DESIGN OF ANTENNAS FOR MILLIMETER WAVE
5G APPLICATIONS

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DESIGN OF ANTENNAS FOR MILLIMETER WAVE 5G APPLICATIONS

by

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Submitted in fulfillment of the requirements of the degree of Doctor of Philosophy to the

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To my mother and father
CERTIFICATE

This is to certify that the thesis entitled, “DESIGN OF ANTENNAS FOR MILLIMETER WAVE 5G APPLICATIONS”, being submitted by Mr. Zamir Ahmad Wani 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 him under our guidance and supervision.

Mr. Zamir Ahmad Wani has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The results contained in this 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 work presented in the thesis is primarily focussed on the design of millimeter wave 5G antennas. Based upon the requirements for the implementation of millimeter wave wireless communication systems, four antenna topologies are presented to counter the issues at millimeter wave 5G communication.

First, a three-element quasi Yagi-Uda antenna array with printed metamaterial surface generated from the array of uniplanar capacitively-loaded loop (CLL) unit-cells printed on the substrate operating in the band 25-30 GHz with 18dB isolation between the ports is presented. The measured peak gain of 11dBi is achieved for all the antenna elements. The three antenna elements radiate in three different directions and cover a radiation scan angle of 64°. This wide angular coverage would be useful to maintain the communication link between the transmitter and receiver.

A four port mmWave multi-input-multi-output (MIMO) antenna with a small size of 11.3 mm × 31 mm is presented. Each antenna element has an end-fire gain of about 10dBi by employing an array of metamaterial unit cells. The isolation between the antenna elements with edge to edge separation < \lambda_0/5.5 at 28 GHz is enhanced by trimming the corners of the rectangular metamaterial region along with a ground stub between antennas. The prototype antenna covers 26-31 GHz band with return loss > 10 dB and isolation > 21 dB. The second design is two port MIMO antenna for 28 GHz band which has dual-beam radiation for each port. The proposed antenna can cover a large radiation area owing to pattern diversity with radiation along \phi = 60° and \phi = 120° when port 1 is excited and along \phi = 150° and \phi = 210° when port 2 excited.

A new technique of electromagnetic wave routing using single-epsilon-high anisotropic media to generate dual-beam radiation at 28-GHz band. This technique is implemented using SIW
dipole antenna loaded with the single-epsilon-high anisotropic media realized using modified asymmetric electric-LC (ELC) metamaterial unit cell loaded vertically in front of the radiator. The effect of the media thickness loaded to the antenna is investigated and dual-beam radiation in the frequency band 26-31 GHz is obtained by choosing the appropriate number of ELC-slabs. The measured results confirm 26-31 GHz impedance bandwidth and dual-beam radiation directed along 50° and 130° with 8dBi beam peaks.

In the last part, mmWave lens antennas are presented for gain enhancement and multibeam MIMO applications. A simple technique of phase correction for gain enhancement using stacked dielectric slabs atop a microstrip patch antenna for 28-GHz application is presented. This arrangement of dielectric slabs enhances the gain of the patch antenna by 4.1dB when loaded to the antenna. Further, a novel technique employing high and low epsilon (HLE) biaxial anisotropic media to enhance the gain of any linearly polarized antenna is presented. The realization of the HLE media using metamaterials is presented which results in a flat 3D lens having $1.9\lambda^2_0$ physical area. The HLE lens has an aperture efficiency of 99% when loaded to a patch antenna with a broadside thickness of $0.6\lambda_0$ at 28 GHz. To further validate the performance, metamaterial lens is loaded to the SIW fed aperture coupled patch antenna, a realized peak gain of 13.6dBi is achieved with 6% 1-dB gain bandwidth which confirms the applicability of this gain enhancement technique for wider frequency range than the zero-index media/resonant cavity techniques. Lastly, a thin planar metasurface (MS) lens is presented for mmWave MIMO applications. The designed MS lens is polarization insensitive and has a peak aperture efficiency of 24.7% when loaded to a three-port antenna array. The MS lens loaded to three antenna array results in a peak gain of 20.2dBi and beam scanning from $-15^\circ$ to $+15^\circ$ is achieved.
सारांश

थीसिस में प्रस्तुत शोध कार्य मुख्य रूप से मिलीमीटर वेब 5G एंटेना के डिजाइन पर केंद्रित है। मिलीमीटर वेब वायरलेस संचार प्रणालियों के कार्यन्वयन की आवश्यकताओं के आधार पर, चार एंटीना टोपोलॉजी प्रस्तुत की गयी हैं।

सबसे पहले, एक तीन-एलिमेंट अर्थ यादि उद्दा एंटीना ऐसे प्रिंटेड मेटामेरियल सर्फेस से बनाया गया है, जो कि 25 से 30 गीगाहर्टज के बैंड में संचालित होगा और साथ में 18 डीबी का पोर्ट इसोलअश्युन होगा। सब एंटीना एलिमेंट्स में मापा हुआ गेन 11 डीबी प्राप्त हुआ है। तीन एंटीना एलिमेंट्स , तीन अलग-अलग दिशाओं में रेडिएट करते हैं और 64 डिग्री के रेडिएशन रेंज एंगल को कवर करते हैं। यह विस्तृत कोणीय कवरेज ट्रांसमीटर और रिसीवर के बीच संचार लिंक को बनाई रखने के लिए उपयोगी होगा।

एक कॉम्पैक्ट आकार के साथ एक चार पोर्ट मिलीमीटर वेब मल्टी-इनपुट-मल्टी-आउटपुट एंटीना प्रस्तुत किया गया है। प्रत्येक एंटेना एलिमेंट में मेटामेरियलअल यूनिट सेल की एक ऐसे को उपयोग करके लगभग 10 डीबी का गेन एंड-फायर दिशा में प्राप्त किया गया है। 28 गीगाहर्टज पर एंटीना एलिमेंट्स के बीच के आइसोलेशन को, एक प्रायोंड स्टब के साथ मेटामेरियल के कोणों को ट्रिम करके बढाया गया है। प्रोटोटाइप एंटीना में 26-31 गीगाहर्टज बैंड है जिसमें रिटर्न लॉस 10 डीबी से और आइसोलेशन 21 डीबी से अधिक है। दूसरा डिजाइन 28 गीगाहर्टज बैंड के लिए दो पोर्ट मीमो एंटीना है जिसमें प्रत्येक पोर्ट के लिए दो बीम हैं। प्रस्तावित एंटीना 60 डिग्री और 120 डिग्री के साथ साथ 150 और 210 डिग्री में रेडिएट करने के कारण एक बड़े क्षेत्र को कवर कर सकता है।

28-गीगाहर्टज बैंड पर दो बीम उत्पन्न करने के लिए एकल-एसिलोन-उच्च अनिसोट्रोपिक मीडिया का उपयोग करते हुए इलेक्ट्रोमाग्नेटिक रूटिंग की एक नई तकनीक का उपयोग किया गया है। यह तकनीक एसआईडब्लू फेड एंटेना के साथ लोड की गई एकल-एसिलोन-उच्च अनिसोट्रोपिक मीडिया के साथ संशोधित एसिमिट्रिक ईलासी मेटामेरियल यूनिट सेल का उपयोग करके रेडिएट करके सामने लंबवत रखकर लागू की गई है। एंटीना में लोड की गई मीडिया मोटाई के प्रभाव की जांच की गयी है और आवृत्ति बैंड 26-31 गीगाहर्टज में ड्यूल बीम रेडिएशन को प्राप्त करने हेतु ईलासी-स्लैब की उचित संख्या का प्रयोग किया गया है। मापा परिणाम के अनुसार 26-31 गीगाहर्टज इमिडेंस बैंडविद्ध और ड्यूल बीम डायरेक्शन 50 डिग्री और 130 डिग्री पे प्राप्त हुआ है, जिसका गेन 8 डीबी है।
अंतिम भाग में, मिलिमीटर वेब लेंस एंटीना का प्रयोग गेन में वृद्धि तथा मल्टीबीम मीमो अनुप्रयोगों के लिए प्रस्तुत किया गया है। 28-गीगाहर्ट्ज़ एप्लिकेशन के लिए एक माइक्रोस्ट्रिप पैच एंटीना के ऊपर स्टैक्ड दलेविक्ट्रॉक स्लैब का उपयोग करके लाभ बढ़ाने के लिए एक सरल तकनीक प्रस्तुत की गई है। स्टैक्ड दलेविक्ट्रॉक स्लैब की वह व्यवस्था एंटीना पर लोड करने पर गेन में 4.1 डीबी तक की वृद्धि हुई है। इसके अलावा, किसी भी लीनियर पोलरिजेशन एंटीना का गेन को बढ़ाने के लिए उच्च और निम्न एप्लिकेशन व्याकिसिअल एनिसोट्रोपिक मीडिया उपयोग किया गया है। मेटामटेरिअल का उपयोग करते हुए उच्छ निम्न एप्लिकेशन मीडिया की प्रस्तुत किया गया है। जिसके परिणामस्वरूप एक फ्लैट 3 डी लेंस बनाया गया है, जिसमें 1.9 लेम्ब्डा वर्ग भौतिक क्षेत्र है। 28 गीगाहर्ट्ज़ पर 0.6 लेम्ब्डा की मोटाई के साथ पैच एंटीना पर लोड होने पर व्याकिसिअल लेंस की 99 प्रतिशत एपर्चर दक्षता है। प्रदर्शन को और अधिक मान्य करने के लिए, अपर्चर कपल्ड पैच पर मेटामटेरिअल लेंस लोड किया गया है, 13.6 डीबी का गेन, 6 प्रतिशत 1-डीबी गेन बैंडविद्ध के साथ हासिल किया गया है, जो व्याक आवृत्ति रेंज की तुलना में इस लाभ वृद्धि तकनीक की प्रमाणित की पुष्टि करता है। अंत में, एक तरल प्लानर मेटासुरफेस लेंस को मिलिमीटर वेब मीमो अनुप्रयोगों के लिए प्रस्तुत किया गया है। डिजाइन किया गया एमएस लेंस पोलरीजेशन असंवेदनशील है और तीन-पोर्ट एंटीना ऐरे में लोड होने पर 24.7 प्रतिशत की शिखर एपर्चर क्षमता है।
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