METAMATERIAL-INSPIRED QUAD-BAND NOTCH FILTER FOR LTE BAND RECEIVERS AND WPT APPLICATIONS

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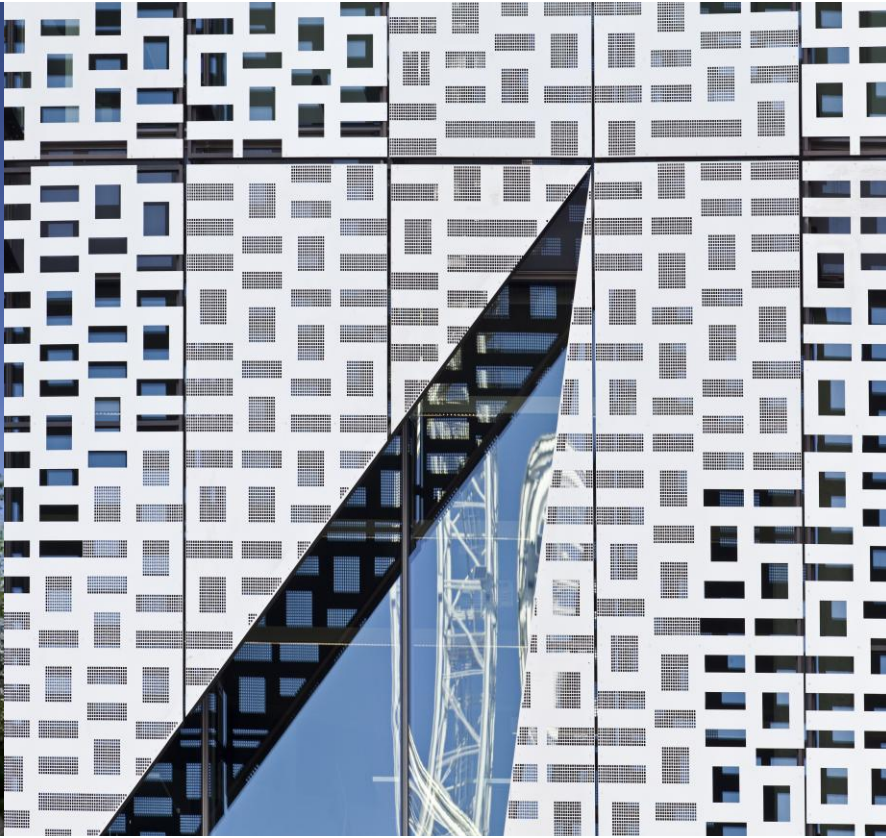

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Metamaterial-Inspired Quad-Band Notch Filter for

LTE Band Receivers and WPT Applications

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Metamaterial-Inspired Quad-Band Notch Filter for LTE Band Receivers and WPT Applications

- A new compact **quad-band notch filter (QBNF)** based on the **extended composite right and left-handed transmission line (E-CRLH TL)** has been presented.
- As known, E-CRLH TL behaves like a quad-band structure. A microstrip TL which is loaded with **an open-ended E-CRLH TL** is presented as a QBNF.
- Four unwanted frequencies were used in a **dual-band LTE receiver** as four notch frequencies which must be eliminated (0.9 GHz, 1.3 GHz, 2.55 GHz, and 3.35 GHz).
- Also, this QBNF can be applied to **simultaneous wireless power and data transfer (SWPDT)** system to isolate the wireless power circuit from the data communication circuit.
- A design technique for the proposed QBNF is presented and its performance is validated using **full-wave simulation results** and **theoretical analysis**.
- The main advantage of this design is an overall rejection greater than **20dB** at selected unwanted frequencies.
- The proposed QBNF is designed on FR-4 substrate and the dimension of the proposed QBNF is **20×22 mm**.

Wireless Communication Systems

- Abstract
- **Introduction**
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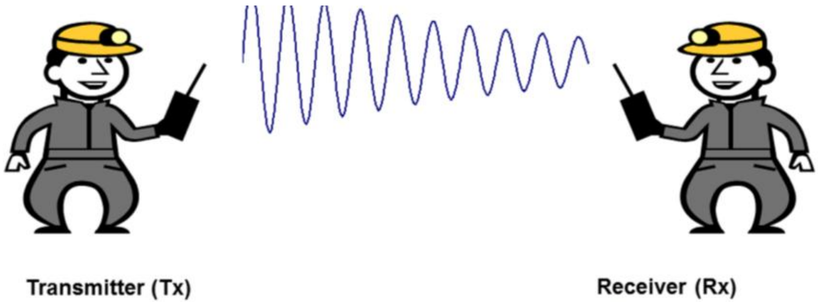
- Wireless Communication is the fastest growing and most vibrant technological areas in the communication field.
- Wireless Communication is a method of transmitting information from one point to another, without using any connection like wires, cables or any physical medium.
- We live in a World of communication and Wireless Communication, in particular, is key in our lives. Some of the commonly used Wireless Communication Systems in our day – to – day life are: Mobile Phones, GPS Receivers, Remote Controls, Bluetooth Audio and Wi-Fi etc [1].



Homodyne and Heterodyne Receivers

- Abstract
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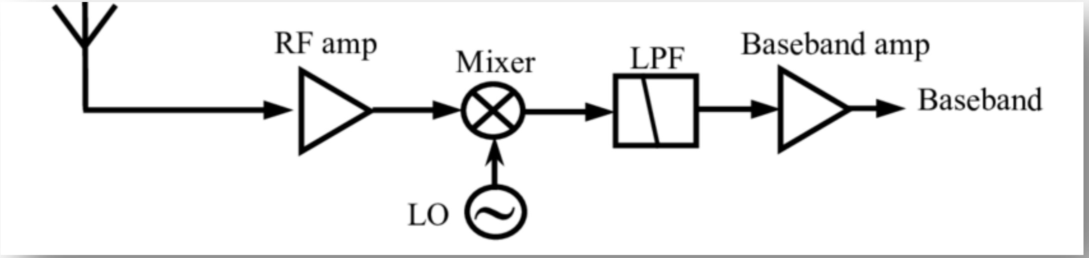
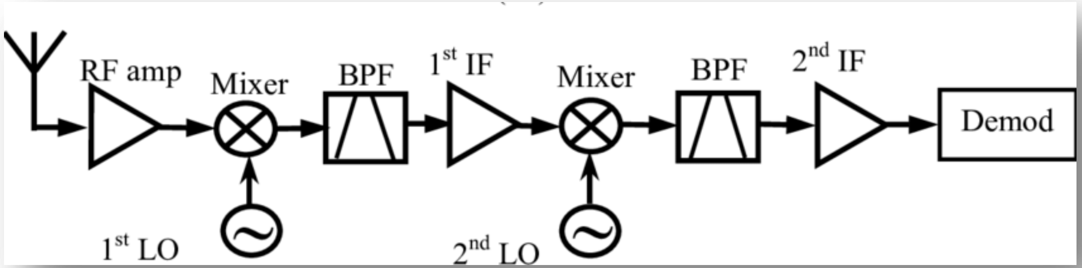
➢ The architectures of wireless receivers can generally be divided into two categories; homodyne and heterodyne receivers [1].



Homodyne receiver



Heterodyne receiver

Drawback in the Heterodyne Receiver

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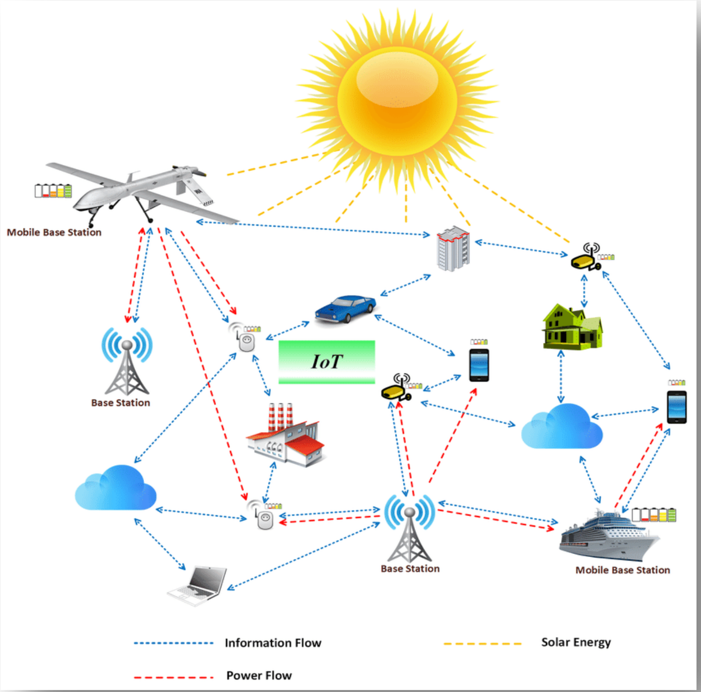
- A homodyne receiver, also known as a **direct-conversion receiver (DCR),** is an RF receiver configuration that down-convert the incoming RF signal using a local oscillator whose frequency is identical to, or very close to the carrier frequency of the input RF signal [1].
- On the other hand, in the heterodyne architecture, the signal goes through a receiver chain where its frequency translated to a lower intermediate frequency (IF).
- One main drawback in the heterodyne receiver is the problem of image frequency (f_{IM}).
- **Image frequency** is an undesired input frequency equal to $f_{RF} + 2f_{IF}$ (if $f_{RF} < f_{LO}$) or $f_{RF} - 2f_{IF}$ (if $f_{RF} > f_{LO}$) [1].
- The image frequency can be received at the same time with the RF signal and down-converted into the IF frequency, thus producing interference in the receiver.
- Image frequencies can be eliminated by sufficient attenuation in the incoming signal using RF notch filter as an **image rejection filter (IRF)** of the heterodyne receiver; then, signal processing operations are performed [1].

Multi-band Notch Filter in Simultaneous Wireless Power and Data Transfer (SWPDT)

- Another application of a multi-band notch filter is using in **wireless power transfer (WPT)** and **energy harvesting (EH)** systems.
- The dual-functional WPT system as **simultaneous wireless power and data transfer (SWPDT)** is an ideal candidate for several applications such as **Internet-of-Things (IoT)** that require simultaneous wireless information and power transfer [2], [3].



Multi-band Notch Filter in Simultaneous Wireless Power and Data Transfer (SWPDT)

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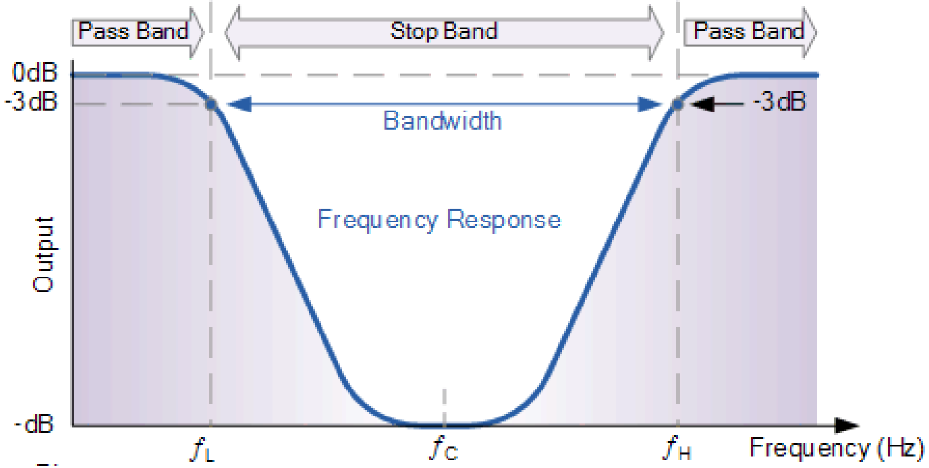
- In this structure, wireless power circuit configured to receive wireless power from antenna at the first frequency, communication circuit coupled to the antenna and configured to receive a signal from the antenna at the second frequency different from the first frequency.
- A notch filter between the antenna and input of the wireless power circuit is required to isolate the wireless power circuit from the data communication circuit.



Extended Composite Right and Left Handed (E-CRLH) Unit Cell

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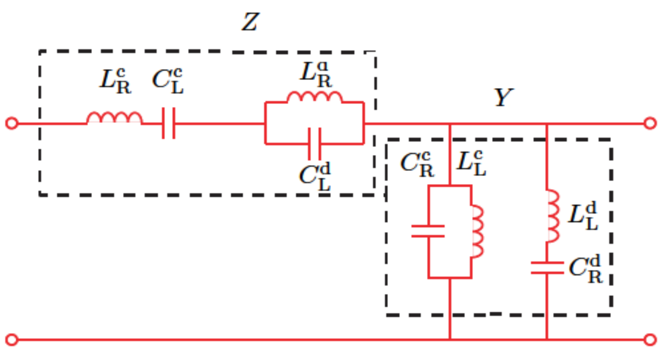
- By combining the conventional **CRLH** and the **dual CRLH (D-CRLH),** an extended CRLH (E-CRLH) with a quad-band performance can be realized [4].



$$Z = j\omega L_R^c/2\left(1-\frac{\omega_{cR}}{\omega^2}\right)-\frac{j}{\omega C_L^d/2\left(1-\left(\omega_{dR}/\omega^2\right)\right)}$$

$$Y = j\omega C_R^c\left(1-\frac{\omega_{cL}}{\omega^2}\right)-\frac{j}{\omega L_L^d\left(1-\left(\omega_{dL}/\omega^2\right)\right)}$$

$$\omega_{cs} = 1/\sqrt{L_R^c C_L^c},\ \omega_{dp} = 1/\sqrt{L_R^d C_L^d}$$

$$\omega_{cp} = 1/\sqrt{L_L^c C_R^c},\ \omega_{ds} = 1/\sqrt{L_L^d C_R^d}$$

Extended Composite Right and Left Handed (E-CRLH) Unit Cell

- The Bloch propagation constant of E-CRLH TL [4]:

$$\cos(\beta p) = 1 + ZY$$

- The Bloch impedance of E-CRLH TL [4]:

$$Z_B = \sqrt{\frac{Z}{Y}}\sqrt{2+ZY}$$

- Around the β=0 frequencies can be approximated by [4]:

$$Z_B = \sqrt{\frac{2Z}{Y}}$$

Quad-band (QB) E-CRLH TL Theory

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➢ A quad-band (QB) device is a component accomplishing the same function at four different arbitrary frequencies $\omega_1, \omega_2, \omega_3$ andω_4 [5].

➢ Such a component is therefore constituted of TL sections inducing equivalent phase shifts [5]:

$$\varphi_i = \beta_i p \qquad i = 1,2,3 and 4$$

Heterodyne Receiver Architecture With QBNF

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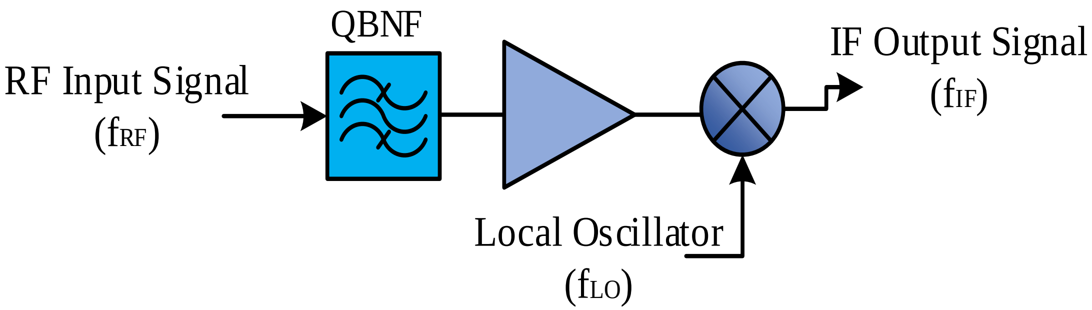
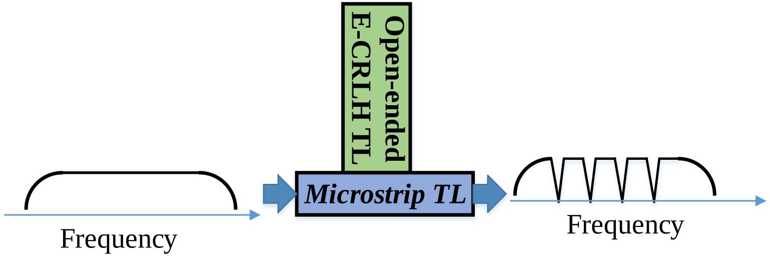
- The notch filter is an essential part of this architecture and without rejection of undesired signals in the operational frequency band, the desired RF and unwanted signals are both mixed down to IF frequency.



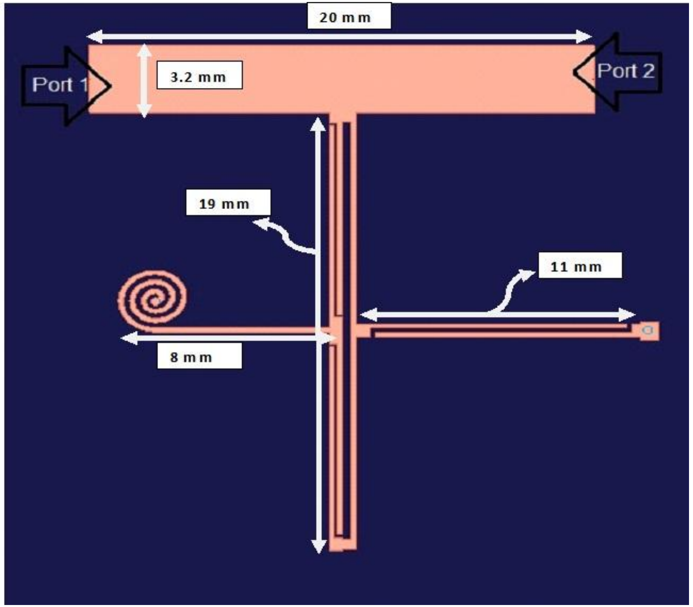
- In order to achieve high performance of the heterodyne receiver, we use QBNF to cancel four interferers (f_{IM1},f_{SH1}, f_{IM2},f_{SH2}) frequencies at two RF frequencies (f_{RF1},f_{RF2}) in a dual-band receiver.

Proposed QBNF on FR4 Substrate

- Schematic of the proposed QBNF



- Layout (top view) of the proposed QBNF



Proposed QBNF on FR4 Substrate

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- The proposed QBNF is designed on the FR-4 substrate with 1.6 mm thickness, loss tangent equal to 0.03 and dielectric constant of 4.7.

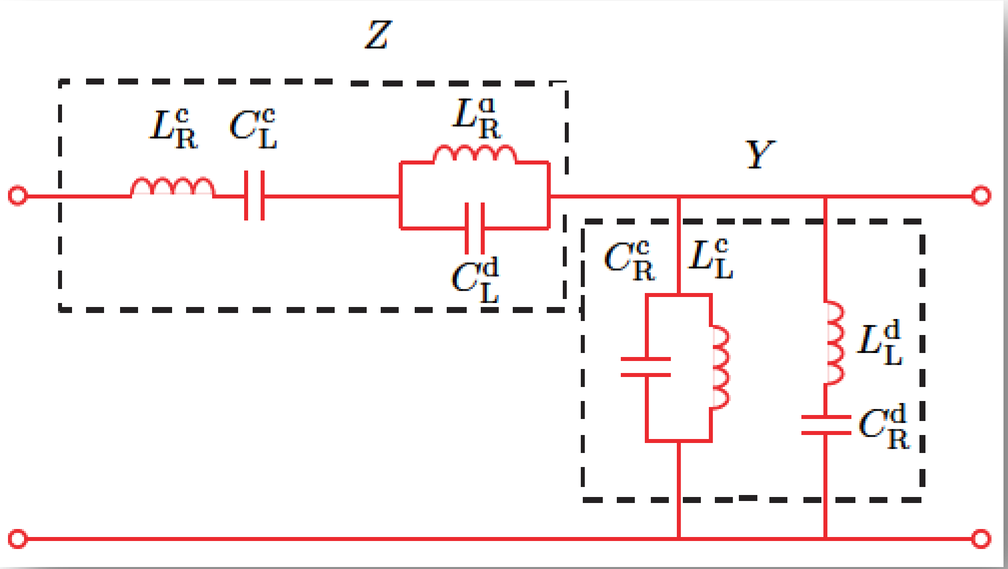
- Select two LTE frequency sets for RF and LO in an assumed dual-band receiver:

$$\begin{cases} f_{RF1} = 1.4\ GHz, & f_{LO1} = 1.15\ GHz, & f_{IF1} = 250\ MHz \\ f_{RF1} = 1.8\ GHz, & f_{LO1} = 1.55\ GHz, & f_{IF1} = 250\ MHz \end{cases}$$

- Unwanted frequencies for two RF frequencies are:

$$set1: \begin{cases} f_{IM1} = 0.9\ GHz \\ f_{SH1} = 2.55\ GHz \end{cases} \qquad set2: \begin{cases} f_{IM2} = 1.3\ GHz \\ f_{SH2} = 3.35\ GHz \end{cases}$$

Lumped Elements Values of E-CRLH Unit Cell



C_R^c	L_L^c	L_L^d	C_R^d	L_R^c	C_L^c	C_L^d	L_R^d
$2.6\ pF$	$3.7\ nH$	$3.3\ nH$	$1.9\ pF$	$6.4\ nH$	$1.5\ pF$	$1.3\ pF$	$4.8 nH$

S-parameters of the proposed QBNF

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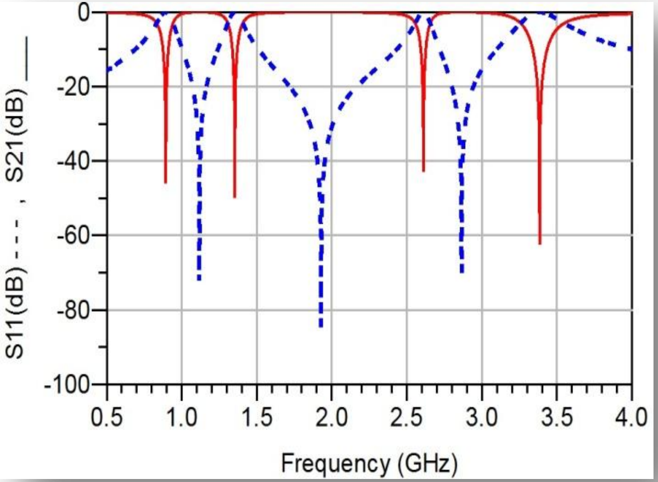
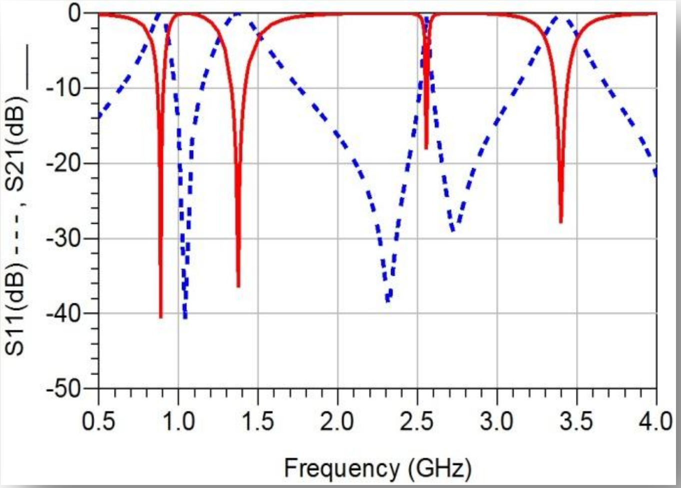
Theoretical analysis (equivalent circuit model)



Full-wave simulation analysis (layout)



Simulation Results

- Unwanted frequencies can be eliminated in a dual-band receiver by using the proposed QBNF.
- It is evident that a quad-band notch filtering performance has been achieved around the design frequencies of 0.9GHz, 1.4GHz, 2.55GHz, and 3.6GHz.
- The rejection of the proposed QBNF in notch frequencies is more than 20dB, which proofs the good performance of the designed IRF at desired frequencies.

Conclusion

- A new type of quad-band notch filter (QBNF) composed of a conventional microstrip line which is loaded with an open-ended E-CRLH TL has been proposed, investigated theoretically and simulated.
- The proposed QBNF with a dimension of 20 × 22 mm exhibits the rejection of 20 dB in four unwanted frequency bands 0.9 GHz, 1.3 GHz, 2.55 GHz, and 3.35 GHz.
- In order to analyze the proposed QBNF, an equivalent circuit model has been presented and validated by full-wave simulation results.
- The proposed QBNF can be used as a notch filter in dual-band LTE receiver configurations or SWPDT systems to reject unwanted frequencies.

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