AMPLEON

Benelux RF Conference 2019

Student Design Competition

The Title of Competition: *Wideband Class-F Termination Network Design*

Submission Deadline: *November 15, 2019*

Sponsor: *Ampleon Netherlands B.V.*

Primary contact name: *Dr. Lazaro Marco-Platon (lazaro.marco@ampleon.com)*

Abstract

This competition will introduce students to the Class-F type termination network which is one of the RF high power amplifier termination networks to boost the efficiency by manipulating the current and voltage waveforms.

A design competition titled “Class-F Termination Network Design” will take place at the 2019 Benelux Rf Conference in Nijmegen. This competition is open to all students in Europe. The main target of the contest is design and realization of a Class-F type network. The competitors will design and fabricate a termination network by considering a low insertion loss at operation band, short termination at the 2nd harmonic frequency, and open termination at the 3rd harmonic frequency. Although students are free to use any topology and material, they need to meet a given set of specifications.

The winner will be the network that demonstrates the widest operation bandwidth. If there is a tie, the lowest insertion loss will be the winner.

A representative of the design team must be present at the competition day. Measurements will be open to all conference participants.

Questions can be sent to Dr. Lazaro Marco-Platon.

Last update: *29 June 2019*

Award: *500 €*

AMPLEON

Design Specifications and Rules

1) The circuit should meet these specifications
   a. Center frequency: 2 GHz
   b. Low insertion loss at operating band (< 0.5 dB)
   c. Low impedance at 2^{nd} harmonic frequency (< 2 Ω)
   d. High impedance at 3^{rd} harmonic frequency (> 500 Ω)
   e. SMA female connector at input and output

2) Each team can participate with a maximum of two circuits. If a team consists of five or more students, three circuits are allowed. Each team can have only one reward, even if all designs have the highest scores. Only one team is allowed from each laboratory/workgroup/advisor.

3) The students will prepare the circuit(s) for the measurements. The implemented circuits will be reliable regarding mechanical issues such as cable connection. The organization committee does not accept any responsibility in case of physical damages during the competition.

4) All measurement tools will be provided by the organizer such as cables, VNA, etc. A 50 Ω VNA will be used for the measurements.

5) The implemented circuit should be suitable for visual inspection. No sealed casing is allowed.

6) Active components, embedded batteries, and supercapacitors are not allowed.

7) The circuit board can have a maximum of two layers (top layer for signal lines, bottom layer for ground). Students are free to choose the material and thickness of the circuit board.

8) No changes in the circuit board are allowed during the measurements.

9) The circuit should look like a PA termination network.

10) There will be three measurements to evaluate the designs:
   a. Operation bandwidth: The band of having less than 0.5 dB insertion loss will be accepted as operation bandwidth
   b. 2^{nd} harmonic shorted termination bandwidth: The band of having less than 2Ω impedance at the 2nd harmonic frequency will be accepted as 2^{nd} harmonic bandwidth.
   c. 3^{rd} harmonic open circuit termination bandwidth: The band having higher than 500 Ω impedance at the 3^{rd} harmonic frequency will be accepted as 3^{rd} harmonic bandwidth.

11) The widest accepted Class-F operation bandwidth will be the winner of the competition. The bandwidth at the 2^{nd} and 3^{rd} harmonics will be also considered to define the Class-F operation bandwidth. The smallest bandwidth of the three measurements (including low and high side regarding center frequency) will be defined as accepted Class-F operation bandwidth. Check the details at evaluation section.

12) Before the competition day, a detailed report including measured data and design files (such as ADS or AWR workspace) should be submitted to the organizing committee.

Evaluation Method

Operation Bandwidth at f_o Insertion loss (< 0.5 dB)		Operation Bandwidth at $2f_o$ Low impedance (< 2 Ω)		Operation Bandwidth at $3f_o$ High impedance (> 500 Ω)	
Low side Δf_1	High side Δf_2	Low side Δf_3	High side Δf_4	Low side Δf_5	High side Δf_6
Bandwidth at f_o $BW@f_0 = 2 \times \min(f_1,f_2)$		Bandwidth at $2f_o$ $BW@2f_0\ [2 \times \min(f_3,f_4)] / 2$		Bandwidth at $3f_o$ $BW@3f_0\ [2 \times \min(f_5,f_6)] / 3$	
Accepted Class-F operation bandwidth = $\min(BW@f_o, BW@2f_o, BW@3f_o)$					

How to Participate

1. *Request the entry form (by e-mail)*
2. *Submit the entry form before November 15, 2019 (a confirmation letter will be sent)*
3. *Students are encouraged to ask questions and for recommendations*
4. *Submit a brief report including simulations, layout, and measurements before the competition.*
   (The selected projects will receive an acceptance letter to attend the competition.)

Output Termination Networks for High Power Amplifiers

To reduce power dissipation on the transistor and to improve efficiency, overlap between current and voltage waves should be prevented at the current source plane of the transistor.

Therefore, waveform shaping at the drain or collector plane is an essential requirement for high power amplifiers. There are several methods to manipulate the current and voltage waveforms. Class-F type one of the most popular and well-known termination structures which can provide proper current and voltage wave-shaping by using the harmonics.

Since high power amplifier has large input signal and operates at saturation region, the output signal also includes harmonics. On the other hand, the harmonic content at the output can be used to improve efficiency. If the odd harmonics are terminated as open and even harmonics are terminated as short, voltage and current waveforms approximate a square wave and a half sine wave, respectively. Figure 1 depicts such a structure.

However, terminating the all harmonics is not feasible for microwave circuits. Termination up to 3rd harmonic is applicable, and it can provide 81.7% efficiency in theory. It is usually sufficient for many applications.

In this competition, a Class-F network design up to 3rd harmonic termination will be designed and implemented. Since there is no active component, the design will be measured as a passive network with a vector network analyzer (VNA). The insertion loss and impedances at the 2nd and 3rd harmonics will be considered to evaluate the performance of the designed networks.

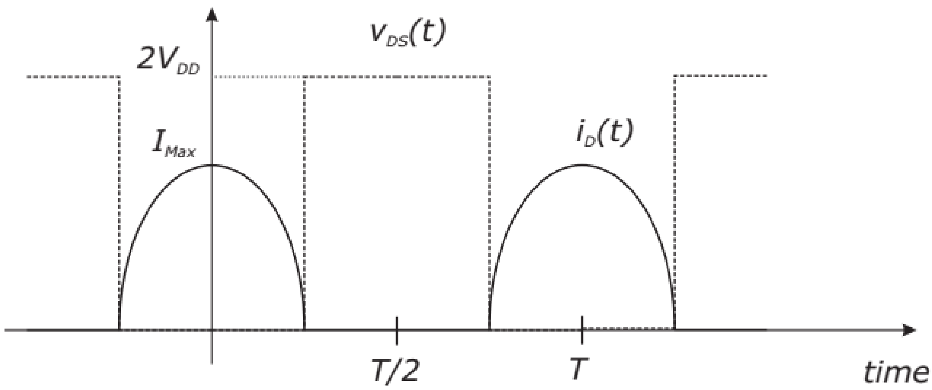

Figure 1. *Ideal voltage and current waveforms for a Class-F amplifier [1].*

AMPLEON

Resources for Biasing Network Design

[1] P. Colantonio, F. Giannini, and E. Limiti, High Efficienct RF and Microwave Solid State Power Amplifiers, section: High Frequency Class-F Power Amplifiers, page:269.

[2] S. Gao, "High Efficiency Class F RF/Microwave Power Amplifiers," MTTs Microw. Mag., vol. 7, no. 1, pp. 40–48, 2006.

[3] F. H. Raab, "Maximum Efficiency and Output of Class-F Power Amplifiers," IEEE Trans. Geosci. Remote Sens., vol. 49, no. 6, pp. 1162–1166, 2001.

[4] J. Moon, S. Jee, J. Kim, J. Kim, and B. Kim, "Behaviors of Class-F and Class-F," IEEE Trans. Microw. Theory Tech., vol. 60, no. 6, 2012.

[5] O. Ceylan, H. B. Yagci, and S. Paker, "Tunable Class-F high power amplifier at X-Band using GaN HEMT," Turkish J. Electr. Eng. Comput. Sci., vol. 26, no. 5, pp. 2327–2334, 2018.

[6] A. Grebennikov, "Load Network Design Technique for Class F and Inverse Class F PAs," High Freq. Electron., vol. 10, no. May, pp. 58–76, 2011.

[7] F. H. Raab and S. Member, "Class-F Power Amplifiers with Maximally Flat Waveforms," IEEE Trans. Microw. Theory Tech.*, vol. 45, no. 11, pp. 2007–2012, 1997.*

Evaluation Example

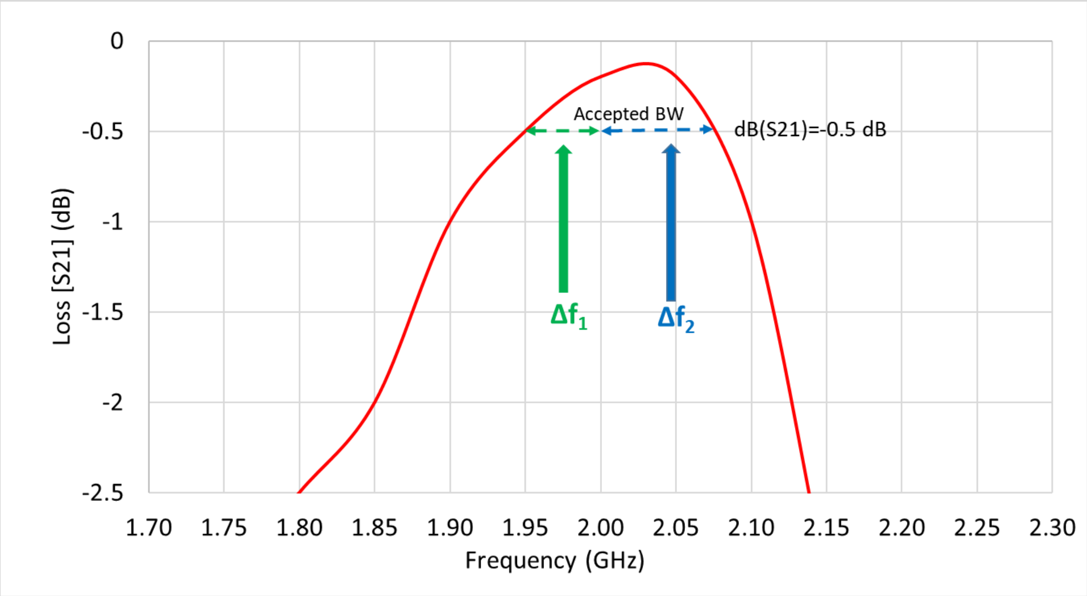

Figure 2. *Insertion loss measurement.*

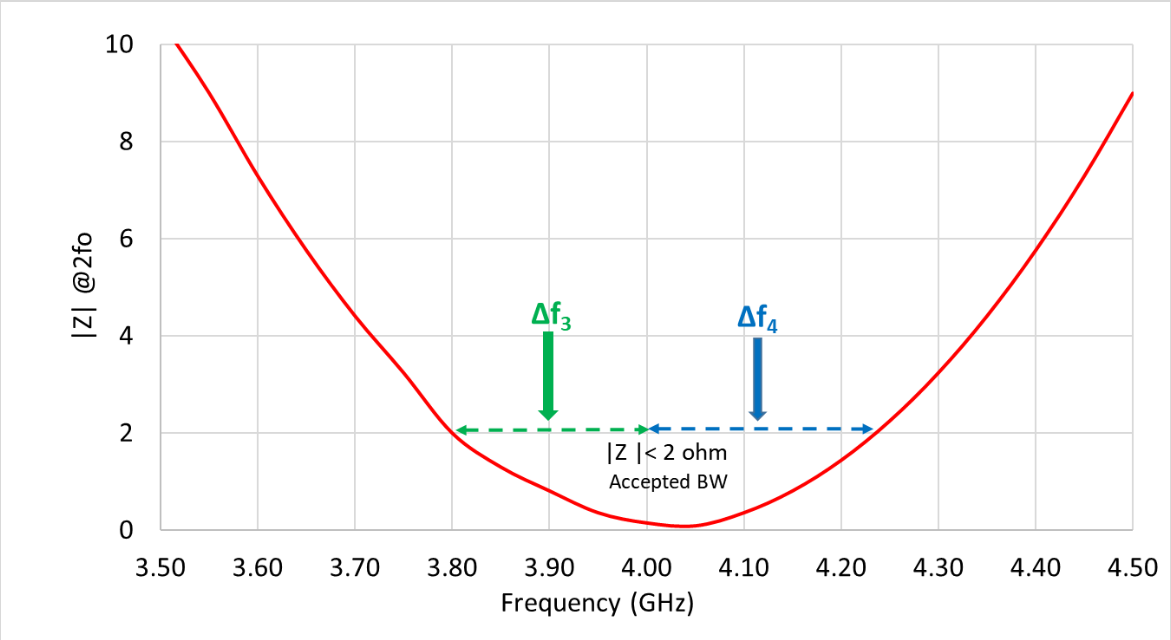

Figure 3. *Impedance measurement at 2nd harmonic frequency 4 GHz.*

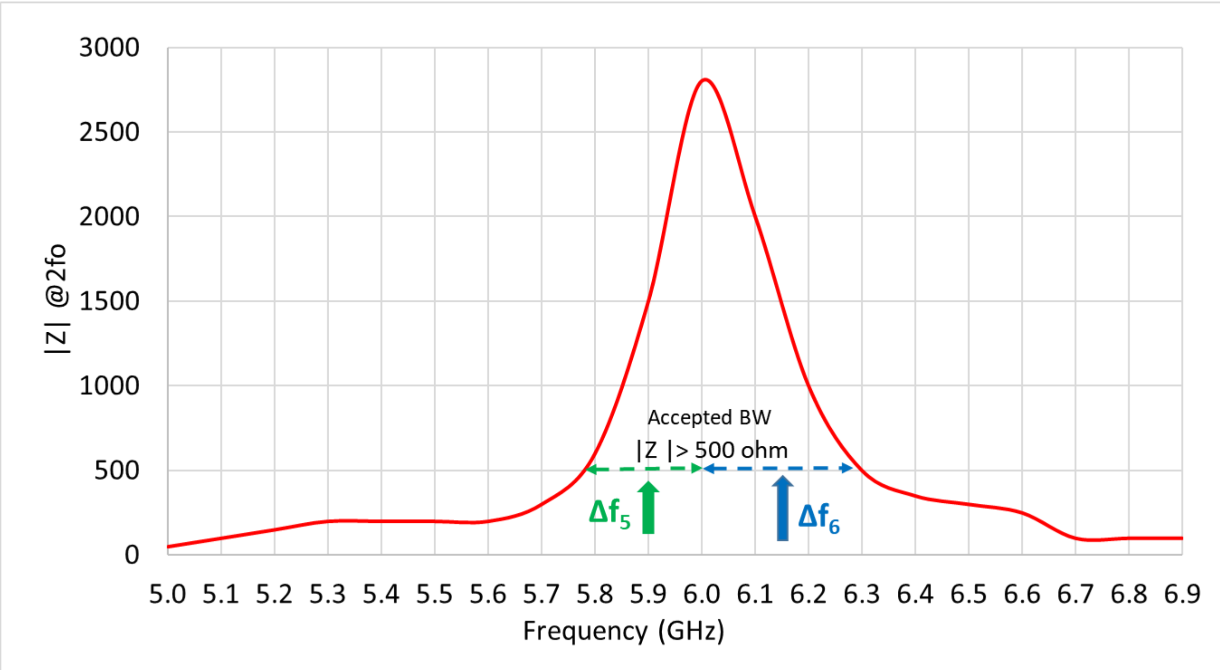

Figure 4. *Impedance measurement at 3rd harmonic frequency 6 GHz.*

Score Board

Δf_1	Δf_2	Δf_3	Δf_4	Δf_5	Δf_6
50 MHz	75 MHz	200 MHz	240 MHz	220 MHz	290 MHz
BW at f_o = 2 x min(f_1,f_2) = 2 x 50 = 100 MHz		BW at $2f_o$ = [2 x min(f_3,f_4)] / 2 = [2 x 200] / 2 = 200 MHz		BW at $3f_o$ = [2 x min(f_5,f_6)] / 3 = [2 x 220] / 3 = 147 MHz	
Accepted Class-F Operation Bandwidth is 100 MHz! (The smallest one)					

Organized by Dr. Osman CEYLAN