Design of a Frequency Reconfigurable Notched-Band Ultra-Wideband Antenna for Cognitive Radio Applications

Muflih Alsulami [1], Hatem Rmili [1], Sondos Mehri [1], Bandar Hakim [1], Muntasir Sheikh [1], and Raj Mittra [1,2]

[1] Electrical and Computer Engineering Department, Faculty of Engineering, King Abdulaziz University
P.O. Box 80204, Jeddah 21589, Saudi Arabia
hmrmili@kau.edu.sa

[2] Electrical and Computer Engineering Department, University of Central Florida
EMC Lab, Orlando, FL 32816, USA
rajmittra@ieee.org

Abstract **─** This paper proposes a frequency reconfigurable notched-band UWB antenna design, which is capable of wide band rejection. We begin with a conventional reconfigurable modified-square monopole printed antenna and insert a U-shaped slot to create the rejection band. Next, we add two identical SMV1249 varactor diodes with variable capacitances in the created slots to tune the rejected band. We modify the capacitances, which, in turn, controls rejected band by controlling the reverse bias voltage applied across the varactor diodes. The proposed structure has been simulated, optimized, fabricated and experimentally tested. Good agreement has been achieved between the simulation and measurement results. Experimental results show that when the bias voltage is varied from 0 to 7 V, the antenna can be reconfigured to achieve various rejection frequency bands, and to maintain good impedance match as well as stable radiation patterns over the explored frequency band ranging from 1 to 6 GHz.

Index Terms **─** Frequency reconfigurability, notched band, varactor diode, ultrawide band.

I. INTRODUCTION

Recently, Ultra-Wideband (UWB) radio technology has drawn increasing attention of communication engineers, owning to its high data transmission rate, low cost and small size. In comparison to many other existing wireless communication standards, UWB has a very wide bandwidth, ranging from 3.1 to 10.6 GHz [1]. Additionally, the UWB can coexist with other narrowband communication standards that occupy the same spectrum. Of course, an overlap of the UWB and other bands may lead to a severe interference between them. To avoid this interference, UWB antennas with single or multiple notch frequencies techniques have been developed, and their band-notch characteristics have been achieved through two main techniques [2-4]. The first of these is based the addition of various slots, either in the radiating patch [5, 6] or in the ground plane [7, 8], while the second employ parasitic elements to achieve the desired goal [9-11].

To realize dynamically-controlled band-notches, UWB antennas integrated with reconfigurable band-notch characteristics have recently been proposed [4]. These antennas have the capability of dynamically altering the notch frequency by using electrical switching circuits [7] such as MEMS switches, PIN diodes, or varactor diodes. Generally speaking, varactor diode [12-14] are the most widely used for tuning technique because they are simple to integrate into antenna system and to achieve different notch frequencies.

In this paper, a reconfigurable band-notched UWB antenna is investigated to achieve wideband rejection. We begin by using the basic structure presented in [15, 16] to realize the UWB behavior. Next, we introduce a U-shaped slot within the patch to obtain two rejected bands. Finally, we insert a pair of varactor diodes into the vertical slots, optimize their positions, and study the effect of varying the capacitance on the frequency of rejection. Next, we numerically optimize the position of the lumped elements before varying their capacitance. The tuning of the rejection frequency was realized by varying the reverse-bias voltages that are applied across the two varactor diodes. Experimental results show that, by properly varying the bias voltage value from 1 to 7 V, the proposed antenna can achieve a wideband behavior from 2 to 6 GHz with a rejection band which ranges from 2 GHz to 2.12 GHz.

This paper is organized as follows: the design procedure for the reconfigurable antenna is described in detail in the next section. In section 3, the simulation and measurement results are presented, compared and

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discussed. Concluding remarks are presented in the last section.

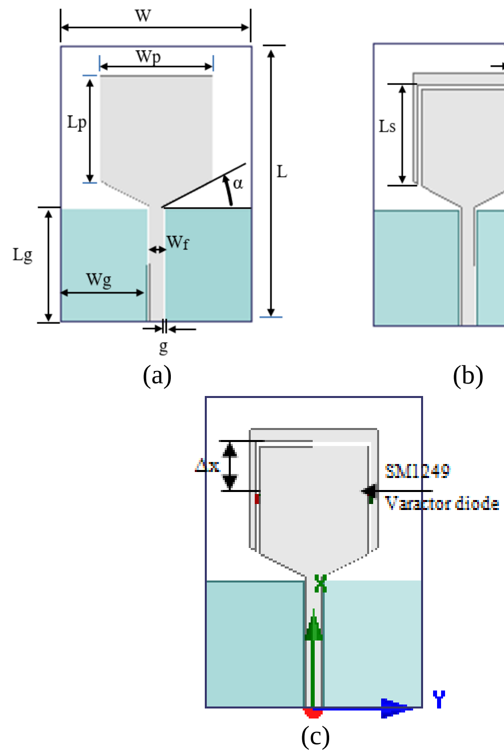


Fig. 1. Schemas of the studied antennas during the design procedure: (a) UWB basic structure, (b) UWB-antenna with slots only, and (c) UWB-antenna with slots and varactor diodes.

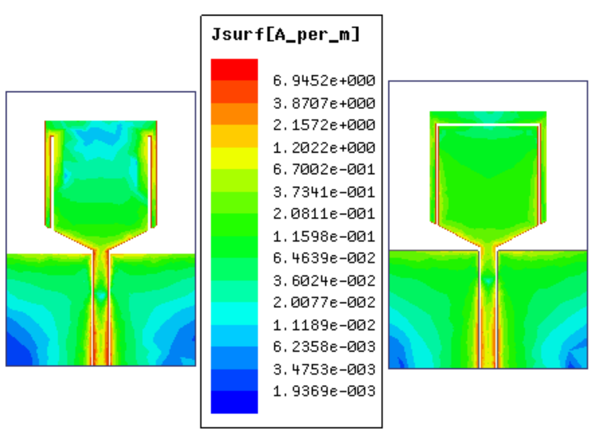


Fig. 2. Surface current distribution at 4 GHz for the basic UWB structure before (a) and after (b) addition of the horizontal part of the U-slot.

II. DESIGN PROCEDURE

The first step, we have designed the basic UWB antenna comprising of a planar CPW-fed structure, in which both the modified square monopole and the CPW ground plane are printed on one face of an Epoxy FR4 substrate whose loss tangent is 0.02 and 0.8 mm thickness. The geometrical parameters are first optimized to cover the UWB frequency band 3.1-10.3 GHz (Fig. 1 (a)). Next, two vertical slots were inserted into the radiating patch to generate a rejection frequency which is proportional to the length of the slot (Fig. 1 (b)). Then, a horizontal slot is inserted to split the patch into two parts in order to place the varactors (Fig. 1 (c)). The position of the horizontal slot was determined by analyzing the surface current distribution on the patch such that the radiation performance of the antenna is not affected (Fig. 2). Finally, we insert the two pin diodes within the two slots and we apply a reverse bias voltage across their electrodes to vary the varactor capacitance. Using the full-wave EM Simulator HFSS, the positions of the varactors are optimized to get high rejection level (mod (S_{11}) > -5 dB) with a wideband tuning capability of the rejected band, as shown in Fig. 3.

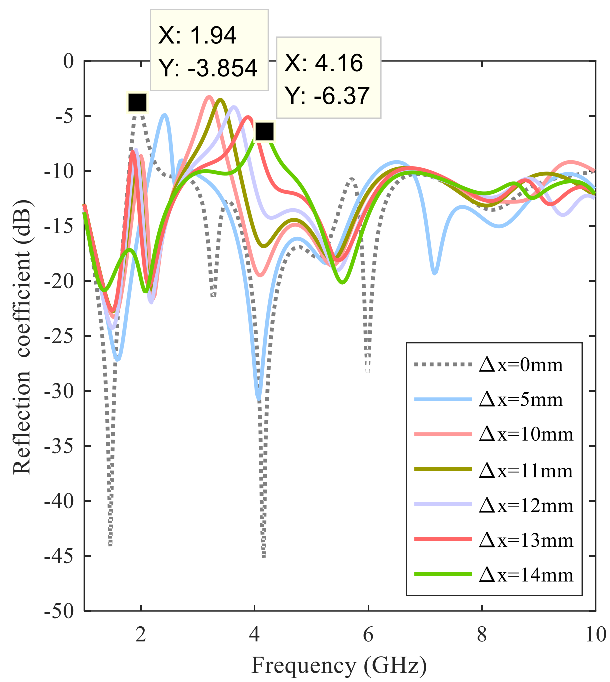


Fig. 3. Evolution of the simulated reflection coefficient of the designed antenna versus frequency, for different position Δx of the inserted varactors.

Table 1: Design parameters of the proposed antenna

Parameter (mm)			
L	76	Wf	4
W	52.5	g	0.75
Lp	36.8	α	27°
Wp	30.8	Ws	1
Lg	31	Ls	26.6
wg	23.6	Δx	11

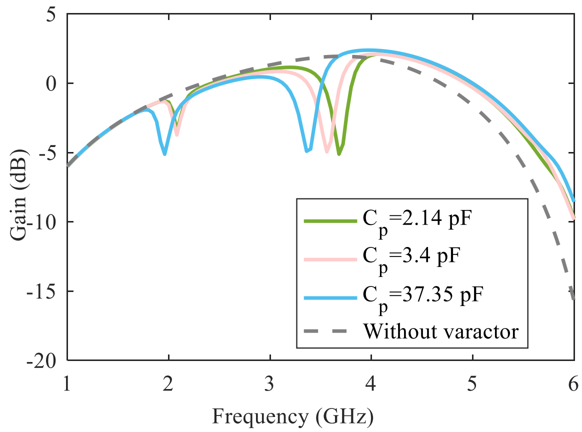


Fig. 4. Simulated gain of the UWB-antenna with slots and varactor diode (Fig.1c) versus frequency for different values of Cp and for Δx=11mm.

The gain variation according the frequency for different values of varactors has also been studied. During the performed simulations, we have modeled the varactor diode according to its equivalent electric circuit delivered by the manufacturer. This circuit consists on a parasitic inductance L in series with a capacitor Cp which is in parallel with an intrinsic resistance R_{ON}. When the varactor diode is active (ON sate), the values of L and R_{ON} for the used SMV 1249 diode are 0.45 nH and 1.7 Ω, respectively, according to the manufacturer's data sheet, whereas the capacitance may be changed. Figure 4 shows the gain variation when the lumped element capacitance is changed within the range 37.35 to 2.14 pF. The simulated results show that for each value of the capacitance 'Cp', a significant gain drop is observed at the rejected frequency. Such results attest that a frequency notch reconfiguration is clearly obtained using the varactor diode. More the capacitance decreases, more the narrow-notched frequency shifts to higher frequencies. Table 1 provides the values of the optimized design parameters for the reconfigurable notched-band antenna.

III. RESULTS AND DISCUSSIONS

A prototype of the reconfigurable notched-band antenna with the two inserted SMV 1249 diodes was fabricated and characterized (Fig. 5). Both the impedance characteristics and radiation patterns were measured. The impedance mismatch as a function of the source frequency was measured by using a vector Network analyzer (VNA), Agilent N5230A, over the frequency range of 1-6 GHz. The radiation pattern were measured were by using the "SATIMO Stargate32" anechoic chamber (IETR, INSA Rennes, France). As shown in Fig. 5, a low-pass filter was added to the antenna structure during the measurement procedure to eliminate the effect of the diode on the radiation pattern of the antenna. In Fig. 6 and Fig. 7, we present the simulated and measured results for S_{11} of the basic UWB structure with and without, slots, respectively. The investigated frequencies were limited to the operating range of 1-6 GHz of the anechoic chamber. It is worth to note that a small difference between simulated and measured results is observed, since in the simulation model the mismatch due to the connector used is not taken into consideration. In addition, the small discrepancy between the diodes and their equivalent circuits used in simulation affects the antenna performance. For the performed experimentation, the effect of the varactor diode capacitance has been investigated by varying the applied voltage across the lumped element. The results of this study, illustrated in Fig. 8, show that a continuous tuning of the notched frequency within the band 2-2.55 GHz has been achieved. For the antennas realized with varactor diodes of capacitances 37.35, 3.40, 2.38 and 2.14 pF, corresponding to the applied simulated and measured results is observed since in the voltages of 0, 3, 5 and 7 V, respectively, the rejected frequencies are 2, 2.05, 2.1 and 2.12 GHz, respectively. Table 2, summarizes all of these details and compares experimental and simulated results. Analysis of results given in Table 2 shows that we obtain a wideband reconfigurability of the rejected frequency (around 550 MHz which corresponds to a fractional bandwidth of 27.5%) by integration of SMV 1249 diodes within the antenna slots. The lumped element capacitance may be changed within the range 37.35 to 2.14 pF by increasing the reverse voltage from 0 to 7 V. This implies, that the capacitance of the loaded varactor is inversely proportional to the applied reverse voltage, and more the voltage increases, more the narrow-notched frequency band shifts to the higher frequencies. We note that a small difference between the simulated and experimental rejected frequency is observed however, for both results the wideband behavior of the antenna is maintained. To better characterize the designed antenna, we have measured its radiation patterns with and without the varactor diodes, at selected operating frequencies close to the rejected bands. Figure 9 compares the 3D radiation patterns for the basic structure without slots (Fig. 5 (a)) and the antenna with integrated SMV 1249 diodes (Fig. 5 (c)) under reverse voltages 0 and 5 V. We note that we have considered identical values for the capacitances of SMV 1249 diodes integrated in both sides of the radiating patch to realize symmetric radiation patterns. The patterns corresponding to the basic UWB structure without band rejection behavior showed maximum gains of 1.28 and 4.7 dB at frequencies 2.5 and 3.7 GHz, respectively against to the structures designed with capacitances 34.35 pF to reject the frequencies 2.0 and 2.3 GHz, have maximum gain values of 1.17 dB and 2.12 dB respectively. Further maximum gain values realized for Cp=2.38 pF are -0.80 dB and -0.11 dB at 2.8 GHz 3.3 GHz, respectively. Analysis of the measured pattern shapes shows also that both the UWB basic structure and the reconfigurable one with diodes are omni-directional.

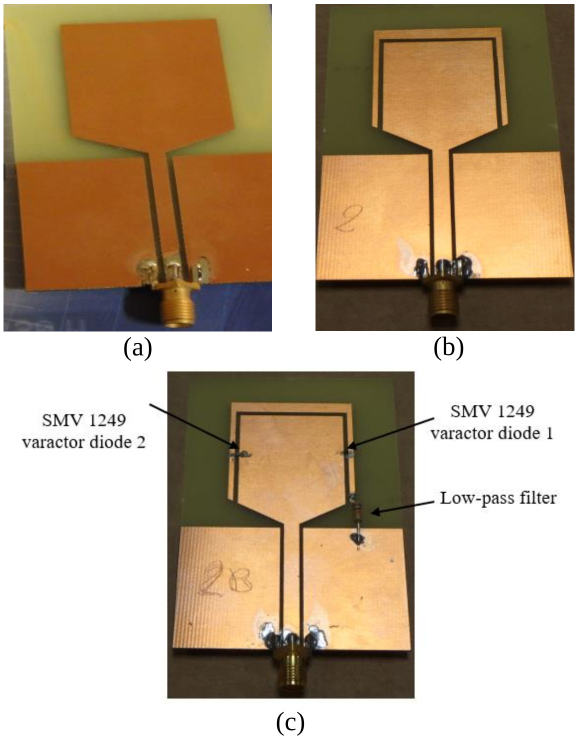


Fig. 5. Schemas of the studied antennas during the design procedure: (a) UWB basic structure, (b) UWB-antenna with slots only, and (c) UWB-antenna with slots and varactor diodes.

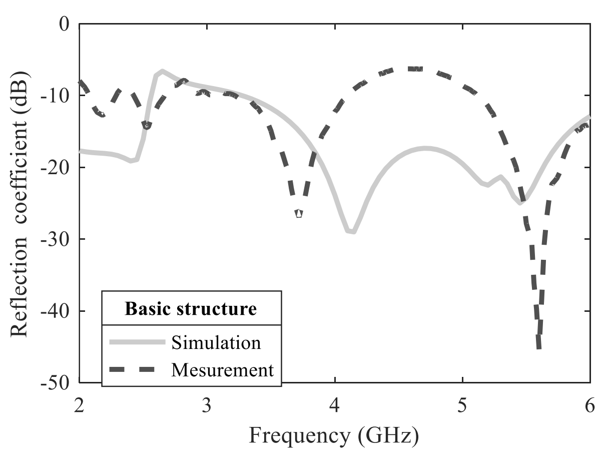


Fig. 6. Simulated and measured reflection coefficient for the basic structure (Fig. 2 (a)).

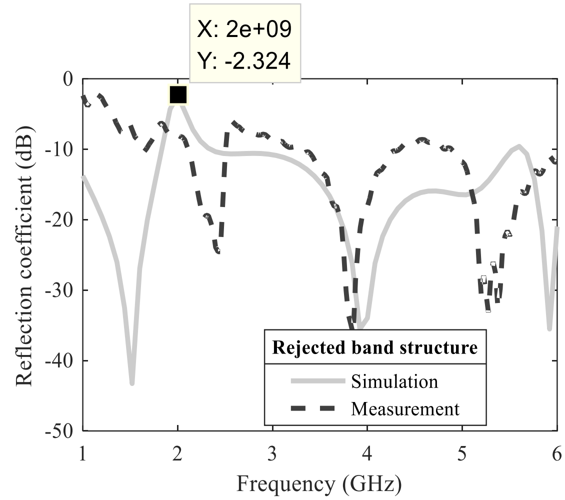


Fig. 7. Simulated and measured reflection coefficient for the rejected band structure (Fig. 2 (b)).

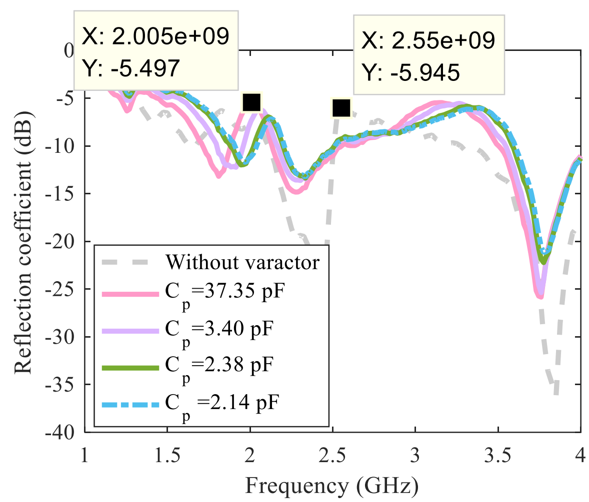
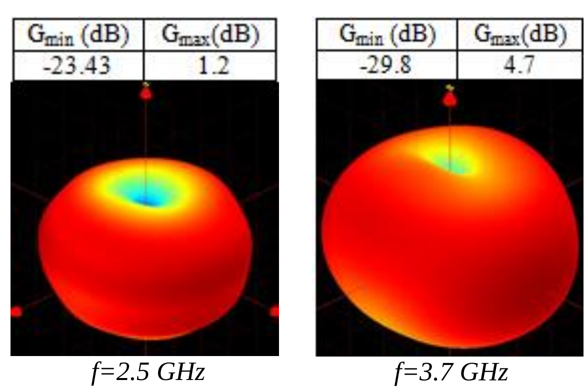
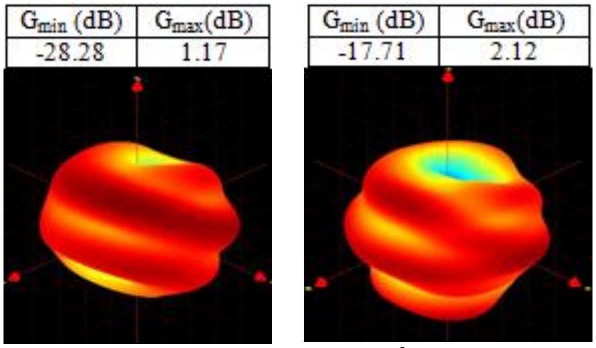


Fig. 8. Measured reflection coefficient S11 for 'Cp' varying from 37.35 pF to 2.14 pF (equivalent to the bias voltage variation from 0 V to 7 V).

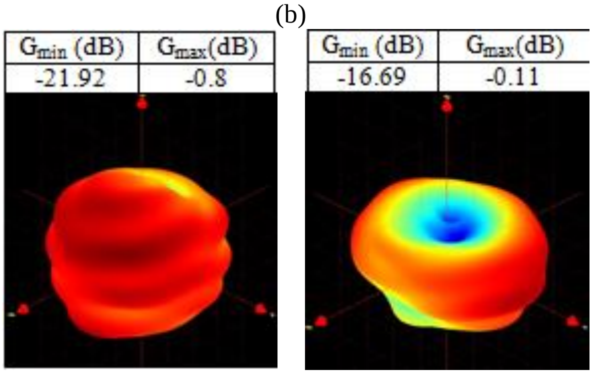


(a)



f=2GHz *f=2.3GHz*

(b)



f=2.8GHz *f=3.3GHz*

(c)

Fig. 9. 3D Measured radiation pattern at selected frequencies for: (a) the basic UWB structure, (b) rejected-band structure with varactor capacitance Cp=37.35 (reverse voltage equal to 0 V), and (c) rejected-band structure with varactor capacitance Cp=2.38 (reverse voltage equal to 5V).

Table 2: Rejected-frequency for different capacitance and reverse voltage values of realized antennas

Capacitance Value (pF)	**Reverse Voltage (V)**	**Rejected Frequency (GHz)**	
		Sim.	**Meas.**
Without varactor diode	--	2	2.55
37.35	0	3.4	2
3.40	3	3.6	2.05
2.38	5	3.62	2.1
2.14	7	3.72	2.12

IV. CONCLUSION

The paper has presented a procedure for designing procedure for a reconfigurable notched-band UWB antenna utilizing electrical switching circuits. The notched-band was dynamically tuned by inserting two identical varactor diodes with variable capacitance and varying the capacitance values from 37.35 pF to 2.14 pF (equivalent to the bias voltage variation from 0 V to 7 V). The rejection band range was tuned from 2 GHz to 2.12 GHz, corresponding to the fractional bandwidth of 27.5% was realized while maintaining good impedance matching.

The desirable attributes of the antenna namely its radiation pattern stability, wideband behavior, capability of the tuning rejection band over a wide range, and moderate gain values, renders it a potential candidate for use in wireless radio applications.

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Muflih Alsulami received the B.Sc. in Electronics and Communication Engineering, King Abdulaziz University, Saudi Arabia, 2012. Currently, he is pursuing his M.Sc. degree in Electronics and Communication Engineering at King Abdulaziz University, Jeddah, Saudi Arabia. He is currently associated with National Grid SA Company, Saudi Arabia. His research interests include designing of compact antennas and wireless communication networks.

Hatem Rmili received the B.S. degree in General Physics from the Science Faculty of Monastir, Tunisia in 1995, and the DEA diploma from the Science Faculty of Tunis, Tunisia, in Quantum Mechanics, in 1999. He received the Ph.D. degree in Physics (Electronics) from both the University of Tunis, Tunisia, and the University of Bordeaux 1, France, in 2004. From December 2004 to March 2005, he was a Research Assistant in the PIOM Laboratory at the University of Bordeaux 1. During March 2005 to March 2007, he was a Postdoctoral Fellow at the Rennes Institute of Electronics and Telecommunications, France. From March to September 2007, he was a Postdoctoral Fellow at the ESEO Engineering School, Angers, France. From September 2007 to August 2012, he was an Associate Professor with the Mahdia Institute of Applied Science and Technology (ISSAT), Department of Electronics and Telecommunications, Tunisia. Actually, he is Associate Professor with the Electrical and Computer Engineering Department, Faculty of Engineering, King Abdulaziz University, Jeddah, Saudi Arabia. His main research activities concern antennas, metamaterials and metasurfaces.

Sondos Mehri has received the Ph.D. degree in 2017 in Electrical Engineering, from the National School of Engineering in Tunis (ENIT), Tunisia and is currently working as a postdoctoral researcher under the supervision of Prof. Raj Mittra. Her research interests are focused on the design of a substrate integrated waveguide slot array for millimeter waves frequencies.

Mehri has been awarded the 2nd Prize of Students Paper Poster Competition of the IEEE Melecon in 2016.

Bandar Hakim is an Assistant Professor of Electrophysics at KAU. He received his Ph.D. degree in Electrophysics from the University of Maryland. He worked with the Medical Robotics Group at the École Polytechnique Fédérale de Lausanne in Switzerland, the Center for Devices and Radiological Health at the Food and Drug Administration in Washington, DC and the Neurology Department at Mount Sinai School of Medicine in the New York, NY. He served as an industrial consultant in the US, Switzerland and Germany.

Muntasir Sheikh received his B.Sc. from King Abdulaziz University, Saudi Arabia, in Electronics and Communications Engineering, M.Sc. in RF Communications Engineering from the University of Bradford, U.K., and Ph.D. from the University of Arizona, U.S.A.

Since then he has been teaching in the Electrical and Computer Engineering Dept. in KAU. His research interests are Antenna Theory and Design, Radar applications, and electromagnetic metamaterials.

Raj Mittra is a Professor in the Department of Electrical & Computer Science of the University of Central Florida in Orlando, FL., where he is the Director of the Electromagnetic Communication Laboratory. Prior to joining the University of Central Florida, he worked at Penn State as a Professor in the Electrical and Computer Engineering from 1996 through June, 2015. He also worked as a Professor in the Electrical and Computer Engineering at the University of Illinois in Urbana Champaign from 1957 through 1996, when he moved to the Penn State University. Currently, he also holds the position of Hi-Ci Professor at King Abdulaziz University in Saudi Arabia,

He is a Life Fellow of the IEEE, a Past-President of AP-S, and he has served as the Editor of the Transactions of the Antennas and Propagation Society. He won the Guggenheim Fellowship Award in 1965, the IEEE Centennial Medal in 1984, and the IEEE Millennium medal in 2000. Other honors include the IEEE/AP-S Distinguished Achievement Award in 2002, the Chen-To Tai Education Award in 2004 and the IEEE Electromagnetics Award in 2006, and the IEEE James H. Mulligan Award in 2011.

Mittra is a Principal Scientist and President of RM Associates, a consulting company founded in 1980, which provides services to industrial and governmental organizations, both in the U.S. and abroad.