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Stepped Impedance Effect on Microstrip Structure: A Review

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Abstract—The optimization technique for size of patch antenna mostly depends on the electrical length of the antenna, the known methods suffer poor VSWR, low radiation resistance and feeding difficulties. The radiation wavelength is one of the factors which change the electrical length of the patch antenna, the electrical length of patch can also be controlled by using lumped parameters. This manuscript review and analyze the the effect of stepped impedance on various performance parameters of patch antenna for different frequency. Here we review the latest research in the field of stepped impedance and lumped parameters which affect the electrical length of microstrip structure along with the basic concept of capacitance slot and inductor slot on radiations. The introduction of stepped impedance patch and discontinuities along with inductance slot increase the bandwidth and gain of different patch antenna, this technique is also very useful in order to get multiband radiation abilities.

Keywords- Mutual decoupling, lumped parameters, stepped impedance resonator, Multiband, Antenna Gain.

I. INTRODUCTION

with the advancement in development of integrated circuit designing the devices became much more complicated as well as compact when we are talking about the communication devices [1] like mobile phone routers etc. Patch antenna plays an important role in increasing compactness of integrated circuit [2]. The metal coupling also plays an important role which is actually reducing the efficiency [3] of antenna as well as the capacity. In order to achieve a higher capacity for a multiband antenna system we normally used isolation between antenna elements there are different methods to provide the isolation between the antenna elements viz electromagnetic band gap (EBG) structure, high impedance surface (HIS), coplanar strip wall, defective ground structure (DGS), split ring resonator (SRR) are among the most [1,2,3] widely used methods to provide reduced mutual coupling. Talking about microstrip patch antenna it is a well-known fact that microstrip patch antenna suffers multiple defects such as narrow bandwidth, lower antenna gain etc. In order to enhance the gain as well as bandwidth of a microstrip patch antenna we use different techniques such as loading parasitic structure, shorting of pins, using folded dipole methods at top of patch as we use multiple slots section in a same structure of patch or even in the ground plane. The mutual coupling due to multiple sections affects the antenna performance in terms of vital parameters. In this paper we consider the stepped impedance resonator (SIR), which is one of the methods to reduce mutual coupling between different radiating slots and hence improve the patch antenna performance. This paper is designed in such a way that it will analyses the effect of stepped impedance resonator as a microstrip patch along with that we will discuss about the various research work which is take place in present era in order to decrease the mutual coupling in a patch antenna. The discontinuities in microstrip structures are one of the most available methods for getting different antenna parameters here we are talking about stepped impedance resonator in which the width of the impedance line for patch structure is changed in step manners that means steps in width can act as an impedance transformer, this impedance transformer act as a whole structure which will influence the working of a patch antenna.

The rest of the paper is organized in following sections section II describe the overview of stepped impedance resonator and the theory associated with it in section III we will discuss about the latest research which is going on in present era to reduce the mutual coupling specially in microstrip patch antenna designing. In section IV we conclude the present era research and on the basis of that will identify our basic design method and present future claims for our research work.

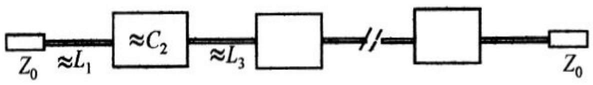
II. THEORY OF STEPPED IMPEDANCE

To design a patch antenna, microstrip structure plays a vital role in the performance parameters of antenna, to find an appropriate realization of microstrip, different lumped element in the form of patch is implemented in antenna design. A microstrip resonant circuit is any structure that is able to encompass at least one oscillating electromagnetic field. There are several measures of implementing microstrip resonators. In general, microstrip resonant circuit for antenna designs may be comprehensive of lumped-element and quasi-lumped-element resonators. There are numerous types of lumped parameter applied on microstrip structure, one of the under rated method is stepped impedance resonator (SIR). Theory of the proposed lumped parameter is described as below:

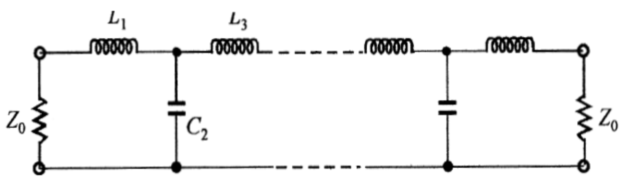
a) Stepped impedance Resonator

Figure 1(a) shows a general structure of the stepped-impedance microstrip structure, which use a cascaded structure of alternating high and low impedance transmission lines. These are much shorter than the associated guided wavelength, so as to act as semi-lumped elements. The high-impedance lines act as series inductors and the low-impedance lines act as shunt capacitors. Therefore, this structure is directly realizing the L-C ladder type of lowpass structure shown in figure 1(b). Some of the priori design information must be provided about the microstrip lines, because expressions for inductance and capacitance depend upon both characteristic impedance and length. It would be practical to initially fix the characteristic impedances of high- and low-impedance lines by consideration of: $Z_{0C} < Z_0 < Z_{0L}$, where Z_{0C} and Z_{0L} denote the characteristic impedances of the low and high impedance lines, respectively, and Z_0 is the source impedance, which is usually 50 ohms for microstrip structures. A lower Z_{0C} results in a better approximation of a lumped-element capacitor, a higher Z_{0L} leads to a better approximation of a lumped-element inductor,

but Z_{0L} must not be so high that its fabrication becomes inordinately difficult as a narrow line, or its current-carrying capability becomes a limitation.



(a)



(b)

Fig.1. (a) General structure of the stepped-impedance lowpass microstrip structure s. (b) L-C ladder type of lowpass structure s to be approximated.

Using the element transformations method [4] the resultant value of capacitance and inductance is given by the following formula:

$$L_1 = L_3 = \left(\frac{Z_0}{g_0}\right)\left(\frac{\Omega_c}{2\pi f_c}\right) g_1 \quad (1)$$

$$C_2 = \left(\frac{g_0}{Z_0}\right)\left(\frac{\Omega_c}{2\pi f_c}\right) g_2 \quad (2)$$

Steps in Width for a symmetrical step, the capacitance and inductances of the equivalent circuit indicated in Figure 2. may be approximated by the following formulation:

$$C = 0.00137h\, \frac{\sqrt{\varepsilon_{re1}}}{Z_{c1}}\left(1 - \frac{W_2}{W_1}\right)\left(\frac{\varepsilon_{re1} + 0.3}{\varepsilon_{re1} - 0.258}\right)\left(\frac{W_1/h + 0.264}{W_1/h + 0.8}\right) pF \quad (3)$$

$$L_1 = \frac{L_{w1}}{L_{w1} + L_{w2}} L,\ L_2 = \frac{L_{w2}}{L_{w1} + L_{w2}} L \quad (4)$$

$$L_{wi} = Z_{ci}\sqrt{\varepsilon_{rei}/C}$$

$$L = 0.00987h\left(1 - \frac{Z_{c1}}{Z_{c2}}\sqrt{\frac{\varepsilon_{re1}}{\varepsilon_{re2}}}\right)^2 (nH)$$

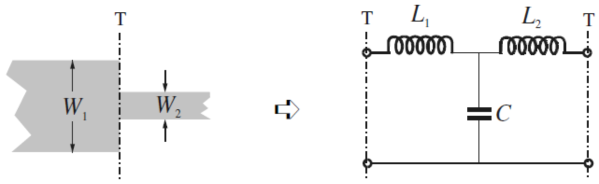


Fig 2. Steps in width for a symmetrical step, and the equivalent circuit.

b) Printed Inductor

Printed inductors are inductor on printed circuit board or on microstrip structure it is further classified into two-dimensional as well as three-dimensional structures. The two-dimensional printed inductors are further classified into four categories that is meander line, rectangular, hexagonal/ octagonal and circular as shown in Figure 3. Out of four type meander line has lower eddy current resistance but lowest inductance and self resonant frequency (SRF) on the other hand rectangular inductor having very easy layout but disadvantages of lower SRF, octagonal and circular inductor are having higher SRF but difficult layout [7].

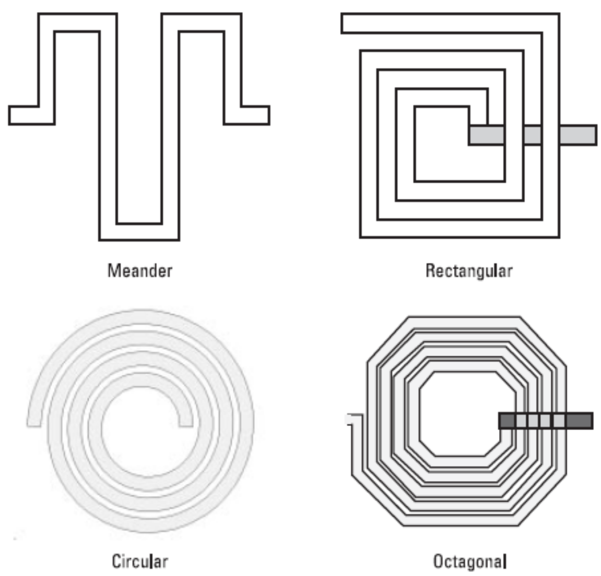


Fig.3. Classification of two-dimensional printed inductor.

When Talking about three dimensional inductance we have helical, Solenoidal or lateral and Rectangular/ circular inductance out of three first two has having lower inductance and last one has higher inductance but lower SRF [7].

The structure impedance distributed over a curvilinear surface influence the surface wave both in amplitude and phase [8,10] there is no straightforward relationship to determine the effect of metamaterial surface on surface-wave propagation properties. The surface impedance is always a function of electro-magnetic properties of material used as well as geometry of design [4,8] .

III. LITERATURE REVIEW

In this part we will discuss on the latest research which is going on in present era specially in the field of mutual coupling reduction and stepped impedance application in microstrip patch antenna designing.

[1] Yapeng Li, Zhipeng Zhao, Zhaoyang Tang and Yingzeng Yin, "Differentially-Fed, Wideband Dual-Polarized Filtering Antenna with Novel Feeding Structure for 5G Sub-6 GHz Base Station Applications", IEEE Access, Volume: 7, December 2019. In this paper, a wideband dual-polarized patch antenna which is differentially fed with filtering response is presented. The feeding structure is an E-shaped with shorted one end with the ground plane which is used to excite a square patch, to get a wider bandwidth an extra resonant mode is induced. Here a symmetric open and short-circuited stepped impedance resonators are also proposed which improve the impedance bandwidth further. The various results show that the proposed antenna has a wide operation band of 22.2% (3.12-3.9 GHz) with unidirectional radiation patterns. The proposed work shows the impact of stepped impedance structure specially for 5G applications.

[2] Cheng Lu, Qiuyi Zhang, Hongye Qi, Shunli Li, Hongxin Zhao, and Xiaoxing Yin. "Compact Postwall Slotline Based Stepped Impedance Resonator Decoupling Structure for Isolation Enhancement of Patch Antenna Array". IEEE Antennas and Wireless Propagation Letters Volume: 18, Issue: 12, Dec. 2019. Here the researcher is implementing stepped impedance concept using post-wall slotline (PWS) for increasing the isolation between patches the SIRs which is placed between microstrip antennas enhances the decoupling concert significantly at resonance frequency. The measured gain of the proposed antenna is around 5.1 dBi with an isolation of 30.4 dB at 5.7 GHz frequency is achieved. With the decrease of electrical element distance isolation between the elements also improve and hence get the compact size for multi-input-multi-output antenna arrays.

[3] QIANG HUA, YI HUANG, CHAOYUN SONG, MOBAYODE O. AKINSOLU. "A Novel Compact Quadruple-Band Indoor Base Station Antenna for 2G/3G/4G/5G Systems". IEEE Access, Volume: 7, Oct. 2019: This manuscript is a work in order to get multiband antenna system which us used for 2G/3G/4G/5G mobile communications, which covers multiple frequency bands with a compact size with its overall dimensions of 204 × 175 × 39 mm^3. The lower frequency bands over 0.8 - 0.96 GHz and 1.7 - 2.7 GHz are achieved through the combination of an asymmetrical dipole antenna and parasitic patches, here also a stepped-impedance based feeding structure is used to improve the impedance matching of the dipole antenna, by using an additional T-shaped patch, an additional band of operation is achieved in 5 GHz range. The results show gain of between 5.4 dBi to 8.5 dBi at different frequencies of 2G/3G/4G/5G communication.

[4] Chi-Yuk Chiu; Fang Xu; Shanpu Shen; Ross D. Murch, "Mutual Coupling Reduction of Rotationally Symmetric Multiport Antennas". IEEE Transactions on Antennas and Propagation, Volume: 66, Issue: 10, Oct. 2018: Here a methodical approach for dropping the mutual coupling of a rotationally symmetric multiport antenna is analyzed using a compact 4-port antenna of dimension $0.28\lambda_o \times 0.28\lambda_o \times 0.04\lambda_o$, where λ_o is the wavelength in free space, and it is compact enough for the use in wearable applications as well. The defected ground structure and slot-lines used in the design are also modeled with an equivalent circuit to explain the achieved high port isolation.

[5] Chao Feng Ding; Xiu Yin Zhang; Yao Zhang; Yong Mei Pan; Quan Xue "Compact broadband dual-polarized filtering dipole antenna with high selectivity for base-station applications". IEEE Transactions on Antennas and Propagation, Volume: 66, Issue: 11, Nov. 2018.

This paper presents a broadband dual-polarized filtering dipole antenna which has core radiator, feeding structure, reflector, and two parasitic loops of size 50 mm × 50 mm × 31.8 mm. The proposed antenna enhanced bandwidth by commissioning two parasitic loops by using an open-ended stub the bandwidth can be improved at 2.7 GHz to 2.9 GHz. Measured results show that the proposed antenna has more than 34 dB port isolation with gain of 8.15 dBi.

[6] Jun Ye Jin; Shaowei Liao; Quan Xue, "Design of Filtering-Radiating Patch Antennas With Tunable Radiation Nulls for High Selectivity". IEEE Transactions on Antennas and Propagation, Volume: 66, Issue: 4, April 2018: This paper is based on filtering-radiating patch (FRP) which is a rectangular patch etched with slots. The results show two radiation nulls at 4.7 and 5.85 GHz with an impedance matching bandwidth of 7% at center frequency of 5.24 GHz, with gain of 6.6 dBi and front-to-back ratio of around 15 dB. The presented method demonstrates how a very simple structures by only using etching slots on the patch a=can improve the performance of patch antenna.

[7] Jian-Feng Li, Zhi Ning Chen, "Dual-Beam Filtering Patch Antennas for Wireless Communication Application". IEEE Transactions on Antennas and Propagation, Volume: 66, Issue: 7, July 2018: Here a dual-beam filtering patch antenna based on a slotted patch with different metal strip and two pins are used to get a wider bandwidth, With total loftiness of 0.058 λ_0 , the projected antenna is realized to get a -10 dB bandwidth of 3.0-3.8 GHz, with realized gain of 6.8 dBi.

[8] Jian-Feng Qian; Fu-Chang Chen; Qing-Xin Chu; Quan Xue; Michael J. Lancaster, "A novel electric and magnetic gap-coupled broadband patch antenna with improved selectivity and its application in MIMO System". IEEE Transactions on Antennas and Propagation, Volume: 66, Issue: 10, Oct. 2018: In this work patch antenna is based on electric and magnetic coupled elements for multiple-input-multiple-output (MIMO) system which improves the broadband of the proposed profile. The study is carried out by the help of 2 and 3 patch based prototypes. Other than broadband improvement, the proposed antenna elements show potential for application in high-isolation MIMO systems.

[9] Tian Li Wu; Yong Mei Pan; Peng Fei Hu; Shao Yong Zheng, "Design of a Low Profile and Compact Omnidirectional Filtering Patch Antenna". IEEE Access, Volume: 5, Jan 2017: In this paper a patch antenna with filtering response is presented, with the help of triangular patch and axially feeding at its center. when we compare it with the ordinary circular patch, the triangular patch can now not solely limit the patch measurement however additionally can generate a radiation null at the higher frequency. The presented work has a 10-dB impedance bandwidth of 8.9% (4.3-4.7 GHz), an gain of 6.0 dBi.

[10] Bohai Zhang, Quan Xue, "Filtering Antenna with High Selectivity Using Multiple Coupling Paths from Source/Load to Resonators". IEEE Transactions on Antennas and Propagation, Volume: 66, Issue: 8, Aug. 2018: This is again a filtering antenna using multiple coupling based resonators, which induces additional coupling between source to load and nonadjacent resonators to construct cross coupling paths, the extra cross-coupling paths, generate a maximum of N radiation nulls with N resonators, which improve the fractional bandwidth of 15.2% at center frequency of 2.3 GHz.

IV. CONCLUSION AND FUTURE WORK

The proposed designs of this manuscript are organized in different section, first we check the basic theory associated with stepped impedance and printed inductance and the design parameters associated with analytical evidence with the help of establish formula. In second part we identify the impact of stepped impedance and mutual coupling on microstrip patch with the help of different literature available.

After concluding the various latest research, we can say that the stepped impedance and lumped parameters which affect the electrical length of microstrip structure along with the basic concept of inductor slot on radiations. The introduction of stepped impedance patch and discontinuities along with inductance slot increase the bandwidth and gain of different patch antenna, this technique is also very useful in order to get multiband radiation abilities. This work opens the door of further research in bandwidth and gain improvement for metamaterial patch antenna structure.

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