Rev. 2016-10-26

IMS2017 Student Design Competition Rules

As part of the technical program, the Student Design Competition (SDC) is one of the most energetic parts of IMS. The SDCs have proven to be very successful events in the past 12 years, as evidenced by the ever increasing student participation and the support it has enjoyed from the organizers, both logistically and financially. The IMS2017 in Honolulu will continue the legendary tradition of enthusiasm with a very strong SDC program.

TC number and name:

MTT-13 MICROWAVE CONTROL MATERIALS AND DEVICES

The title of Student Design Competition:

Magnetless Parametric Circulator Design

Submission Deadline: Friday, 31 March 2017

Sponsors:

MTT-13 Microwave Control Materials and Devices

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

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A short abstract or summary describing the competition:

MTT-13 announces the first student parametric circulator design contest, which will take place at IMS2017. The contestants are required to design and build a magnetless, parametric circulator that uses the circuit topology introduced by the research group of Dr. Andrea Alù of the University of Texas at Austin [REF: Estep, et al. *Nature Physics* **10.12**, 923-927 (2014). Fleury, et al. *Phys Rev B* **91.17**, 174306 (2015). Estep, et al. *IEEE Trans. Micro. Theory and Tech.* **64.2**, 502-518 (2016).]

and is optimized for operation at 433.92 MHz – the center frequency of an ISM band commonly used for amateur service. The contest ranking will be based on the optimization of four figures of merit that will include insertion loss, nonreciprocal isolation, output port isolation, and the 1-dB compression point for the output power signal. Circulators (and other non-reciprocal components) are commonly used in communication, RADAR, and electronic warfare systems. For microwave operating frequencies, these devices typically require relatively large permanent magnets for polarizing the magnetic domains of ferromagnetic materials. The use of permanent magnets in microwave components adds significant increase to size, weight, and cost metrics. The purpose of the proposed contest is to engage students in exploring a novel, non-magnetic alternative to traditional circulator designs.

Contest Description:

During the contest, each team's circulator will be connected in-circuit as illustrated in Fig. 1. All circulators will be characterized using the same apparatus, which includes a network analyzer and a signal generator (which can provide power levels ranging up to 0 dBm and frequencies ranging up to 500 MHz). In the configuration, the external generator will provide a continuous wave sinusoidal signal for the purpose of parametric modulation [REF: Estep, et al. *Nature Physics* **10.12**, 923-927 (2014). Fleury, et al. *Phys Rev B* **91.17**, 174306 (2015). Estep, et al. *IEEE Trans. Micro. Theory and Tech.* **64.2**, 502-518 (2016).]. During the competition, the competitors will be required to specify the magnitude (in terms of dBm) and frequency (in terms of MHz) of the modulating signals for which their circuits are optimized. A network analyzer will be used to characterize circuit performance in terms of four Figures of Merit (FoM) (insertion loss, nonreciprocal isolation, output port isolation, and 1-dB output power compression point), which are described in the subsequent text.

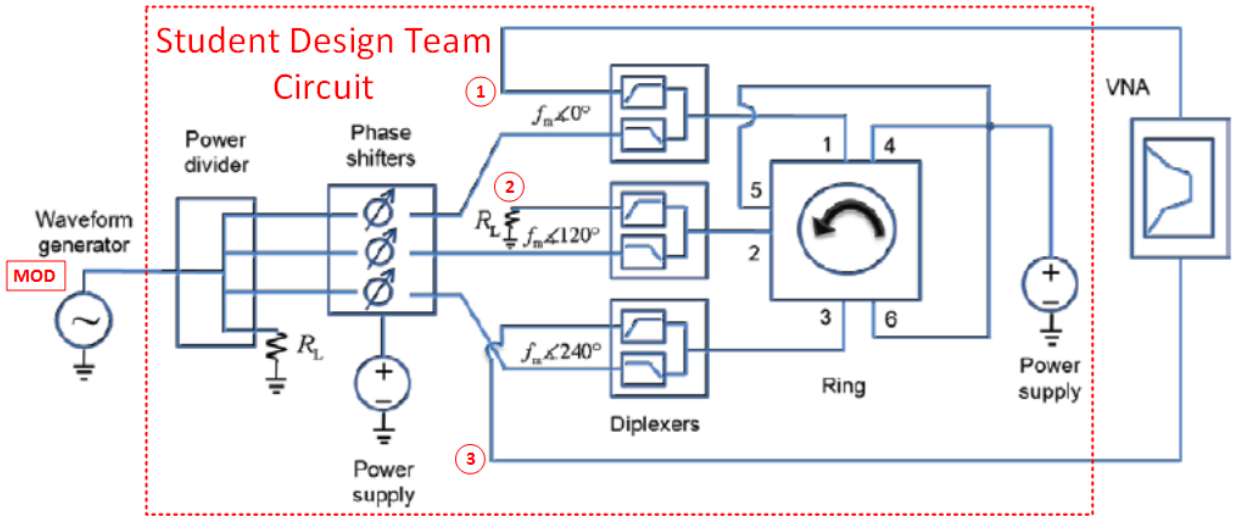

Fig. 1. Contest scheme for characterizing the insertion loss and nonreciprocal isolation parameters. In this picture, port 2 is terminated while the S31 parameter is measured. Details of *experimental setup* are discussed in *Supplementary Information* document of Estep, et al. *Nature Physics* **10.12**, 923-927 (2014).

In Fig. 1, the modulating signal is applied to the port labeled, “MOD,” which is shown boxed in red. The circulator ports 1, 2, and 3 are denoted by their respective circled numbers (also shown in red). During the contest, the judges will name port 1 randomly, and the port with greater coupling to port 1 will be called port 2. Conversely, the port with greater isolation from port 1 will be called port 3. This element of "chance" should persuade students to ensure that their circuits operate with three-fold rotational symmetry.

Insertion Loss:

The insertion loss parameter ($Loss$) will be expressed in units of dB and defined (in the context of this contest) as a positive quantity given by the magnitude of the S_{21} scattering-parameter, such that:

$$Loss\ \{\text{dB}\} \equiv |S_{21}|\ \{\text{dB}\}.$$

This FoM will be characterized using a test signal with a power level of -15 dBm and frequency of 433.92 MHz.

Nonreciprocal Isolation:

The nonreciprocal isolation parameter (*12-Isolation*) will be expressed in units of dB and defined (in the context of this contest) as a positive quantity given by the magnitude of the S_{12} scattering-parameter, such that:

$$\text{12-Isolation}\,\{\text{dB}\} \equiv |S_{12}|\,\{\text{dB}\}.$$

This FoM will be characterized using a test signal with a power level of -15 dBm and frequency of 433.92 MHz.

Output Port Isolation:

The output port isolation parameter (*31-Isolation*) will be expressed in units of dB and defined (in the context of this contest) as a positive quantity given by the magnitude of the S_{31} scattering-parameter, such that:

$$\text{31-Isolation}\,\{\text{dB}\} \equiv |S_{31}|\,\{\text{dB}\}.$$

This FoM will be characterized using a test signal with a power level of -15 dBm and frequency of 433.92 MHz.

1-dB Output Compression Point $P_{o,1dB}$:

In accordance with the output power P_o versus input power P_i transfer function shown in Fig. 2, the parameter $P_{o,1\text{dB}}$ will be defined in terms of the output power that deviates from an extrapolated linear response by an amount of 1 dB. This parameter will be measured in units of dBm.

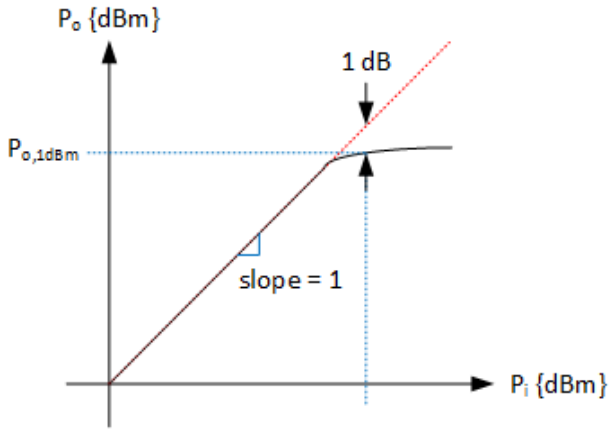

Fig. 2. Transfer function that will be used to determine $P_{o,1\text{dB}}$ {dBm}.

Scoring:

Scoring for the competition will be based on the three Figures of Merit (FoM), which will include: insertion loss, isolation, and 1-dB output power compression point. For each FoM, a column will be generated with a list that indicates the order in which the teams achieved the best values. The teams should strive to have the lowest possible insertion loss, the highest possible values of isolation, and the highest possible 1-dB output power compression point.

Scoring Example (with arbitrarily chosen values):

Team	$\boldsymbol{Loss}$ {dB}	*12-Isolation* {dB}	*31-Isolation* {dB}	$\boldsymbol{P_{o,1\text{dB}}}$ {dBm}
A	10	20	30	2.9
B	20	10	25	3.1
C	30	15	40	10
D	40	6.0	20	0.0
E	50	3.0	10	-10

Scoring is determined by adding the *Loss, 12-Isolation, 31-Isolation*, and $P_{o,1\text{dB}}$ Place values for each team. The team with the lowest *Total Score* wins.

Team	$\boldsymbol{Loss}$ {**dB**} **Place**	***12-Isolation*** {**dB**} **Place**	***31-Isolation*** {**dB**} **Place**	$\boldsymbol{P_{o,1\text{dB}}}$ {**dBm**} **Place**	**Total Score**	**Contest Place**
A	1	1	2	3	7	1 (tie)
B	2	3	3	2	10	3
C	3	2	1	1	7	1 (tie)
D	4	4	4	4	16	4
E	5	5	5	5	25	5

In the unlikely event of a first-place tie (as shown in the example above), the teams that are tied for first place will receive even distributions of the $2000 (USD) award money.

Contestant Participation Requirements:

As depicted in Fig. 1, each team's circuit should interface to the contest characterization apparatus through four SMA connectors corresponding to ports 1, 2 and 3 (circled in red) and the MOD port (boxed in red). The power supplies shown in Fig. 1 are considered to be part of the design team's circuit and should be brought to the contest by the students. Each circuit should be accompanied by a detailed, poster-sized schematic, and each circuit

should be inspectable (for comparison to the schematic) – no permanently sealed enclosures.

The judges will reserve the right to disqualify any team from the competition on the grounds of submitting a circuit whose topology does not match that shown in Fig. 1 or does not actually behave as a true circulator. For example, a team intending to win first place in the *Loss*, *31-Isolation*, and $P_{o,1\mathrm{dB}}$ categories (and expecting to place last in the *12-Isolation* category) by competing with a circuit that consists of nothing more than a short length of cable connected from port 1 to port 2 would definitely be disqualified.

Prizes:

One-level competition.

Maximum number of anticipated awards: 1.

The winning team will receive the full standard prize of $2000 (USD) – winner takes all.