

IN BAND FULL DUPLEX ANTENNA DESIGNS WITH INTEGRATED DECOUPLING TECHNIQUES

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IN BAND FULL DUPLEX ANTENNA DESIGNS WITH INTEGRATED DECOUPLING TECHNIQUES

by

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Dedicated to the loving memory of my grandparents,

Choudhary Ram Kishan

ℰ

Smt. Ajmero Devi

Certificate

This is to certify that the thesis entitled “**IBFD ANTENNA DESIGNS WITH INTEGRATED DECOUPLING TECHNIQUES**”, submitted by **Miss. Rupa Laller** to the Centre for applied Research in Electronics, Indian Institute of Technology Delhi, New Delhi, India, for the award of the degree of **Doctor of Philosophy**, is a record of the original, bonafide research work carried out by her under our supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

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 to the best of our knowledge.

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Abstract

Full-duplex mode is the future of modern wireless communication systems because of its ability to transmit and receive simultaneously. But the mutual coupling between the transmit (Tx) and receive (Rx) antennas of the same node is the biggest challenge for an in-band full-duplex system, also known as self-interference. This thesis presents the design and development of highly isolated, co-polarized, in-band, full-duplex planar antennas. In this dissertation, different simple and effective techniques are introduced for self-interference cancellation (SIC). The proposed decoupling schemes are formulated in a manner that they do not deteriorate the antenna's radiation performance.

In the first work, a dual-substrate-layer-based highly isolated in-band full-duplex antenna is introduced. The decoupling configuration consists of two resonated microstrip lines placed on the 2nd layer of substrate (beneath the patch) and a rectangular slot in the ground plane. The decoupling mechanism is illustrated based on mode cancellation theory. The feasibility of the reported method for array applications is also demonstrated.

One, a compact and highly isolated in-band full-duplex antenna is proposed. This work introduces the concept of neutralizing the electric field coupling between the adjacent edges of the antennas. This concept is validated and applied to increase the isolation between the Tx and Rx ports of the in-band full-duplex antenna. Furthermore, a method is presented to increase the antenna's bandwidth without compromising its isolation level. Additionally, the usability of the proposed work for the array is examined. The antenna is simple, compact, and has high isolation enhancement & bandwidth, which makes it a good candidate for the IBFD applications.

The capacity of in-band full-duplex antennas can be enhanced by using them for integrated sensing and communication applications (ISAC), and it can be extended to high gain by placing the antennas in an array configuration. One such possibility is explored by designing an in-band full-duplex array at mmWave frequencies for the array configurations. The coupled wave at the Rx antenna is cancelled by dividing the Tx wave into two parts of equal amplitude and 180° phase shift. In the presented array, the Tx and Rx ports are highly isolated and each port has a dual beam function (one of each beam for communication and sensing).

Furthermore, the coupling is also a major challenge for antenna arrays, specially for the compact configurations where antennas are placed in a very close proximity. So, the decoupling methods are discussed for both E-plane and H-plane array configurations.

सारांश

पूर्ण-डुप्लेक्स प्रणाली आधुनिक वायरलेस संचार तकनीक का भविष्य मानी जाती है, क्योंकि इसमें एक ही समय तथा एक ही आवृत्ति पर संकेतों का प्रेषण (ट्रांसमिट) और ग्रहण (रिसीव) संभव होता है। किन्तु, एक ही नोड के ट्रांसमिट एवं रिसीव एंटेना के मध्य उत्पन्न होने वाला पारस्परिक युग्मन (म्यूचुअल कपलिंग), जिसे स्व-अवरोधन (सेल्फ-इंटरफेरेंस) कहा जाता है, इन-बैंड फुल-डुप्लेक्स प्रणालियों की सबसे बड़ी चुनौती है। प्रस्तुत शोध-प्रबंध में उच्च पृथक्करण (हाई आइसोलेशन) वाले सह-ध्रुवित (को-पोलराइज़्ड) इन-बैंड फुल-डुप्लेक्स प्लानर एंटेना के अभिकल्पन एवं विकास का अध्ययन किया गया है। इस शोध में स्व-अवरोधन निरस्तीकरण (सेल्फ-इंटरफेरेंस कैंसलेशन) हेतु विभिन्न सरल एवं प्रभावी तकनीकों का प्रतिपादन किया गया है। प्रस्तावित डिक्प्लिंग तकनीकों को इस प्रकार विकसित किया गया है कि वे एंटेना के विकिरण गुणों (रेडिएशन प्रदर्शन) को प्रभावित न करें।

प्रथम कार्य में द्वि-सबस्ट्रेट-परत आधारित एक उच्च पृथक्करण युक्त इन-बैंड फुल-डुप्लेक्स एंटेना प्रस्तुत किया गया है। डिक्प्लिंग संरचना में दो अनुनादी (रेज़ोनेट) माइक्रोस्ट्रिप रेखाएँ सबस्ट्रेट की दूसरी परत पर, अर्थात् पैच के नीचे स्थापित की गई हैं तथा ग्राउंड-प्लेन में एक आयताकार स्लॉट निर्मित किया गया है। डिक्प्लिंग तंत्र की व्याख्या मोड-निरस्तीकरण सिद्धांत (मोड कैंसलेशन थ्योरी) के आधार पर की गई है। साथ ही, इस तकनीक की एरे संरचनाओं में उपयोगिता भी प्रदर्शित की गई है।

इसके पश्चात्, एक संक्षिप्त (कॉम्पैक्ट) एवं उच्च पृथक्करण युक्त इन-बैंड फुल-डुप्लेक्स एंटेना प्रस्तावित किया गया है। इस कार्य में एंटेना के समीपस्थ किनारों के मध्य उत्पन्न विद्युत-क्षेत्र युग्मन (इलेक्ट्रिक फील्ड कपलिंग) को निरस्त करने की अवधारणा प्रस्तुत की गई है। इस सिद्धांत को सत्यापित करते हुए ट्रांसमिट एवं रिसीव पोर्ट्स के मध्य पृथक्करण में उल्लेखनीय वृद्धि प्राप्त की गई है। इसके अतिरिक्त, एंटेना के पृथक्करण स्तर को प्रभावित किए बिना उसकी बैंडविड्थ में वृद्धि करने की विधि भी प्रस्तुत की गई है। साथ ही, प्रस्तावित संरचना की एरे विन्यासों में उपयोगिता का भी परीक्षण किया गया है। यह एंटेना सरल, संक्षिप्त तथा उच्च पृथक्करण एवं विस्तृत बैंडविड्थ युक्त होने के कारण इन-बैंड फुल-डुप्लेक्स अनुप्रयोगों के लिए अत्यंत उपयुक्त सिद्ध होता है।

इन-बैंड फुल-डुप्लेक्स एंटेना की क्षमता को एकीकृत संवेदन एवं संचार (इंटीग्रेटेड सेंसिंग एंड कम्युनिकेशन) अनुप्रयोगों में उपयोग करके और अधिक बढ़ाया जा सकता है। साथ ही, एंटेना को एरे संरचना में विन्यस्त कर उच्च लाभ (हाई गेन) भी प्राप्त किया जा सकता है। इसी संभावना का अध्ययन मिलीमीटर-वेव आवृत्तियों पर इन-बैंड फुल-डुप्लेक्स एरे के अभिकल्पन द्वारा किया गया है। रिसीव एंटेना पर प्राप्त युग्मित तरंग (कपल्ड वेव) को ट्रांसमिट तरंग को समान आयाम एवं 180° चरण-अंतर वाली दो तरंगों में विभाजित कर निरस्त किया गया है। प्रस्तुत एरे में ट्रांसमिट एवं रिसीव पोर्ट्स के मध्य उच्च पृथक्करण प्राप्त होता है तथा प्रत्येक पोर्ट द्वि-किरण (ड्यूल बीम) कार्यक्षमता प्रदान करता है, जिसमें एक किरण संचार तथा दूसरी संवेदन (सेंसिंग) हेतु प्रयुक्त होती है।

इसके अतिरिक्त, युग्मन (कपलिंग) एंटेना एरे प्रणालियों के लिए भी एक प्रमुख चुनौती है, विशेषकर उन संक्षिप्त विन्यासों में जहाँ एंटेना अत्यंत निकट दूरी पर स्थित होते हैं। अतः, इस शोध में ई-प्लेन तथा एच-प्लेन दोनों प्रकार की एरे संरचनाओं हेतु डिक्प्लिंग तकनीकों का विस्तारपूर्वक अध्ययन एवं विकास किया गया है।

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Abbreviations

BW	B andwidth
CM	C ommon M ode
CST	C omputer S imulation T echnology
D	D imensional
dB	D ecibel
dB_i	decibels relative to I sotropic
DGS	D efected G round S tructure
DM	D ifferential M ode
DS	D ecoupling S tructure
E-plane	E lectric field-plane
EBG	E lectromagnetic B and G ap
ECD	E quivalent C ircuit D iagram
FBW	F ractional B andwidth
FBR	F ront-to- B ack R atio
FD	F ull D uplex
GHz	G iga H ertz
H-plane	M agnetic field-plane
IBFD	I n B and F ull D uplex
IE	I solation E nhancement
mmWAVE	m illi m eter W ave
NFC	N ear F ield C ancellation
R_x	R eceiver
SIC	S elf I nterference C ancellation
SI	S elf I nterference
SW	S urface W aves
T_x	T ransmitter

Symbols

c	speed of light in vacuum
ϵ	dielectric constant/permittivity
Z	impedance
ω	angular frequency
λ	wavelength
λ_o	free space wavelength
C	Capacitance
L	inductance