Design of Class E Power Amplifier for Wireless Communication

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Abstract, The power amplifier is one of the challenging blocks in the implementation of the handset of wireless communication transceivers. In optimum class E, the drain voltage drops to zero and has zero slopes just as the transistor turns on which result is an ideal efficiency of 100%, reduction of switching losses and increase tolerance of component variation. The proposed class E power amplifier using (MOSFET mf_phi_LF2802A_19930106), (FET_GaAs_fll101_me19931021) and (BJT_BC_32719961209) transistors have been designed in the frequency range of (300MHz- 1.5GHz) and note the change in efficiency and power delivered to the load between these types of transistors.

Keyword: class E, power amplifier, switch, efficiency

1 Literature review:

In 2010 [1] "designed class-E amplifier in CMOS at freq. 900MHz. The power is delivered to a 50 Ω load from a 2.2 V supply and achieved a maximum Power Added Efficiency (PAE) of 43%". In 2013 [2] "designed two class-E circuits using the GaN (HEMT) in both(infinite DC-feed, shunt inductor conf.) .in infinite dc-feed 69% drain eff., 64% PAE, and 21.46 dBm load power, in the case of shunt indictor design 71% eff., 64.5% PAE, and 15.93 dBm load power". In 2015 [3] " designed, constructed, and tested class-E power amplifier of 1 MHz operating frequency to generate (PWM) switching signal and drive the IRF510 MOSFET microcontroller board with PIC16F877A is used, with output power 9.45W and drain efficiency of 98.44%". In 2016 [4] "observed performance parameters relationships to the load and duty cycle with 12V dc and efficiency of 98.44% powered, at 50% duty cycle and 1MHz to produce a stable sinusoidal signal". In 2016 [5] " simulated power amplifier by (ADS) CMOS simulation results from 1.8 V supply voltage at 2.4/5.15 GHz, 21.407/21.523 dBm output power to 50 Ω standard load with 55.1/51.07% Power-Added-Efficiency (PAE) and drain efficiency (DE) 55.5/51.4 %". In 2016 [6] "designed class E power amplifier operates to a broadband range of 6.78MHz-2.45GHz which achieved by low power and high power transistor. By increasing the order of (input-output) matching network the Efficiency of the power amplifier is increased. A GaN-HEMT transistor is used for the high power, GaAs HBT is used for low power design". In 2017[7] " designed class E use device of RF3931GaN HEMT in the frequency range of 1GHz, to increasing gain up to 14.327dB and achieving high output power and operates. The designed Power Added Efficiency (PAE) is 64% after maximum source power achieved is 32dBw". In 2018 [8] "presented a power amplifier with single-stage and 2-stage 2.4 GHz, the simulated gain and power added efficiency (PAE) for single stage PA are 17.58dB and 53%, correspondingly. While the experimental gain and PAE are 16.7dB and 49.5%. Conversely, for 2-stages PA, the simulated gain comes out to be 34.6dB and PAE is 55%, whereas the experimental gain and PAE are 30.5dB and 53.1%, respectively".

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2 Introduction:

"Class E power amplifiers can provide power at a theoretical efficiency of 100% at the expense of linearity. Therefore they are most suitable for systems using constant envelope modulation schemes such as GSM. Class-E full differential amplifier designed in 0.35 µm CMOS process. The differential implementation provides twice the voltage swing across the load compared to a single-ended amplifier which results in a four-time increase in output power delivered "[1]. "The saturation mode of the transistor allows it to operate as a switch so either voltage or current (depending on amplifier class) is switched on and off. To be specific, the switch is “on” for almost half of the ac period and “off” for the remainder of the period. A low pass or bandpass filter may be included at the load network to may transform the load impedance and accommodate load reactance and suppress harmonics of the switching frequency at the load" [3]. "Class-E power amplifier offers wonderful advantages and has attracted a great deal of attention in recent years. After that, to expand the applications of the class E circuit, various topologies have appeared such as class E (DC/DC) converter, inverter and rectifier. Also, the class E circuits are applied to RF power amplifier, induction heating system and RF power" [4]. "The implementation of multi-band systems is a very important issue for the next generation of wireless communication. While base-band and analog circuits can be integrated within a single chip for multi-band polar transmitters without significant problem. Wireless connectivity in portable applications demands high-efficiency RF transmitters to save battery life. The class E power amplifier is a single switch connection they have ON and OFF switch, the switches should be connected in the load network, because to reduce the power dissipation, if that decreases automatically, the output power should increase and also the efficiency and the main aim is to reduce the size by using the class E power amplifier, theoretically which gives 100% efficiency" [7].

3 Switch mode of class E power amplifier :

"The point of use transistor operates on a saturation region is to take advantage of switch-mode of either voltage or current on and off. Figure 1 is a block diagram of a single-ended switch-mode amplifier" [3]. "The class E amplifier is designed to provide high efficiency, and it is typically used at high frequencies. An inductor is used in class E power amplifier design to connect to the supply, and a shunting capacitance across the switch to decrease the power loss and shape the standard waveforms for both current and voltage" [6].

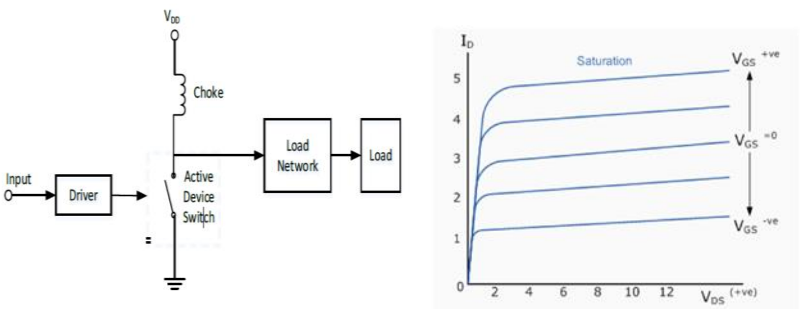

Fig. 1. Switch-mode class E Block Diagram and output characteristic

4 Simulation and Design of Proposed Power Amplifiers:

The proposed class E power amplifier is designed using three types of transistors (BJT-FET – MOSFET) to compare the efficiency and power in the same range of frequency. A conventional Class-E amplifier as shown in Figure(2) consists of a transistor with a shunt capacitor C1 present at its output when it is increased, the output current increased also and when it decreases the output voltage increases. The output load RL is connected via a series LC filter tuned at the frequency of operation *fo*. DC power supply VDD is connected to the drain of the transistor via an RF choke L1. The presence of the series LC filter ensures that only the fundamental harmonic current will flow through the load. "This means that the total current through the transistor and the shunt capacitor is the sum of the ac and dc currents through the load and the choke respectively"[1]. "To find the value of power amplifier efficiency the main parameters needed are DC input voltage, DC input current, output voltage and output current" [8].

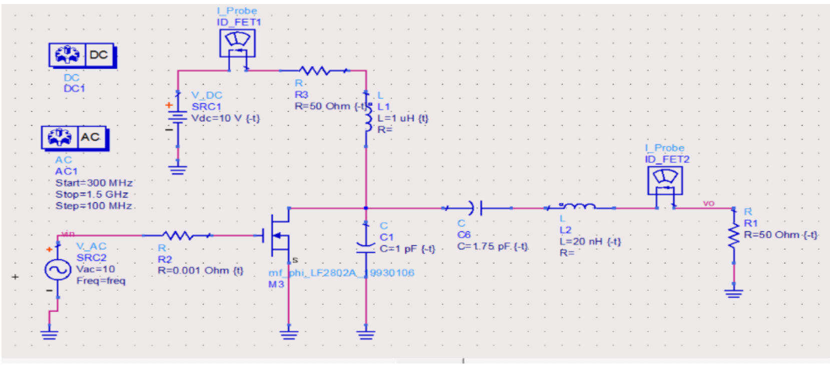

Fig. 2. Proposed Power Amplifier circuit diagram in ADS

5 Results: The circuit in figure (2) illustrates the design of class E power amplifier, the first circuit designed using (MOSFET mf_phi_LF2802A_19930106) ADS, Iout, Vout, Idc are measured and Pout, Pdc and eff% are calculated as follow

$$P_{out} = V_{out} * I_{out} \qquad (1)$$
$$P_{dc} = V_{dc} * I_{dc} \qquad (2)$$
$$Eff = \frac{P_{out}}{P_{dc}} \qquad (3)$$

And dc voltage is set to $V_{dc} = 11v$

While DC is measured $I_{dc} = 174.3mA$

Table (1) shows measured and calculated values for the frequency range (300MHz-1.5GHz) for (MOSFET mf_phi_LF2802A_19930106) transistor, where figures (3 through 6) illustrate the graphs of Efficiency, output AC current, output AC voltage and output AC power of the chosen transistor, the figures indicate that the maximum values are at a frequency (1.3 GHz) with BW=300MHz.

Table 1. Measured and calculated values for MOSFET mf_phi_LF2802A_19930106

EFF	PDC	IDC	VDC	POUT	VOUT	IOUT	F
0.000367	1.9184	0.1744	11	0.000704	0.176	0.004	300
0.000951	1.9184	0.1744	11	0.001824	0.304	0.006	400
0.002685	1.9184	0.1744	11	0.00515	0.515	0.01	500
0.007683	1.9184	0.1744	11	0.014739	0.867	0.017	600
0.020638	1.9184	0.1744	11	0.039592	1.414	0.028	700
0.045823	1.9184	0.1744	11	0.087906	2.093	0.042	800

0.078784	1.9184	0.1744	11	0.15114	2.748	0.055	900
0.126908	1.9184	0.1744	11	0.24346	3.478	0.07	1000
0.233984	1.9184	0.1744	11	0.448875	4.725	0.095	1100
0.554502	1.9184	0.1744	11	1.063756	7.286	0.146	1200
0.751725	1.9184	0.1744	11	1.44211	8.483	0.17	1300
0.275862	1.9184	0.1744	11	0.529214	5.138	0.103	1400
0.110558	1.9184	0.1744	11	0.212095	3.263	0.065	1500

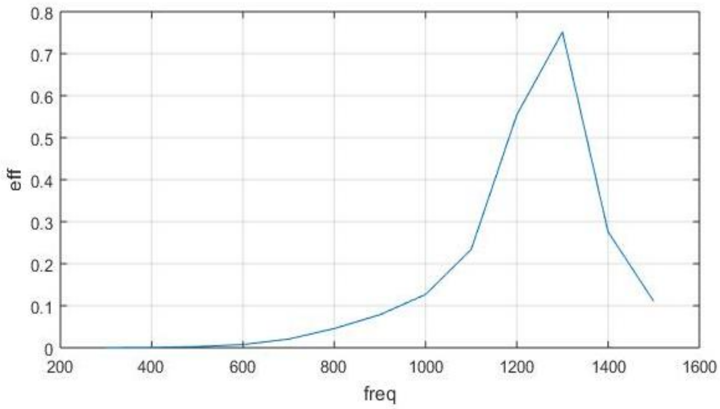

Fig. 3. Efficiency with frequency for MOSFET mf_phi_LF2802A_19930106

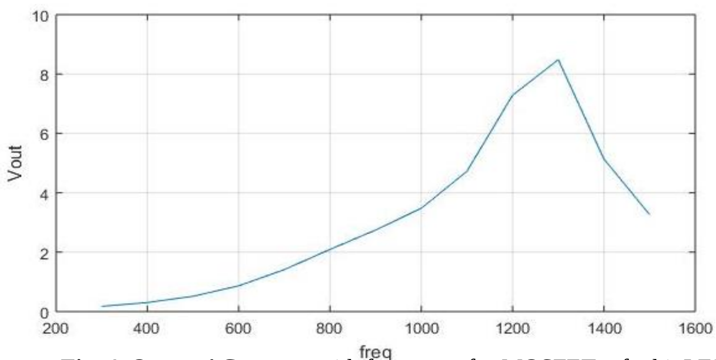

Fig. 4. Output AC current with frequency for MOSFET mf_phi_LF2802A_19930106

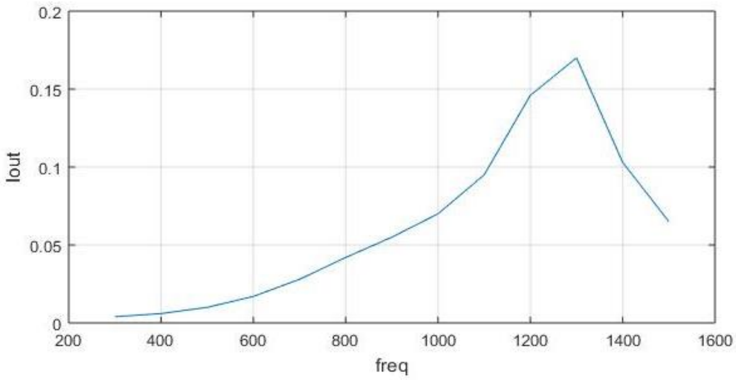

Fig. 5. Output AC voltage with frequency for MOSFET mf_phi_LF2802A_19930106

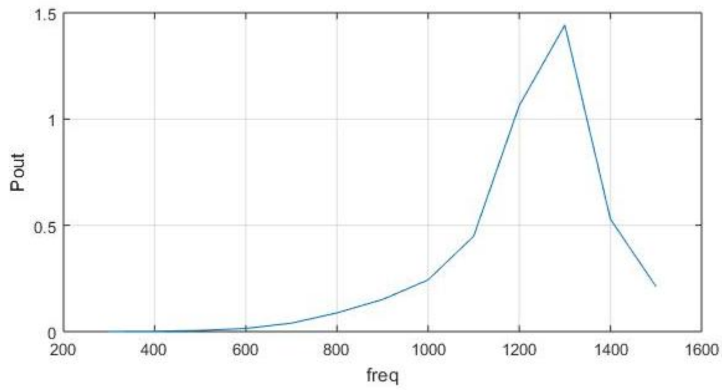

Fig. 6. Output AC power with frequency for MOSFET mf_phi_LF2802A_19930106

The second proposed circuit used ,(FET_GaAs_fll101_me19931021) transistor with dc voltage sets to $V_{dc} = 11v$ While DC is measured $I_{dc} = 212.3mA$

Table (2) shows measured and calculated values for the frequency range (300MHz-1.5GHz) for (FET_GaAs_fll101_me19931021) transistor where figures (7 through 10) clarify the graphs of Efficiency, output AC current, output AC voltage and output AC power of the chosen transistor, the figures indicate that the maximum values are at the frequency (0.8 GHz) with BW=442.6 MHz.

Table 2. Measured and calculated values for this circuit (FET_GaAs_fll101_me19931021)

EFF	PDC	IDC	VDC	POUT	VOUT	IOUT	F
2.61208E-05	2.3353	0.2123	11	0.000061	0.061	0.001	300

9.50627E-05	2.3353	0.2123	11	0.000222	0.111	0.002	400
0.000311737	2.3353	0.2123	11	0.000728	0.182	0.004	500
0.000734809	2.3353	0.2123	11	0.001716	0.286	0.006	600
0.001645613	2.3353	0.2123	11	0.003843	0.427	0.009	700
0.002581253	2.3353	0.2123	11	0.006028	0.548	0.011	800
0.002571832	2.3353	0.2123	11	0.006006	0.546	0.011	900
0.001807477	2.3353	0.2123	11	0.004221	0.469	0.009	1000
0.001353145	2.3353	0.2123	11	0.00316	0.395	0.008	1100
0.001016144	2.3353	0.2123	11	0.002373	0.339	0.007	1200
0.00076821	2.3353	0.2123	11	0.001794	0.299	0.006	1300
0.000575943	2.3353	0.2123	11	0.001345	0.269	0.005	1400
0.000526699	2.3353	0.2123	11	0.00123	0.246	0.005	1500

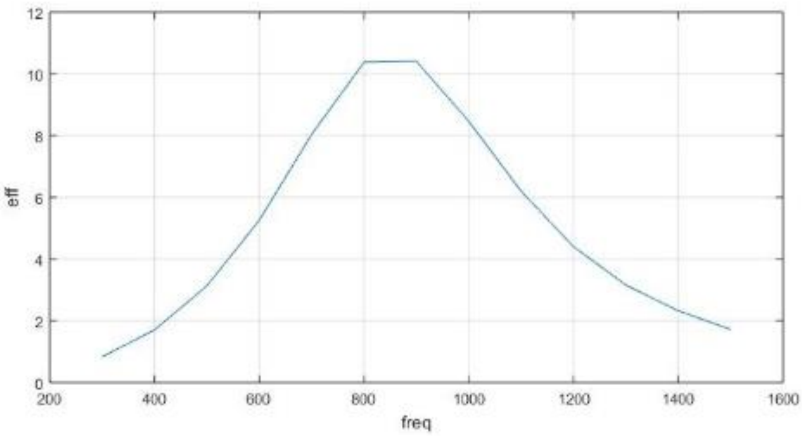

Fig. 7. Efficiency with frequency for FET_GaAs_fll101_me19931021

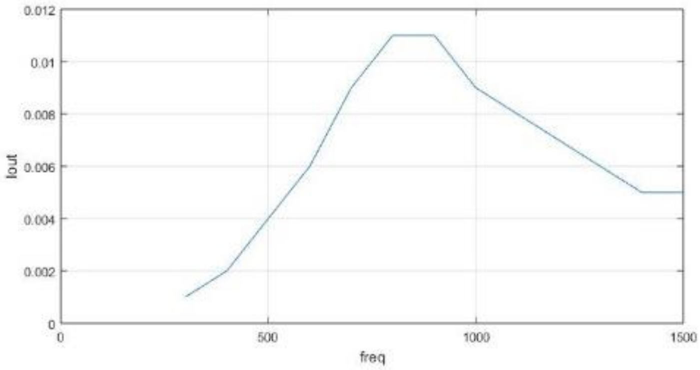

Fig. 8. Output AC current with frequency for FET_GaAs_fll101_me19931021

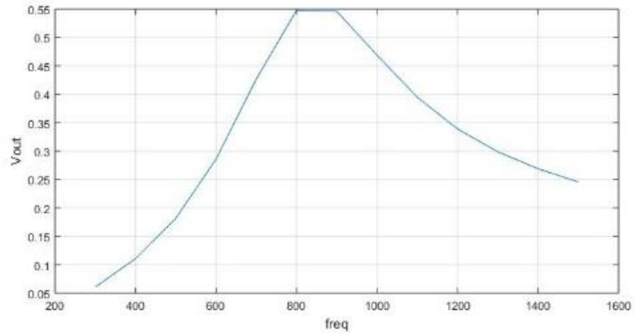

Fig. 9. Output AC voltage with frequency for FET_GaAs_fll101_me19931021

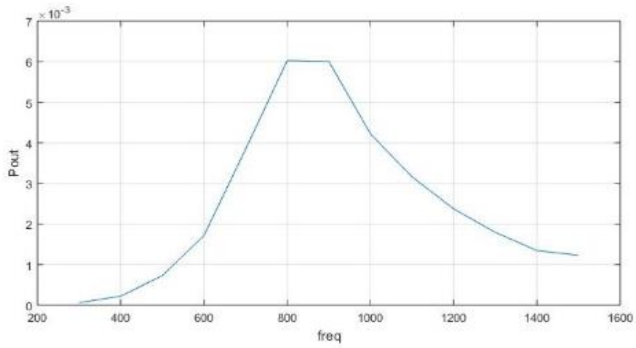

Fig. 10. Output AC power with frequency for FET_GaAs_fll101_me19931021

The third circuit used (BJT_BC_32719961209) transistor with dc voltage sets to

$V_{dc} = 11v$

While DC is measured $I_{dc} = 7.49mA$

Table (3) shows measured and calculated values for the frequency range (300MHz-1.5GHz) for (BJT_BC_32719961209) transistor where figures (11 through 14) explain the graphs of Efficiency, output AC current, output AC voltage and output AC power of the chosen transistor, the figures indicate that the maximum values are at a frequency (0.9 GHz) with BW=556.4 MHz.

Table 3. Measured and calculated values for this circuit (BJT_BC_32719961209)

EFF	PDC	IDC	VDC	POUT	VOUT	IOUT	F
0.831703	0.08239	0.00749	11	0.068524	1.852	0.037	300
1.704697	0.08239	0.00749	11	0.14045	2.65	0.053	400
3.131157	0.08239	0.00749	11	0.257976	3.583	0.072	500
5.255589	0.08239	0.00749	11	0.433008	4.656	0.093	600
8.035623	0.08239	0.00749	11	0.662055	5.757	0.115	700
10.37633	0.08239	0.00749	11	0.854906	6.526	0.131	800
10.40813	0.08239	0.00749	11	0.857526	6.546	0.131	900
8.46008	0.08239	0.00749	11	0.697026	5.907	0.118	1000
6.194356	0.08239	0.00749	11	0.510353	5.053	0.101	1100
4.398046	0.08239	0.00749	11	0.362355	4.263	0.085	1200
3.155626	0.08239	0.00749	11	0.259992	3.611	0.072	1300
2.32453	0.08239	0.00749	11	0.191518	3.089	0.062	1400
1.719493	0.08239	0.00749	11	0.141669	2.673	0.053	1500

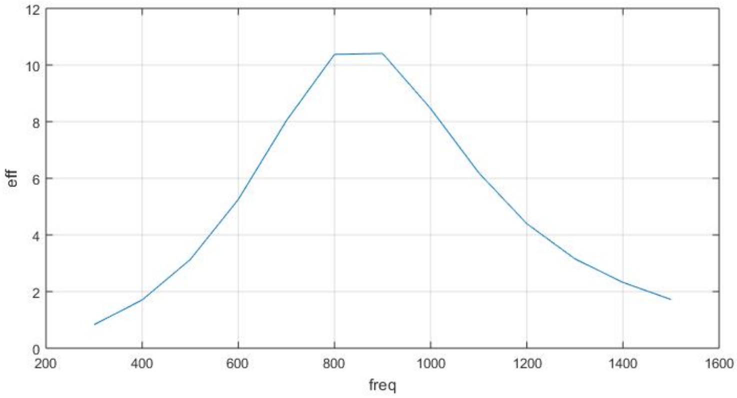

Fig. 11. Efficiency with frequency for BJT_BC_32719961209

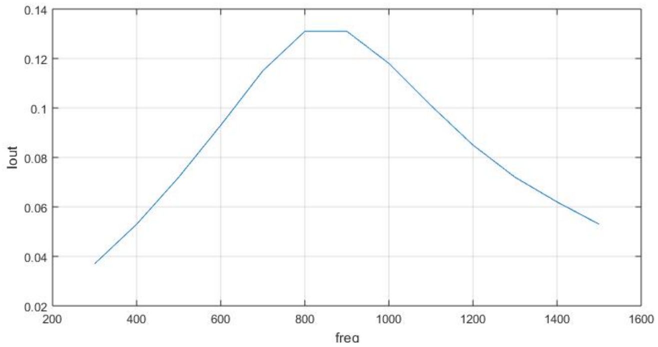

Fig. 12. Output AC current with frequency for BJT_BC_32719961209

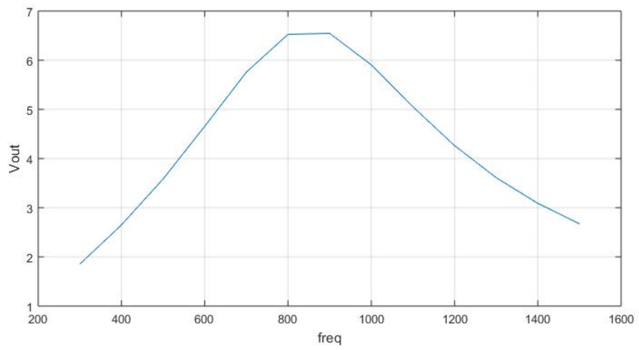

Fig. 13. Output AC voltage with frequency for BJT_BC_32719961209

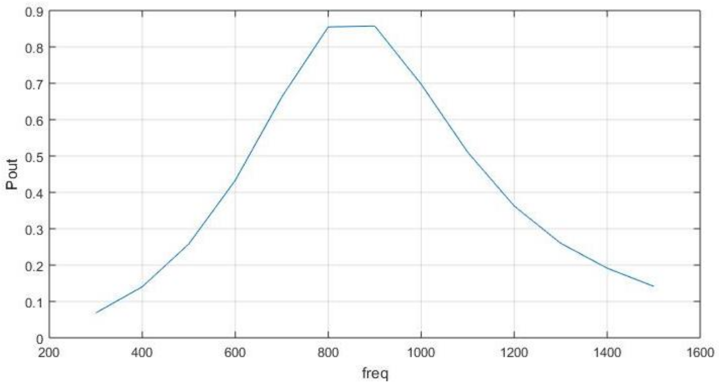

Fig. 14. Output AC power with frequency for BJT_BC_32719961209

6 Conclusion:

Various types of MOSFET active devices have been presented through a design process of a E-Class power amplifier. The results concern the maximum efficiency, AC output current, AC output voltage and output power have been illustrated. MOSFET (mf_phi_LF2802A_19930106) shows a better operation at 1.3 GHz, while for, (FET_GaAs_fll101_me19931021) the maximum point is at frequency 0.8GHz and finally BJT_BC_32719961209 was best performed 0.9GHz. It is expected that these frequencies can be best fit the white space of terrestrial television broadcasts.

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