

PATTERN DIVERSITY ANTENNAS FOR WIRELESS COMMUNICATION

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**CENTRE FOR APPLIED RESEARCH IN ELECTRONICS
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PATTERN DIVERSITY ANTENNAS FOR WIRELESS COMMUNICATION

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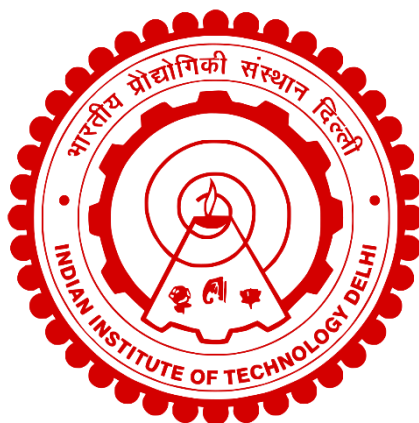
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Dedicated to Richard Dawkins

CERTIFICATE

This is to certify that the thesis titled, "**PATTERN DIVERSITY ANTENNAS FOR WIRELESS COMMUNICATION**", being submitted by **Ms. Swapna S** for the award of the degree of Doctor of Philosophy to the Centre for Applied Research in Electronics, Indian Institute of Technology Delhi, New Delhi, is a record of bonafide research work carried out by her under our guidance and supervision.

Ms. Swapna S has fulfilled the requirements for the submission of the thesis, which to our knowledge has reached the requisite standard. The results contained in the thesis have not been submitted in part or in full to any other university or institute for the award of any degree or diploma.

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ABSTRACT

The research findings presented in this thesis are primarily on the designs of pattern diversity antennas for 5 GHz Wireless Local Area Network (WLAN) access points. The novel antenna designs consist of two/three port antennas with equalized gain throughout the band and across the port. An FPC antenna design and an all dielectric superstrate that enhances the gain in the oblique incidence is proposed. 3-D printing technology is also used in antenna fabrication that helps to design complicated antenna structures. With the help of 3-D printing, a wideband antenna with a consistent peak gain for 20% of the antenna bandwidth was proposed. A brief description on these novel antenna design is as follows.

A multi-port pattern diversity antenna with a common aperture for 5 GHz WLAN applications is first proposed. The antennas resonate at 5.2 GHz with 10% or 540 MHz impedance bandwidth. The particular focus is to maintain uniform gain enhancement using a common aperture for the individual antennas. The first design is a two-port antenna system that provides a pattern diversity of 0° and $+90^\circ$. The proposed metamaterial structures shared by the antennas provide a 3.6 dB gain enhancement to realize a 10 dBi individual gain of the antennas. The second design is a three-port antenna system that provides a pattern diversity of $0^\circ, \pm 45^\circ$. The metamaterial structures enhance the gain by 3.4 dB for realizing a 10 dBi antenna gain. The gain enhancement for individual ports is equalized by strategically loading complementary transformed H-shaped Double Negative (DNG) resonator structures in the endfire due to localized changes in the refractive index. The front-to-back ratio of the antennas is also enhanced by 4 dB.

Three-port pattern diversity antennas with equal gain throughout the ports are proposed next. The first three-port design demonstrates a coaxial fed antenna system for WLAN access points. The antenna system consists of two dipoles and a patch that radiates at 5.2 GHz, with an impedance bandwidth of 150 MHz. The antennas are designed for pattern diversity in the broadside and endfire orientation with an individual gain of 4.5 dBi. The antenna gain is further enhanced to 6 dBi, after integration with unit-cell structures.

The gain enhancement for each antennas is achieved by strategically integrating reflective type and transmission type sub-wavelength structures for the two dipoles and the patch respectively. The antenna has an isolation of less than 26 dB throughout the band and across the ports for a port-to-port distance of 0.25λ . The second three-port design utilizes a partially reflective surface (PRS) with a Fabry-Perot cavity (FPC) for 5.2 GHz WLAN access points. The topology of the three-port coaxial-fed circular patch antennas provide an initial beam tilt of 15° . The PRS aperture, placed at a height of approximately $\lambda/2$, is designed to aid the antenna radiations at 0° , $+25^\circ$, and -25° , providing a 90° beam coverage. The impedance bandwidth of the antenna system is 2%, ranging from 5.16 GHz to 5.25 GHz (90 MHz bandwidth) with a gain of 10 dBi throughout the band and across the ports. The shaped PRS structure provides a gain enhancement of 4.5 dB. The mutual coupling between any two ports in the three-port antenna system is less than 20 dB for a port-to-port distance of 0.67λ .

Next, a four-port pattern diversity antenna with a 3-D printed all-dielectric superstrate for 5.2 GHz WLAN access points is proposed. The topology of four-port coaxial-fed circular patch antennas provides a beam tilt of $\pm 45^\circ$ and $\pm 15^\circ$ with an angular coverage of $\pm 60^\circ$. The beam gets tilted due to this unique topology and without the need for any additional phase shifting circuits. Then, a low-cost 3-D printed dielectric superstrate is designed to enhance and equalize the gain without compromising the beam tilt and polarization purity of individual antennas. The antenna module has an impedance bandwidth of 80 MHz (5.16 GHz - 5.24 GHz) for a gain of 9 dBi throughout the band and across the four ports. The dielectric superstrate provides a gain enhancement of 3.8 dB for antennas at the edges, and 5.4 dB gain enhancement for antennas at the center of the topology.

Finally, a wide-band directional cavity antenna is proposed. The design reports a low scanning loss for 20% antenna bandwidth and a wide 20% 1-dB gain bandwidth over the antenna beam scanning angle. The antenna operates in the 5 GHz band of IEEE 802.11 ac WLAN applications. A beam scanning of 20° is demonstrated by varying the height of a slider within the antenna cavity. The broadside peak gain of 9.6 dBi is maintained for 20%

of the antenna bandwidth with a gain reduction of only 0.3 dB throughout its operating frequency range. Besides, the scanning loss suffered by the antenna when scanning from the broadside to the maximum scanned angle is only 0.8 dB. The proposed scan performance is verified for a single element antenna and a two-element antenna array.

सार

इस थीसिस में प्रस्तुत शोध निष्कर्ष मुख्य रूप से 5 गीगाहर्ट्ज वायरलेस लोकल एरिया नेटवर्क (डब्ल्यूएलएएन) एक्सेस पॉइंट के लिए पैटर्न विविधता एंटेना के डजाइन पर हैं। नए एंटेना डजाइन में दो/तीन पोर्ट एंटेना होते हैं जो पूरे बैंड और पूरे पोर्ट में समान लाभ के साथ होते हैं। एक एफपीसी एंटीना डजाइन और एक सभी ढांकता हुआ सुपरस्ट्रेट जो तरछी घटना में लाभ को बढ़ाता है, प्रस्तावित है। 3-डी प्रिंटिंग तकनीक का उपयोग एंटीना निर्माण में भी किया जाता है जो जटिल एंटीना संरचनाओं को डजाइन करने में मदद करता है। 3-डी प्रिंटिंग की मदद से, एंटेना बैंडविड्थ के 20% के लिए लगातार शखर लाभ के साथ एक वाइडबैंड एंटीना प्रस्तावित किया गया था। इन उपन्यास एंटीना डजाइन पर एक संक्षिप्त विवरण इस प्रकार है।

5 गीगाहर्ट्ज (डब्ल्यूएलएएन) अनुप्रयोगों के लिए एक सामान्य एपर्चर के साथ एक बहु-पोर्ट पैटर्न विविधता एंटीना पहले प्रस्तुत किया जा रहा है। एंटेना 5.2 गीगाहर्ट्ज पर 10% या 540 मेगाहर्ट्ज प्रतबाधा बैंडविड्थ के साथ प्रतध्वनित होते हैं। विशेष ध्यान व्यक्तिगत एंटेना के लिए एक सामान्य एपर्चर का उपयोग करके समान लाभ वृद्ध को बनाए रखना है। पहला डजाइन एक दो-पोर्ट एंटेना सिस्टम है जो 0° और $+90^\circ$ की पैटर्न विविधता प्रदान करता है। एंटेना द्वारा साझा की गई प्रस्तावित मेटामटेरियल संरचनाएं एंटेना के 10 डीबीआई व्यक्तिगत लाभ का एहसास करने के लिए 3.6 डीबी लाभ वृद्ध प्रदान करती हैं। दूसरा डजाइन एक तीन-पोर्ट एंटेना सिस्टम है जो 0° , $\pm 45^\circ$ की पैटर्न विविधता प्रदान करता है। मेटामटेरियल संरचनाएं 10 डीबीआई एंटीना लाभ को साकार करने के लिए 3.4 डीबी तक लाभ बढ़ाती हैं। अलग-अलग बंदरगाहों के लिए लाभ वृद्ध को अपवर्तक सूचकांक में स्थानीय परिवर्तनों के कारण एंडफायर में रणनीतिक रूप से लोड किए गए पूरक रूपांतरित एच-आकार वाले डबल नेगेटिव (डीएनजी) रेजोनेटर संरचनाओं द्वारा बराबर किया जाता है। एंटेना के फ्रंट-टू-बैक अनुपात को भी 4 डीबी तक बढ़ाया गया है।

पूरे बंदरगाहों में समान लाभ वाले तीन-पोर्ट पैटर्न विविधता एंटेना अगले प्रस्तावित हैं। पहला थ्री-पोर्ट डजाइन डब्ल्यूएलएन एक्सेस पॉइंट्स के लिए एक समाक्षीय फेड एंटीना सिस्टम को प्रदर्शित करता है। एंटीना प्रणाली में दो द्विध्रुव और एक पैच होता है जो 5.2 गीगाहर्ट्ज पर विकिरण करता है, जिसमें 150 मेगाहर्ट्ज की प्रतबाधा बैंडविड्थ होती है। एंटेना को 4.5 डीबीआई के व्यक्तिगत लाभ के साथ ब्रॉडसाइड और एंडफायर ओरिएंटेशन में पैटर्न विविधता के लिए डजाइन किया गया है। यूनिट-सेल संरचनाओं के साथ एकीकरण के बाद, एंटीना लाभ को 6 डीबीआई तक बढ़ाया जाता है। प्रत्येक एंटीना के लिए लाभ वृद्ध क्रमशः दो द्विध्रुवों और पैच के लिए परावर्तक प्रकार और संचरण प्रकार उप-तरंग दैर्घ्य संरचनाओं को रणनीतिक रूप से एकीकृत करके प्राप्त की जाती है। 0.25λ की पोर्ट-टू-पोर्ट दूरी के लिए एंटीना में पूरे बैंड और बंदरगाहों के बीच 26 डीबी से कम का अलगाव है।

दूसरा श्री-पोर्ट डज़ाइन 5.2 गीगाहर्ट्ज़ डब्ल्यूएलएन एक्सेस पॉइंट्स के लिए फ़ैब्री-पेरोट कैविटी (एफपीसी) के साथ आंशक रूप से परावर्तक सतह (पीआरएस) का उपयोग करता है। श्री-पोर्ट कोएक्सियल-फेड सर्कुलर पैच एंटेना की टोपोलॉजी 15° का प्रारंभक बीम झुकाव प्रदान करती है। लगभग $\lambda/2$ की ऊंचाई पर स्थित पीआरएस एपर्चर को 90° बीम कवरेज प्रदान करते हुए 0° , $+25^\circ$, और -25° पर एंटीना विकिरणों की सहायता के लिए डज़ाइन किया गया है। एंटेना सिस्टम की प्रतबाधा बैंडविड्थ 2% है, जो 5.16 गीगाहर्ट्ज़ से 5.25 गीगाहर्ट्ज़ (90 मेगाहर्ट्ज़ बैंडविड्थ) के बीच है और पूरे बैंड और बंदरगाहों में 10 डीबीआई का लाभ है। आकार की पीआरएस संरचना 4.5 डीबी की वृद्ध प्रदान करती है। श्री-पोर्ट एंटेना सिस्टम में किसी भी दो पोर्ट के बीच आपसी युग्मन 0.67λ की पोर्ट-टू-पोर्ट दूरी के लिए 20 डीबी से कम है।

इसके बाद, 5.2 गीगाहर्ट्ज़ डब्ल्यूएलएन एक्सेस पॉइंट्स के लिए 3-डी प्रिंटेड ऑल-डाइलेक्ट्रिक सुपरस्ट्रेट के साथ चार-पोर्ट पैटर्न विविधता एंटीना प्रस्तावित है। फोर-पोर्ट कोएक्सियल-फेड सर्कुलर पैच एंटेना की टोपोलॉजी $+60^\circ$ के कोणीय कवरेज के साथ $\pm 45^\circ$ और $\pm 15^\circ$ का बीम झुकाव प्रदान करती है। इस अनूठी टोपोलॉजी के कारण और बिना किसी अतिरिक्त फेज शफ्टिंग सर्किट की आवश्यकता के बीम झुक जाती है। फिर, एक कम लागत वाला 3-डी प्रिंटेड डाइलेक्ट्रिक सुपरस्ट्रेट व्यक्तिगत एंटेना के बीम झुकाव और ध्रुवीकरण शुद्धता से समझौता किए बिना लाभ को बढ़ाने और बराबर करने के लिए डज़ाइन किया गया है। एंटेना मॉड्यूल में 80 मेगाहर्ट्ज़ (5.16 गीगाहर्ट्ज़ – 5.24 गीगाहर्ट्ज़) की प्रतबाधा बैंडविड्थ है, जो पूरे बैंड में और चार बंदरगाहों पर 9 डीबीआई के लाभ के लिए है। ढांकता हुआ सुपरस्ट्रेट किनारों पर एंटेना के लिए 3.8 डीबी की वृद्ध प्रदान करता है, और टोपोलॉजी के केंद्र में एंटेना के लिए 5.4 डीबी लाभ वृद्ध प्रदान करता है।

अंत में, एक वाइड-बैंड दिशात्मक गुहा एंटीना प्रस्तावित है। डज़ाइन 20% एंटीना बैंडविड्थ के लिए कम स्कैनिंग हानि और एंटीना बीम स्कैनिंग कोण पर व्यापक 20%1 –डीबी लाभ बैंडविड्थ की रिपोर्ट करता है। एंटीना आईईईई 802.11 एसी डब्ल्यूएलएन अनुप्रयोगों के 5 गीगाहर्ट्ज़ बैंड में संचालित होता है। एंटीना गुहा के भीतर स्लाइडर की ऊंचाई को बदलकर 20° की बीम स्कैनिंग प्रदर्शित की जाती है। 9.6 डीबीआई के व्यापक शिखर लाभ को एंटेना बैंडविड्थ के 20%1 के लिए बनाए रखा जाता है, इसके पूरे ऑपरेटिंग फ्रीक्वेंसी रेंज में केवल 0.3 डीबी की कमी के साथ। इसके अलावा, ब्रॉडसाइड से अधिकतम स्कैन किए गए कोण पर स्कैन करते समय एंटीना को होने वाली स्कैनिंग हानि केवल 0.8 डीबी है। प्रस्तावित स्कैन प्रदर्शन को एकल तत्व एंटीना और दो-तत्व एंटीना सरणी के लिए सत्यापित किया गया है।

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