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DESIGN of DUPLEXER for 5G MIMO ANTENNA

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Abstract:- Duplexer requires stability in terms of fast signal switching between transmitting and receiving channels on full duplex cellular telephone equipment. In this experiment, The duplexer device is the Band Stop Filter (BSF) L-shaped method with the 7th and 9th order Butterworth response. The design begins by determining the desired frequency limit, namely 3.7 GHz.

The experimental results show that the Butterworth response BSF has a better level of stability and insulation performance. In terms of order level, it has been proven that the higher order (order 9) has a better isolation performance value than the lower order (order 7).

Keywords:- *Duplexer, BSF, Isolation.*

I. INTRODUCTION

Entering year 2022, Indonesia is preparing to implement 5G technology which is planned to operate in the 3.7 GHz frequency band. 5G technology has advantages in terms of high access speeds and data transfer of up to 20 terabytes (TB) in just a few seconds.

A duplexer is a switching system that absolutely must be owned by full duplex telecommunications equipment by using a single antenna that functions as a transmitting and receiving antenna (reciprocity). Full duplex telecommunications equipment contains a series of transmitters and receivers to enable uninterrupted communication between users from different locations. One example of full duplex telecommunications equipment is a cellular telephone. Cellular phones have transmitters and receivers (transceivers) with different frequency values. The difference between the transmitting and receiving frequencies is called the duplex space. This duplex space allows for uninterrupted reciprocal communication between users even though they are in remote locations.

Duplexer is the main key factor in establishing cellular communication between subscribers who operate at high frequencies, especially the UHF (Ultra High Frequency) band. The adaptive signal-preselection function of the duplexer affects the performance of the transmitter and receiver (transceiver) system to process electromagnetic wave signals and suppress unwanted signals, namely interference. As an example of a multiplexed radio device, adaptive full duplex in a duplexer circuit in a microwave transceiver system must operate simultaneously and dynamically according to the desired frequency band.

This study implements a Band Stop Filter (BSF) circuit as a duplexer. Band Stop Filter is a filter or frequency filter that rejects and blocks frequencies that are between two cut-off points, while all frequencies that are below a certain frequency (below the cut-off point) and all frequencies that are above a certain frequency (above cut-off point) will be missed. In other words, the Band Stop Filter will eliminate all frequencies that are outside the two sides of the cut-off point range. Band Stop Filter or also often referred to as Notch Filter is basically a combination of Low Pass Filter and High Pass Filter connected in parallel. This connection is different from the Band Pass Filter which connects the Low Pass Filter and High Pass Filter in series. Another name for this Band Stop Filter is the Band-Elimination Filter or Band-Reject Filter. The following is research on the Band Stop Filter.

This study presented a fully integrated dual-band CMOS RF front-end design to ensure the operation in the 0.7−2.2 GHz frequency band. In order to realize a TX blocker rejection scheme over the wideband frequency range, the band switchable hybrid transformer based EBD and the wideband LNA with an N-path filter were employed to support the wideband frequency range. Through performance verification, the implemented design consistently attains greater than 55 dB TX-RX isolation or SIC in the FDD and IBFD modes for all the measured frequency bands and its linearity performance is truly maintained with a TX leakage power up to +25 dBm. The designed dual band CMOS RF front-end offers a highly integrated solution for reducing the complexity and cost of the RF front-end design of high-end transceiver systems. [1]

Here, the comparison of three different configurations is done. The spurline band stop filter is included in previously done work. Analysis of interdigital capacitance as a defected ground structure shows that it not only exhibits good band stop characteristics, but it has tunable central frequency that can be achieved by changing the capacitance. Moreover, the features of this microstrip interdigital band stop filter are smaller than those of the conventional band stop filter. Both the above explained configurations are compared with proposed structure [2].

A new, modified L-shaped resonator bandstop filter that was implemented for Microwave applications is presented. Two methods to tune its bandwidth and center frequency of the filter have been identified, which are the width varying method and the cascading method. A bandwidth improvement of up to 6% has been verified using the cascading method, through simulation and measurement carried out in this work [3].

II. THEORICAL BACKGROUND

A. Bandstop Transformation

The frequency transformation from lowpass prototype to bandstop is achieved by the frequency mapping [4]:

$$\Omega = \frac{\Omega_C FBW}{(\frac{\omega_0}{\omega} - \omega/\omega_0)} \quad (1)$$

$\omega_0 = \sqrt{\omega_1 \omega_2}$

FBW = $\frac{\omega_1 - \omega_2}{\omega 0}$

where ω2 − ω1 is the bandwidth. This form of the transformation is opposite to the bandpass transformation in that an inductive/capacitive element g in the lowpass prototype will transform to a parallel/series LC resonant circuit in the bandstop filter. The elements for the LC resonators transformed to the bandstop filter are

$$Cp = \left(\frac{1}{FBW \omega_0 \Omega_C}\right)\frac{1}{\gamma_0 g} \quad (2)$$

$$Lp = \left(\frac{\Omega_C FBW}{\omega_0}\right)\gamma_0 g \quad (3)$$

for g representing the inductance

$$Ls = \left(\frac{1}{FBW \omega_0 \Omega_C}\right)\frac{\gamma_0}{g}$$

$$Cs = \left(\frac{\Omega_C FBW}{\omega_0}\right)\frac{g}{\gamma_0}$$

The duplexer device is the Band Stop Filter (BSF) L-shaped method with the 7th and 9th order Butterworth response. The design begins by determining the desired frequency limit, namely 3.7 GHz. After that, calculate the width and length of the device using the following equation:

- *Resonator Width*

To obtain the width of the resonator channel, the equation is used:

$$A = \frac{Zo}{60}\frac{\sqrt{\varepsilon r+1}}{2} + \frac{\varepsilon r-1}{\varepsilon r+1}\left(0{,}23 + \frac{0{,}11}{\varepsilon r}\right) \quad …….. \quad (4)$$

Diketahui Zo= 50 Ω ε_r = 4,4

$$A = \frac{50}{60}\frac{\sqrt{4{,}4+1}}{2} + \frac{4{,}4-1}{4{,}4+1}\left(0{,}23 + \frac{0{,}11}{4{,}4}\right) = 1{,}5298619493$$

$$\frac{W}{h} = \frac{8e^{A}}{e^{2A}-2} \quad ………….. \quad (5)$$

$$W = 1{,}9118593644$$

$$w = \frac{W}{h}.h \quad ………… \quad (6)$$

$$w = 1{,}9118593644 \ x\ 1{,}6 = 3{,}058974893 \text{ mm}$$

- *Resonator Lenght*

$$\lambda_g = \frac{300}{f(GHz)\sqrt{\varepsilon_{re}}} \quad ………… \quad (7)$$

$$\lambda_g = \frac{300}{3.7\sqrt{4{,}4}} = 38{,}65389$$

$$1/4 \cdot \lambda_g = 9.66347$$

- *The size of the distance between each resonator and the main lane*

To design a BSF, the distance between elements is determined by the reactance value of each element (n) according to the desired order. The value of n is known from table 1 which shows the value of each element of the 7th and 9th order Butterworth lowpass prototype.

Table 1. Element values of the Butterworth Lowpass Filter Prototype.

n	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g9	g10
Orde 7	0,4450	1,2470	1,8019	2,0000	1,8019	1,2470	0,4450	1,0		
Orde 9	0,3473	1,0000	1,5321	1,8794	2,0000	1,8794	1,5321	1,0000	0,3473	1,0

Note that Zo = 50 Ω dan Ω_C = 1

So :

$$FBW = \frac{w2 - w1}{w0} = \frac{3{,}8 - 3{,}6}{3{,}7} = 0{,}054$$

For x_n Value as follows

$$x_n = Z_0 \frac{1}{g_0\, g_{orde+1}} \frac{g_0}{g_n \Omega_C FBW} \quad …….. …...(5)$$

$$x_1 = 50 \frac{1}{1 \text{ X } g_{7+1}} \frac{1}{0{,}4450 \text{ X } 1 \text{ X } 0{,}054} = 2080{,}732$$

$$\frac{x_1}{z_0} = 41{,}6145$$

The calculation continues up to x_7. For order 9, calculations are carried out with the same equation to obtain x_9. The calculation results are compared with the curve in Figure 2 to obtain the size of the 7th and 9th order BSF designs.

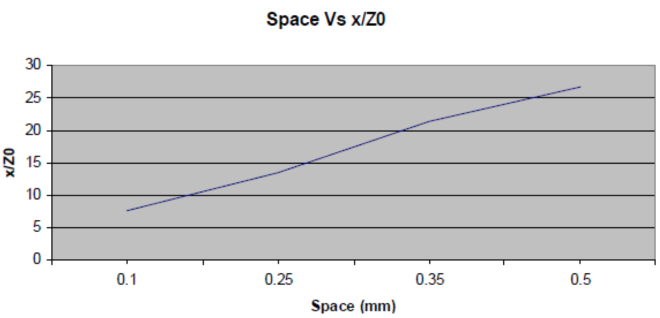

Fig 2. Comparison of Curves Between Reactance and Distance Slope Parameters

III. RESULT

From the results of the comparison of reactance values x 1 to x 7 for BSF of order 7 and the comparison of reactance values x 1 to x 9 for BSF of order 9 to distance, it is concluded in table 2 below:

Table 2. Results of Comparison of Each Reactance Value to Distance

Parameter of Reactance Slope		**Value**		**Distance (mm)**	
Orde 7	**Orde 9**	**Orde 7**	**Orde 9**	**Orde 7**	**Orde 9**
$x_1 / Z_0 ; x_7 /Z_0$	$x_1 / Z_0 ; x_9 /Z_0$	41.6145	53,321	0,64	0,7
$x_2 /Z_0 ; x_6 /Z_0$	$x_2 / Z_0 ; x_8 /Z_0$	12,597	18,518	0,2	0,31
$x_3 / Z_0 ; x_5 /Z_0$	$x_3 / Z_0 ; x_7 /Z_0$	10,277	12,087	0,18	0,2
X_4 / Z_0	$X_4 / Z_0 ; x_6 /Z_0$	9,259	9,853	0,17	0,16
	X_5 / Z_0		9,259		0,17

Design of 7th-order and 9th-order BSF is used CST (Central Studio Time). From the calculation results, the design size of the 7th-order BSF is obtained as follows:

From the calculation results, the 7th order BSF design size is obtained as follows: (a). The width of the resonator size is 3 mm. (b). The length of the resonator is 12.66 mm. (c). The size of the slide factor (connector between resonators) is 3 mm. (d). The dimension length is 86,99 mm (CST optimization). (e). Dimension width is 55 mm (CST optimization) and (f). The distance between the resonators is 6,66 mm.

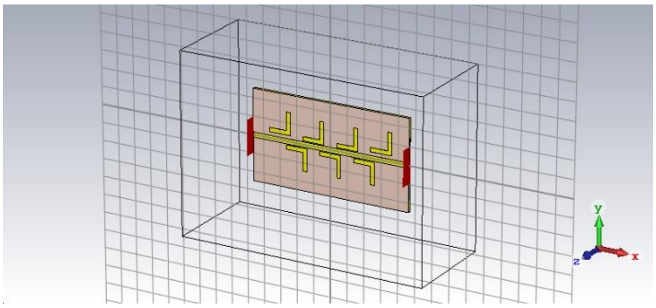

Fig 3. Design of 7th-order BSF

For a 9th order BSF design, the design size is (a). The width of the resonator size is 3 mm. (b). The length of the resonator size is 12,66 mm. (c). The size of the slide factor (connector between resonators) is 3 mm. (d). The dimension length is 86,99 mm (CST optimization). (e). The dimension width is 55 mm (CST optimization). (d). The distance between the resonators is 6,66 mm. CST optimization is needed to produce the right BSF lay-out design size on FR4 type microstrip printed boards.

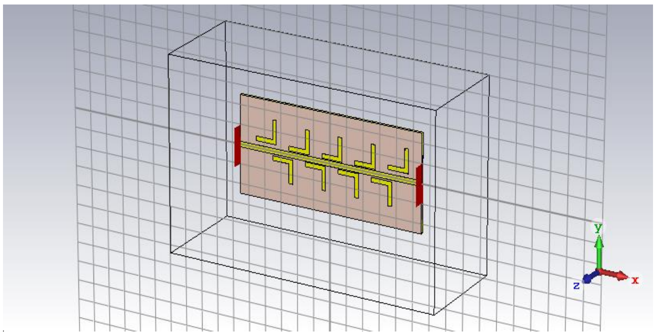

Fig 4. Design of 9th-order BSF

The simulation results of the two orders show different values. Order 9 shows a better isolation value than order 7.

The following is the simulation results of the 7th and 9th order BSF Butterworth responses.

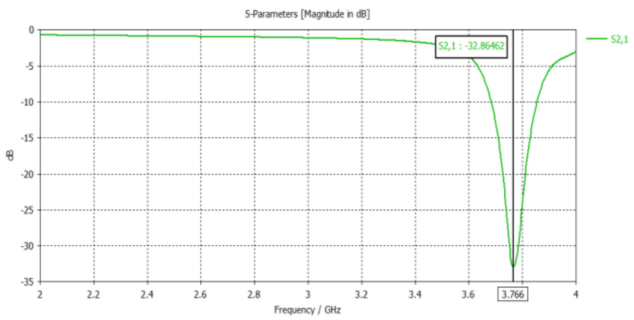

Fig 5. 7th order simulation result

In the previous study [5], the results of the Chebyshev response BSF measurements were the same as the butterworth response BSF simulation results.

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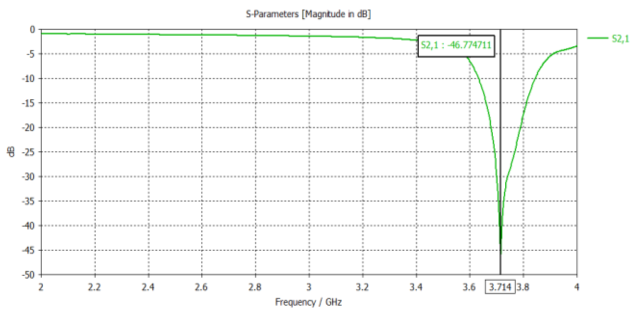

Fig 6. 9th BSF simulation result

The measurement results are summed up in table 3 below:

Table 3. *Duplexer Device* Simulation Results – BSF order 7 and order 9

Types of measurements	Value	
	Orde 7	Orde 9
Insertion Loss (dB)	0,564	0,465
Isolasi Tx/Rx (dB)	-32,864	-46,774
VSWR	1,428	1,021
Frekuensi (GHz)	3,766	3,714

From the data above it can be seen that the responses of Butterworth and Chebyshev [5] show nearly the same isolation values. The difference from both Butterworth's response and BSF Chebyshev is the insertion loss value where Butterworth has flat stability compared to Chebyshev which has ripple in its passband area.

Duplexer requires stability in terms of fast signal switching between transmitting and receiving channels on full duplex cellular telephone equipment.

Duplexers as tunable filtering devices are key high frequency components in these systems. Note that the adaptive signal-selection function carried out by them directly affects the performance of the entire transceiver for any electromagnetic (EM) conditions in terms of desired RF signal to be processed and unwanted interferences to be suppressed. A particular class of these circuits are reconfigurable microwave duplexers for adaptive full-duplex frequency-multiplexed radios, in which the transmitter and receiver must simultaneously operate at different and dynamically selectable bands [6].

The ideal performance of a duplexer is the ability to isolate the signal transfer between the transmitting system and the receiving system within the range of -64 dB to -20 dB.

From the experimental results of the duplexer in the form of Butterworth and Chebyshev response BSF [5] it can be concluded that the Butterworth response BSF has a better level of stability and isolation performance than the Chebyshev response BSF.

In terms of order level, it has been proven that the higher order (order 9) has a better isolation performance value than the lower order (order 7).

IV. CONCLUTION

From the results of experiments that have been carried out, it can be concluded that :

- Duplexer in the form of BSF microstrip Butterworth response has a good level of stability in signal transfer on full duplex devices.
- Duplexer that has a higher order level produces better isolation performance than a lower order one.
- Nilai perfomansi isolasi berada dalam range -64 dB sampai dengan -20 dB.

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