Multiband RF Power Amplifiers for 5G and Beyond

5G IS coming and wireless communication not only has changed our life but also is becoming one of the core infrastructure supports for multiple vertical industries. Different industrial applications require different standards with different data-rate demands, accompanied by a burst of new standards and frequency bands. It is the basic requirement that a 5G mobile terminal must support 4G/3G even 2G, which means that 5G/4G/3G/2G coexist in a mobile device for supporting all existed mobile standards and frequency bands. The trend is that mobile and wireless are merging, resulting in a single device to support both various mobile/wireless standards and frequency bands. Table I summarizes various frequency bands of the existing mobile and wireless standards.

To support multiple frequency ranges and different standards, multiband and multimode operations are highly desirable, particularly for the RF power amplifiers (PAs) of any transceivers. A PA not only consumes a large portion of power but also introduces distortion that can limit data transmission capacity. To enable multiband operations, PA faces significant challenges. It requires to provide high back-off efficiency to accommodate high peak-to-average power ratio (PAPR) signals and, in the meantime, must maintain high linearity performance at all operation bands to support high data transmission rates.

Recently, many efforts have been made to design PAs of covering multibands and multistandards. Technically, it is very hard to design ultrawideband matching circuits for wideband PAs, higher power consumption and the poor linearity limit the realizations of wideband PAs. Multiband PAs are feasible by adopting new matching network topologies, tunable elements, reconfigurable circuits, and various design methodologies. It is difficult to simultaneously cover multiple frequency ranges and maintain wide modulation bandwidths in PA designs, especially in Doherty PAs (DPAs) where a complex load modulation process needs to be considered. The reported multiband DPAs in the literature can only support a limited number of bands, and they often suffer from narrowband performance in each operation band, which affects their applications in 5G and beyond.

The article published in this issue by Pang *et al.* [item 1) in the Appendix] introduces a six-band DPA that covers at least 150-MHz modulation bandwidth for all the operation bands with improved back-off efficiency. Different from the conventional multiband designs where the multiband matching network is usually considered, in [item 1) in the Appendix], a broadband matching network with phase periodicity is used to design the impedance inverters, off-set elements, and phase compensators in the DPA. The multiband Doherty operation is achieved due to the phase periodicity and it is illustrated that by transferring the functional elements in a wideband DPA to the phase periodic matching networks, a dual-mode DPA with wide bandwidth in each mode can be realized. To increase the number of operation bands, a reciprocal gate bias technique is introduced to enable the DPA to be operated in dual mode, where at one mode, the PA covers two bands, while at the other mode, the PA covers four bands, without changing the matching network circuits. Compared with other multiband designs, the approach reported in [item 1) in the Appendix] provides a relatively simple design that enables the DPA to achieve multiple operation bands distributed over multioctaves, which is usually difficult to achieve in Doherty design.

Since early publish in IEEE Xplore, the article has drawn much attention and got the highest numbers of “Full Text Views” in IEEE Xplore among all the articles presented in this issue. The article [item 1) in the Appendix] demonstrates that the fabricated GaN DPA can be simultaneously operated at two bands (1.8–2.2 and 3.9–4.3 GHz) in Mode I, and four bands (1.52–1.72, 2.38–2.53, 3.67–3.82, and 4.53–4.68 GHz) in Mode II. It achieves 8.7–13.5-dB gain and 39.6–41.5-dBm peak output power at all the designed bands. The drain efficiency at 6-dB back-off is 49.2%–54.5% and 42.2%–56.7% in Modes I and II, respectively. When excited by a five-carrier 100-MHz OFDM signal with a 7.7-dB PAPR, the adjacent channel power ratio (ACPR) is better than −48.9 dBc after digital predistortion, with 35.5%–50.1% average drain efficiency at 1.65/1.95/2.45/3.75/4.1/4.6 GHz, respectively. The overall performance of the PA is impressive.

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Jianguo Ma, *Editor-in-Chief*
School of Computers
Guangdong University of Technology
Guangzhou, 510006 China

Appendix
Related Works

1) J. Pang, Z. Dai, Y. Li, M. Li, and A. Zhu, “Multiband dual-mode Doherty power amplifier employing phase periodic matching network and reciprocal gate bias for 5G applications,” *IEEE Trans. Microw. Theory Techn.*, early access, Feb. 19, 2020, doi: 10.1109/TMTT.2020.2971481.

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TABLE I
FREQUENCY BANDS OF MOBILE/WIRELESS COMMUNICATIONS

5G NR by 3GPP			
Band	Frequency (MHz)	Band	Frequency (MHz)
n1	1920-1980/2110-2170	n70	1695-1710/1995-2020
n2	1850-1910/1930-1990	n71	663-698/617-652
n3	1710-1785/1805-1880	n74	1427-1470/1475-1518
n5	824-849/869-894	n75	1432-1517
n7	2500-2570/2620-2690	n76	1427-1432
n8	880-915/925-960	n77	3300-4200/3300-4200
n20	832-862/791-821	n78	3300-3800/3300-3800
n28	703-748/758-803	n79	4400-50004400-5000
n38	2570-2620/2570-2620	n80	1710-1785
n41	2496-2690/2496-2690	n81	880-915
n50	1432-1517/1432-1517	n82	832-862
n51	1427-1432/1427-1432	n83	703-748
n66	1710-1780/2110-2200	n84	1920-1980
LTE/LTE-Advanced/LTE-Advanced Pro: FDD（MHz）			
1	1920-1980/2110-2170	19	830-845/875-890
2	1850-1910/1930-1990	20	832-862/791-821
3	1710-1785/1805-1880	21	1447.9-1462.9/1495.9-1510.9
4	1710-1755/2110-2155	22	3410-3490/3510-3590
5	824-849/865-894	23	2000-2020/2180-2200 (LTE only)
6	830-840/875-885	24	1626.5-1660.5/1525-1559 (LTE only)
7	2500-2570/2620-2690	25	1850-1915/1930-1995
8	880-915/925-960	26	814-849/859-894
9	1749.9-1784.9/1844.9-1879.9	27	807-824/852-869 (LTE only)
10	1710-1770/2110-2170	28	703-748/758-803 (LTE only)
11	1427.9-1447.9/1475.9-1495.9	29	717-728 (LTE only)
12	699-716/729-746	30	2305-2315/2350-2360 (LTE only)
13	777-787/746-756	31	452.5-457.5/462.5-467.5 (LTE only)
14	788-798/758-768	32	1452-1496
15	1900-1920/2600-2620 (Europe only)	65	1920-2010/2110-2200 (LTE only)
16	2010-2025/2585-2600 (Europe only)	66	1710-1780/2110-2200 (LTE only)
17	704-716/734-746 (LTE only)	67	738-758 (LTE only)
18	815-830/860-875 (LTE only)	68	698-728/753-783 (LTE only)
LTE/LTE-Advanced/LTE-Advanced Pro: TDD（MHz）			
33	1900-1920	40	2300-2400
34	2010-2025	41	2496-2690 (LTE only)

TABLE I

(Continued.) FREQUENCY BANDS OF MOBILE/WIRELESS COMMUNICATIONS

35	1850-1910	42	3400-3600 (LTE only)
36	1930-1990	43	3600-3800 (LTE only)
37	1910-1930	44	703-803 (LTE only)
38	2570-2620	45	1447-1467 (LTE only)
39	1880-1920	46	5150-5925 (LTE only)
WCDMA/HSPA/HSPA+			
1	1920-1980 /2110-2170	11	1427.9- 1447.9/1475.9-1495.9
2	1850-1910/1930-1990	12	699-716/729-746
3	1710-1785/1805-1880	13	777-787/746-756
4	1710-1755/2110-2155	14	788-798/758-768
5	824-849/869-894	19	830-845/875-890
6	830-840/875-885	20	832-862/791-821
7	2500-2570/2620-2690	21	1447.9-1462.9/1495.9-1510.9
8	880-915/925-960	22	3410-3490/3510-3590
9	1749.9-1784.9/1844.9-1879.9	25	1850-1915/1930-1995
10	1710-1770/2110-2170	26	814-849/859-894
TD-SCDMA			
33	1900-1920	37	1910-1930
34	2010-2025	38	2570-2620
35	1850-1910	39	1880-1920
36	1930-1990	40	2300-2400
GSM/GPRS/EDGE/EDGE Evolution/VAMOS			
T-GSM 380	380.2-389.8/390.2-399.8	GSM 850	824-849/869-894
T-GSM 410	410.2-419.8/420.2-429.8	P-GSM 900	890-915/935-960
GSM 450	450.4-457.6/460.4-467.6	E-GSM 900	880-915/925-960
GSM 480	478.8-486/488.8-496	R-GSM 900	876-915/921- 960
GSM 710	698-716/728-746	OCS 1800	1710-1785/1805-1880
GSM 750	777-793/747-763	PCS 1900	1850-1910/1930-1990
T-GSM 810	806-821/851-866	ER-GSM 900	873-915/918-960
CDMA2000 1xEV-DO/CDMA2000 1xRTT/ 1xAdvanced			
BC0	815-849/860-894	BC11	410-483/420-493
BC1	1850-1910/1930-1990	BC12	870-876/915-921
BC2	872-915/917-960	BC13	2500-2570/2620-2690
BC3	887-925/832-870	BC14	1850-1915/1930-1995
BC4	1750-1780/1840-1870	BC15	1710-1755/2110-2155
BC5	410-483/420-493	BC16	2502-25682624-2690
BC6	1920-1980/2110-2170	BC17	2624-2690 (Not for 1xRTT)
BC7	776-788/746-758	BC18	787-799/757-769
BC8	1710-1785/1805-1880	BC19	698-716/728-746
BC9	880-915/925-960	BC20	1626-1660/1525-1559
BC10	806-901/851-940	BC21	2000-2020/2180-2200

TABLE I
(Continued.) FREQUENCY BANDS OF MOBILE/WIRELESS COMMUNICATIONS

WiMAX/WiMAX Advanced			
M2300T-01	2300 to 2400	M3500T -02	3400 to 3600
M2300T-02	2300 to 2400	M3500T -03	3400 to 3600
M2500T-01	2496 to 2690	M3500T -05	3400 to 3600
TETRA/TETRA 2(TED S)			
	351 to 356/361 to 366		450 to 460/460 to 470
	380 to 390/390 to 340		806 to 825/861 to 870
	410 to 420/420 to 430		
LTE D2D (FDD)			
2	1850-1910/1930 - 1990	20	832-862/791 - 821
3	1710-1785/1805 - 1880	26	814-849/859 - 894
4	1710-1755/2110 - 2155	28	703-748/758 - 803
7	2500-2570/2620 - 2690	31	452.5-457.5/462.5 - 467.5
14	788-798/758 - 768	68	698-728/753 - 783
Project 25/APCO-25			
VHF	136 to 174	UHF	450 to 512
UHF	380 to 470	700/800	764 to 870
NB-IoT (FDD)			
1	1920-1980/2110-2170	17	704-716/734-746
2	1850-1910/1930-1990	18	815-830/860-875
3	1710-1785/1805-1880	19	830-845/875-890
5	824-849/869-894	20	832-862/791-821
8	880-915/925-960	26	814-849/859-894
12	699-716/729-746	28	703-748/758-803
13	777-787/746-756	66	1710-1780/2110-2200
SIGFOX			
Europe	863 to 870	North America	902 to 928
LoRaWAN			
Europe	863 to 870	North America	902 to 928
WLAN/WiFi (IEEE 802.11a,b,g,n,p,ac,ax)			
802.11b,g, n,ax	2400-2497	802.11p	5850-5925
802.11a,b,g ,n,ac,ax	5150-5250	802.11p（Japan）	755-765
	5250-5350 (with DFS)		
	5470-5725(with DFS)		
	5725-5850		
WLAN/WiFi HaLow(IEEE 802.11ah)			
Europe	863-868	Korea	917.5-923.5
USA	902-928	China	755-787
Japan	916.5-927.5	Singapo re	866-869 & 920-925
ZigBee/Thread/6LoWPAN (IEEE 802.15.4)			
	169.4 to 169.475		1427 to 1518
	250 to 750		2360 to 2483.5
	779 to 787		3244 to 4742
	863 to 879		5944 to 10234
	896 to 960		2360 to 2483.5

*Collected from the Internet