Design of an Ultrawideband Planar Guanella Balun

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***Abstract*—This article presents the design and implementation of an ultrawideband multioctave planar Guanella balun (balanced-to-unbalanced) using double-sided parallel strip lines (DSPSLs). The operating frequency of the balun is found to be 0.5–2.6 GHz. The DSPSL is a type of balanced transmission line where two metal strips are present on the opposite sides of a flat dielectric substrate. Wideband transition between these balanced lines to a microstrip line has also been implemented. The measured amplitude and phase imbalance between the output signals at the balanced ports are less than 0.75 dB and 7°, respectively. The impact of these amplitude and phase imbalances on the combining loss of the balun has been presented. In order to understand the behavior of the balun with respect to differential and common mode signals, the mixed-mode *S*-parameters have been calculated. The physical size of the fabricated balun is 27.25 mm x 49 mm. The design has been validated with the help of its measurement results.**

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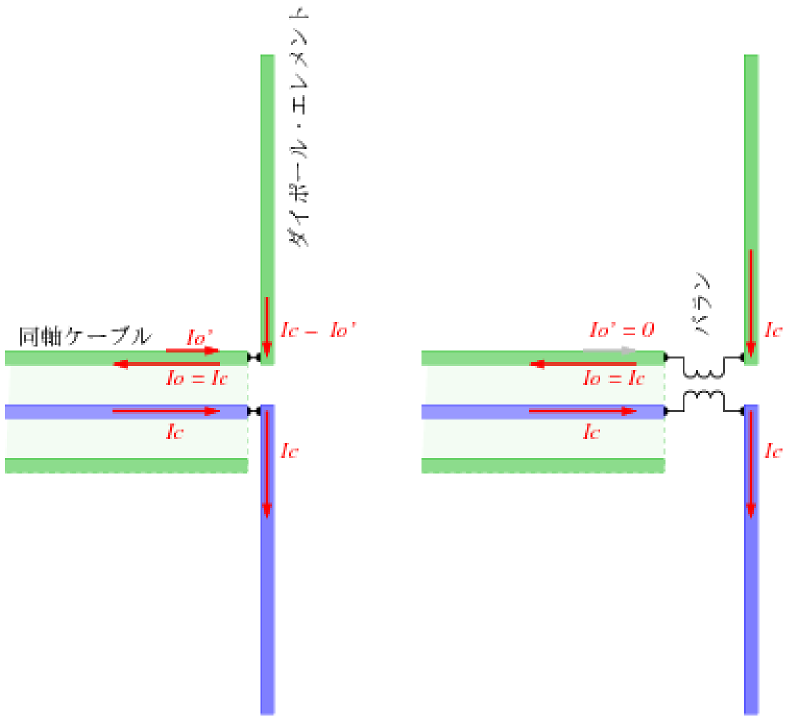
Outline

- Introduction
  - ✓ What is ‘Balun’ ?
  - ✓ Conventional Balun
  - ✓ Ultra Wideband Planar Balun
- Method
  - ✓ Planar Guanella Balun
- Result (Evaluation)
  - ✓ Imbalance
  - ✓ Mode Analysis
- Unknown

Introduction: What is ‘Balun’ ?

- Balun's Role:
  - ✓ Converts signal from balanced to unbalanced line
    - Balanced line: Sum of going and returning potentials of the signals equals 0 (e.g., dipole antenna)
    - Unbalanced lines: Other than above (e.g., coaxial cables)
- Without Balun ?
  - ✓ Common mode signal (two signals flowing in the same direction) is exist
    - ➔ Undesirable effects on operation
- Examples of Use:
  - ✓ antenna feed networks
  - ✓ differential mixers
  - ✓ high efficiency power amplifiers

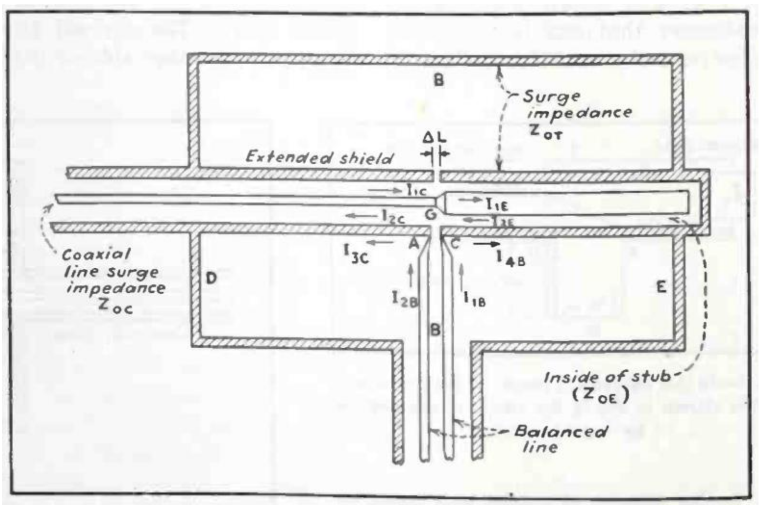


http://t-sato.in.coocan.jp/terms/balun.html

Introduction: Conventional Balun Type

Marchant Balun

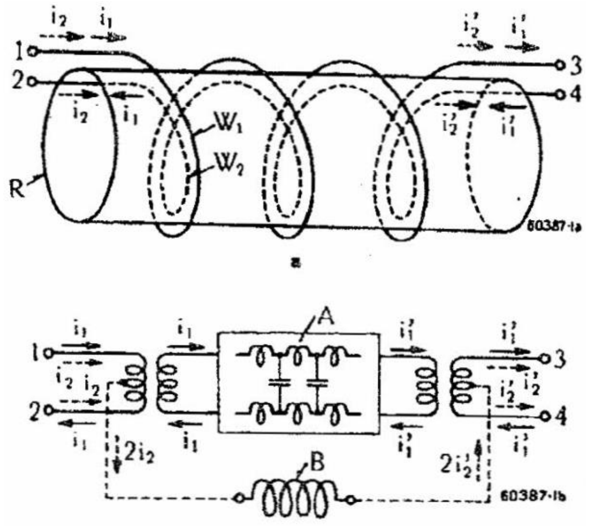
- Utilizes ¼ wavelength tube walls and open stubs ➔ suppress common mode current
- **Pros:** wideband
- **Cons:** Usually assumes 1:1 impedance conversion



Marchand (1944)

Guanella Balun

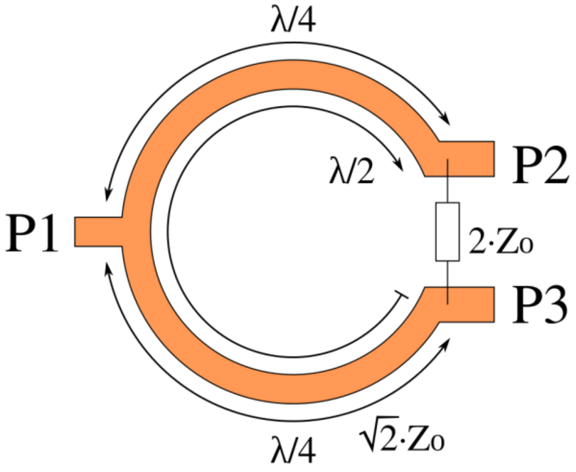
- Winded two coils:
  ➔ suppress common mode current
- **Pros:**
  - ✓ Also act as $1\!:\!n^2$ Impedance Transformer
  - ✓ Simple, wideband
- **Cons:** poor isolation (**?**)



Guanella (1944)

Wilkinson Power Divider

- Combined with 180° phase inversion structure, common mode current is suppressed
- **Pros:** good isolation (few signal port2⇔3)
- **Cons:** Resistors are used to take isolation and imbalance is likely to occur

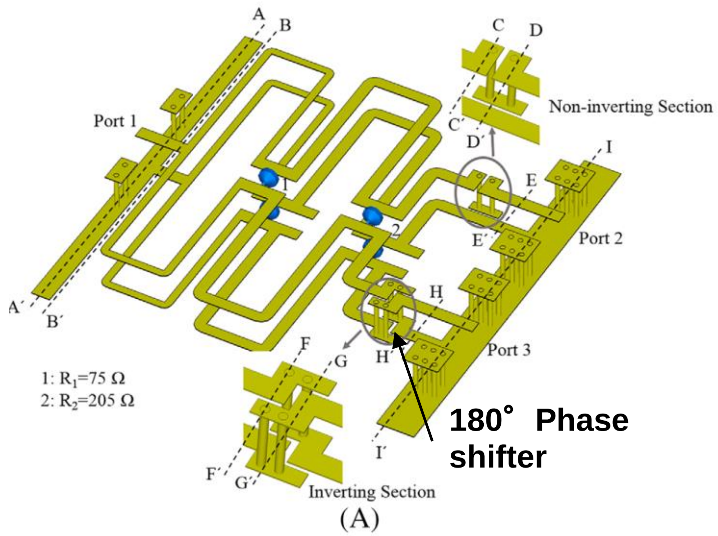


https://en.wikipedia.org/wiki/Wilkinson_power_divider

Introduction: Ultra Wide band Planar balun

- Wideband: Cover Ultra High Frequency band
- Planar: Easy integration of elements → Compact

[23] Wilkinson Power divider: Tamjid et al. (2020)
- Wilkinson power divider + 180° Phase shifter
- **Pros:** Ultra wideband and compact
- **Cons:** Much imbalance even if optimized probably because there are registers



(A)

Ref.	Balun scheme
[14]	Higher (5th) order Marchand balun
[15]	Multi-layer, slot-coupled Marchand balun
[16]	Transformer type Marchand balun using Integrated Passive Device
[17], [18]	Substrate Integrated Waveguide power divider + Phase inversion
[19], [22], [23]	Wilkinson Power Divider + Phase inversion
[20]	Trans-directional coupler
[21]	Resistive Power Divider + Phase inversion
This work	Planar Guanella Balun

Ref.	f_0 (GHz)	FBW	Amp. Imb. (dB)	Phase imb.	Insertion Loss (dB)	MMS
[14]	2.1	131%	2	20°	<4	No
	2.1	152%	2	20°	<4	No
[15]	2.02	90%	0.69	1.4°	<4.1	No
[16]	2.45	106%	0.4	7°	<6*	No
	2.45	110%	1	2°	<5*	No
[17]	24	42%	1	10°	<4*	No
[18]	60	42%	0.8	10°	<5*	No
[19]	2.5	64%	0.3	10°	<4*	No
[20]	2.31	32%	0.76	10°	<4*	No
	0.41	20%	0.18	2°	<4*	No
[21]	2.27	196%	NA	NA	<9	No
[22]	1.42	126%	0.92	8°	<4.2*	No
[23]	1.94	160%	0.8	10°	<4.7*	No
This work	1.55	135%	0.75	7°	<4.7	Yes

*: Approximated values calculated from the paper; NA: Data not available; MMS: Mixed-mode S-parameter.

This Work: Planar Guanella balun

Purpose: To Develop ultra broadband planar balun with reduced Imbalance

1. Without resister (Lamped Element)
2. Optimize the distance between Port1⇔2,3 considering the via length

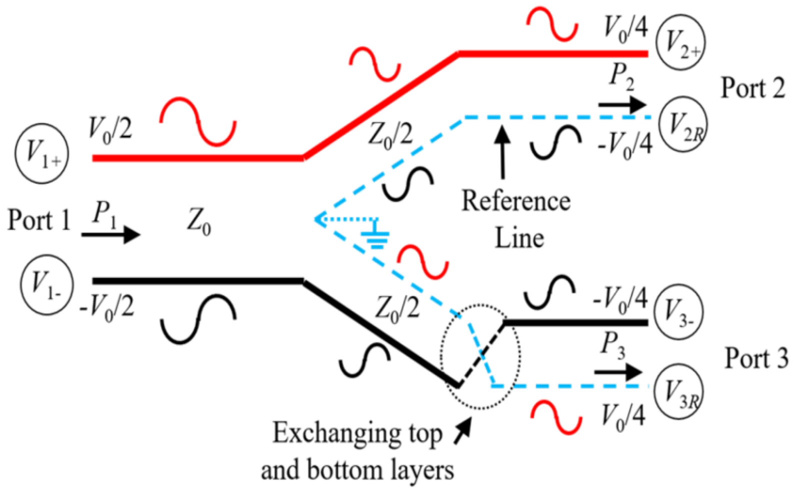


Fig. 3. Transmission line representation of the proposed balun showing equal power division at the output. The "floating line" between ports 2 and 3 indicates the reference line.

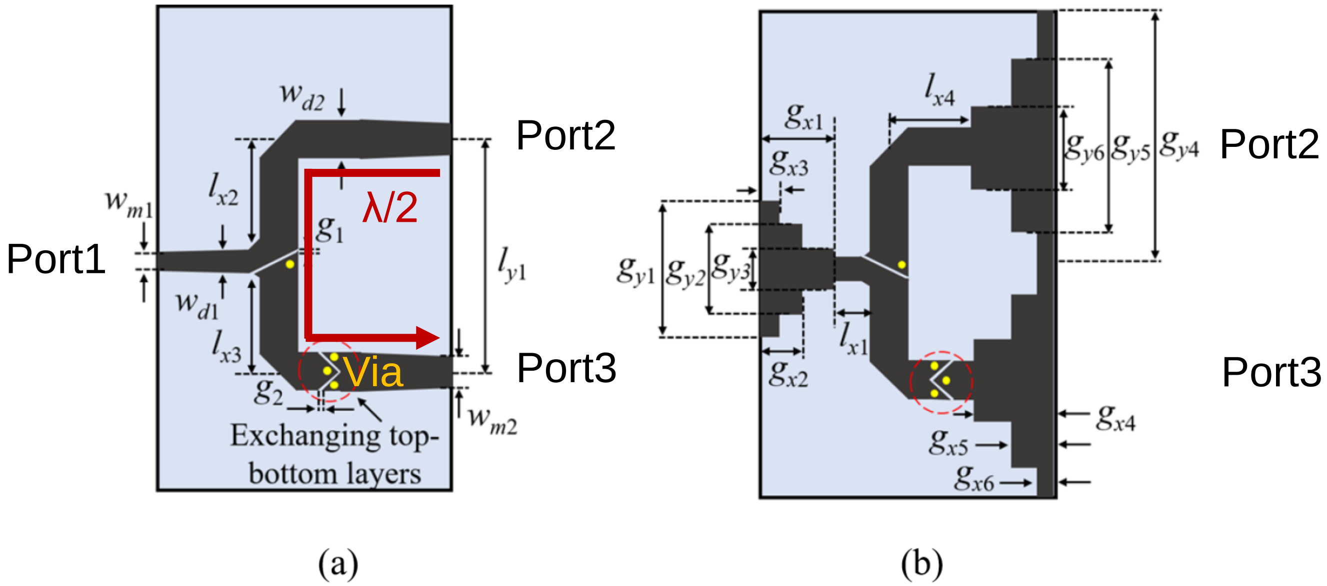


Fig. 7. Layout of the proposed balun. (a) Top view. (b) Bottom view. (The number of vias is more in the fabricated circuit than that shown here).

- Operation:
  - ✓ Switch upper and lower conductors in Via ➔ Pass differential mode only
  - ✓ Keep side-arm length at ½ wavelength ➔ Reference potentials of Port2 and 3 are reverse potentials

Surface current distribution

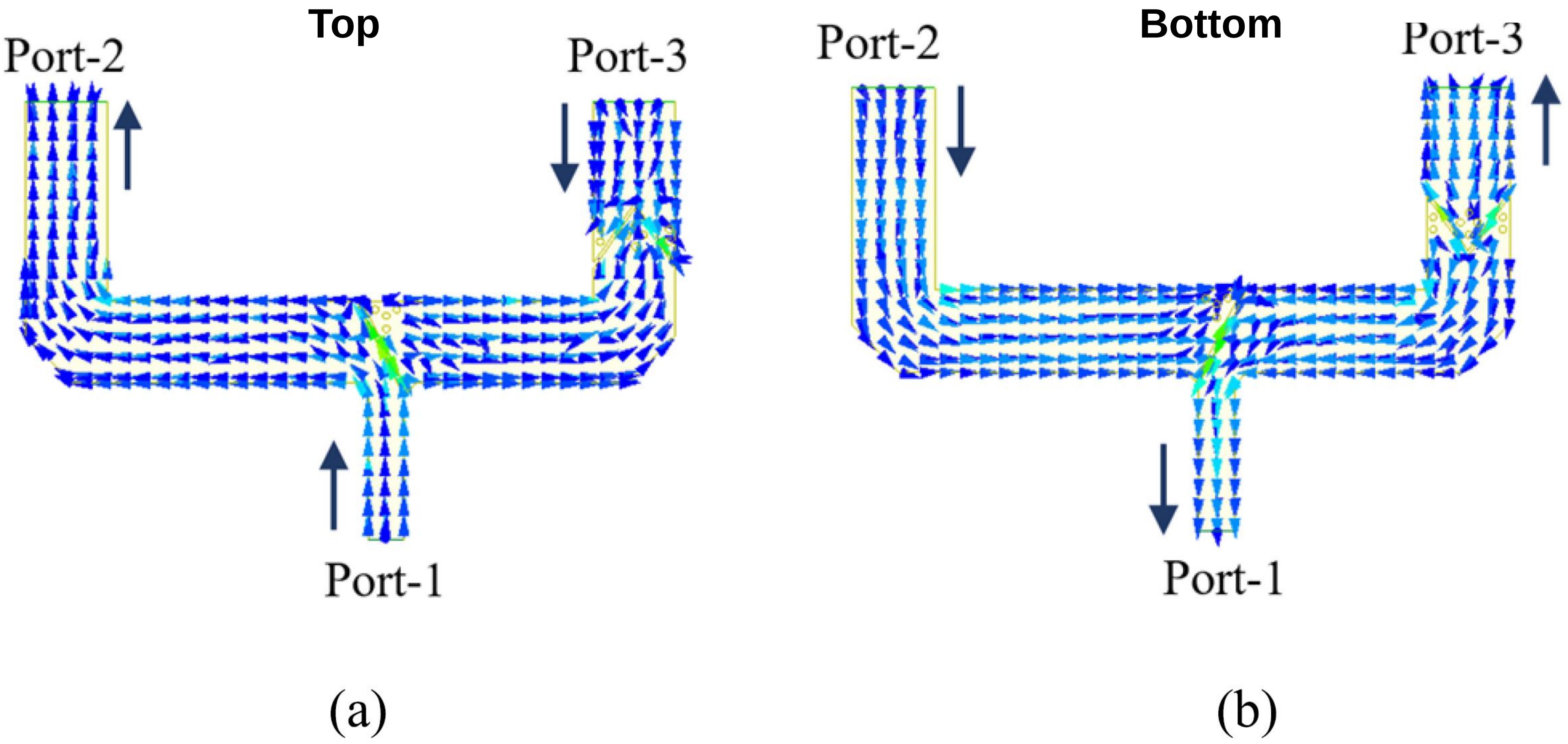


Fig. 4. Surface current distribution of the balun. (a) Top side. (b) Bottom side.

Evaluation: Imbalance

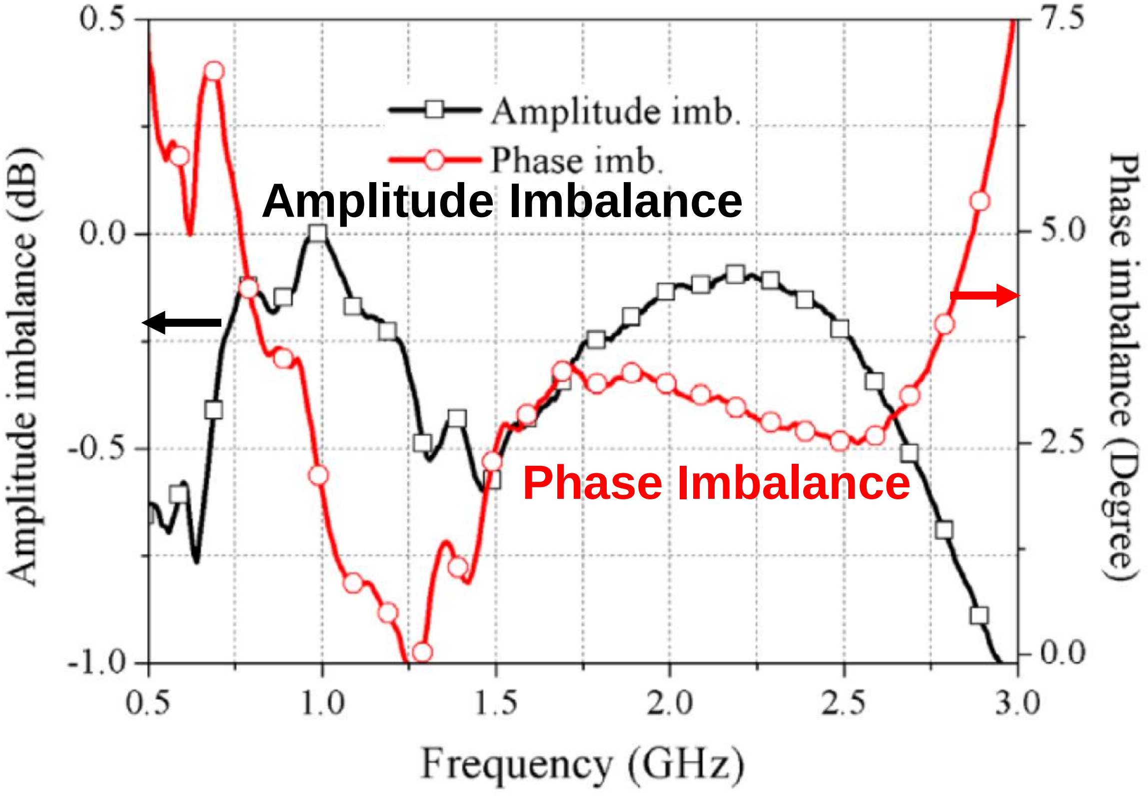


Fig. 12. Measured amplitude imbalance ($|S_{31}|-|S_{21}|$) and phase imbalance ($\angle S_{31}-\angle S_{21}-180°$) of the proposed balun.

Amplitude Imb:
(Port1→3) / (Port1→2) Power Ratio

- 0.5dB: x1.12
- -0.5dB: x0.89
- -1.0dB: x0.79

- Band width: 0.5-2.6GHz (135%, 5.2:1)
- Amplitude Imbalance: 0.75dB < 0.8dB
- Phase imbalance: 7° < 10°

Ref.	f_0 (GHz)	FBW	Amp. Imb. (dB)	Phase imb.	Insertion Loss (dB)	MMS
[23]	1.94	160%	0.8	10°	<4.7*	No
This work	1.55	135%	0.75	7°	<4.7	Yes

➔ Relatively Narrow band width, but good Imbalance

Evaluation: Mode Analysis

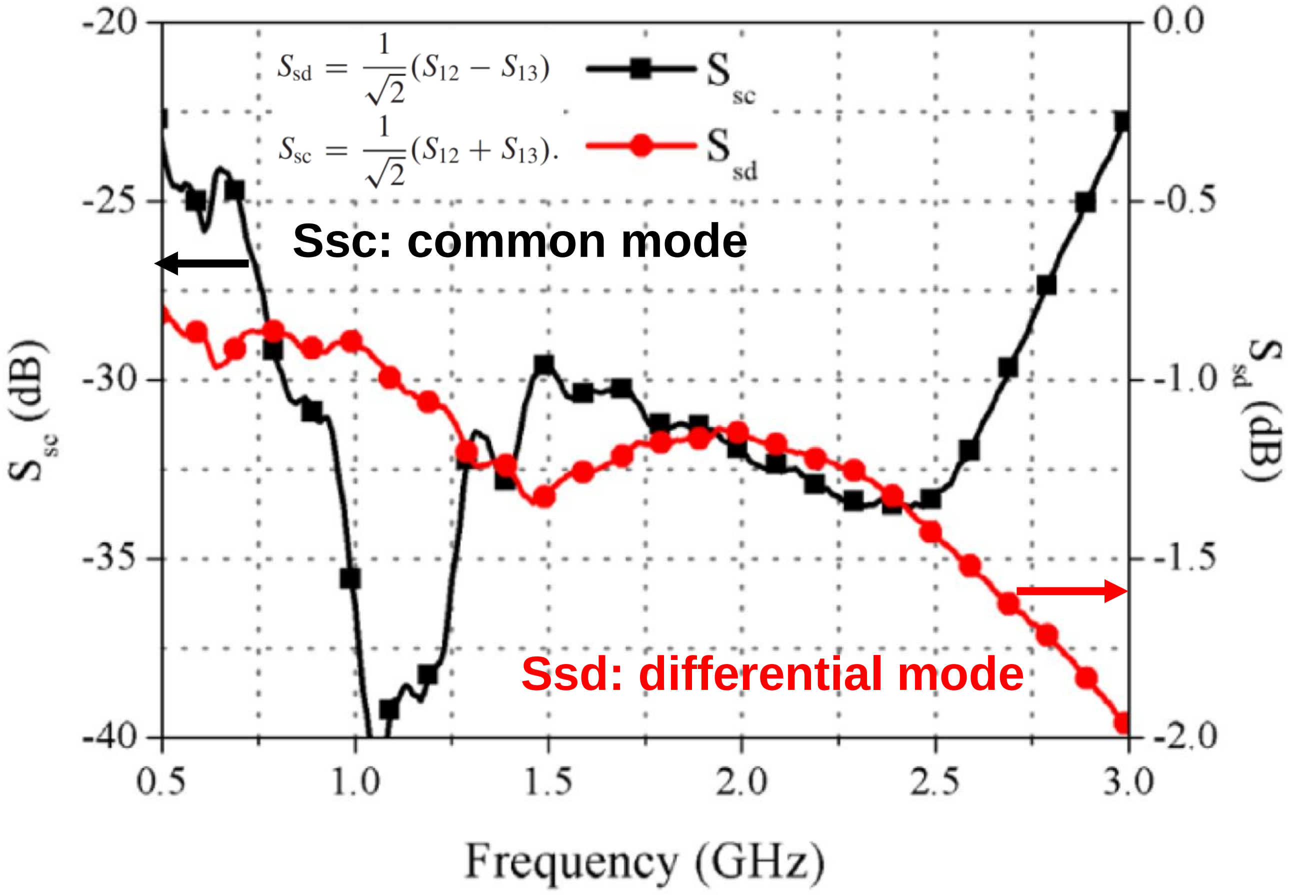


Fig. 13. Measured MMS of the proposed balun.

Output/Input power ratio

- -1dB: x0.79
- -2dB: x0.63
- -3dB: x0.50
- -20dB: x0.01
- -30dB: x0.001

- Common mode signal: < 20dB
- Differential mode > 1.5dB

➔ Common mode is suppressed properly

Summary

- Purpose:
  - Development of ultra-broadband planar balun with low Imbalance
- Problem:
  - Prior studies have shown that the signal Imbalance is large
    - ✓ Factor: Using resistance
- Solution:
  1. Planar Guanella Balun is used and no resistor is used.
  2. Compensate for and optimize line lengths that differ by Via.
- Result
  - Small Imbalance and ultra-broadband solutions were obtained.
    - ✓ Band width: 0.5-2.6GHz (135%, 5.2:1)
    - ✓ Amplitude Imbalance: < 0.75dB,
    - ✓ Phase Imbalance: < 7°
    - ✓ Common mode < -20dB

Unknown

- Fair comparison is not possible because the following two points are not shown
  - ✓ Return loss: Reflection at Port i→i
  - ✓ Isolation: Signal leakage between Port 2 and 3