

# Design and Modeling of S band circular patch and Ka band horn Antenna, Integration with future Multifunctional Radio over Fiber Network

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**Abstract:** Radio over Fiber is an integration of microwave and optical fiber technologies having numerous benefits. RoF technology can give a scope of advantages including the capacity for backing multiple radio services and standards. In coming future there is need of integrated wireless service with high speed satellite broadband and multifunctional indoor/outdoor antennas. Radio over fiber is most favorite candidate to meet all these requirements of future multifunctional integrated wireless communication. Due to planer profile, small size and low cost patch antennas are most favorite to use for multi-frequency applications. In this paper we present system level design for future multifunctional radio over fiber network. Under FTTH (Fiber To The Home) technology it will be possible to use multi-frequency applications on single fiber medium. Firstly we designed S band circular patch antenna (2.5 GHz) and Ka band (29 GHz) horn antenna. Circular patch antenna performance is estimated with different substrate height. After getting S parameters and far-field results we did modeling of Radio over Fiber system over (10 Km) with same parameters from antenna results.

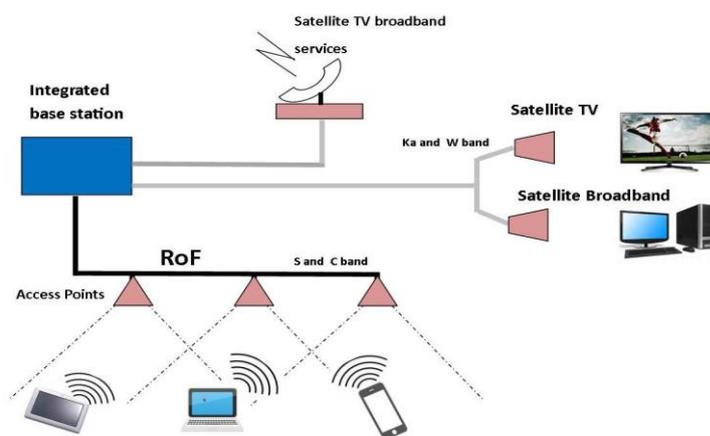
**Keywords:** Radio over Fiber, S-band, Ka-band, March Zehnder Modulator, CW Laser.

**Classification:** Optical systems

## 1 Introduction

Future high speed wireless communication is based on millimeter waves but High Air link loss reduces the communication distance in millimeter wave systems. Radio over fiber is one good technology to extend the coverage in which Rf signals traveled through optical fiber. With Radio over Fiber is just sending the radio signals over optical fiber. Easy maintenance, low power units, simple remote antennas, low attenuation loss, large bandwidth and reduced power consumption are few benefits of RoF link. RoF is an auspicious solution to accomplish the increasing demand of wireless and user bandwidth. In RoF system the only task of Base station is to convert optical signal into Radio signal. In recent advancement laser, photodiode and circulator are replaced with a single electronic device called electro absorption modulator. [1-7] EAM acts as photodiode for downlink and modulator for uplink. No light source is needed at RAU which makes it much simpler and cheaper. In 2012 A. Kumar & N. Agarwal worked on RoF integration microwave and optical communication is accesses to broadband wireless communications [6]. Three methods implemented into RoF and compared with Attenuation, Scattering, BER and CNR. Satellite Communication, mobile radio communication, broadband and wireless LAN are few application of RoF [3, 5, 6]. Radio-over-fiber (RoF) is an attractive technology for multi broadband services [8-16].

Due to light weight, low cost and small size micro strip antennas are getting popular for future high speed communication. Most commonly used patch antennas are circular and rectangular shaped antennas. In triangular shape antenna bandwidth is the biggest problem in many applications that's why circular patch antennas are widely used in numerous wireless communications [17, 18]. Micro strip antennas are always preferred for integrated wireless applications due to its broad bandwidth for maximum performance [19].



**Fig.1:** Radio Over Fiber Integrated Wireless System design

In this Paper we first Designed S band (2.5 GHz) circular patch antenna and Ka band (29 GHz). Circular patch antenna performance was measured with different

substrate height. Then System level design of Radio over fiber is demonstrated with multi-frequency parameters, Fig.1 Shows a typical RoF network for indoor communication.

## 2 Antenna Design

Future RoF needs multi-functional and multi-frequency antennas because indoor wireless applications works on different frequencies. To do RoF system demonstration we designed two different frequencies antenna and use parameters for RoF system simulation.

### 2.1 S band Circular Patch Antenna (2.5 GHz)

Circular patch antennas are attention seekers in both single elements [20-25] and in arrays [26] and [27]. Cavity Model [21, 24, 25] can be used for conveniently analysis of circular patch antenna. Circular patch antenna occupies less space as compared to rectangular patch antenna. We deigned 2.5GHz circular patch antenna and get S parameters. Design Parameters of antenna is shown in Fig.2. Due to low cost and small size such antenna can be used for multifunctional application in future radio over fiber activities. Radius of patch is found by Eq.1[28, 29].

$$r_{eff} = r \sqrt{1 + \frac{2h}{\pi r \epsilon_r} \left[ 1 + n \frac{\pi r}{2h} \right] + 1.7726} \quad (1)$$

Where  $r$  = physical radius of circular patch

$h$  = height or thickness of the substrate

$\epsilon_r$  = Dielectric Constant

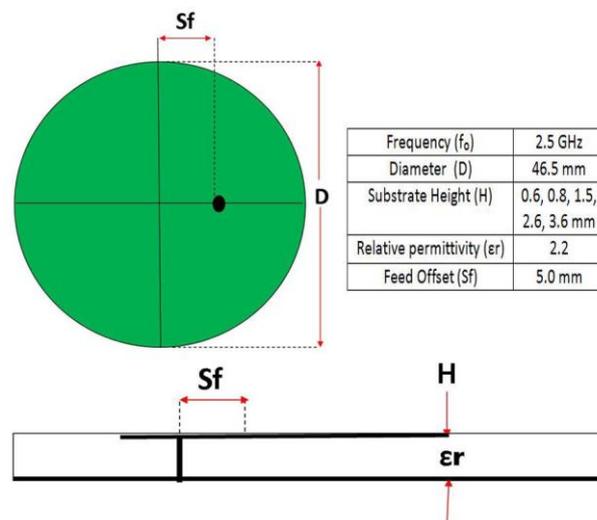


Fig 2: 2.5 GHz Circular patch antenna design parameters

## 2.2 Ka band Horn Antenna 29 GHz

First horn antenna was constructed by Indian radio researchers in 1897. In 1962 they become widely used for microwave and satellite antennas. Horn antenna has very little loss so directivity is roughly equals to its gain. Due to absent of resonant elements horn can operate over wide bandwidth. Low SWR, wide band width and simple architecture are advantages of horn antennas. We designed waveguide-fed pyramidal horn antenna for Ka band (29 GHz). This can be used for satellite and broadband application in Radio over fiber network. Parameters of antenna are shown in Fig.3

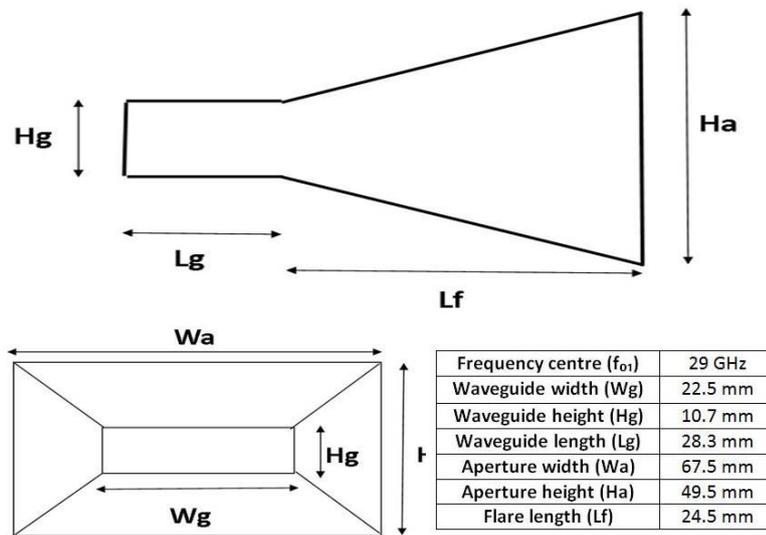


Fig 3: 29 GHz Horn Antenna design parameters

## 3 Antenna Results

S parameters show input and output relationship. S11 shows total reflected power from antenna also called reflection coefficient. Fig.4 shows S parameters for circular patch antenna with different substrate height while Fig.5 shows S parameters of Ka band Horn antenna.

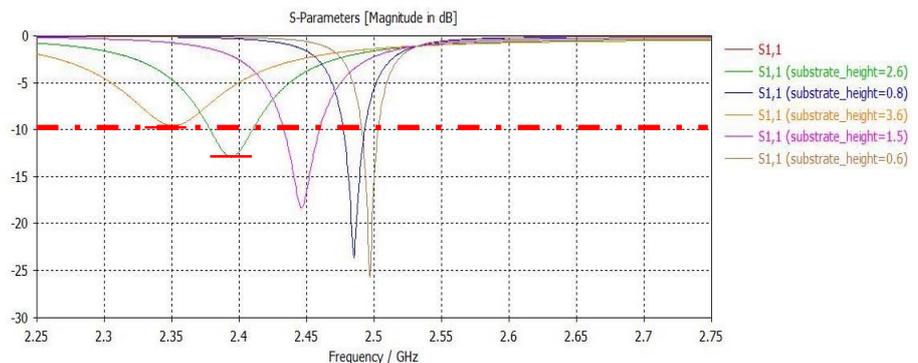
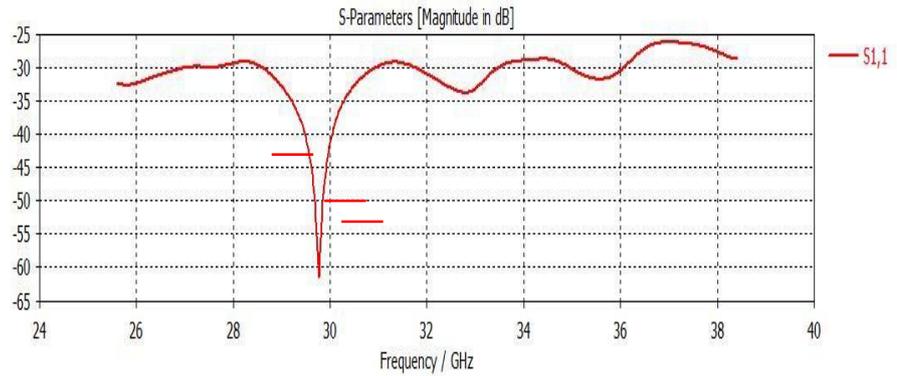


Fig 4: S parameters for circular patch with different substrate height



**Fig 5:** S parameters for Ka band Horn antenna

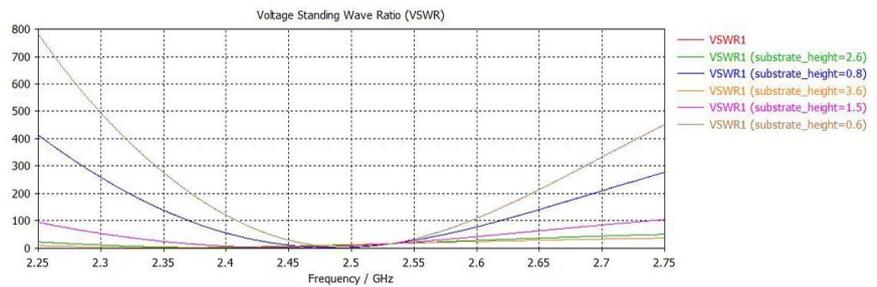
### 3.1 VSWR

VSWR (Voltage standing wave ratio) also related to S parameters, smaller the VSWR more power will be delivered to antenna. It's necessary to calculate reflection coefficient Eq.2. If reflection coefficient is given by  $\Gamma$  then VSWR can be calculated by Eq. 3. Figure 6 shows VSWR for both horn and patch antennas.

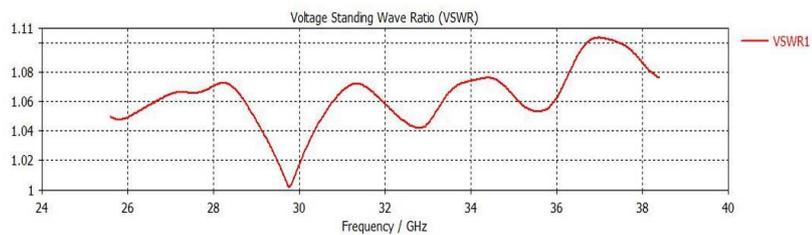
$$\Gamma = \frac{V_{rev}}{V_{fwd}} \quad (2)$$

Where  $\Gamma$  = Complex Number (magnitude & phase shift of reflection)

$$VSWR = \frac{|V_{max}|}{|V_{min}|} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (3)$$



(a)

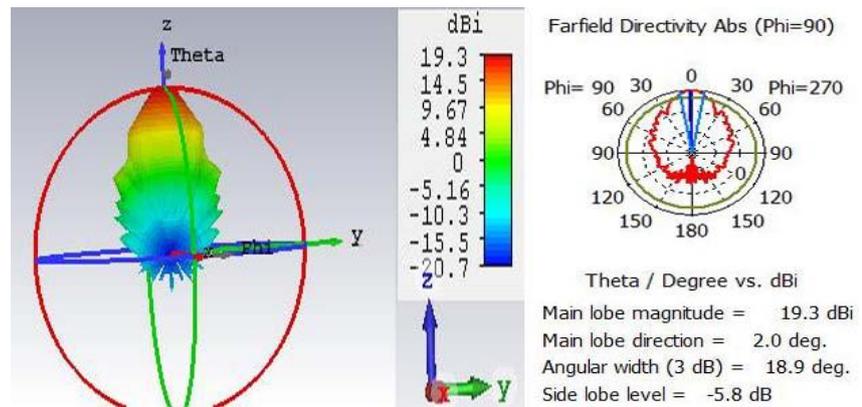


(b)

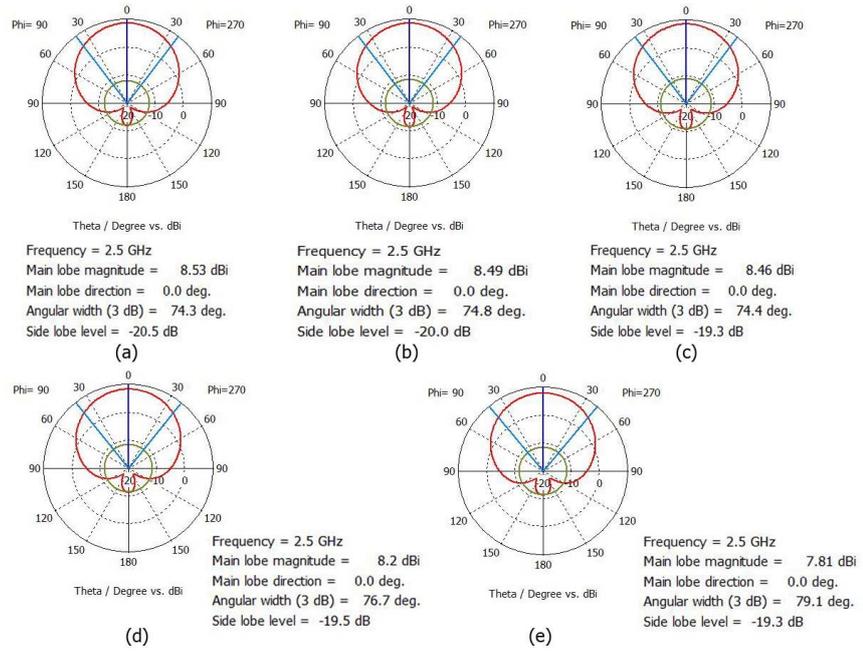
**Fig 6:** (a) VSWR for 2.5 GHz circular patch antenna with different substrate height.  
(b) VSWR for 2.9 GHz horn antenna

### 3.2 Radiation Pattern:

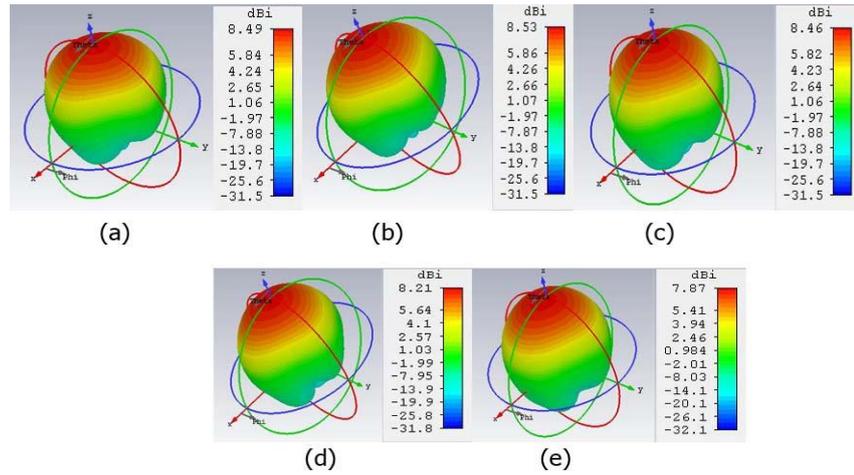
In Reference [30] Radiation Pattern is defined as “A mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far-field region and is represented as a function of the directional coordinates.” Antenna transmitted and receiving power can be seen by radiation pattern. Fig.7 shows Radiation pattern for Horn antenna while Fig.8 and Fig.9 shows circular patch antenna radiation pattern. There is quite difference with different substrate height



**Fig 7:** Far Field Directivity for 29 GHz horn antenna



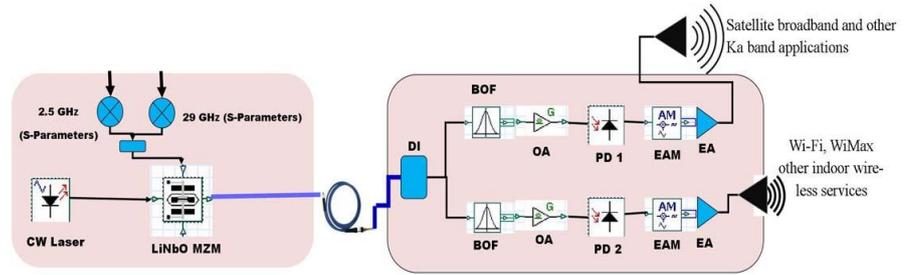
**Fig 8:** Far field for 2.5 GHz antenna with different substrate height. (a) 0.8mm (b) 0.6 mm (c) 1.5 mm (d) 2.6 mm (e) 3.6 mm



**Fig 9:** Radiation Pattern for 2.5 GHz antenna with different substrate height (a) 0.6 mm (b) 0.8 mm (c) 1.5 mm (d) 2.6 mm (e) 3.6 mm

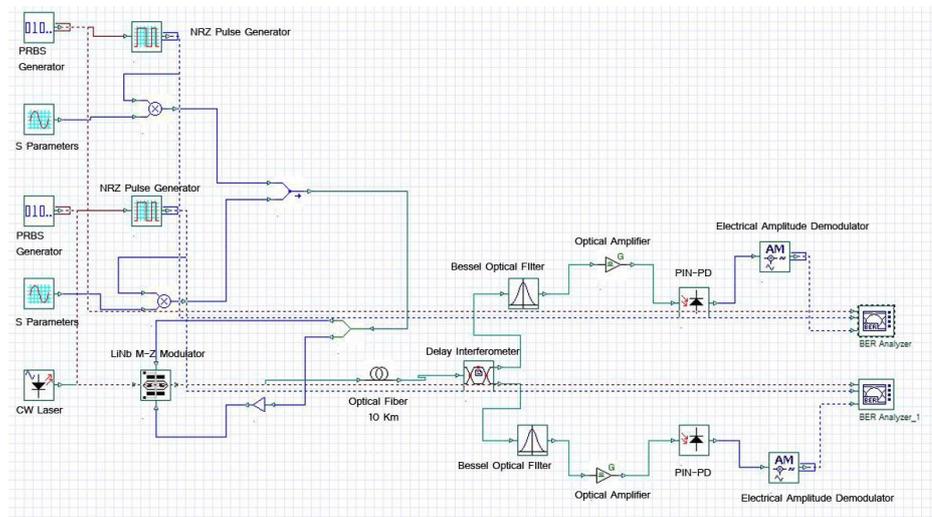
#### 4 Radio Over Fiber design

Figure 10 shows system diagram of experiment. On transmitter side we used S parameters of 2.5 GHz antenna and also 29 GHz RF signal, both signals are received successful on receiver through 10 Km optical link.

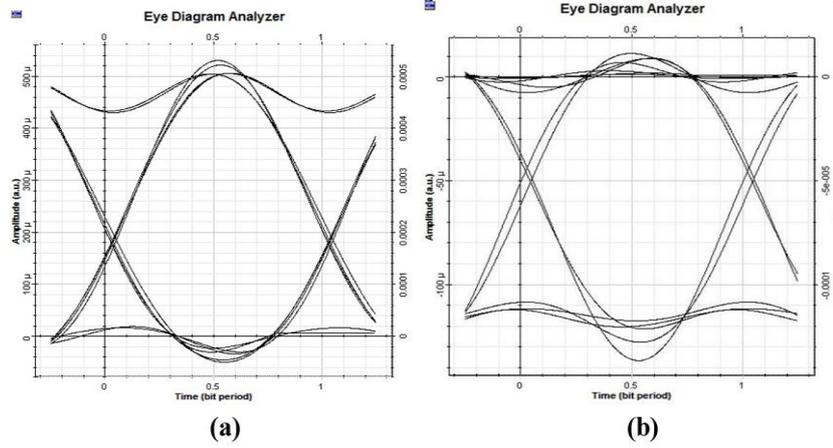


**Fig 10:** Experiment Radio over Fiber system over view. DI= Delay Interferometer, BOF=Bessel Optical Filter, OA= Optical Amplifier, PD= Photodiode, EAD= Electrical Amplitude Demodulator, EAD= Electrical Amplitude Demodulator

On transmitter side two different frequencies Rf signals are input and on receiver side successful received. Figure 11 shows RoF system diagram designed in OptiSystem 14. In transmission side two Rf signal generator are used instead of antenna module. In first generator the s parameters were used from 2.5GHz antenna and 29 GHz antenna s parameters were used in second Rf signal generator. Dual Drive March Zehnder Modulator is used with CW laser and both Rf signals were transmitted through single optical fiber of 10 Km length. Fig. 11 shows Eye diagram of both signals successfully received.



**Fig 11:** Multi-Frequency Radio over Fiber System



**Fig 11:** Eye diagram for 2.5GHz and 29 GHz received signal

## 6 Conclusions and Discussion

We designed 2.5 GHz circular patch and 29 GHz horn antenna for RoF wireless applications. Both antennas show good results. S band circular patch antenna performance is compared in Table I [31, 32]. Secondly S parameters and Ka band Rf signal were used in RoF system design and on receiver side received different frequencies signal with eye diagram shown in Fig.11. In future multi-band antennas will be designed and parameters will be using in RoF system. As RoF is integrated with multi frequencies applications, So on system level it's important to consider emission wavelength of laser, length of fiber and transmitted frequencies for better signal integrity. RoF is easy to expand and flexible. RoF will be core technology for future indoor and outdoor wireless applications.

**Table I:** Far-Field Comparison

No.	Frequency (Fo)	Far-Field (dBi)
[31]	2.5 GHz	8.1
[32]	2.5 GHz	4.53
Presented	2.5 GHz	8.53

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## References

- [1] J. Liu, M. Beals, A. Pomerene, S. Bernardis, R. Sun, J. Cheng, *et al.*, "Waveguide-integrated, ultralow-energy GeSi electro-absorption modulators," *Nature Photonics*, vol. 2, pp. 433-437, 2008.
- [2] S. KAJIMA, K. Tsukamoto, and S. Komaki, "Proposal of fiber-optic radio highway networks using CDMA method," *IEICE transactions on electronics*, vol. 79, pp. 111-117, 1996.
- [3] W. Way, "Optical fiber-based microcellular systems: An overview (special issue on fiber-optic microcellular radio communication system and their technologies)," *IEICE Transactions on Communications*, vol. 76, pp. 1091-1102, 1993.
- [4] R. Kashif and F. Lin, "Signal integrity problems in electronic designing," in *Microwave Conference (APMC), 2015 Asia-Pacific*, 2015, pp. 1-3.
- [5] H. Al-Raweshidy and S. Komaki, *Radio over fiber technologies for mobile communications networks*: Artech House, 2002.
- [6] R. Karthikeyan and S. Prakasam, "A survey on Radio over Fiber (RoF) for wireless broadband access technologies," *International Journal of Computer Applications*, vol. 64, 2013.
- [7] E. Lach, K. Schuh, and M. Schmidt, "Application of electroabsorption modulators for high-speed transmission systems," in *Ultrahigh-Speed Optical Transmission Technology*, ed: Springer, 2005, pp. 347-377.
- [8] W. Ji and J. Chang, "Design of WDM-RoF-PON for wireless and wire-line access with source-free ONUs," *Journal of Optical Communications and Networking*, vol. 5, pp. 127-133, 2013.
- [9] W.-J. Jiang, C.-T. Lin, P.-T. Shih, L.-Y. W. He, J. Chen, and S. Chi, "Simultaneous generation and transmission of 60-GHz wireless and baseband wireline signals with uplink transmission using an RSOA," *IEEE photonics technology letters*, vol. 22, pp. 1099-1101, 2010.
- [10] Y.-T. Hsueh, Z. Jia, H.-C. Chien, J. Yu, and G.-K. Chang, "A novel bidirectional 60-GHz radio-over-fiber scheme with multiband signal generation using a single intensity modulator," *IEEE photonics technology letters*, vol. 21, pp. 1338-1340, 2009.
- [11] Y.-T. Hsueh, M.-F. Huang, S.-H. Fan, and G.-K. Chang, "A novel lightwave centralized bidirectional hybrid access network: Seamless integration of RoF with WDM-OFDM-PON," *IEEE Photonics Technology Letters*, vol. 23, pp. 1085-1087, 2011.
- [12] J. Ma, J. Yu, C. Yu, X. Xin, J. Zeng, and L. Chen, "Fiber dispersion influence on transmission of the optical millimeter-waves generated using LN-MZM intensity modulation," *Journal of Lightwave Technology*, vol. 25, pp. 3244-3256, 2007.
- [13] Z. Jia, J. Yu, G. Ellinas, and G.-K. Chang, "Key enabling technologies for optical-wireless networks: optical millimeter-wave generation, wavelength reuse, and architecture," *Journal of Lightwave Technology*, vol. 25, pp. 3452-3471, 2007.
- [14] H. Li, J. Hajipour, A. Attar, and V. C. Leung, "Efficient HetNet

- implementation using broadband wireless access with fiber-connected massively distributed antennas architecture," *IEEE Wireless Communications*, vol. 18, 2011.
- [15] G.-K. Chang, Z. Jia, J. Yu, A. Chowdhury, T. Wang, and G. Ellinas, "Super broadband optical wireless access technologies," in *Optical Fiber Communication Conference*, 2008, p. OThD1.
- [16] M. Sauer, A. Kobayakov, and J. George, "Radio over fiber for picocellular network architectures," *Journal of Lightwave Technology*, vol. 25, pp. 3301-3320, 2007.
- [17] P. N. Shinde and J. P. Shinde, "Design of compact pentagonal slot antenna with bandwidth enhancement for multiband wireless applications," *AEU-International Journal of Electronics and Communications*, vol. 69, pp. 1489-1494, 2015.
- [18] J. P. Shinde and P. N. Shinde, "M-shape electromagnetic-bandgap structures for enhancement in antenna performance," *AEU-International Journal of Electronics and Communications*, vol. 70, pp. 842-849, 2016.
- [19] Y. Doraisingam, "Bandwidth enhancement of microstrip antenna for wireless local area network applications," School of Graduate Studies, Universiti Putra Malaysia, 2007.
- [20] L. Shen, S. Long, M. Allerdin, and M. Walton, "Resonant frequency of a circular disc, printed-circuit antenna," *IEEE Transactions on antennas and propagation*, vol. 25, pp. 595-596, 1977.
- [21] A. Derneryd, "Analysis of the microstrip disk antenna element," *IEEE Transactions on Antennas and Propagation*, vol. 27, pp. 660-664, 1979.
- [22] S. Long and M. Walton, "A dual-frequency stacked circular-disc antenna," *IEEE Transactions on Antennas and propagation*, vol. 27, pp. 270-273, 1979.
- [23] S. B. D. Assis, "Microstrip Disk Antenna, Part 1: efficiency of space wave launching."
- [24] S.B.De, "Microstrip disk antennas, partll: the problem of surface wave radiation by dielectric truncation."
- [25] J. T. Aberle and F. Zavosh, "Analysis of probe-fed circular microstrip patches backed by circular cavities," *Electromagnetics*, vol. 14, pp. 239-258, 1994.
- [26] F. Zavosh and J. T. Aberle, "Infinite phased arrays of cavity-backed patches," *IEEE transactions on antennas and propagation*, vol. 42, pp. 390-398, 1994.
- [27] J. T. Aberle and D. M. Pozar, "Analysis of infinite arrays of one-and two-probe-fed circular patches," *IEEE transactions on antennas and propagation*, vol. 38, pp. 421-432, 1990.
- [28] C. Kaufman, "Rocky Mountain Research Lab," *Boulder, CO, private communication*, 1995.
- [29] T. Lai, W. N. L. Mahadi, and N. Soin, "Circular patch microstrip array antenna for ku-band," *World Academy of Science, Engineering and Technology*, vol. 48, pp. 298-302, 2008.

- [30] C. A. Balanis, *Antenna theory: analysis and design*: John Wiley & Sons, 2016.
- [31] S. Dwivedi, A. Rawat, and R. N. Yadav, "Design of U-shape microstrip patch antenna for WiMAX applications at 2.5 GHz," in *Wireless and Optical Communications Networks (WOCN), 2013 Tenth International Conference on*, 2013, pp. 1-5.
- [32] A. G. Koutinos, G. A. Ioannopoulos, M. T. Chryssomallis, G. A. Kyriacou, and D. Caratelli, "Bandwidth enhancement of a supershape patch antenna using multiple feeding technique," in *Antenna Technology: Small Antennas, Innovative Structures, and Applications (iWAT), 2017 International Workshop on*, 2017, pp. 211-214.