Modelling of carbon nanotubes with different structures at millimeters wavelength antennas

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Ag	Silver
B-SWNTs	Bundle of Single-Walled Carbon Nanotubes
CB-PSM	Circular bundle of the proposed structure material
CB-SWNTs	Circular bundle of single-walled carbon nanotubes
CB-SWNT	Circular bundle of the single-walled carbon nanotube
CNTs	Carbon Nanotubes
CST (MWS)	Computer Software Toll (Microwave Studio)
D	Diameter
DWNT	Double-Walled Carbon Nanotubes
E-BM	Equivalent bulk material
EDS	Energy dispersive spectroscopy
EMETS	Electromagnetic Engineering Tools Solver
EMG	Electromagnetic
GHz	Gigahertz
HFSS	High frequency structural simulator
HTEM	High-resolution transmission electron microscopy
IR	Infrared
MD	Molecular Dynamic
MWNT	Multi-Walled Carbon Nanotubes
NFI	Normalized Fixed Impedance
Ni	Nickel
NSTM	Nano solid tube material

NWR	Nano-wire
PEC	Perfect metal
PMS	Proposed material structure
PSM-rod	Rod of the proposed structure material
RF	Radio frequency
SCM	Single conductor model
SiO2	Silicon dioxide
SMA-OPL	Simple matching approach based on optimization loop
SnO2	Tin Oxide
SWNTs	Single-Walled Carbon Nanotubes
SWNTs-DA	Single-Walled Carbon Nanotubes Dipole Antenna
SWNT-GR	SWNT coated by thin layer of graphite material
TEM	Transmission electron microscopy
TEOS	Tetraethoxysilane
THz	Terahertz
TL	Transmission line
TRF	Transformation factor
XRD	X-ray diffraction
C	Carbon atom

LIST OF SYMBOLS

m, n	Integers
K	Relative position vector
a_1, a_2	Lattice basis vectors
r	Radius of SWNT
b	Interatomic distance in graphene sheet
σ_{SWNT}	Surface conductivity of the armchair-SWNT
e	Electron charge
h	Reduced Plank's constant
V_f	Fermi velocity of CNT
v	Phenomenological relaxation frequency
T	Temperature in kelvin
w	Angular frequency
$\sigma_{SWNT,r}$	Real part of SWNT surface conductivity
$\sigma_{SWNT,i}$	Imaginary part of SWNT surface conductivity
ε_c	Relative complex permittivity of SWNT
ε'	Real part of the relative complex permittivity of SWNT
ε''	Imaginary part of the relative complex permittivity of SWNT
$\tan\delta$	Loss tangent of CNTs
L	Length of SWNT dipole antenna
$Z_{in,SWNT}$	Impedance of SWNT
R_s	Quantum resistance of SWNT
ζ_s	Kinetic inductance of SWNT

R_{sB}	Quantum resistance of B-SWNT
ζ_{sB}	Kinetic inductance of B-SWNT
BW_{CNT}	Bandwidth of CNTs-dipole antenna
f_l	Lower frequency limit
f_u	Upper frequency limit
f_c	Central frequency
FB_{CNT}	Fractional bandwidth of CNT
RF-cct	Radio frequency circuit
C_{ES}	Electrostatic capacitance
CQ	Quantum capacitance value
F_r	Resonant frequency
λ	Wavelength
V_P	Phase velocity
λ	Wavelength
λ_P	Plasmon wave length
λ_o	Free-space wave length
c	Speed light in a vacuum
S_r	Velocity factor
K^o	Free space wave vector
K_P	Plasmon wave vector
$\varepsilon_{r,med}$	Relative permittivity of dielectric medium
μ_{med}	Magnetic permeability of dielectric medium

σ_{med}	Conductivity of dielectric medium
L_B	Length of the bundle
L_S	Length of the SWNT
Δ	Lattice constant
R_B	Radius of B-SWNT
N	Number of SWNTs in the bundle
Nx	Number of SWNTs that formed the outer side of the bundle
Z_{bundle}	B-SWNTs impedance per length
Z (z, w)	General distribution impedance
I (z, w)	Electric current that pass through SWNT
Ez(z, w)	Electric field that applied along z-axis
Z_{SW} (z, w)	Surface impedance of the SWNT
Z_{equvl}	Linear distributed impedance of equivalent NSTM
σ_{equvl}	Equivalent conductivity of NSTM
K	Uniform surface current density
J	Current density of an equivalent NSTM
I	Line current density of NSTM
σ_{Bulk}	Bulk conductivity
N^D	Number of electrons per (m^3)
m_e	Mass of electron
N_{eq}	Number of electrons per (m^3) of SWNT
w_p	Plasma frequency
w_{PSW}	SWNTs plasma frequency

σ_{bundle}	Equivalent conductivity of B-SWNTs
σ_{scalar}	Scalar matrix function
I_d	Identity matrix
C_{SWNT}	Cross-section area of individual SWNT (circumference of SWNT)
A_B	Cross-section area of the bundle
σ_{SCM}	Equivalent conductivity of SCM
ε_{B}	Complex permittivity of B-SWNT
w_{PB}	Plasma frequency of B-SWNT
v_B	Phenomenological relaxation frequency of B-SWNT
$N_{eq,B}$	Number of electrons per unit volume for the bundle
$\varepsilon_B^{'}$	Real part of the complex permittivity of the bundle
$\varepsilon_B^{''}$	Imaginary part of the complex permittivity of the bundle
d	Feed gap of dipole antenna
t	Average thickness layer
$\varepsilon_G^{'}$	Real part of complex permittivity for graphite material
$\varepsilon_G^{''}$	Imaginary part of complex permittivity for graphite material
$\sigma_{\text{Structure}}$	effective conductivity of the proposed structure (SWNT coated by other different materials)
σ_{coat}	Conductivity of a selected coating material
A	Average radial cross-section area of coating material

$W_{P,struct}$	Plasma frequency of PSM
v_{struct}	Phenomenological relaxation frequency of PSM
$\varepsilon'_{Structure}$	Real part of complex permittivity of the PSM
$\varepsilon''_{Structure}$	Imaginary part of the complex permittivity of the PSM
N^{D}_{coat}	Number of electrons per (m^3) of the coating material
v_{coat}	Relaxation frequency of the coating material
$\sigma_{\text{E-BM}}$	Effective conductivity of the equivalent bulk material
L_{psm}	Length of PSM dipole antenna
R_{psm}	Radius of PSM dipole antenna
Rq_{psm}	Quantum resistance of the PSM
ζq_{psm}	Quantum inductance of the PSM
$Z_{in,PSM\text{-}rod}$	Input impedance of the PSM-rod dipole antenna
$Z_{\text{in,CB-PSM}}$	Input impedance of the CB-PSM
R_{ZBPSM}	Quantum resistance of PSM
ζ_{CBPSM}	Quantum inductance of PSM
DL	Length of copper dipole antenna
R_{cu}	Radius of copper dipole antenna
S_{11}	S_{11} parameters (reflection coefficient)

Pemodelan Tiub Nano Berdinding-Tunggal dengan Struktur Berbeza pada Antena Panjang Gelombang Milimeter

ABSTRAK

Perkembangan teknologi yang pesat dalam pelbagai bidang dan aplikasi telah membawa kepada kemunculan keperluan segera untuk menentukan bahan-bahan terbaru bagi merekabentuk dan pelaksanaan antena moden yang berciri saiz yang kecil, tenaga yang rendah, yang mana memerlukan kadar pemindahan data yang tinggi, julat frekuensi yang tinggi, fleksibiliti yang tinggi untuk menukarkan frekuensi operasi disebabkan proses yang mudah, jangka hayat yang panjang, dan kecekapan yang boleh diterima. Berdasarkan ciri-ciri ini, bahan-bahan yang sesuai untuk merekabentuk antena dengan ciri-ciri yang luar biasa dan unik serta tahan lama seiring dengan perubahan masa atau alam sekitar adalah diperlukan. Oleh itu, matlamat utama kajian ini ialah untuk mengemukakan bahan-bahan yang mempunyai ciri-ciri yang baik serta berupaya untuk memenuhi permintaan pembangunan teknologi yang berkembang pesat dalam aplikasi antena. Bahan-bahan asas yang dicadangkan di dalam kerja-kerja ini adalah berdasarkan sifat-sifat dan strukturnya bagi tiub nano karbon – *Carbon Nanotubes*(CNTs) dan bahan komposit tiub nano karbon. Kajian ini juga bertujuan untuk menganggarkan tingkah laku elektromagnet (EM) pada bahan-bahan ini melalui alat penyelesaian kejuruteraan CST (MWS) untuk tujuan reka bentuk antena dan aplikasi. Oleh itu, untuk mencapai matlamat ini, analisis matematik untuk bahan-bahan ini dilakukan dalam usaha untuk mengira parameter-parameter penting. Tambahan lagi, di dalam kerja-kerja ini, dua pendekatan pemodelan dibentangkan untuk kedua-dua CNTs berdinding-tunggal –*Single-Walled* (SWNTs) dan seberkas – *Bundle of* SWNTs (B-SWNTs). Di mana, model yang sama dengan bahan tiub nano-pepejal – *Nano-Solid Tube Material* (NSTM) digunakan untuk personafikasi SWNTs dan model yang sama dengan model konduktor pepejal – *Solid Conductor Model* (SCM) digunakan untuk personafikasi B-SWNTs. Oleh itu, pendekatan pemodelan yang dibentangkan dalam kajian ini memberi manfaat kepada penganggaran parameter EM antena dwikutub yang direka berdasarkan bahan-bahan ini. Menariknya, model antena dwikutub digunakan untuk mengkaji sifat-sifat EM pada bahan-bahan ini dan model-model sepadan. Proses pengesahan pendekatan pemodelan yang dibentangkan dicapai berdasarkan perbandingan yang menyeluruh bagi model-model ini dengan kerja-kerja asal yang berkaitan. Selepas itu, struktur bahan yang dicadangkan – *Proposed Structured Material* (PSM) berdasarkan bahan SWNTs itu dikemukakan untuk memperbaiki tingkah laku EM pada antena SWNTs dwikutub pada frekuensi rendah di bawah 100 GHz, terutama di dalam julat frekuensi (40-100) GHz. PSM telah dibina dari SWNT dan disalut dengan bahan lain. Penambahbaikkan kepada antena ini termasuk meningkatkan jalur frekuensi, kecekapan dan meningkatkan faktor pecahan jalur lebar, kecekapan radiasi, keupayaan untuk memancarkan gelombang EM pada frekuensi rendah di bawah 100 GHz serta meningkatkan pemindahan kadar data, dan sifat-sifat mekanikal. Antena dwikutub yang menggunakan bahan struktur yang dicadangkan direka bentuk dan dilaksanakan melalui CST (MWS), berdasarkan pendekatan model bahan pukal bersamaan – *Equivalent-Bulk Model* (E-BM). Sifat-sifat EM pada seberkas rod PSM (CB-PSM) akan dibentangkan dan dibandingkan dengan B-SWNTs yang sepadan berdasarkan konfigurasi antena dwikutub. Dalam tesis ini, semua antena dwikutub yang dibentangkan beroperasi dalam julat panjang gelombang milimeter untuk aplikasi yang berbeza. Isu galangan masukan yang sepadan untuk antena dwikutub SWNTs dan B-SWNTs juga dibincangkan bagi menangani isu ini. Sebagai tambahan, isu ini juga dibincangkan bagi antena dwikutub komposit SWNTs. Hasilnya, ia dipercayai bahawa kerja ini akan memberi inspirasi kepada jalan baru dalam penyiasatan dan penyampaian bahan-bahan baru untuk reka bentuk dan pelaksanaan antena pada masa hadapan. Begitu juga, penemuan daripada kajian ini dijangka boleh dijadikan asas awal bagi penyelidik lain untuk menawarkan dan menganalisa pelbagai bahan antena yang memberi sumbangan ketara kepada system komunikasi generasi seterusnya.

Modelling of Carbon Nanotubes with Different Structures at Millimetres Wavelength Antennas

ABSTRACT

The accelerated technological development in different fields and applications led to the emergence of an urgent need to present new materials for the design and implementation of modern antennas which are characterized by upgrade characteristics. These characteristics need to have the required materials for designing these antennas with remarkable properties that have durable despite the time or environment changes. Therefore, the main aim of this research is to present the materials which have good properties as well as have the ability to meet the required demands of the rapidly growing technological development in antenna applications. The basic materials proposed in this work are based on the carbon nanotubes (CNTs) properties and their structures as well as the carbon nanotubes composite materials. The problem statement of this research is present for the first time adequate modelling approaches for different CNTs structures and proposed a new material structure for antenna applications. This research also aims to estimate the electromagnetic (EM) behaviour of these materials through CST (MWS) for the purpose of antenna design and applications. Therefore, to achieve this aim, the mathematical analysis for these materials are done in order to compute their important parameters. Moreover, in this work, two modelling approaches are presented for both single-walled CNTs (SWNTs) and bundle of SWNTs (B-SWNTs). Where, the equivalent nano-solid tube material (NSTM) model is utilized for the personification of the SWNTs and the equivalent solid conductor model (SCM) for the personification of the B-SWNTs. Hence, these modelling approaches presented in this study are indicate to benefit the estimation of the EM parameters of the dipole antennas that are designed based on these materials. Interestingly, the dipole antenna model is employed for studying the EM properties of these materials and their corresponding models. The validation process of the presented modelling approaches is achieved based on a comprehensive comparison for these models with the corresponding original related work. Thereafter, the proposed structure material (PSM) based on the SWNTs material is presented to improve the EM behaviour of the SWNTs dipole antennas at frequencies lower than 100 GHz, especially in a frequency range (40-100) GHz. The PSM was constructed from SWNT coated by other materials. The improvement of these antennas included increasing the frequency band, efficiency and enhancing the fractional bandwidth factor, radiation efficiency, ability to radiate the EM wave at frequencies lower than 100 GHz as well as increasing the transfer of data rate, and mechanical properties. The dipole antenna of the proposed structure material will be designed and implemented through CST (MWS), based on an equivalent bulk material (E-BM) modelling approach. The EM properties of bundle of the PSM rod (CB-PSM) will be presented and compared with the corresponding B-SWNTs based on dipole antenna configuration. In this thesis, all presented dipole antennas are operated within millimetre wavelength range for different applications. The matching input impedance issue for the SWNTs and B-SWNTs dipole antenna are also discussed in order to mitigate this issue. Additionally, this issue is discussed for the SWNTs composite dipole antenna. As a result, it is believed that this work will be inspired to new avenues of inquiry and presentation of new materials for the design and implementation of the antennas in the future. Likewise, the findings from this research are expected to provide an initial basis for other researchers to offer and analyze various materials for antennas which significantly contributes to the next generations of communication systems.