Student Design Competition Submission Form for IMS2018 in Philadelphia, PA 10-15 June 2018

Your TC number and name of your TC:

- *MTT-8 (Filters and Passive Components)*

Primary contact name(s), email address, and phone number (of host or competition leader(s)):

- Eric Naglich: eric.naglich@nrl.navy.mil
- Sanghoon Shin: sang.shin@nrl.navy.mil

The title of your Student Design Competition:

"Reconfigurable Bandpass Filter Design"

A short abstract or summary describing the competition:

Tunable bandpass filters with very wide center frequency tuning ranges have long been sought as one of the most desirable components for reconfigurable radios. However, quick and accurate control of these filters over varying environmental conditions has proven to be one of the challenges that have limited practical adoption relative to their promising capabilities. Filters with a static center frequency and reconfigurable response shape can be highly valuable to systems that experience dynamic interference while being simpler to control. This competition will explore the design of such a filter. Entries will be scored based on passband insertion loss (passive filters) or noise figure (active filters) at specified frequencies, stopband attenuation at specified frequencies, and physical size.

Which prizes will you offer and will this be a one level competition with all students combined or a two level contest so that undergraduates are judged separately from graduate students?

The prize money allocated is $2000 per contest. The forecasted prize division is: First place will receive $1200, second place will receive $500, and third place will receive $300. The judges reserve the right to change this allocation based on the number and quality of the entries, as well as score ties or other unforeseen scoring events. This will be a one level competition.

Brief description of competition and rule(s). Make this as long as you want.

The challenge will be to build an electronically-reconfigurable bandpass filter that performs optimally in three different interference scenarios: interference below the passband frequencies, interference above the passband frequencies, and interference in the middle of passband frequencies. The passband frequency will be 1.1 GHz to 1.3 GHz. Note that 1.1 GHz to 1.3 GHz is the frequency range over which minimal insertion loss is desired and does not necessarily correspond to the 3 dB bandwidth. The bandpass filter may consist of any electronic components and substrate materials, including but not limited to active devices, varactors, switches, diodes, and/or lumped elements. Note that in this competition, the filter's frequency response must be electronically reconfigurable. Final mechanical tuning will be allowed before the beginning of the evaluation of the filter, but only electronic tuning will be allowed once measurement has started. For passive filter entries, the passband metric will be insertion loss. For active filter entries, the passband metric will be noise figure. Note that filters that use varactors, switches, and other control components only are considered passive filters for this competition. Filters that use HEMTs or other transistors for gain or Q-improvement are considered active filters for this competition.

The filter must have traces or wires that are soldered to female SMA connectors on the edges of the substrate. It will be evaluated based on the performance measured between the SMA connector interface reference planes. An algorithm using the result of these measurements and the size of the filter will be used to compute a composite score. A network analyzer, two voltage sources (0-20 Volts, 0-100 mA), and a yet-to-be-determined apparatus for measuring noise figure using the Y-factor method will be available for measurements and filter reconfiguration.

Scoring of entries will be based on a quantitative point system. The entries with the highest number of points will win the prizes. Points will be assessed according to the following specifications:

1. Size: If there are three-dimensional filter entries, the volume of the filters will be measured. If all of the entries are planar filters, size will be measured as the area of the circuit, and the height of the surface-mount components will be neglected. Please note that in this competition the volume or area will be defined as the product of the longest two or three dimensions (rounded to the nearest mm) and include the area required by the connector launches. This definition will be adopted to reduce measurement time. The score total from the remaining measurements will be divided by half of the size of the filter in cm^2 or cm^3 to compute the composite score for the filter.
2. Scenario 1, interference below the passband frequencies: This scenario evaluates the filter's capability to attenuate an interferer at 1.0 GHz while having a low-loss passband from 1.1 GHz to 1.3 GHz. The attenuation at 1.0 GHz will be measured in dB, and positive points will be awarded for each dB of attenuation. The insertion loss (passive filters) or noise figure (active filters)

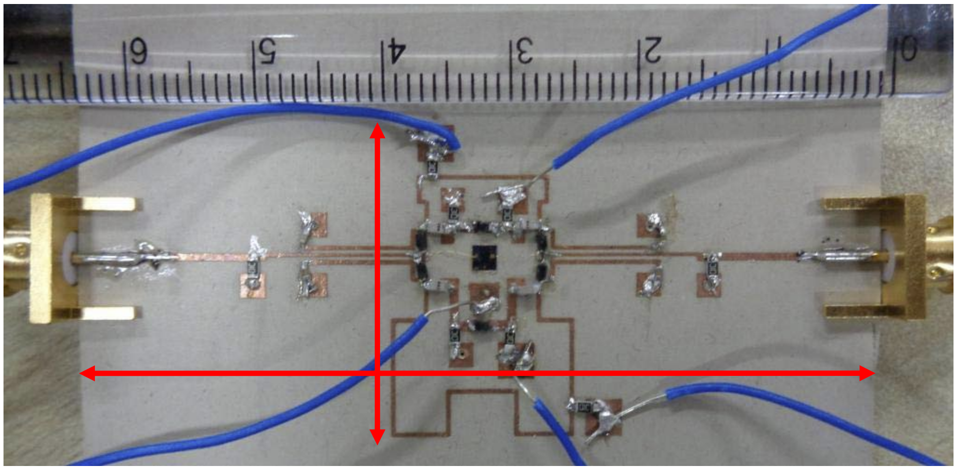
will then be measured at 1.1 GHz, 1.2 GHz, and 1.3 GHz, and negative points will be given for each dB of insertion loss or noise figure.

3. Scenario 2, interference above the passband frequencies: This scenario evaluates the filter's capability to attenuate an interferer at 1.4 GHz while having a low-loss passband from 1.1 GHz to 1.3 GHz. The attenuation at 1.4 GHz will be measured in dB, and positive points will be awarded for each dB of attenuation. The insertion loss (passive filters) or noise figure (active filters) will then be measured at 1.1 GHz, 1.2 GHz, and 1.3 GHz, and negative points will be given for each dB of insertion loss or noise figure.
4. Scenario 3, interference in the middle of passband frequencies: This scenario evaluates the filter's capability to attenuate an interferer at 1.2 GHz while having a low-loss passband from 1.1 GHz to 1.15 GHz and 1.25 GHz to 1.3 GHz. The attenuation at 1.175 GHz, 1.2 GHz, and 1.225 GHz will be measured in dB, and positive points will be awarded for each dB of attenuation. The insertion loss (passive filters) or noise figure (active filters) will then be measured at 1.1 GHz, 1.15 GHz, 1.25 GHz, and 1.3 GHz, and negative points will be given for each dB of insertion loss or noise figure.
5. In order to keep the competition length within a reasonable amount of time, students will have three minutes to tune their filters for each scenario. Once scenario 1 has been measured, all tuning must be electronic.

An example of filter scoring is shown below:

Before measurement, each team will be asked to describe their design to the other students. Please feel free to bring diagrams that will aid in explanation.

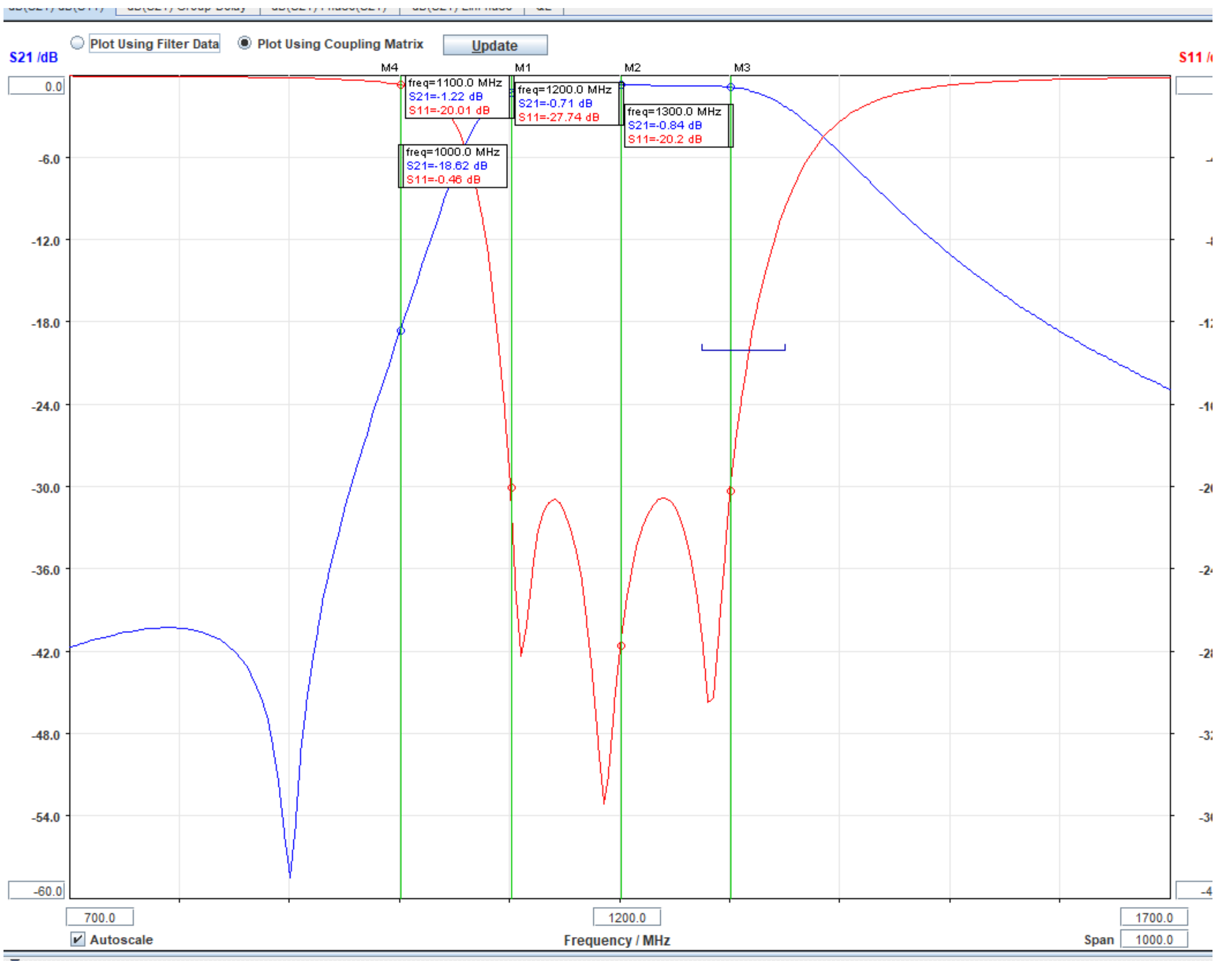
Size: The following design from [1] will be used to demonstrate how size will be measured, assuming that size is decided to be area (instead of volume) at the competition:



This filter will be measured to be 6.3 cm wide and (approximately) 2.5 cm long, for a total size of 15.75 cm^2. Red arrows have been added to show the measurements.

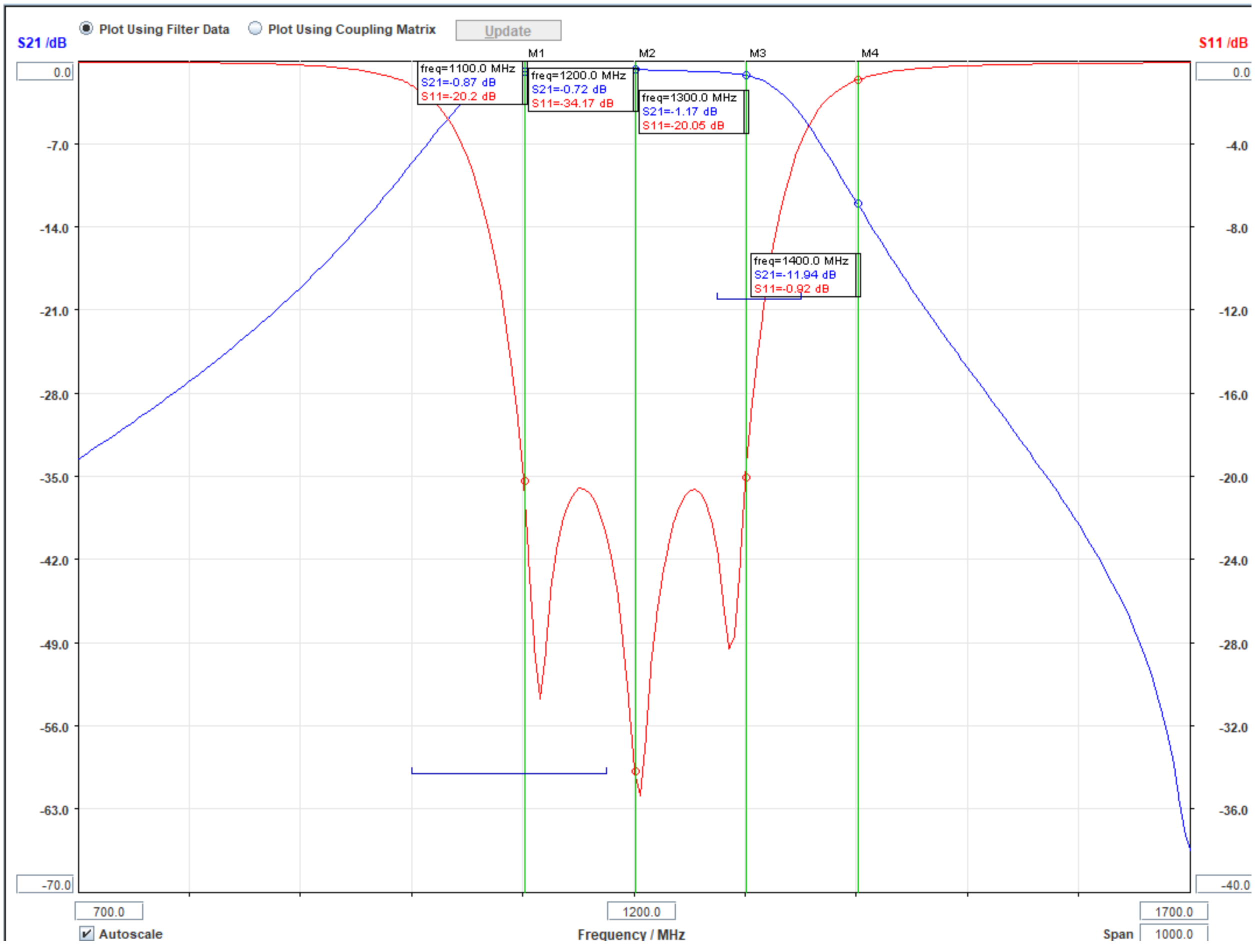
Please note that showing this filter to demonstrate size measurement is not a suggestion or relevant way to implement your filter for the competition. It is merely a convenient image for demonstrating size measurement.

Scenario 1: Suppose the submitted filter is passive and has a frequency response as shown below, which is the response of a 3-pole bandpass filter with a transmission zero at 900 MHz and Q of 100:



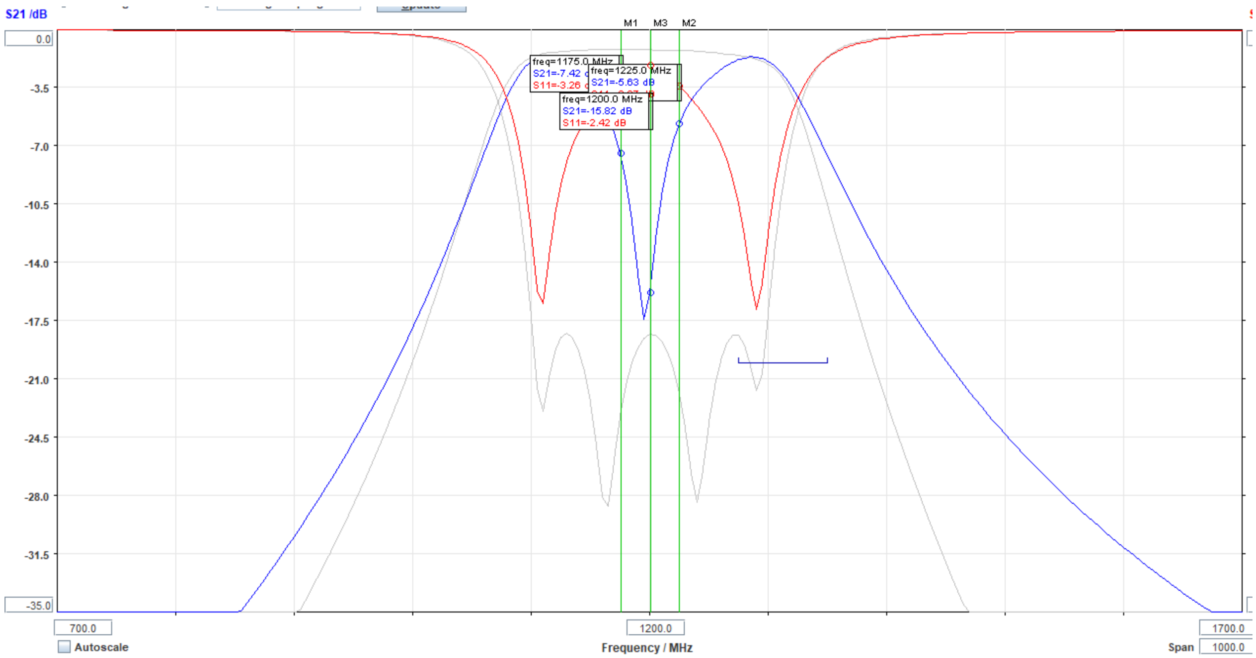
The insertion loss is measured at 1.0, 1.1, 1.2, and 1.3 GHz as 18.6, 1.2, 0.7, and 0.8 dB, respectively. The score for scenario 1 will be computed as 18.6 – 1.2 – 0.7 – 0.8 = 15.9. 15.9 is the score for this filter for scenario 1.

Scenario 2: Suppose the submitted filter is passive and has a frequency response as shown below, which is the response of a 3-pole bandpass filter with a transmission zero at 1700 MHz and Q of 100:

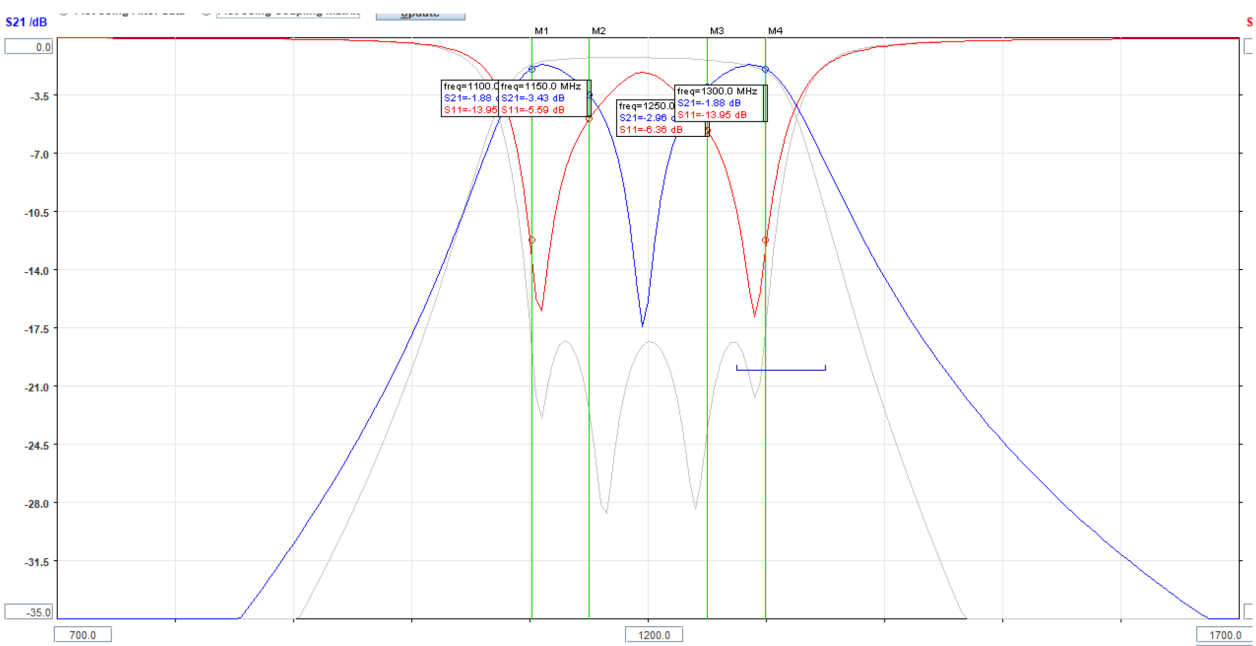


The insertion loss will be measured at 1.1, 1.2, 1.3, and 1.4 GHz as 0.9, 0.7, 1.2, and 11.9 dB, respectively. The score for scenario 2 will be computed as 11.9 – 0.9 – 0.7 – 1.2 = 9.1. 9.1 is the score for this filter for scenario 2.

Scenario 3: Suppose the submitted filter is passive and has a frequency response as shown below, which is the response of a 3-pole bandpass filter with a coupled bandstop resonator and Q of 100. Please disregard the light gray lines.



At 1.175, 1.2, and 1.225, the attenuation is 7.4, 15.8, and 5.6 dB. These measurements provide a positive point total of 28.8.



At 1.1, 1.15, 1.25, and 1.3 GHz, the attenuation is 1.9, 3.4, 3.0, and 1.9 dB, respectively. These measurements provide a negative point total of -10.2. The entire point total for scenario 3 is 28.8 - 10.2 = 18.6.

The final score for the filter is calculated as (15.9 + 9.1 + 18.6) / (0.5 * 15.75) = 5.537. This number will be compared to all other filter entries and ranked for the competition.

Note: There are many filter topologies and design methods that are relevant to this competition. The passband bandwidth was set to a relatively broad specification to minimize scoring discrepancies related to the quality factor of the resonators in most of the measurements. However, the measurements of the stopband in Scenario 3 provide a stimulus for having a high Q notch in the center of the bandwidth. Similarly, active filters may have a significant size advantage. However, measuring their noise figure instead of insertion loss may be a significant disadvantage. Also consider that reconfiguration is not necessary between scenario measurements if a higher score can be achieved with a static filter. We hope to see a variety of strategies in this competition and also hope that such an open competition will generate discussions between teams about the benefits of their chosen design methods.

Student contestants must notify by e-mailing to eric.naglich@nrl.navy.mil of their intention to compete in the contest before March 13th, 2018. This notification should include the university or educational affiliation of the entry, the name and contact information of the contestant's adviser, and the names of all students involved in the design.

References

The references below serve as examples of reconfigurable bandpass filters. It is not an exhaustive list, and the references below are not recommendations or limitations on what can be done in the competition.

[1] N. Kumar and Y. K. Singh, "RF-MEMS-Based Bandpass-to-Bandstop Switchable Single- and Dual-Band Filters With Variable FBW and Reconfigurable Selectivity," in IEEE Transactions on Microwave Theory and Techniques, vol. PP, no. 99, pp. 1-14.

[2] S. Nam, B. Lee, B. Koh and J. Lee, "Reconfigurable Bandpass Filter With Resonators in Cul-De-Sacs for Producing Notches," in IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 7, no. 9, pp. 1531-1542, Sept. 2017.

[3] H. J. Tsai, B. C. Huang, N. W. Chen and S. K. Jeng, "A Reconfigurable Bandpass Filter Based on a Varactor-Perturbed, T-Shaped Dual-Mode Resonator," in IEEE Microwave and Wireless Components Letters, vol. 24, no. 5, pp. 297-299, May 2014.

[4] W. M. Fathelbab and M. B. Steer, "A reconfigurable bandpass filter for RF/microwave multifunctional systems," in IEEE Transactions on Microwave Theory and Techniques, vol. 53, no. 3, pp. 1111-1116, March 2005.

[5] Y. H. Cho and G. M. Rebeiz, "0.73–1.03-GHz Tunable Bandpass Filter With a Reconfigurable 2/3/4-Pole Response," in IEEE Transactions on Microwave Theory and Techniques, vol. 62, no. 2, pp. 290-296, Feb. 2014.

[6] H. I. Baek, Y. H. Cho, X. G. Wang, H. M. Lee and S. W. Yun, "Design of a Reconfigurable Active Bandpass Filter Based on a Controllable Slope Parameter," in IEEE Microwave and Wireless Components Letters, vol. 21, no. 12, pp. 670-672, Dec. 2011.

[7] W. H. Tu, "Switchable Microstrip Bandpass Filters With Reconfigurable On-State Frequency Responses," in IEEE Microwave and Wireless Components Letters, vol. 20, no. 5, pp. 259-261, May 2010.

[8] H. Zhang and K. J. Chen, "Bandpass filters with reconfigurable transmission zeros using varactor-tuned tapped stubs," in IEEE Microwave and Wireless Components Letters, vol. 16, no. 5, pp. 249-251, May 2006.

[9] E. J. Naglich, D. Peroulis and W. J. Chappell, "Low-Order Filter Response Enhancement in Reconfigurable Resonator Arrays," in IEEE Transactions on Microwave Theory and Techniques, vol. 61, no. 12, pp. 4387-4395, Dec. 2013.

[10] D. Psychogiou, R. Gómez-García and D. Peroulis, "RF Wide-Band Bandpass Filter with Dynamic In-Band Multi-Interference Suppression Capability," in IEEE Transactions on Circuits and Systems II: Express Briefs, vol. PP, no. 99, pp. 1-1.

Y-factor noise figure measurement references

Note: The passband noise figure will be measured instead of the passband insertion loss for active filters. If there are no active filter participants and students want to see the Y-factor method, we will stay after the competition to prove that the insertion loss of a passive filter is equal to its noise figure using the Y-factor method.

[1] https://www.maximintegrated.com/en/app-notes/index.mvp/id/2875

[2] http://literature.cdn.keysight.com/litweb/pdf/5952-3706E.pdf?id=1000000179:epsg:apn