



**AKADEMIA GÓRNICZO-HUTNICZA  
IM. STANISŁAWA STASZICA W KRAKOWIE**

# **Investigation on coupled inductors and their application in miniaturized broadband directional couplers**

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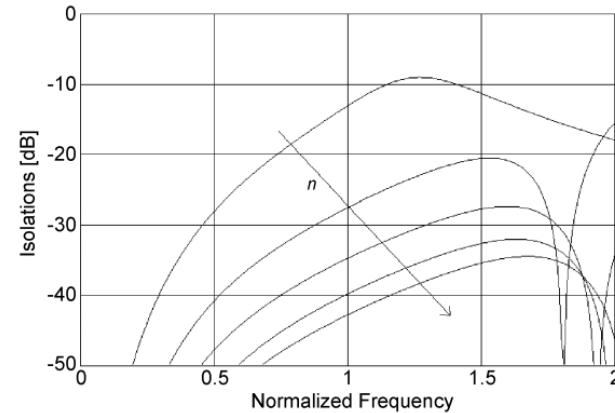
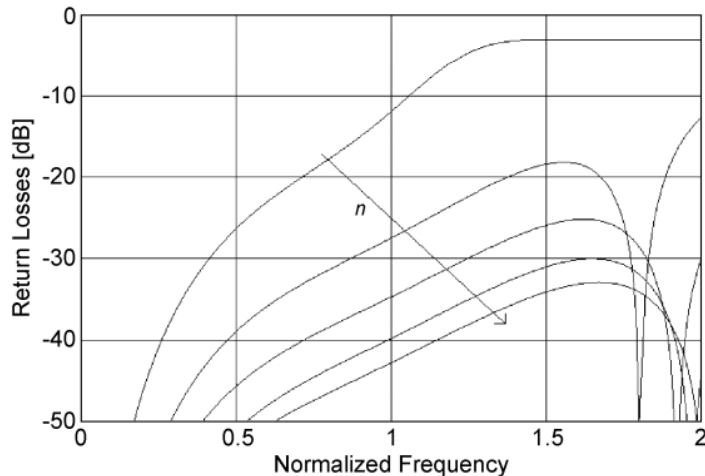
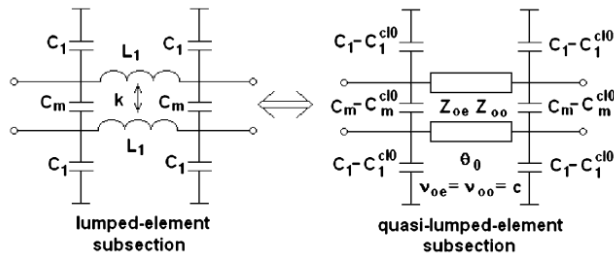
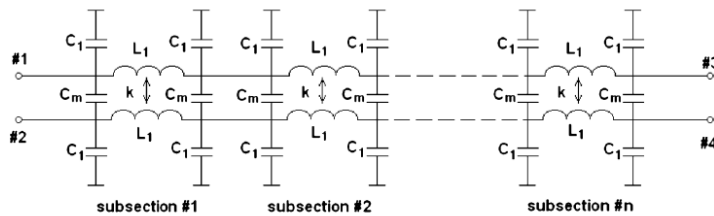
# Outline

- Techniques of directional couplers' miniaturization
  - a) quasi-lumped element approach
  - b) connection of tightly coupled and uncoupled lines
- The influence of parasitic couplings between L and C elements in directional couplers
  - a) modelling of folded coupled inductors
  - b) utilization of the proposed model to improve directivity and impedance match
- Possibility of realization and miniaturization of the directional couplers designed in LTCC technology
- Possibility of realization and miniaturization of the directional couplers designed in thick-film technology and the thick-film-laminate technology
- Results



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# The miniaturization techniques of directional couplers: quasi-lumped element approach



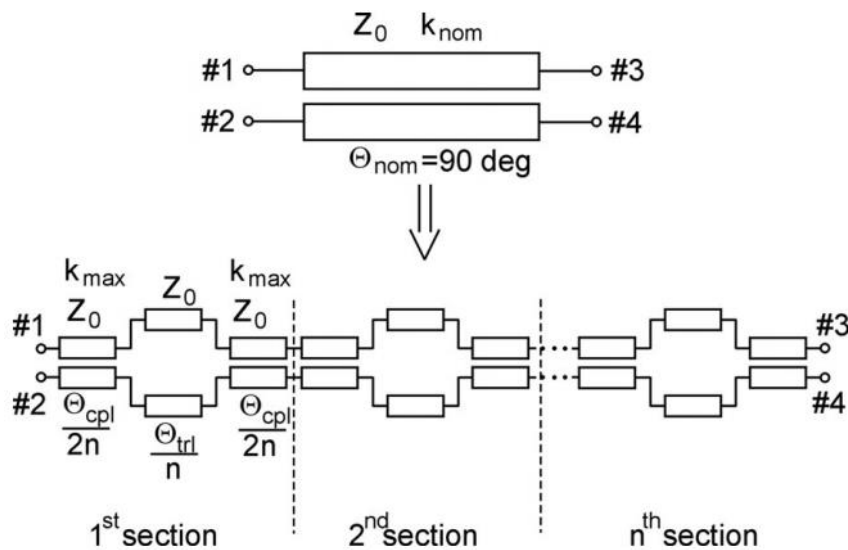
## Project steps

- choice of the operating frequency, characteristic impedance and coupling  $k$  of the coupler
- division of the directional coupler into  $n$  subsections
- calculation of the values of lumped elements composing the coupler based on the formulas given in [1]

## Influence of the number of subsections $n$ on the directional coupler's parameters

- the influence of  $n$  on the isolation characteristic
- the influence of  $n$  on the return losses

# The miniaturization techniques of directional couplers: connection of tightly coupled and uncoupled lines



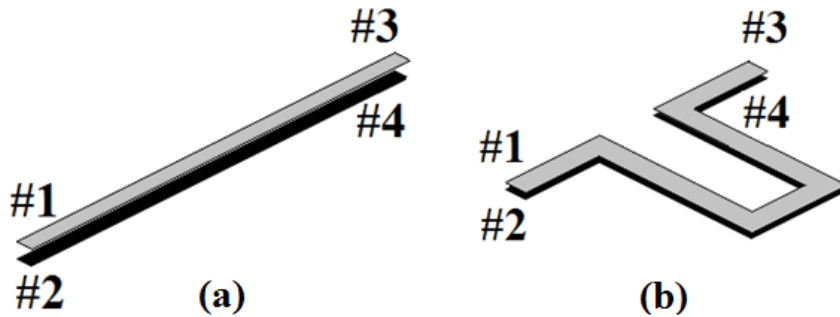
## Project steps

- choice of the operating frequency, characteristic impedance and the coupling  $k$  ( $k_{nom}$ ) of the directional coupler
- calculation of the required mutual capacitance [2]
- calculation of the coupled-line section's length  $\theta_{cpl}$  [2].
- calculation of the uncoupled-line section's length  $\theta_{trl}$  [2].

## Influence of the number of subsections $n$ on directional coupler parameters

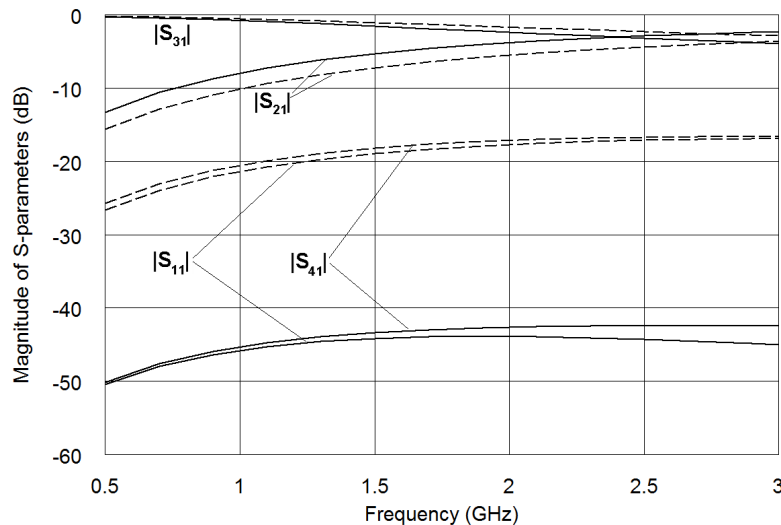
- number of  $n$  has no influence on isolation and impedance match
- lower  $n$  causes the increase of the error of  $\theta_{cpl}$  and  $\theta_{trl}$  calculations
- the smaller  $n$  the greater the shortening of  $\theta_{trl}$  is required

# The influence of couplings between L and C elements in directional coupler



## Assumptions

- Physical length and width of the strips (a) and (b) are the same
- The coupled inductors have been designed in the same dielectric structure



ground

$h = 1.525$  mm

metal #1

$h = 0.025$  mm

metal #2

ground

$\epsilon_r = 3.38$



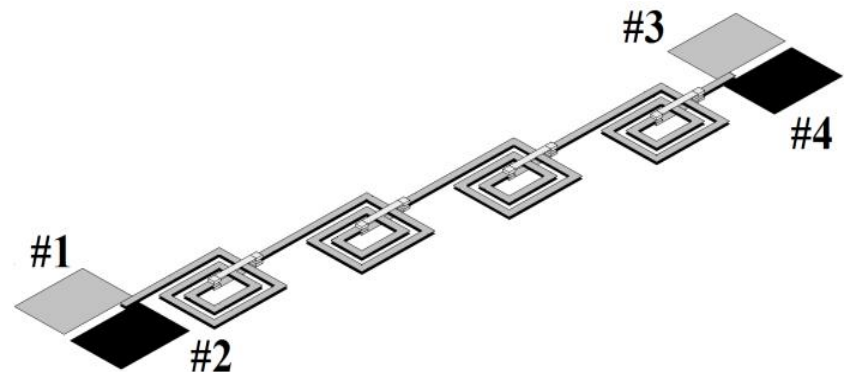
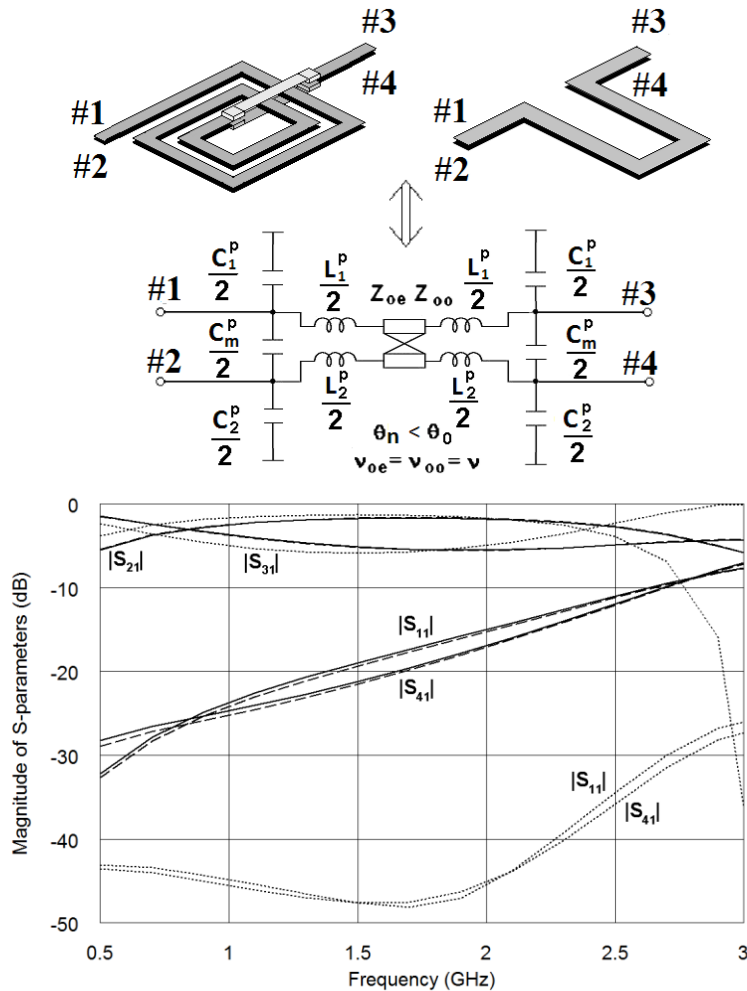
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# The influence of coupling between L and C elements in directional:

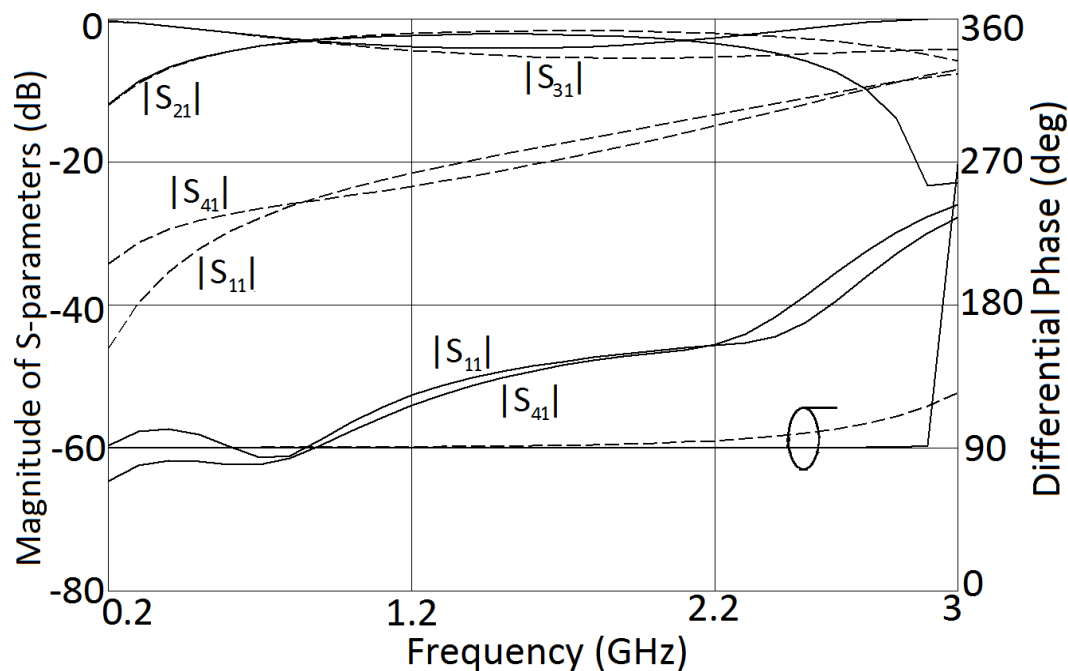
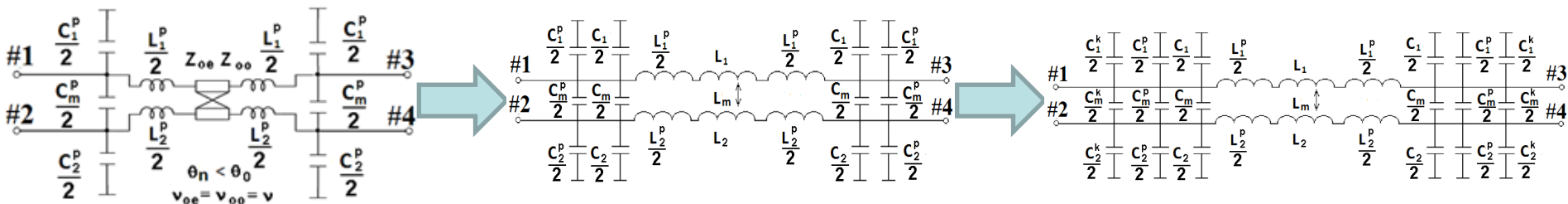
## Modeling of folded coupled inductors

### Modeling of the influence of coupled inductors' folding

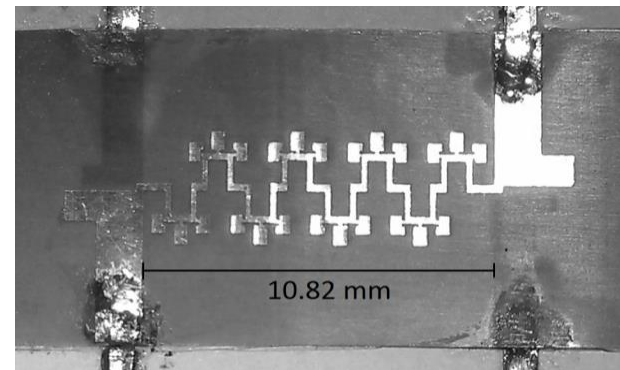
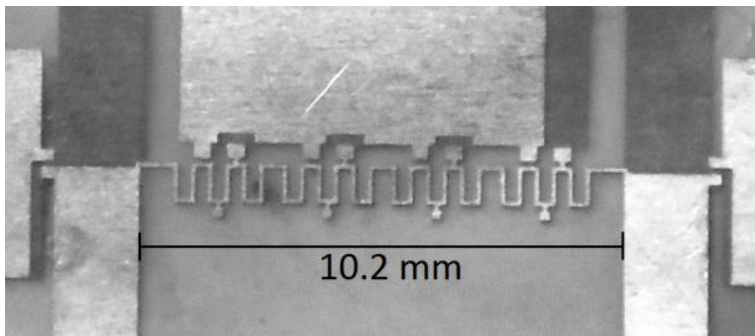
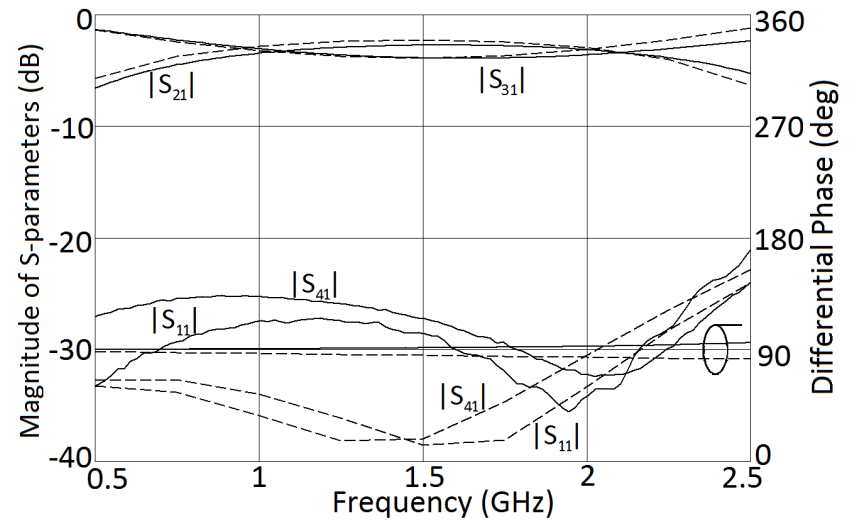
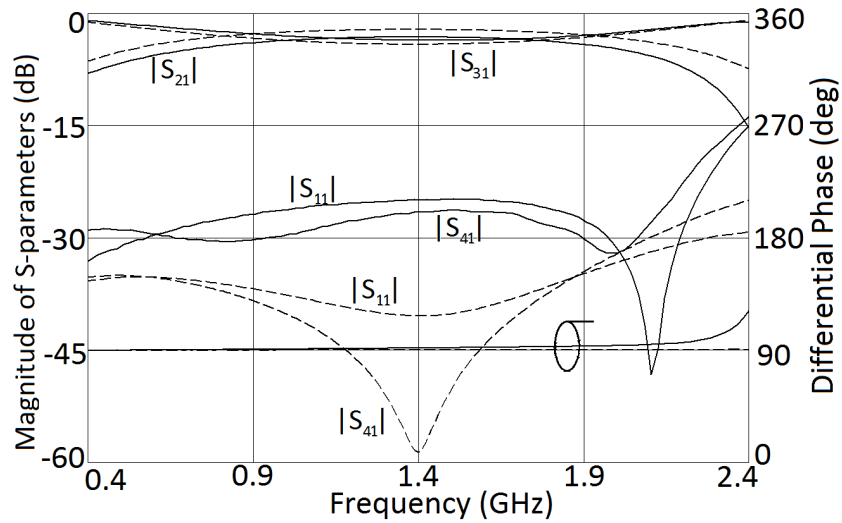
- design of directional coupler with the use of quasi-lumped element technique (assuming  $k$ ,  $f_0$ ,  $Z_0$  and  $n$ ) [1]
- calculation of the parameters of the stright coupled-line section designed in a chosen dielectric layer ( $Z_{oe}$ ,  $Z_{oo}$ )
- Modeling of the influence of folding with the use of lumped elements added to the ideal coupled-line section (curves' fitting)



# Utilization of the proposed model to improve directivity and impedance match

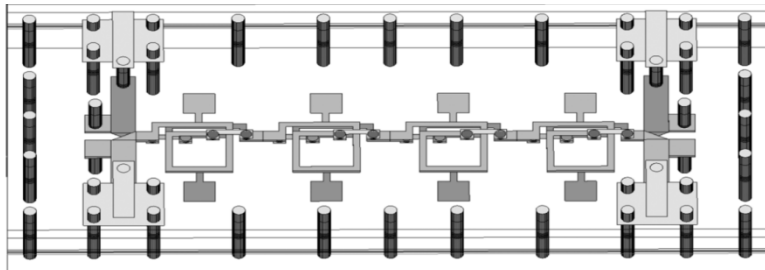
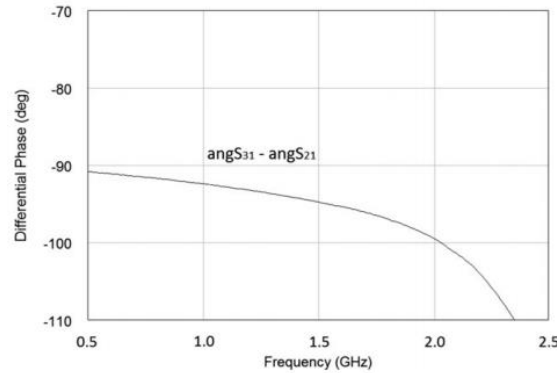
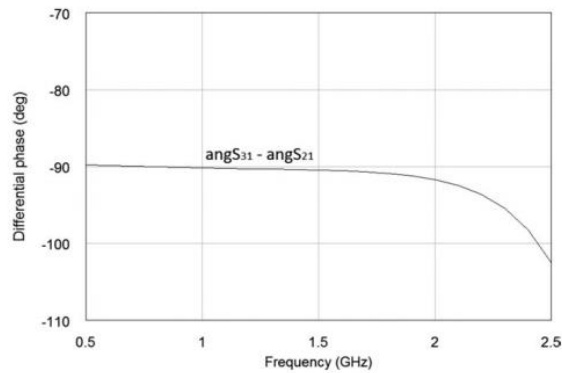
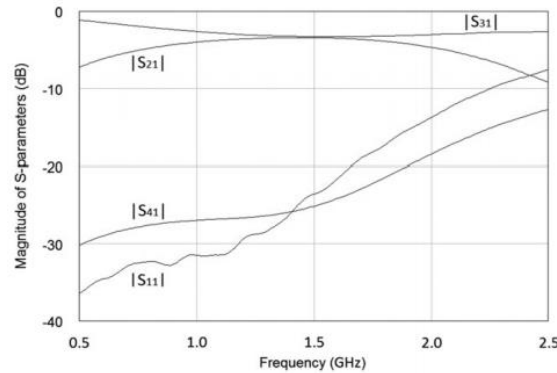
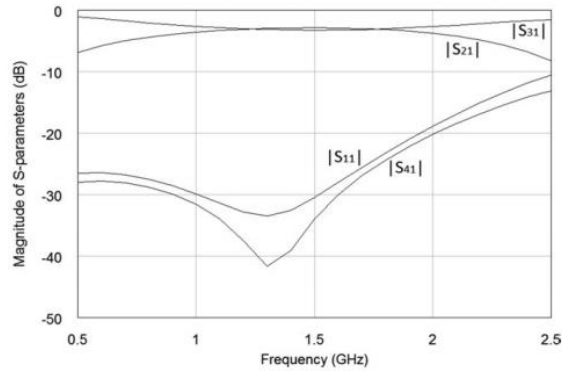


# Experimental verification of the proposed model



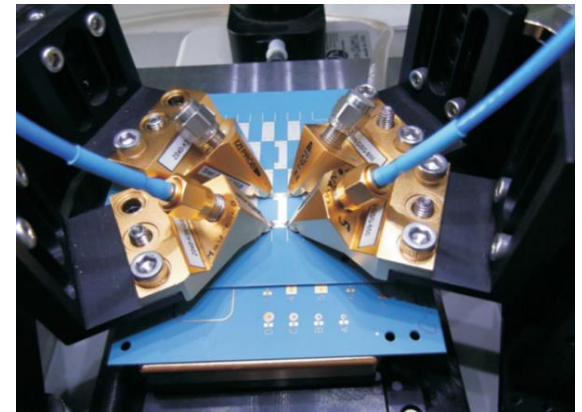


# Possibility of realization and miniaturization of the directional couplers designed in LTCC technology

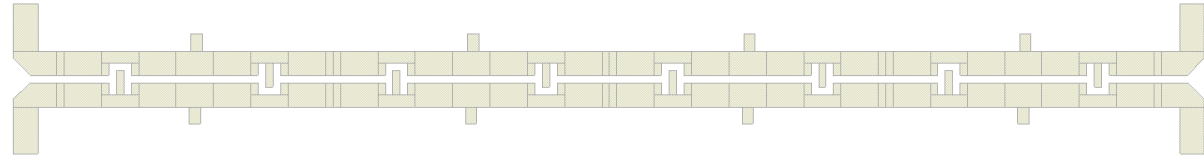
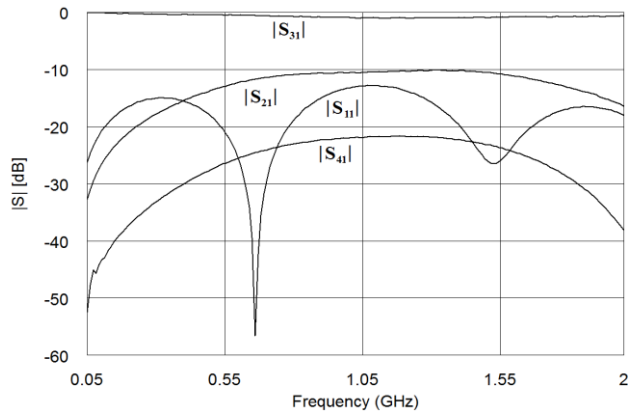
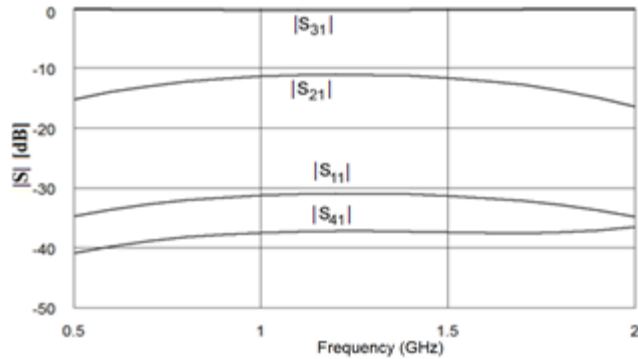


## Advantages of the LTCC

- Compact design
- 2- and 3-D are possible



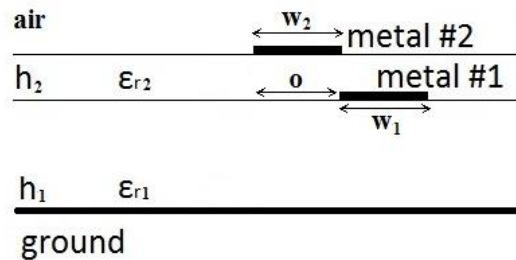
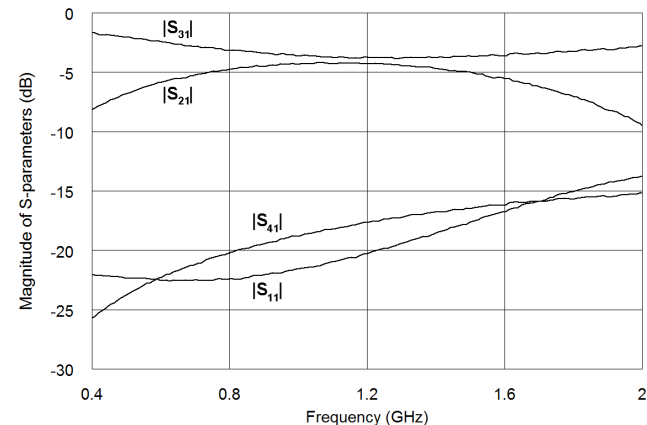
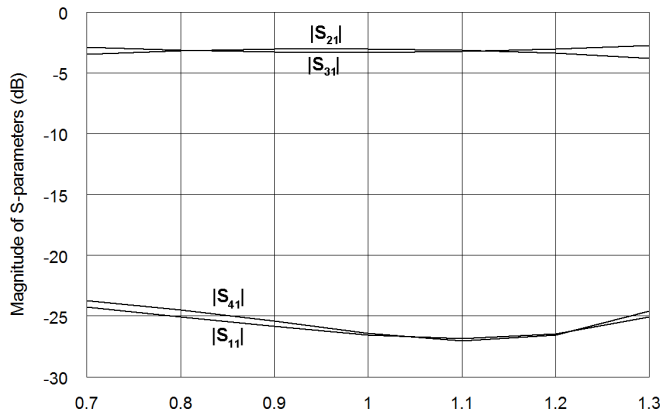
# Possibility of realization and miniaturization of the directional couplers designed in thick-film technology



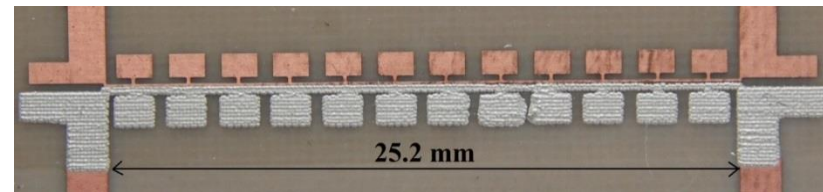
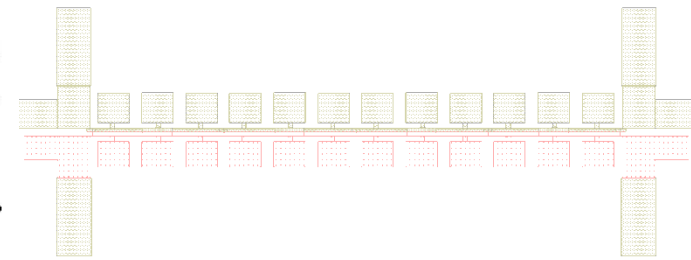
## Advantages of the thick-film technology

- Low cost in high volume
- Compact design

# Possibility of realization and miniaturization of the directional couplers designed in thick-film-laminate technology



$$w_{1,2} = 0.15 \text{ mm}, \quad \varepsilon_{r1} = 3.38, \quad \varepsilon_{r2} = 30, \\ h_1 = 0.762 \text{ mm}, \quad h_2 = 0.16 \text{ mm}$$



## Advantages of thick-film-laminate technology

- Low cost in high volume
- Compact size
- High coupling coefficients can be obtained

1. I. Piekarz, J. Sorocki, K. Wincza, S. Gruszczynski, J. Muller, T. Welker, “Miniaturized quasi-lumped coupled-line single-section directional coupler designed in multilayer LTCC technology”, *Microw. Opt. Techn. Lett.*, vol. 55, no. 6, pp. 1401-1405, Jun. 2013.
2. I. Piekarz, J. Sorocki, K. Wincza, S. Gruszczynski, “Modeling and performance improvement of folded coupled lines in miniaturized quasi-lumped directional couplers”, *Int. J. RF Microw. Comput.-Aided Eng.*, early view
3. I. Piekarz, J. Sorocki, K. Wincza, S. Gruszczynski, “Meandered coupled-line single-section directional coupler designed in multilayer LTCC technology”, *20th Telecommunications Forum , TELFOR 2012*, Belgrade, Serbia, 20-22 Nov. 2012, pp. 983-986
4. I. Piekarz, J. Sorocki, I. Slomian, M. Sloma, P. Kaminski, K. Wincza, S. Gruszczynski, “Miniaturized coupled-line directional coupler designed with the use of Photoimageable Thick-Film technology”, in *Proc. 23rd International Crimean Conference on Microwave and Telecommunication Technology*, CriMiCo 2013, Sevastopol, Ukraine, 9-13 Sep., 2013, pp.705-707