International Journal of Research in Engineering & Technology (IJRET)
ISSN 2321-8843
Vol. 1, Issue 2, July 2013, 135-142

UPSWING THE BANDWIDTH AND DIMINISH THE SIZE OF RECTANGULAR FLAT PANEL DIRECTIONAL DEVICE WITH METAMATERIAL COVER

BIMAL GARG & AKASH AGRAWAL

Department of Electronics Engineering, Madhav Institute of Technology and Science, Gwalior, Madhya Pradesh, India

ABSTRACT

Rectangular flat panel directional device with putative metamaterial cover at resonating frequency 2.292 GHz shows impressive increment in bandwidth and reduction in size as compared to lone flat panel directional device. Putative metamaterial cover improves bandwidth by 193%, cut down size by 32% and reduces return loss by 200%. Double negative left handed metamaterial structure was introduced as a cover to the rectangular flat panel directional device at a height of 3.2mm from the ground plane.

The purpose of this work is to design a compact and efficient directional device with simultaneous negative permittivity and permeability or so-called LH MTM. Nicolson-Ross-Weir approach has been used for verifying the double-negative properties of the suggested double negative metamaterial cover.

KEYWORDS: Rectangular Flat Panel Directional Device (RFPDD), Left-Handed Metamateria (LH-MTM), Permittivity and Permeability, Nicolson-Ross-Weir (NRW)

INTRODUCTION

Metamaterial is also known as double negative metamaterial because it shows negative permeability and negative permittivity. Metamaterial was first theoretically introduced by Victor Georgievich Veselago[1] in 1967. Veselago's speculation remained silent for 29 years until 1996, J. B. Pendry[4] published a paper about artificial metallic construction which exhibit negative permittivity and negative permeability. Later on in 2001, it was experimentally verified that the metamaterials exhibits negative effective refractive index. Since then, it has been arousing a great interest in Microwave society. By using the unusual properties of metamaterial, the flat panel directional device's potential characteristics can be boosted to a desired level.

A flat panel directional device is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or patch of metal, mounted over a larger sheet of metal called a ground plane. In this work, shortcomings of flat panel directional device i.e. directional device parameters are overcome by metamaterial structure. Metamaterial is used because it is easy to fabricate, simulate and convenient to ameliorate the directional device parameters.

Computer Simulation Technology (CST-MWS) Software has been used for all the simulation and designing. MS Excel Software is used for verifying the double negative properties of the proposed metamaterial cover.

CALCULATION AND DESIGNING

The rectangular flat panel directional device parameters are calculated from the formulae given below.

Desired Parametric Analysis Calculations [2][3]

Width (W):

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Effective dielectric constant:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \tag{2}$$

The actual length of the Patch (L):

$$L = L_{eff} - 2\Delta L \tag{3}$$

Where,

$$L_{eff} = \frac{C}{2f_r\sqrt{\varepsilon_{eff}}} \tag{4}$$

Calculation of Length Extension:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{5}$$

Where,

C = Velocity of light in free space,

ε_r = Dielectric constant of substrate,

f_r = Resonating frequency,

ε_{reff} = Effective dielectric constant,

h = Height of dielectric substrate,

W = Width of patch,

L = Length of patch and

ΔL = Effective Length

The rectangular flat panel directional device is etched on FR4 lossy substrate of thickness h = 1.6 mm, and dielectric constant ε_r =4.3 by using Perfect Electric Conductor (PEC)[5] material as the conducting plane.

After calculation, the value of width is 39.210 mm and the value of length is 30.425 mm for operating frequency 2.292 GHz.

Designing and Simulation

The Rectangular Flat Panel Directional Device (RFPDD) parameters are calculated from the above formulae. Area of ground and FR-4 lossy substrate is same and it is 110 X 110 mm^2.

All parameters of lone RFPDD for resonating frequency 2.292 GHz are shown in figure 1.

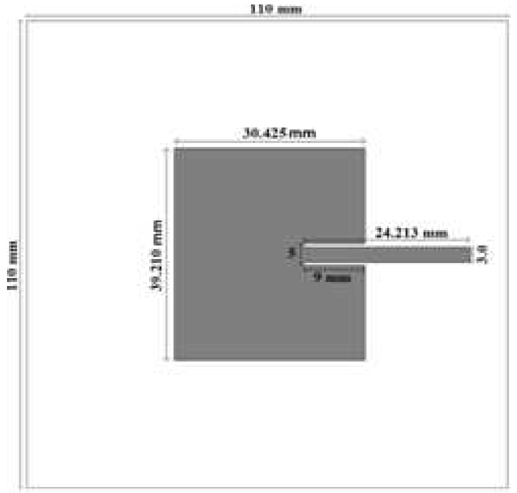

Figure 1: Dimensional View of RFPDD at 2.292 GHz. Panel Length = 39.21mm, Panel Width = 30.425mm, Cut Depth = 9mm, Cut Width = 5mm, Feed Length = 24.213mm, Feed Width = 3mm, Ground Length = 110 mm, Ground Width = 110mm

The return loss is an important parameter in directional device system analysis. It measures the directional device's absorption of the fed power over the total power fed. A good directional device should indicate a return loss of less than -10 dB, which indicates that the directional device absorbs more than 90% of the fed power. Initially, the impedance bandwidth [17] of the RFPDD is 26.5 MHz and the Return Loss is -11 dB, as shown in figure 2.

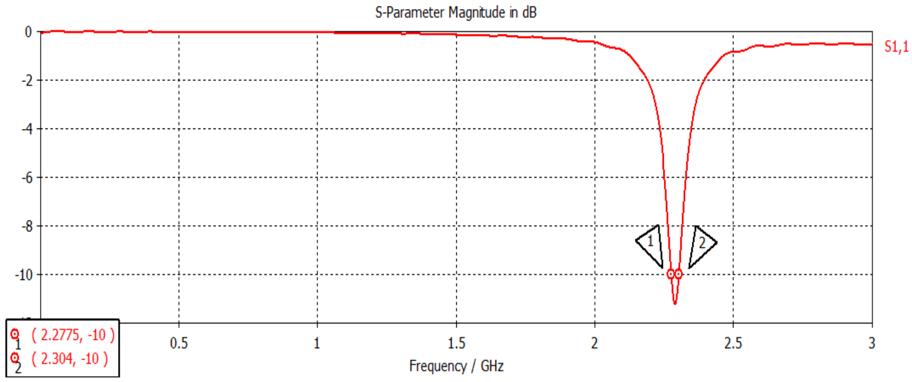

Figure 2: Simulated Result of RFPDD Showing Return Loss of -11 dB and Bandwidth of 26.5 MHz

The radiation pattern of a directional device determines the distribution of radiated energy in space. It is the first property of a directional device that is specified. The Radiation Pattern of the RFPDD operating at 2.292 GHz is shown in figure 3.

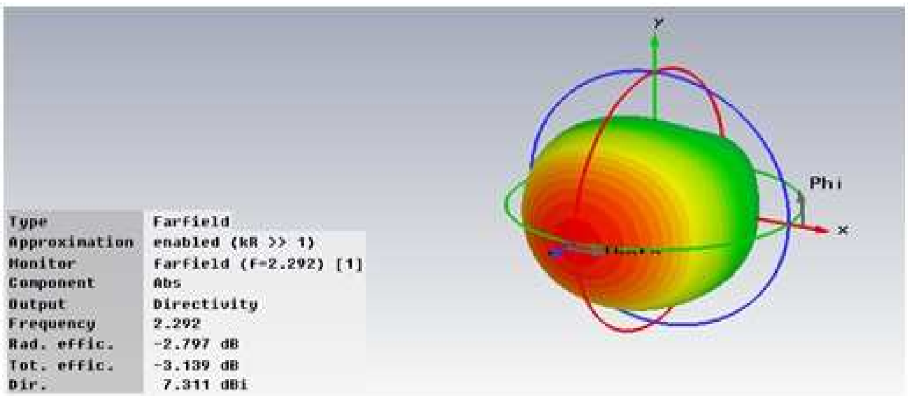

Figure 3: Radiation Pattern of RFPDD Showing 48.54% Total Efficiency & 7.311 dBi Directivity

After designing & simulating the lone RFPDD, the suggested material cover is placed on the RFPDD at a height of 1.6 mm from the designed directional device. The design of material cover consists of five circles, five octagons and four rectangle strips. Dimensions of all the circles are the same and all the octagons also have the same dimensions except the centered circle and octagon. Suggested cover is shown in figure 4.

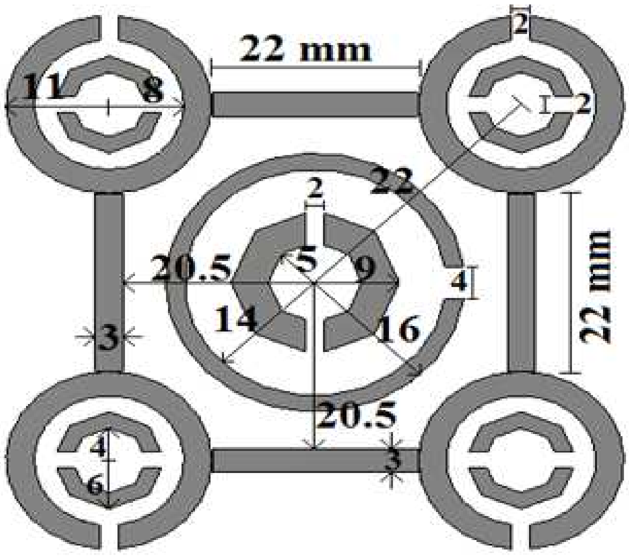

Figure 4: Dimensional View of the Suggested Cover (All Dimensions in mm)

Nicolson-Ross-Weir (NRW) Approach

The suggested material cover design is placed between the two waveguide ports [17] at the left & the right of X-Axis as shown in figure 5, in order to calculate S_{11} and S_{21} parameters[11][16]. The excitation of the signal is done from the left side to the right side of the structure assuming the surrounding is air. Y-Plane is defined as Perfect Electric Boundary (PEB) and Z-Plane is defined as Perfect Magnetic Boundary (PMB). Subsequently, the wave is excited from the negative X-axis (Port 1) towards the positive X-axis (Port 2).

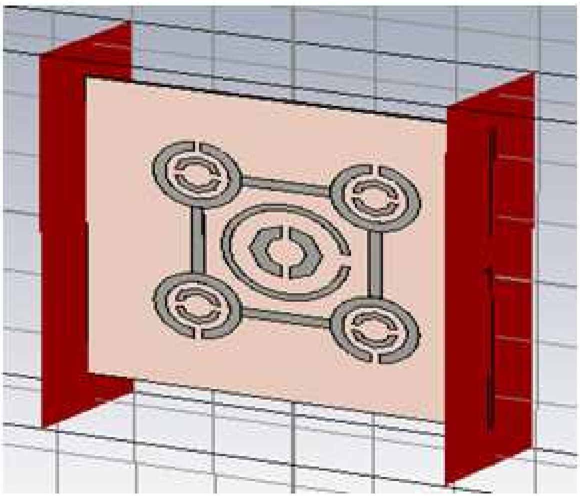

Figure 5: Suggested Material Cover Placed between the Two Waveguide Ports at the Left & Right of the X-axis

According to this approach, the value of S_{11} and S_{21} parameters are obtained in complex form, which are then exported to Microsoft Excel program for verifying the double-negative properties of the proposed material cover structure by using NRW approach.

Formulae for determining the value of permittivity & permeability using NRW approach [9][10][12]:

$$\mu_r = \frac{2.c(1-v_2)}{\omega.d.i(1+v_2)} \quad (6)$$

$$\varepsilon_r = \mu_r + \frac{2.S_{11}.c.i}{\omega.d} \quad (7)$$

Where,

$v_1 = S_{11} + S_{21}$

$v_2 = S_{21} - S_{11}$

ω = Frequency in Radian,

d = Thickness of the Substrate,

c = Speed of Light,

v_1 = Voltage Maxima, and

v_2 = Voltage Minima.

The values of permittivity (ε_r) and permeability (μ_r) are calculated by using equations 6 & 7 in the simulated frequency range. Graph in figure 6 & 7 shows that the proposed material cover possesses negative values of permittivity & permeability at the resonating frequency.

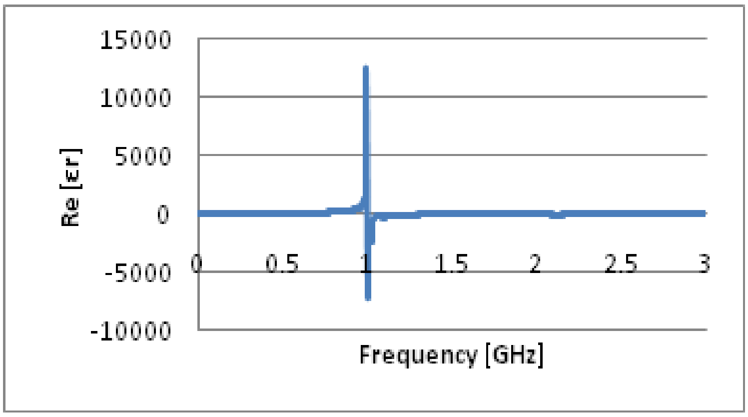

Figure 6: Permittivity versus Frequency Graph Obtained from Microsoft Excel Software

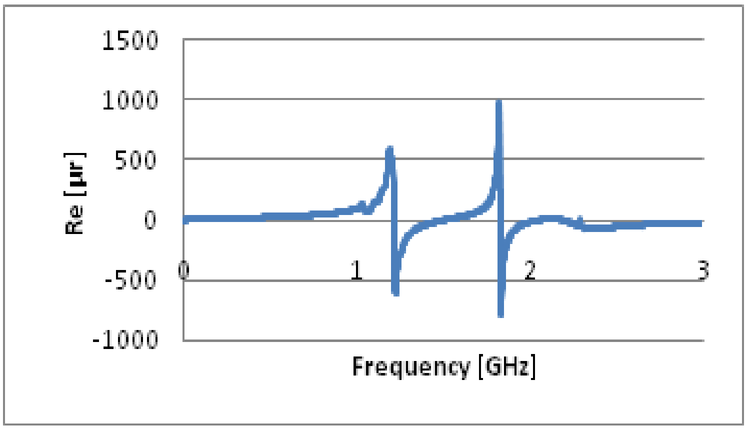

Figure 7: Permeability versus Frequency Graph Obtained from Microsoft Excel Software

Tables generated for permittivity and permeability using MS-Excel software are too large, therefore table 1 and table 2 shows the negative values of permittivity and permeability only in the operating frequency range 2.270–2.360 GHz.

Table 1: Negative Values of Permittivity at 2.270 – 2.360 GHz Frequency Range

Sample Point	Frequency (GHz)	Real value of Permittivity Re (ε_r)
761	2.270	-39.4891
767	2.288	-35.6967
773	2.306	-33.0497
779	2.324	-30.2765
785	2.342	-27.8723
791	2.360	-25.9440

Table 2: Negative Values of Permeability at 2.270 – 2.360 GHz Frequency Range

Sample Point	Frequency (GHz)	Real Value of Permeability Re (μ_r)
761	2.270	-44.5426
767	2.288	-49.2290
773	2.306	-58.7297
779	2.324	-60.7464
785	2.342	-65.1297
791	2.360	-66.4112

Reduction in Size

After placing the suggested material cover on the RFPDD at a height of 1.6 mm from the designed directional device, the reduction in size is shown in table 3.

Table 3: Reduction in RFPDD Parameters

Parameter	Dimension of RFPDD	Dimension of Proposed Reduced Size RFPDD	Unit
Length (L)	30.425	24.242	mm
Width (W)	39.210	33.440	mm
Cut Width	5	6.4	mm
Cut Depth	9	8.4	mm
Path Length	24.213	21.721	mm
Width Of Feed	3	4	mm
Length of Ground plane & Substrate	110	100	mm
Width of Ground plane & Substrate	110	100	mm

Simulated Result after Placing Suggested Cover

When the proposed structure is incorporated with the RFPDD, it shows the improved impedance bandwidth of 77.6 MHz and return loss of -33 dB as shown in Figure 8.

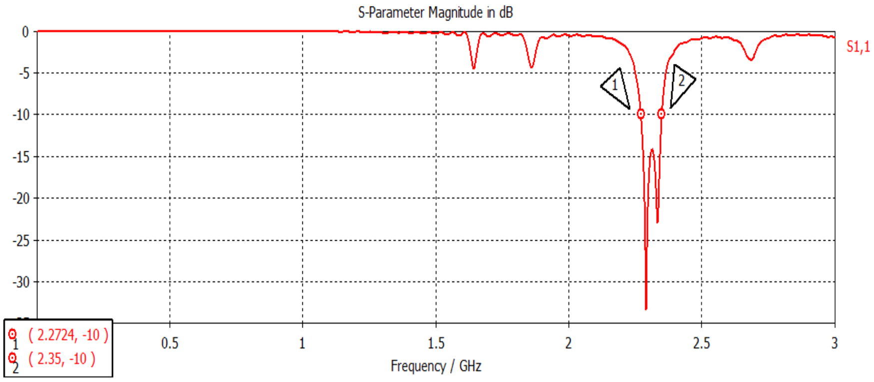

Figure 8: Simulated Result of the RFPDD along with Suggested Material Cover Showing Return Loss of -33 dB and Bandwidth of 77.6 MHz

Figure 9 shows the directivity of 6.948 dBi and total efficiency of 51.19%.

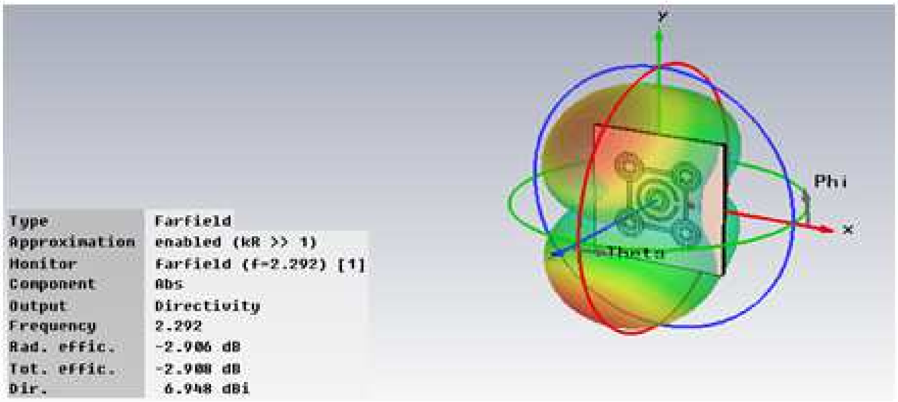

Figure 9: Radiation Pattern of the RFPDD along with the Suggested Material Cover Showing Total Efficiency of 51.19%

Smith Chart in figure 10 shows that the proposed Metamaterial Structure is matched at 2.292 GHz frequency.

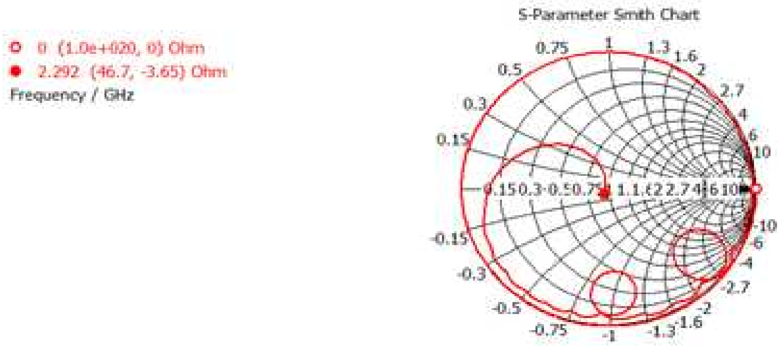

Figure 10: Smith Chart of the RFPDD along with Suggested Material Cover at 2.292 GHz

In this section, simulation results are presented. When the proposed Metamaterial Structure is simulated using CST software at the resonating frequency of 2.292 GHz, it has been found that potential parameters [14][15] of the proposed directional device increases significantly in comparison to RFPDD alone. Figure 2 and 8 shows that the return loss of the proposed metamaterial structure is reduced by 22 dB and bandwidth increases by 51.1 MHz. Radiation Pattern in figure 3 and 9 shows that the total efficiency [12] is slightly improved by 2.65%. Smith Chart[7] in figure 10 shows that the proposed metamaterial structure is matched at 2.292 GHz. Figure 6 & 7 verifies double negative[11] properties of the proposed inspired metamaterial Structure.

CONCLUSIONS

In this work, the behavior of a RFPDD loaded with double negative metamaterial structure at a height of 3.2mm from the ground plane is examined. It is found that the insertion of metamaterial structure on RFPDD ultimately reduces the return loss and increases the bandwidth hugely. The proposed directional device could be used in several microwave applications that require improved bandwidth and reduced return loss at the operating frequency. From the results it is observed that the minimum return loss obtained at design frequency of the proposed directional device is -33 dB and the bandwidth is 77.6 MHz with 51.19% efficiency.

REFERENCES

1. V.G. Veselago “The electrodynamics of substances with simultaneously negative value ε and μ” Sov. Phys. Uspekekhy.10 (4), 509-514,1968.

2. Constantine A.Balanis, Antenna Theory and Design. John Wiley & Sons, Inc., 1997.
3. W.L. Stutzman, G.A. Thiele, Antenna Theory and design, John Wiley & Sons, 2nd Ed., New York, 1998.
4. J. B. Pendry, A. J. Holden, W. J. Stewart and I. Youngs " Extremely Low Frequency Plasmons in Metallic Mesostructures", Phys. Rev. Lett., Vol 76, pp 4773-4776, 1996.
5. D.R. Smith, W.J. Padilla, D.C. Vier, et al, Composite medium with simultaneously negative permeability and permittivity, Phys Rev Lett 84, 4184–4187,May 2000.
6. J.B. Pendry, Negative refraction males a prefect lens, Phys Rev Lett, 85 , 3966–396,2000
7. David M. Pozar, "Microwave Engineering", 3rd Edition, John Wiley & Sons, 2004.
8. Nadar Engheta, Richard W. Ziolkowski, "Metamaterial Physics & Engineering Explorations", July 11, 2006.
9. Ahmad A. Sulaiman, Ahmad S. Nasaruddin, "Bandwidth Enhancement in patch antenna by metamaterial substrate", European Journal of scientific research, 2010.
10. Huda A. Mazid, Mohammad Kamal A. Rahim, Thelasa Masri, "Left-handed metamaterial design for microstrip antenna application", IEEE International RF and Microwave conference, 2008.
11. G. Lovat, P. Burghignoli, F. Capolino, and D.R. Jackson, ""R.W. Ziolkowski, "Combinations of low/high permittivity and/or permeability substrates for highly directive planar metamaterial antennas", IET Microw. Antennas Propag. 1,177 (2007).
12. S. Pyo, S. –M. Han, J. –W. Baik, W. –S. Yoon, and Y.-S. Kim, "Offset-fed metamaterial antenna for radiation mode generation with efficiency improvement", IET Microw. Antennas Propag. 4, 1481 (2010).
13. H.A. Majid, M.K.A. Rahim and T. Marsi, Microstrip Antenna gain enhancement using left-handed metamaterial structure, progress in Electromagnetic Research M. Vol.8, 235-247, 2009.
14. P. K. Singhal, Bimal Garg, Nitin Agrawal "A High Gain Rectangular Microstrip Patch Antenna Using "Different C Patterns" Metamaterial Design In L-Band", published in Advanced Computational Technique in Electromagnetics July 2012.
15. P. K. Singhal, Bimal Garg "A High Gain & Wide Band Rectangular Microstrip Patch Antenna Loaded With Interconnected SRR Metamaterial structure", published in International Journal of Engineering and Technology, August 2012.
16. P. K. Singhal, Bimal Garg "Design and Characterization of Compact Microstrip Patch Antenna Using "Split Ring" Shaped Metamaterial Structure" published in international journal of electrical and computer engineering, Vol.2, No.5, October 2012.
17. J. Lee and S. Lim, " Bandwidth-enhanced and polarization-insensitive metamaterial absorber using double resonance", Electron Lett. 47, 8 (2011).