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A mechanical reliability study of 3-dB waveguide hybrid couplers in submillimeter and terahertz bands

Key words: Directional coupler; 3-dB waveguide hybrid coupler; Submillimeter-wave device; Terahertz circuit; Mechanical reliability

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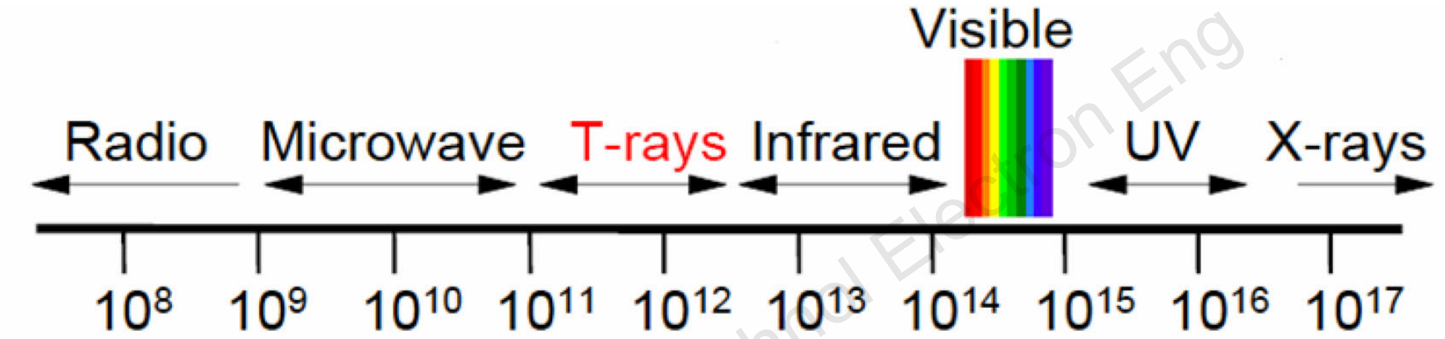
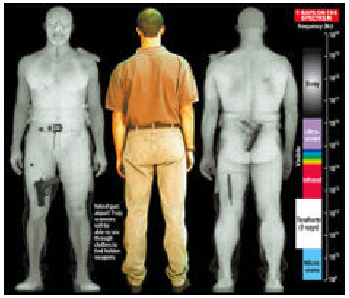
Background

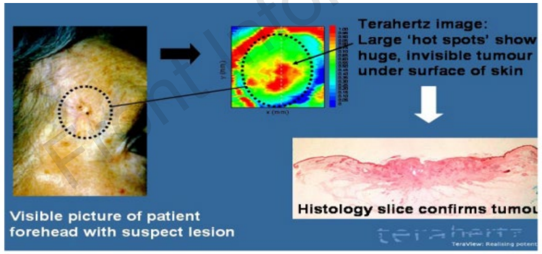
- The terahertz (THz) region, which includes the millimeter and submillimeter wave ranges, is situated between the microwave and infrared frequencies .



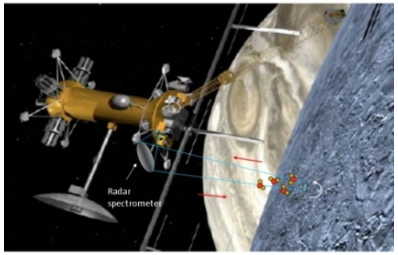
- Many applications of THz technology



THz
imaging system



THz
bio-medical system



THz astronomical
remote sensing

THz wireless
communication system

Tendency and challenges

- With the development of CNC and MEMS processing technologies, micromachining of terahertz band circuits has been realized.

0.01 mm level

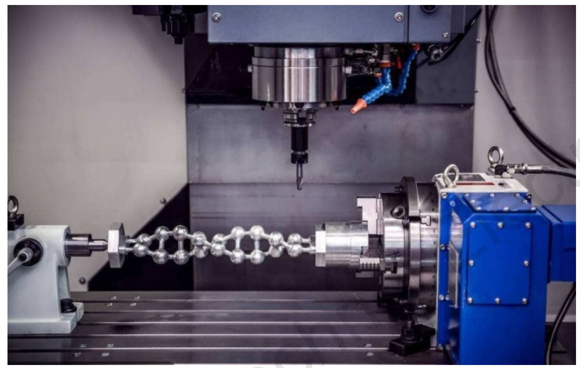
Terahertz wave

Submillimeter wave

Millimeter wave

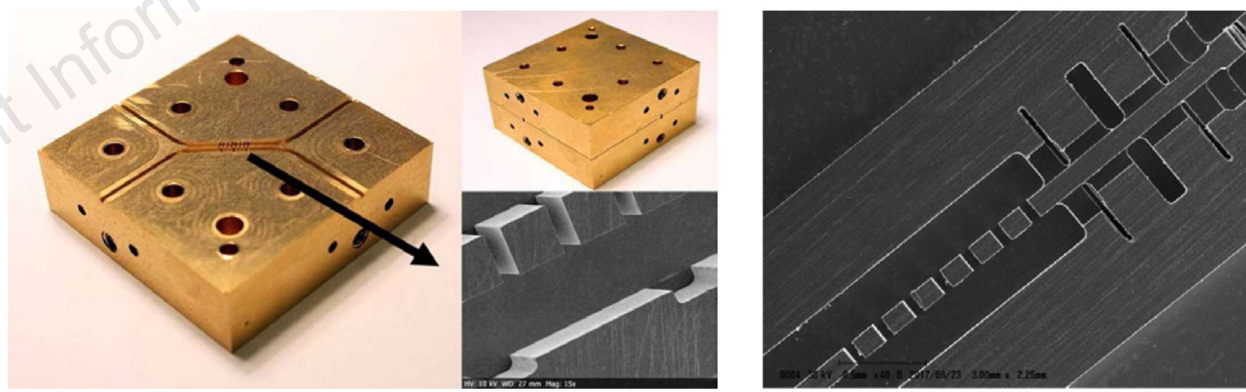
Microwave

10 mm level



CNC processing technology

MEMS processing technology



Terahertz hybrid couplers under microscope

The size of a terahertz circuit is too small and the mechanical reliability is poor, especially for aerospace applications.

Motivation

- When used for an aerospace application or in other extreme environmental applications, high performance is not the only advantage that needs to be considered.
- In order to show the necessity of improving the mechanical properties of the coupler's branch, a comprehensive study regarding the displacement of hybrid branch variation and the vibration experiment needs to be done.

Theoretical analysis

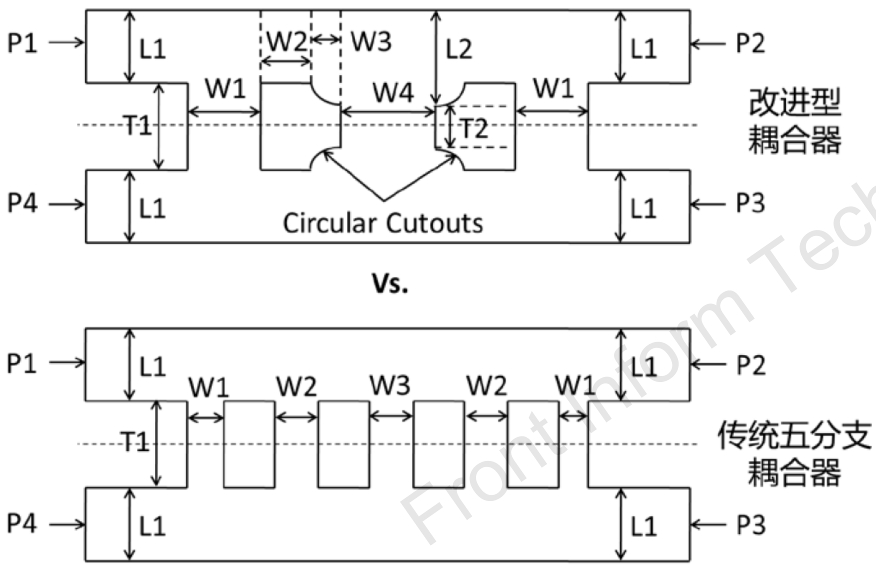
Random vibration experiment

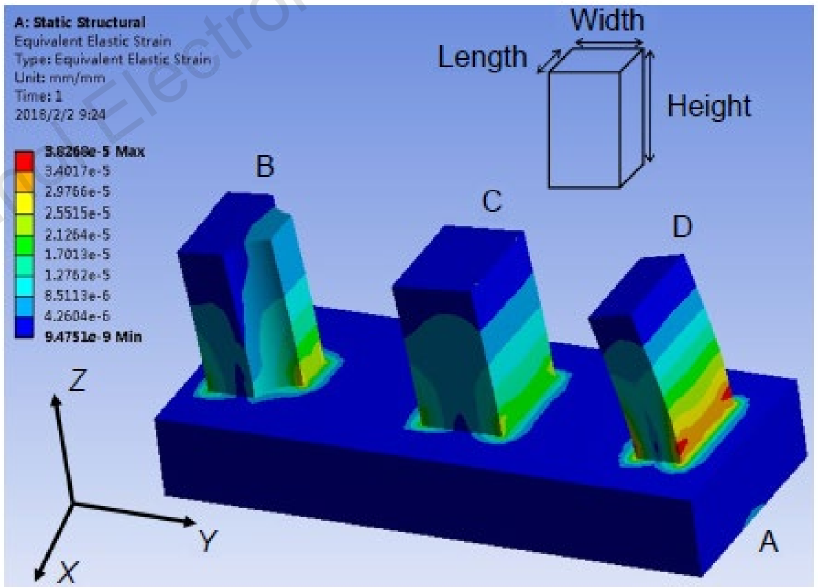
Impact experiment

The displacement of the branch caused by random vibration or impact stress cannot be ignored. Therefore, the mechanical properties of the hybrid branch need to be considered.

Analysis of mechanical properties

- The design of a traditional waveguide hybrid coupler is often based on several rectangle shunt-branch structures. The signal is fed from port 1 (P1), and port 2 (P2) is the throughout port. Port 3 (P3) is the coupling port, where the coupling ratio can be manually designed. Port 4 (P4) is the isolation port. In addition, the phase difference between P2 and P3 is 90°.





- For comparison, three models are built and simulated together. The mechanical analysis model is based on the provided HFSS 3D models, and then remodeling and local simplification are done through ANSYS Workbench software.

Analysis of mechanical properties (Cont'd)

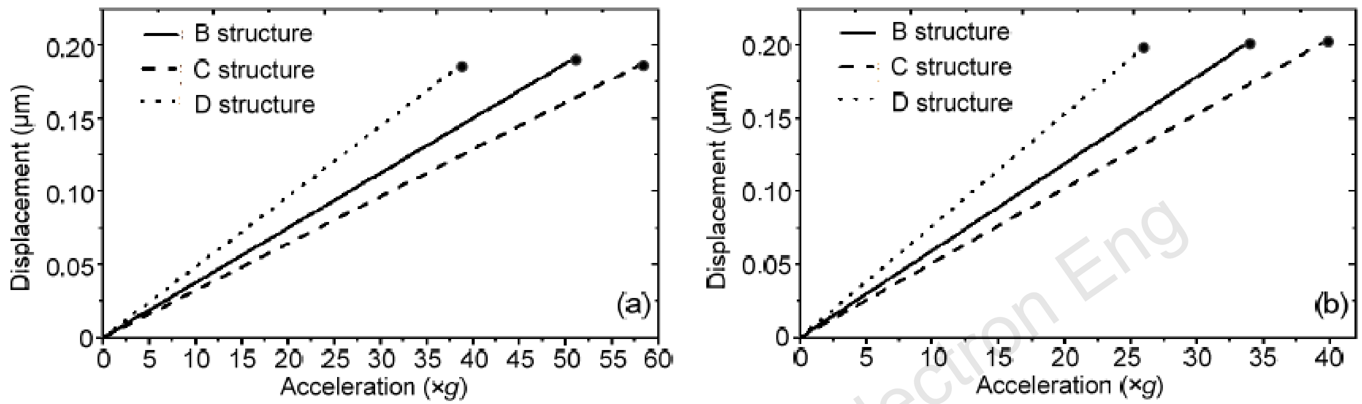


Fig. 9 Displacement of the top of the branch varying with acceleration regarding these three structures: (a) aluminum; (b) copper

The solid point means that the stress reaches the material's yield limit and will soon fracture

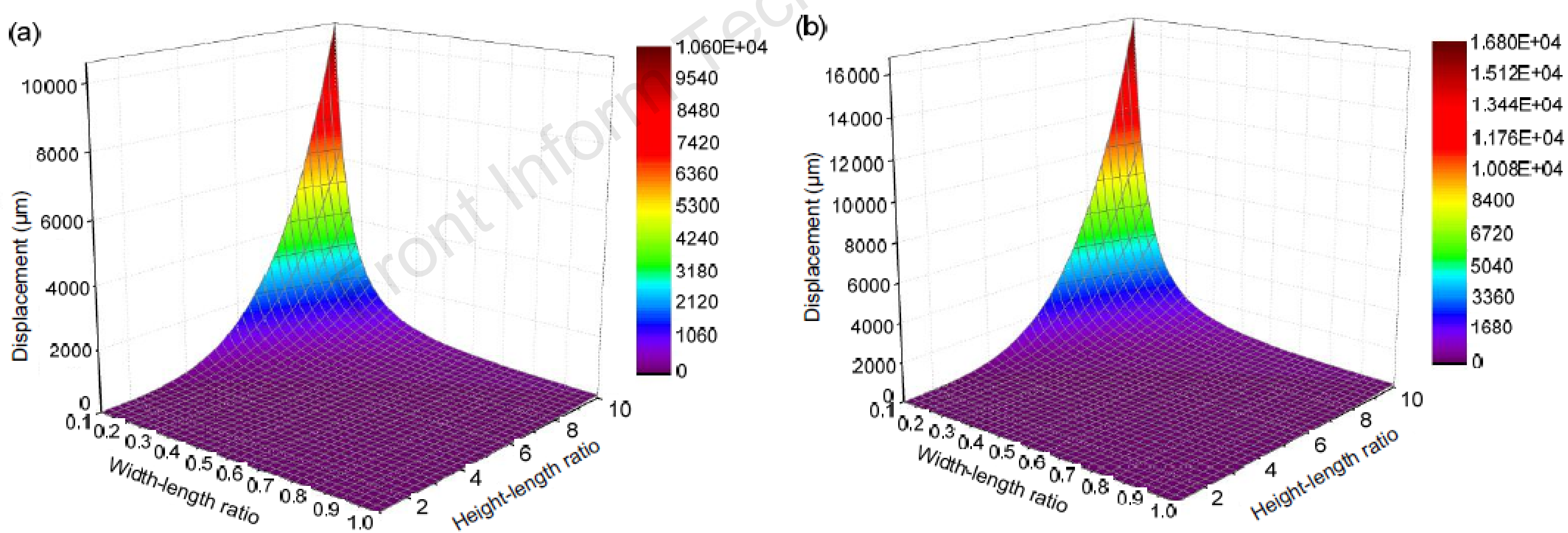
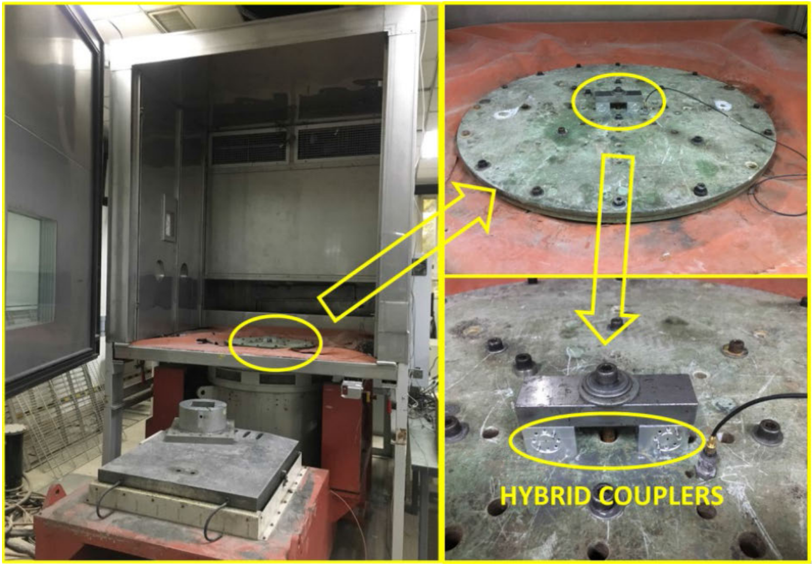
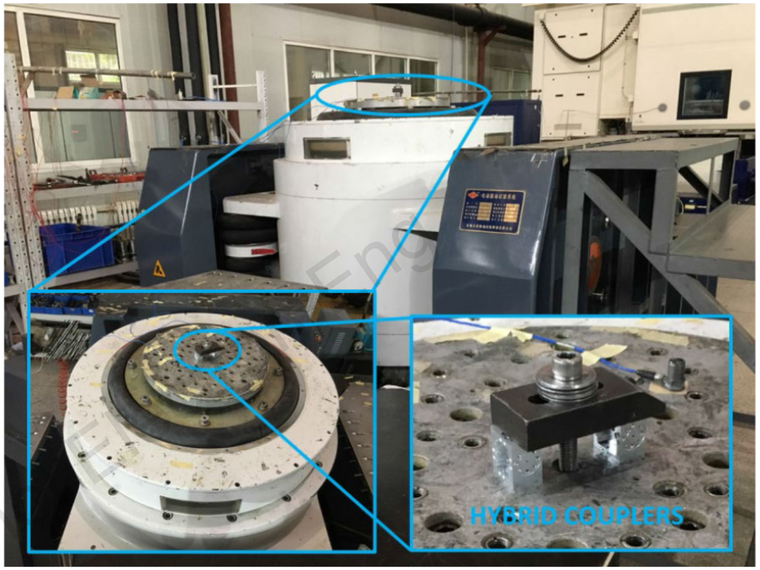


Fig. 10 Displacement of the general rectangle branches changing with varying width-length ratio and height-length ratio (the length value is 0.39 mm) at a certain acceleration of the random vibration at 20.3*g* when the block material is aluminum (a) or copper (b)

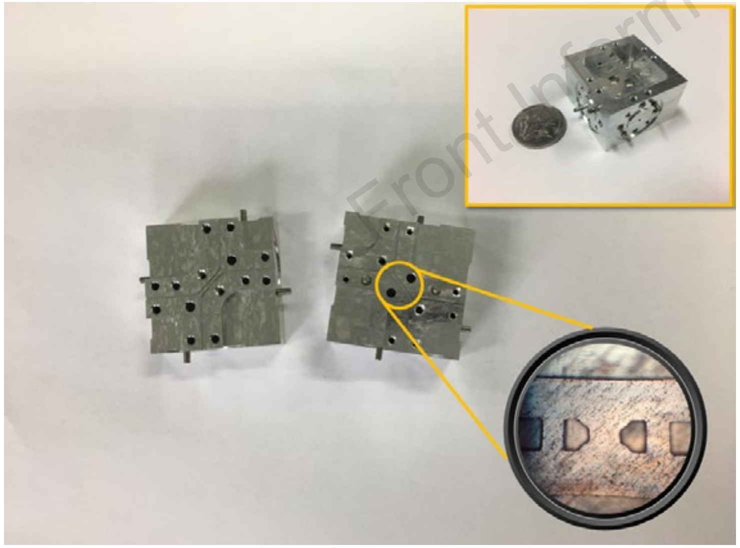
Measurement and results



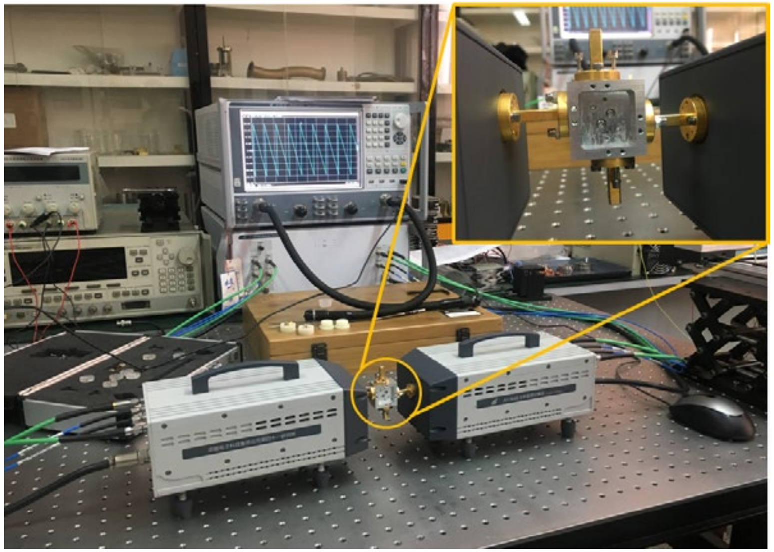
Random vibration experimental platform



Impact experimental platform



Block of the hybrid coupler



Measurement setup

Measurement and results (Cont'd)

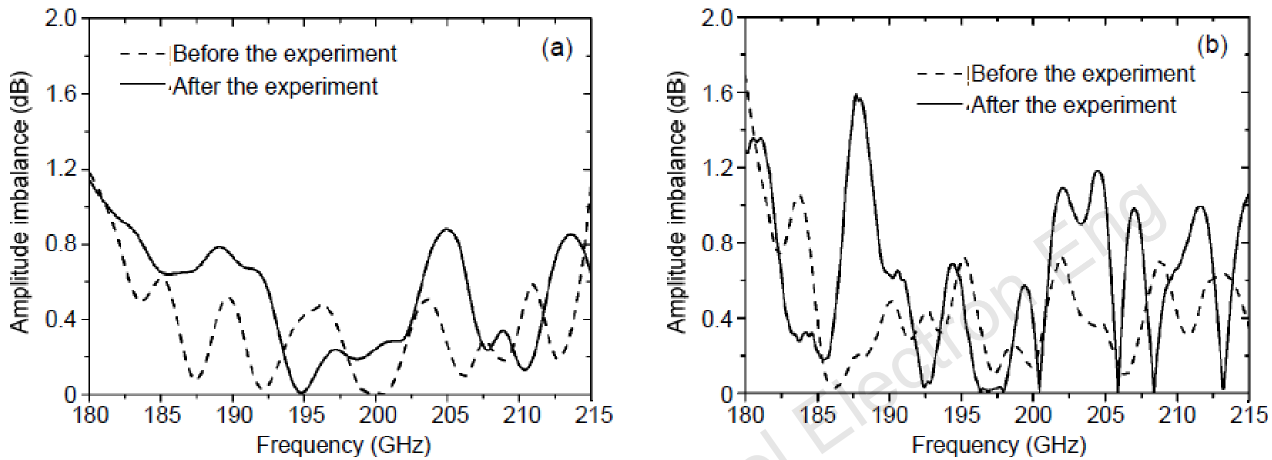


Fig. 15 Measured and simulated amplitude imbalances of the modified branch hybrid coupler (a) and the traditional structure hybrid coupler (b)

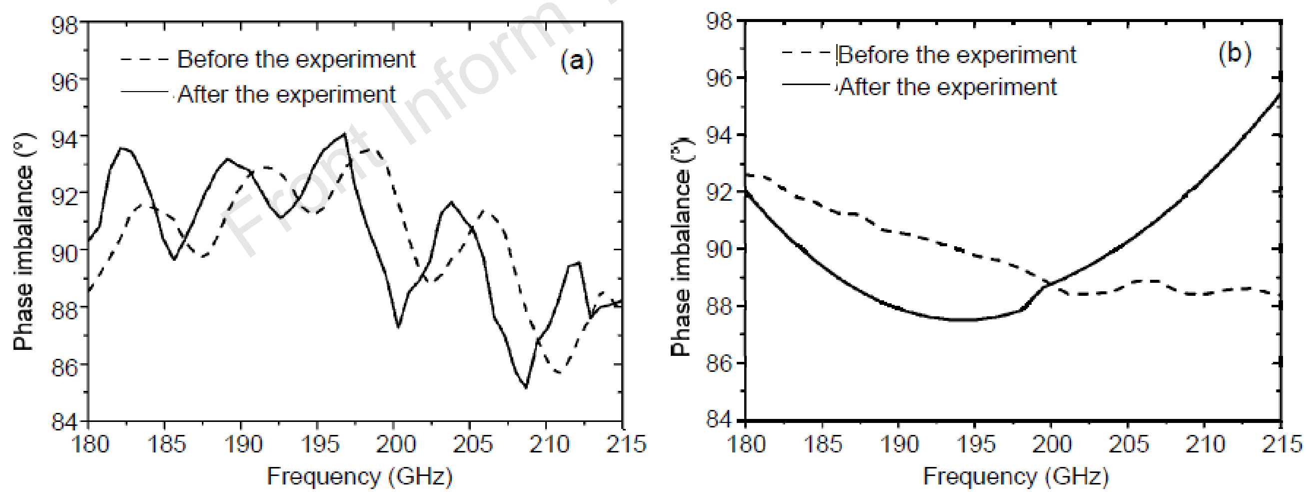


Fig. 17 Measured and simulated phase imbalances of the modified branch hybrid coupler (a) and the traditional structure hybrid coupler (b)

Conclusions

A comprehensive mechanical reliability study of 3-dB waveguide hybrid couplers in submillimeter and terahertz bands has been presented. By concentrating on the analysis of the displacement variation with different width-length ratios and height-length ratios caused by random impact vibrations in the couplers, the necessity of improving the mechanical properties of the coupler’s branch has been shown.

牛中乾，博士，IEEE会员，电子科技大学在站博士后。分别于2014和2020年获电子科技大学电磁场与微波技术学士和博士学位，2019~2020年，国家公派新加坡国立大学，攻读联合培养博士学位。长期从事电磁场与微波技术领域科研工作，主要研究领域为全固态太赫兹关键技术与系统。目前参与国家863重点项目1项，自然科学基金重大研究计划1项，自然科学基金国家重大科研仪器研制项目1项。目前主要研究方向：（1）太赫兹新型无源电路；（2）太赫兹低损耗有源电路；（3）太赫兹高分辨成像雷达系统和高速无线通信系统。

张波，博士，教授/博导，IEEE高级会员，太赫兹技术教育部重点实验室副主任，中英欧太赫兹国际学术会议秘书长。分别于2004、2007和2011年获电子科技大学电磁场与微波技术学士、硕士和博士学位，2012~2015年为电子科技大学信息与通信工程专业博士后，2014~2015年国家公派访问英国伦敦大学；长期从事电磁场与微波技术领域科研与教学工作，主要研究领域为全固态太赫兹关键技术与系统，获电子科技大学“十大先进工作者”称号。目前主持太赫兹项目30余项，其中主持自然科学基金优秀青年基金1项，重大研究计划1项，民口863主题项目2项，航天院太赫兹项目6项。目前主要研究方向：（1）太赫兹芯片；（2）太赫兹电路；（3）太赫兹高分辨成像雷达系统和高速无线通信系统。