is used to represent the amplification device. DC supply voltage is required to be applied to the drain terminal of the FET without disturbing the RF signal path over all frequency bands of interest. It means the impedances seen looking from point 0 toward the BN must be effectively high, ideally open within the designed frequency bands. For doing so, RF chokes are generally used for blocking RF while allowing DC current to pass to the FETs. However, the choke requires very high inductance and is limited to hybrid design and low frequency due to the self-resonance frequency [7]. The proposed technique uses only transmission lines and can also be applied to microwave monolithic integrated circuits (MMIC).

As shown in Fig. 1, the proposed BN consists of a transmission line (TL), quarterwave open stubs (QWOSs) that have electrical lengths of $\lambda/4$ at the center frequencies of the corresponding frequency bands. The positions of these QWOSs along the main transmission line TL must be calculated and then adjusted step by step in an appropriate manner. The impedances (Z_i) of $QWOS_i$ should be high to miniaturize the biasing network. The frequency bands 1, 2 ... n have center frequencies $f_1, f_2 \dots f_n$ and the corresponding wavelengths $\lambda_1, \lambda_2 \dots \lambda_n$ respectively. Here, the convention $f_1 > f_2 \dots > f_n$ is used.

The operating principle of the proposed BN is now described. For the first band that has the center frequency of f_1 , the $QWOS_1$ with electrical length of $\lambda_1/4$ will create a short at point 1 on the transmission line. TL section ℓ_1 with electrical length of $\lambda_1/4$ will transform the short at point 1 to open at point 0 on the TL. At point 1, the remaining of the BN is shorted and will not affect band 1. The same argument is applied to the remaining points i ($i = 2 \dots n$). From band 2 to band n the shunt capacitive loading on the TL due to the open stubs of bands 1 ... $n-1$ must be taken into account for the adjustment of the BN design. The procedure for designing BN for bands from 2 to n is as follows:

Firstly, all the lengths ℓ_i ($i = 2 \dots n$) are calculated using (1) and (2) to construct a temporary BN.

$$\ell_i = \ell_{i-1} + x_i \quad (1)$$

where,

$$x_i = \frac{\lambda_i}{4} (1 - k_i) \quad \text{for open at point 0} \quad (2)$$

$$x_i = \frac{\lambda_i}{2} (1 - k_i) \quad \text{for short at point 0} \quad (3)$$

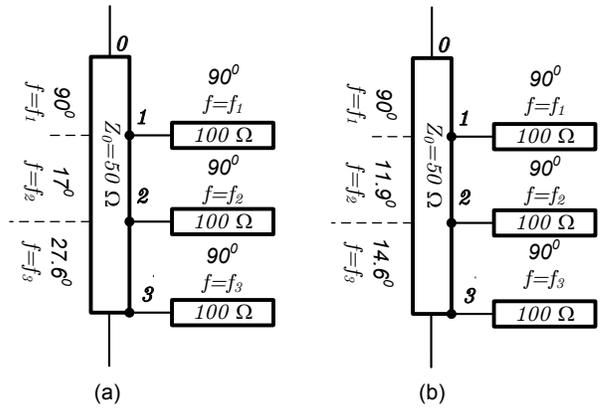


Fig. 2: The designed tri-band BN (a) temporary BN before tuning and (b) final BN after tuning.

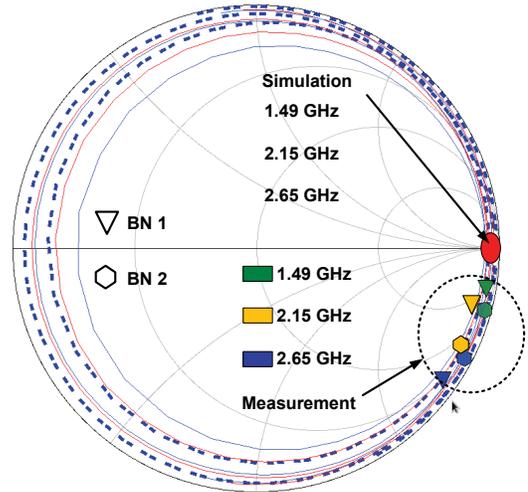


Fig. 3: Measured impedances of two BNs at the center frequencies of bands.

and $k_i = f_i/f_{i-1}$.

As shunt capacitive loading tends to increase the length of the TL, the next step is to shorten the length x_i such that the short point i is transformed to open at point 0 on the TL at frequency f_i . There are a number of solutions for doing so but the longer the x_i is, the narrower the bandwidth of the BN becomes. Moreover, it will affect band $i+1$ and requires (1) and (2) to be adjusted accordingly. To avoid unnecessary complexity, shortening TL sections x_i is considered the best choice. The above steps should be done in sequence from band 2 to band n for the completion of a multiband BN. It must be also noted here that for the purpose of harmonic termination, additional QWOSs can be added in the same manner. For doing so, harmonics are considered as additional bands. However, depending on the class of the PA to be designed harmonics can be controlled to open or short at point 0 by applying (2) or (3) accordingly.

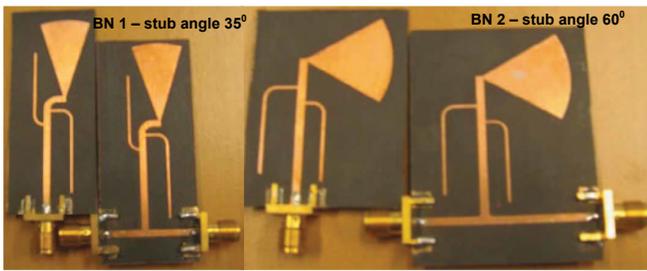


Fig. 4: Fabricated tri-band biasing networks, BN1 and BN2.

III. DESIGN AND TESTING OF TRI-BAND BNS

For demonstration of a simplest case (without fully controlling harmonics), two samples of BN were designed for 1.49/2.15/2.65 GHz bands. As can be seen from the schematic in Fig. 1, the number of QWOSs is the same as the number of bands and $n = 3$ in this case. Also, for these three bands, $k_2 = 0.811$ and $k_3 = 0.693$ are found. The characteristic impedances $Z_i = 100 \Omega$ were chosen at the corresponding frequencies f_i and the transmission line of characteristic impedance $Z_0 = 50 \Omega$ was used in the design. For the first band, $\ell_1 = \lambda_1/4$. Using (1) and (2), the electrical lengths of TL sections for bands 2 and 3 can be found as $x_2 = 0.0473\lambda_2$, $\ell_2 = \lambda_1/4 + 0.0473\lambda_2$, $x_3 = 0.0767\lambda_3$ and $\ell_3 = \lambda_2/4 + 0.0767\lambda_3$. For more convenience, the electrical lengths are generally used instead as shown in Fig. 2(a).

Fig. 2(b) shows the BN after tuning the lengths x_i to appropriate values. In the real design, $QWOS_3$ was replaced with an open radial stub to increase the bandwidth of band 3. The difference between BN1 and BN2 lies in the different angles of the used radial stubs, which are 35° and 60° , respectively. Fig. 3 shows the simulation and measurement results revealing that the input impedances seen looking toward the BNs at point 0 are close to open in all the three bands. There is a minor difference between simulation and measurement due to fabrication process and the uncertain offset length used for de-embedding the SMA connector. To avoid the inaccuracy of the measured reference plane, two other two-port structures shown in Fig. 4 were fabricated to measure the insertion loss between FET and matching network. As can be seen in Fig. 5, the measured results of BN1 display a very good performance with an insertion loss of 0.143 dB, 0.239 dB and 0.189 dB at the center frequencies of 1.49 GHz, 2.15 GHz and 2.65 GHz, respectively, while the measured results of BN2 show a slight improvement in bandwidth associated with an increase in insertion loss in all bands of 0.162 dB, 0.266 dB and 0.202 dB.

IV. APPLICATION OF THE DESIGNED BN IN A 10 W CLASS-AB TRI-BAND PA

To demonstrate the feasibility of the proposed technique, the designed tri-band biasing network BN1 was applied in a concurrent tri-band 10 W power amplifier, which is designed for the 1.49 GHz, 2.15 GHz and 2.65 GHz bands. A 10 W GaN HEMT from CREE is used for this application. For

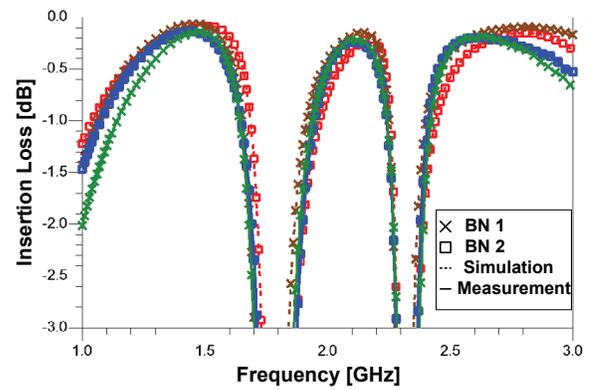


Fig. 5: Simulated and measured insertion loss of BN1 and BN2.

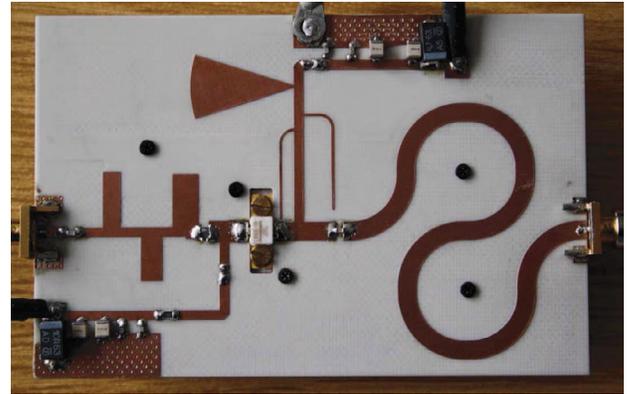


Fig. 6: The tri-band 10 W Class-AB PA.

simulation, a large-signal model provided by the manufacturer was used. The transistor is biased with a drain supply voltage $V_{DD} = 28 \text{ V}$ and the gate-to-source bias voltage $V_{GS} = -2.1 \text{ V}$ (simulated) and -3.0 V (measured). Roger RO4003C substrate $\epsilon_r = 3.55$ and thickness $h = 813 \mu\text{m}$ was used for this PA.

Fig. 6 shows the implemented tri-band PA. The simulated and measured output power, drain efficiency for an input power of $\leq 30 \text{ dBm}$ are plotted in Fig. 7. As shown in this figure, both simulation and measurement results of the PA show an output power of greater than 40 dBm and peak drain efficiency of over 55 % in all the frequency bands. Fig. 8 plots the measured output power, power gain, drain and power added efficiencies of the PA for the 1.49 GHz band. Similarly, Fig. 9 and Fig. 10 show the measured results of the PA for the 2.15 GHz band and the 2.6 GHz band respectively. As can be seen in these figures, the power gain of greater than 12 dB can be observed at the 1 dB compression point.

V. CONCLUSION

In this work, a novel technique for designing concurrent multiband biasing networks for multiband RF power amplifiers has been introduced. The design technique can theoretically

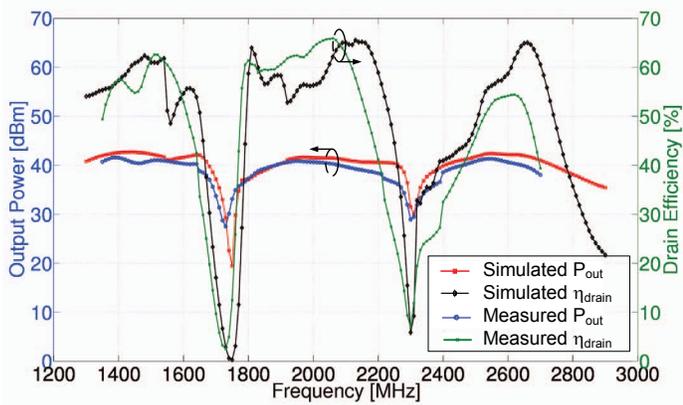


Fig. 7: Output power and drain efficiency of the tri-band PA.

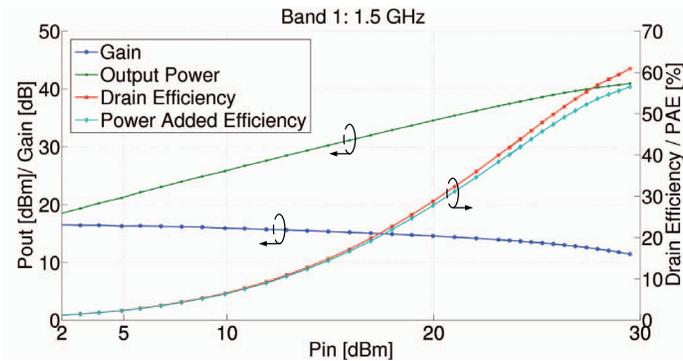


Fig. 8: Measured results of the designed PA for 1.49 GHz band.

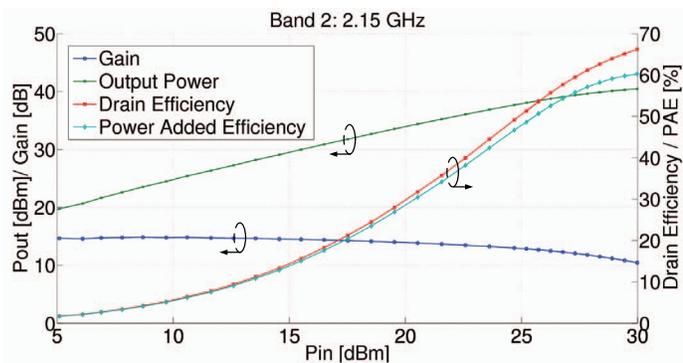


Fig. 9: Measured results of the designed PA for 2.15 GHz band.

be applied for a large number of frequency bands. The methodology is to insert high impedance open stubs of $\lambda_i/4$ (QWOS) to appropriate points along a transmission line. Using the same technique, harmonics can also be controlled to short or open seen by the device depending on the class of the PA to be designed. For demonstration, two BNs were designed, fabricated and measured. The measurement results agree well with simulation, *i.e.* the impedances seen looking toward the BN from FET are close to an open circuit. The measured insertion

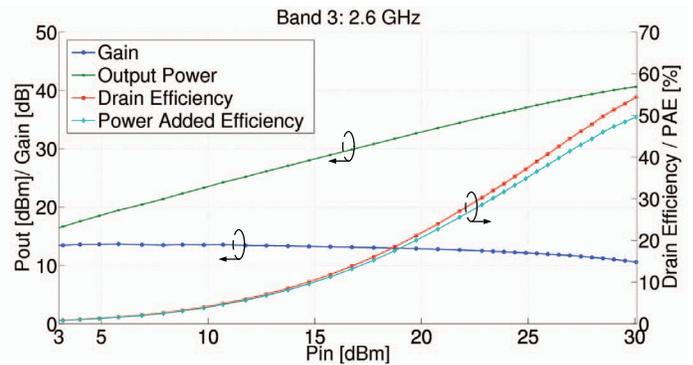


Fig. 10: Measured results of the designed PA for 2.65 GHz band.

loss from FET to matching network is 0.143 dB, 0.239 dB and 0.189 dB at the center frequencies of 1.49 GHz, 2.15 GHz and 2.65 GHz respectively. For verifying the technique, a tri-band 10 W Class-AB PA using the one of the designed biasing networks was introduced. Both simulations and measurements of the PA result in high output power of greater than 40 dBm and peak drain efficiency of over 55 % in all the three bands.

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