ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 10(16), DOI: 10.17485/ijst/2017/v10i16/114315, April 2017*

A Review of Various Multi-Frequency Antenna Design Techniques

Geetanjali[1*] and Rajesh Khanna[2]

[1]Thapar University, Patiala – 147004, Punjab, India; geetanjalikapur@rediffmail.com
[2]ECED, Thapar University, Patiala – 147004, Punjab, India; rkhanna@thapar.edu

Abstract

Background/Objectives: The paper caters to the need for multi banding of Micro Strip Antennas (MSAs) , that has been well recognized as one of the major research issue in antenna engineering in 21st century. **Methods/Statistical analysis:** Wireless applications, supporting multiband standards have put new demands on antennas related to bandwidth, gain, size and efficiency. Recent efforts by several researchers around the world to achieve multiband geometry have led to an emergence of new and innovative antenna designs which are presented in this paper. **Findings:** This paper gives a comprehensive review of various techniques to design compact, multiband planar antennas for wireless devices and applications. The theoretical concept to achieve multi frequency antenna along with related issues for designing have been generally and briefly discussed. Especially, the design examples, some of which are published in literature are presented for the illustration purpose. Recent techniques like EBG/AMC, SRR/CRR, FSS and DGS have also been included in this review. **Application/Improvements:** These antennas find their extensive use in different wireless applications in the field of communication, medical stream and satellite communication. The innovations in technology have been presented which includes improved antenna designs using better techniques for enhanced performance in the respective fields.

Keywords: Defected Ground Plane Structures, Electromagnetic Band-Gap, Fractals, Frequency Selective Surfaces, Micro Strip Antenna, Multi Banding, Notching, Slotting, Split Ring Resonators

1. Introduction

Wireless technology has undergone enormous changes in recent times as regards its frequency of allocation, standards of operation, the device size and techniques to improve and enhance the performance of wireless systems. The demand for wireless devices has greatly increased with the emergence of new wireless standards that are not only compact but also multi-functional in nature[1]. Antenna is one of the integral parts of these wireless devices. The miniaturization of hand held devices has led to a requirement for compact and lightweight antennas that can be easily integrated to RF packages. Therefore, the demand for antennas covering different homogeneous and heterogeneous wireless communication bands on the same platform has greatly increased. With multi banding features being introduced by different wireless standards, the antenna engineers are met with the challenging task of designing antennas that are efficient, conformable, and compact with low profile and cost and have sufficient bandwidth to support various bands[2].

These compact antennas are designed using time-domain electromagnetic and circuit modeling techniques and optimized using parametric analysis to achieve improved antenna performance. The antenna systems thus obtained are used for practical wireless communications systems such as IEEE802.11a WLAN, IEEE802.16 WiMAX, Bluetooth Industrial-Scientific-Medical (ISM) devices, Global System of Mobile Communications (GSM) and Local Multipoint Distribution Systems (LMDS).

The most suitable candidate for such systems is Micro Strip Antenna (MSA) possessing many characteristics like small size, low profile, conformable, and cost effective[3,4].

*Author for correspondence

Improving these parameters and creating multiband antennas are becoming main design considerations of MSAs for wireless applications. Many techniques for antenna miniaturization with multiband functionality have been proposed in literature[5]. This paper aims to present a comprehensive review of the various techniques and designs for compact multiband microstrip antennas. Of the much research done in this field we mainly refer to the frequently cited papers.

2. Multi Banding Techniques

A suitable patch structure can be made to operate at different frequencies wide apart at the same time thereby avoiding use of multiple antennas.. Multiple resonances can be achieved by various techniques like slotting, notching, lumped element loading, shorting posts, parasitic and fractal elements as discussed below in brief[6].

2.1 Slot Loading:

Slotting refers to cutting out an area from the patch in specific pattern to change the resonant characteristics of the micro strip antenna Figure 1 Cutting slots causes the surface currents to redistribute on the metal radiating patch so that multi-banding is achieved. It also provides compactness, bi-directional radiation patterns and multiband performance. In[6] the author designed a triangular monopole printed antenna, fed by a coplanar waveguide with three slots cut in it to redistribute surface currents. Addition of slots on the two equilateral sides of the triangular antenna changes the path length of the current flow resulting in multi banding.

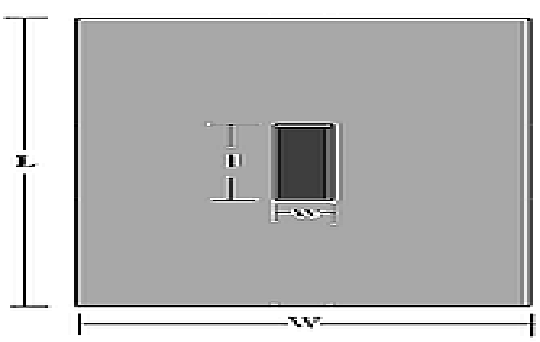

Figure 1. Geometry of Triangular slot-loaded antenna.

2.2 Notch Loading

Notch loading is a type of reactive loading whereby a notch is cut in the metal radiator which lies parallel to the current lines Figure 2 The notch introduces series inductance and capacitance to the initial resonant circuit which results in strong interaction between the main patch and the notch[7]. The notch can be used in various ways like rejecting unwanted bands, making wideband antenna and introducing multiple resonances.

In[8], three wide bands in WLAN/ WiMAX are covered using the effects of the band-notching slit in the PIFA structure. The slit acts as a quarter-wavelength resonant structure, creating notched band at around 4 GHz. Also, it creates an additional resonance at a frequency of 3.5 GHz. It is observed that decreasing the length of the notch, causes the notched band to shift to higher frequencies.

Figure 2. Notching slit in rectangular patch micro strip antenna.

2.3 Lumped Element Loading

Micro strip antennas can be loaded with passive (inductor, capacitor, resistance) elements which cause an increase in the radiation resistance, the impedance bandwidth, reduce the size. It also creates multiple resonances and modifies the radiation pattern of antenna. Each type of loading has its own advantages and disadvantages. The resistive loading causes lowering of Q factor of antenna[9]. The inductive or capacitive loading can cause broadband and multiband operations by controlling the frequency separation between two radiating modes and makes antenna more compact by tuning the frequency of higher resonant modes to lower value[10]. The chip capacitors are used across the slots of unequal-length on a square patch which strongly modifies the distribution of current.

2.4 Short Circuit Micro Strip Antennas

In some applications, multiple bands at different resonances require same input impedance, polarization and radiation characteristics. Short circuit micro strip antenna can obtain the same resonant characteristics, reducing its size to half at the same time. The construction of shorted micro strip antenna involves by short-circuiting the zero-potential plane of micro strip antenna using shorting wall or plate Figure 3 which reduces antenna size and a resonant trace length is maintained at the same time causing enhancement in the bandwidth[4]

Single Shorting pin can be used to make antenna compact and electronically tunable two shorting pins make it either multiband or broadband. For example, in[11], the designer designs a circular patch and uses two shorting pins separated by an angle that generates multi-band operation shown in Figure 4 The frequency can be varied over a wide range by changing the position of the shorting pin[11].Broadbanding is obtained when the feed lies on x-axis (φ=0) with frequency range from 1.9-2.9 GHz, whereas inserting feed at (r_o,45°) we get multiband antenna.

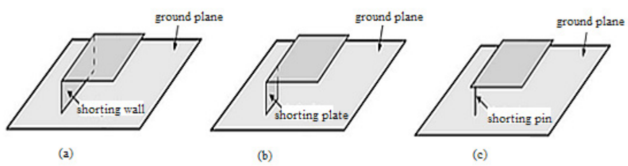

Figure 3. A micro strip patch antenna with (a) a shorting wall, (b) a shorting plate and (c) a shorting pin [4].

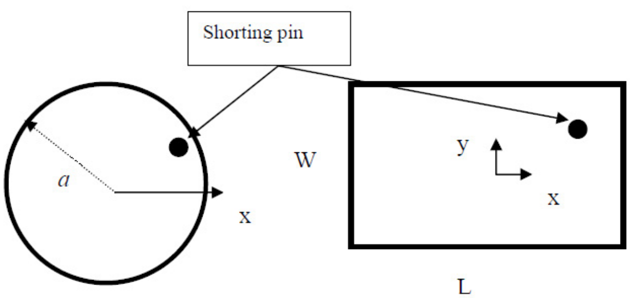

Figure 4. Circular and rectangular patch with a shorting pin [11].

2.5 Fractals for Introducing Multiple Resonances

Fractals are irregular or broken shapes having the properties of Self-Avoidance, Simplicity and Self-Similarity. These shapes are self-similar structures which get repeated at various scale sizes giving it the same view at different scales[12], as shown in Figure 5 Cohen, who developed an antenna using the fractal structures, demonstrated the use of fractals to reduce the antenna size without degrading the performance and to achieve multi banding or broad banding at each band.

In[13], antenna geometry has been proposed using a space-filling curve, each successive stage of which comprises of four replicas of the previous one, attached with additional segments. Conceptually, antenna resonance frequency is inversely proportional to the size of antenna, so as the iterations increase, it generates different antenna lengths and so do the resonances making the antenna exhibit multiband functionality[14].

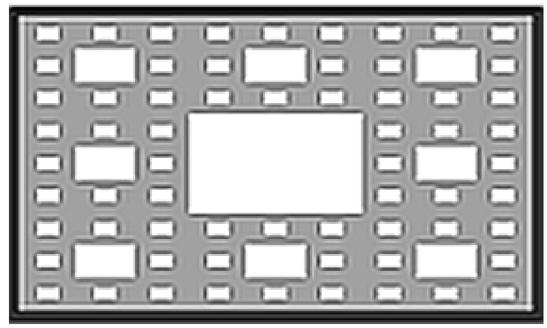

Figure 5. Fractal antenna.

2.6 Artificial Magnetic Conductors

The AMC surface consists of small conducting patch elements which are, shorted independently to the ground which forms a magnetic ground plane, as shown in Figure 6. This causes the image currents to be in phase with the patch current[15]. These AMC patch elements interact with each other to generate parallel resonance to the radiating patch enhancing the gain and impedance bandwidth to a great extent. The shorting pins because the reduction in size by increasing the AMC patch inductance[15-17].

In[18] an Artificial Magnetic Conductor (AMC)-based multiband low-profile antenna for vehicle applications is designed. A wideband printed circular disc monopole antenna uses the dual-band AMC as a ground plane resulting in a low-profile, multiband and platform-tolerant antenna system.

In[19] authors presented an Electromagnetic Band-Gap (EBG) structure with four spiral shaped arms which replaces the conventional ground plane of MPA. The authors showed that the change in length and width of the spiral ground plane helps in adjusting the inductance and capacitance which creates multiple bands, reduces antenna size and improves antenna gain.

2.7 Electromagnetic Bandgap (EBG) Structures

Electromagnetic band gap structures are artificial periodic elements that prevent or assist the propagation of EM waves in a particular frequency band for all polarization states and incident angles all[15-18]. The basic design of EBG structure and its equivalent circuit is shown in Figure 7 called mushroom EBG structure[15-17]. It has a frequency range with very high surface impedances due to which the structure starts acting as a filter. In the equivalent LC circuit the current through the vias results in the inductor L, and the gap effect between the adjacent patches forms the capacitor C[17,18].

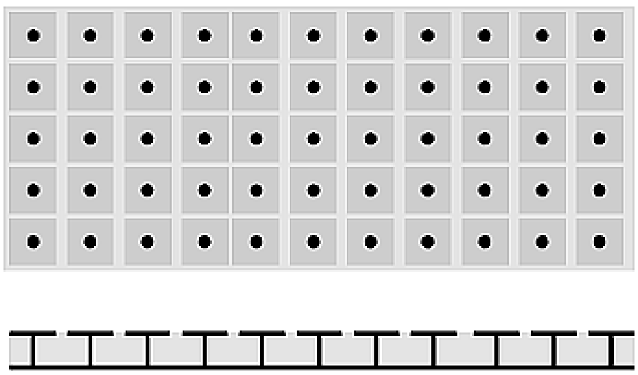

Figure 6. Microstrip patch with AMC substrate[15].

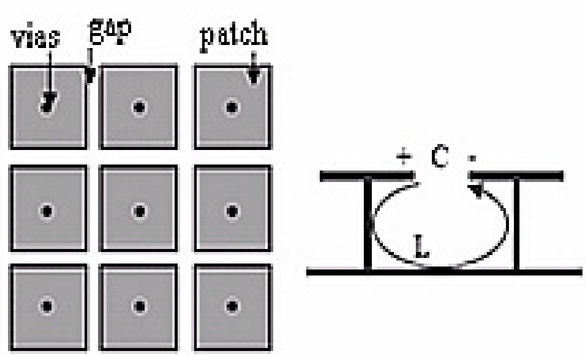

Figure 7. 2D EBG Structure and its -equivalent circuit.

In[20], the authors presented a dual-frequency, broadband circular patch antennas using the concept of epsilon-negative transmission line (ENG TL). The ENG TL is formed by putting N shorting pins along its circumferences. Four different circular patches of different radii(DF) and with variable N shorting pins named as DF-N were simulated and designed on ENG TL to obtain multiband operation for all four different structures.

The above PBG structures have been useful in designing low profile antennas with good radiation efficiency but it poses the problem of modeling such a structure and radiation from the periodic etched defects[20].

2.8 Defected Ground Plane Structures (DGS)

DGS consists of periodic or non-periodic defects etched beneath the planar transmission line (e.g., micro strip line, coplanar etc) in the ground plane. It alters the shield current distribution by changing line capacitance and inductance and confines it to the periphery of the perturbation. A unit DGS (dumbbell) comprises of two rectangular areas etched in the ground plane connected by a slot[21,22] as shown in Figure 8 The DGS can be used to create stop band and also produces slow-wave effect and high impedance[22].

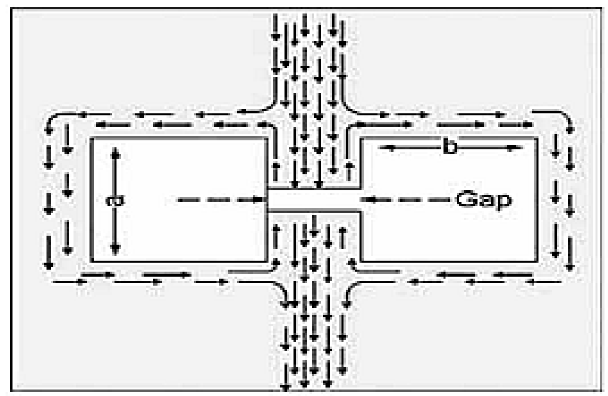

Figure 8. Current distribution in the Ground Plane of DGS Microstrip line.[21]

Various types of slots with different kinds of attached area shapes can be etched beneath the planar Transmission line, in the ground plane to bring about an improvement in the performance of micro strip antenna.

In[23] the authors presented a radiating element loaded with protruding strips fed with a cross-shaped strip line and employed with DGS obtained by cutting slots in ground plane. The DGS increases the impedance matching by exciting other resonant modes thereby increasing the bandwidth of the proposed antenna.

2.9 Split Ring Resonators (SRRs)/ Complementary SRRs (CRRs)

A single cell Split Ring Resonators (SRR) is an artificially created structure similar to metamaterial. The aim of SRR is to produce the desired -magnetic response in different types of metamaterial up to a frequency of 200 terahertz.

SRRs consist of a pair of concentric metallic rings, having slits cut on opposite sides. SRR can be etched in the back side of the substrate, under the slots, to attain high magnetic coupling between the transmission line and the rings at resonance. In SRR the real part of magnetic permeability becomes positive below the resonant frequency, and above the resonant frequency, it becomes negative. This property can be used with the negative dielectric constant of another structure to produce negative refractive index materials[24,25].

SRRs are used in MSA for size reduction, broad banding and multi banding. In[26] author designs a dual-band electrically small antenna (ESA) using a small ring and two concentric SRR on an FR-4 substrate Figure 9 The coupling among two split-ring resonators and the small ring provides an additional capacitance which reduces the resonant electrical length. A large amount of electric field energy is stored in the side gap of the SRR, which is presented as capacitance of a resonator.

The SRRs gap separation and the circumference of the ring antenna can be used to tune resonant frequencies of the dual-band ESA. Outer SRR represents the lower band and the length of the inner SRR affects the high band.

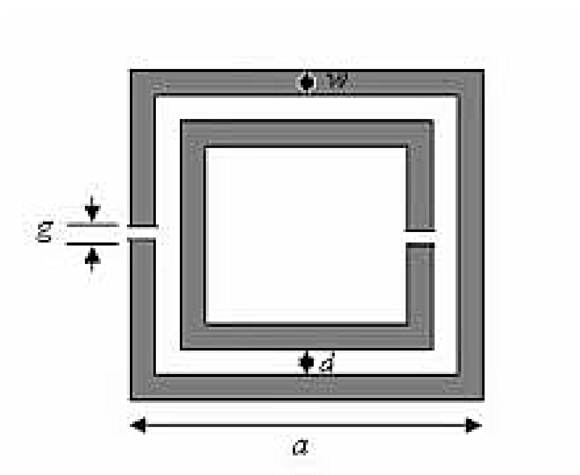

Figure 9. Split Ring Resonator of DGS Micro strip line.[21]

2.10 Frequency Selective Surfaces (FSS)

FSS is a two dimensional array of periodic metallic patches on a dielectric substrate which may be capacitive or inductive. In a "capacitive" surface the metal plates are not connected thus transmitting low frequencies and reflecting higher Figure 10[27]. While "Inductive" surface, transmits high frequencies and reflect low frequencies Figure 10. By properly manipulating the shape and dimensions of the metallic elements, strong stop bands and pass bands in the FSS spectra can be achieved. One primary advantage of FSSs over dielectric multilayers is that multiple resonances can be achieved with a single layer of elements, whereas a dielectric device would require several multilayer structures to achieve a multiband response[27,28].

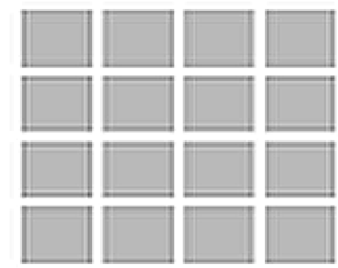

Figure 10(a). A "capacitive" surface.

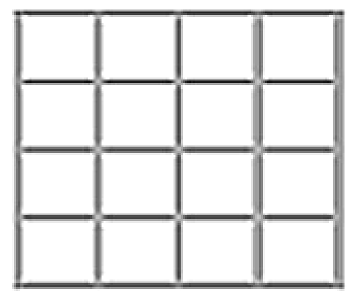

Figure 10 (b). An "inductive" surface.

In[28] authors describe the design of multiband infrared Frequency Selective Surfaces (FSSs) that consist of self-similar fractal cross dipole metallic elements patterned on flexible dielectric substrates. The stage 2 cross dipole fractals, which serve as the metallic elements of this FSS, exhibit two resonances corresponding to the two iterations of the fractal structure.

3. Conclusion

Various types of micro strip antenna design techniques and micro strip-antenna-designs are discussed, and the new techniques making the micro strip antenna a low profile, compact multiband antenna are discussed. To show the characteristic features of multiband micro strip antennas, different types of antenna elements and their correlation to improved characteristics with their unique geometrical properties is presented. This paper shows that the micros trip antennas are very useful for civilian and military wireless applications. The field of antenna engineering is quite challenging as the efficiency of the complete communication system relies on the effectiveness of the transmitting and the receiving antenna thus it anticipates much more innovative advancement in this field.

4. References

1. WiMAX/WLAN standards. http://en.wikipedia.org/ wiki/ WiMAX/ WLAN. Date Accessed: 21/01/ 2014.
2. Zing Ning Chen, Michael Y.W. Chia -Broadband Planar Antennas – Design and Applications. John Wiley & Sons Ltd. 2006.
3. Balanis CA. Micro strip Antennas Antenna Theory Analysis and Design. 2nd Edition. John Wiley & Sons Ltd United Kingdom. 1997.
4. Guha D, Anta YMM. Microstrip and Printed Antennas-New trends techniques and applications.1st edition John Wileyand Sons Ltd. United Kingdom. 2011.
5. Singla G, Khanna R. Modified CPW-fed rotated E-slot antenna for LTE/WiMAX applications. International Journal of Microwave and Wireless Technologies. Published online by Cambridge University Press. 2014Jun;7 (5):535–42.
6. Cai RN. Simulation and Experimental Research on the Multiband Slot-loaded Printed Antenna. Proceedings of 12th IEEE Conference on Communication Technology (ICCT). 2010. p. 500–3.
7. Shivnarayanan, Babau R, Vishvkarma. Analysis of notch loaded patch for dual band operation. Indian journal of Radio and Space Physics. 2006; 35:435–42.
8. Lee CT, Wong KL. Uniplanar Printed Coupled-Fed PIFA with a Band-Notching Slit for WLAN/WiMAX Operation in the Laptop Computer. IEEE Transactions on Antennas and Propagation. 2009; 57(4):1252–258. Available from: Crossref
9. Hum SV, Chii J, Jolinston RH, Okoniewski M. Improving the Bandwidth of Micro strip Patch Antennas Using Resistive Loading. Antenna and Propagation Society Symposium. 2003, 2, pp. 276-279.
10. Huang CY, Ling CW, Kuo JS. Dual-band micro strip antenna using capacitive loading. IEEE Proc.-Micro w. Antennas Propagation. 2003;150 (6): 401–4.
11. Mahmoud SF. Compact broadband micro strip patch antennas. Proceedings of 24th National Radio Science Conference. 2007.p. 1–6.
12. Felber P. Fractal Antennas A literature study as a project for ECE 576. Illinois Institute of Technology. 2000. PMCID:PMC1370046
13. Prombutr N, Akaraektharin P. Analysis and Design Hilbert Curve Fractal Antenna Feed with Co-planar Waveguide for multi-band wireless communications. International Journal of Engineering. 2008;2(3):1–50.
14. Manimegalai B, Raju S, Abhaikumar V. A Multifractal Cantor Antenna for Multiband Wireless Applications. IEEE Antennas and Wireless Propagation Letters. 2009;8:359–62. Available from: Crossref
15. Eleftheriades GI, Balmain KG. Negative-Refraction Metamaterials Fundamental Principles and Applications. John Wiley & Sons Inc. 2005.Available from: Crossref
16. Fan Yang, Rahmat-Samii Y. Electromagnetic Band Gap Structures in Antenna Engineering. Cambridge University Press. 2009.
17. Tie Jun C, Smith D, Liu R. Metamaterials - Theory Design and Applications. 2010.
18. Abbasi NA, Langley RJ. Multiband-integrated antenna/ artificial magnetic conductor. Microwaves Antennas & Propagation. 2010; 5(6):711–17.Available from: Crossref
19. Elsheakh DN, Elsadek HAM, Abdallah EAF. Four Arms Spiral Ground of MPA with Different Feed Techniques for Size Reduction and Multi-Band Operation. IEEE Symposium on Antenna and Propagation (APSURSI). 2011.p.286–88.Available from: Crossref
20. Hou Q, Tang H, Liu Y, Zhao X. Dual-Frequency and Broadband Circular Patch Antennas with a Monopole-Type Pattern Based on Epsilon-Negative Transmission Line. IEEE Antennas and Wireless Propagation Letters. 2012,;11:442–45.Available from: Crossref
21. Arya AK, Patnaik A, Machavaram K. Defected Ground Structure in the perspective of Microstrip Antennas A Review. 2010;64 (5-6):78–84.
22. Weng LH, Guo YC, Shi XW, Chen XQ. An Overview on Defected Ground Structure. Progress in Electromagnetics Research B. 2008;7:173–189.Available from: Crossref
23. Liu WC, Wu CM, Dai Y. Design of Triple-Frequency Micro strip-Fed Monopole Antenna Using Defected Ground Structure. IEEE Transactions on Antennas and Propagation. 2011;59 (7):2457–246. Available from: Crossref
24. SRR (Split Ring Resonators). http://en.wikipedia.org/wiki/ SRRs. Date Accessed: 10/ 01/ 2014.
25. Baena JD, Bonache J, Martín F, Sillero RM, Falcone F, Lopetegi T, Laso MAG, García–García J. Equivalent-Circuit Models for Split-Ring Resonators and Complementary Split-Ring Resonators Coupled to Planar Transmission Lines. IEEE Transactions on Microwave Theory and Techniques. 2005;53 (4):1451–466.Available from: Crossref
26. Wang L, Yuan MQ, Liu QH. A Dual-Band Printed Electrically Small Antenna Covered by Two Capacitive Split-Ring Resonators. IEEE Antennas and Wireless Propagation Letters. 2011;10:824–26.Available from: Crossref
27. Jeffrey A, Reed. Frequency Selective Surfaces with Multiple Periodic Elements. 1997. PMCID:PMC1722154

28. Drupp R, Bossard J, Werner DH, Mayer TS, Ye YH. Multiband Infrared Frequency Selective Surfaces. +Department of Electrical Engineering and The Center for Nanoscale Science The Pennsylvania State University. 2003.