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Designing 16*16 m-MIMO Array Antennas

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ABSTRACT

Massive MIMO base Stations are a subject of great interest in 5G. mMIMO systems enhance 5G Antennas capability to increase data speeds and bandwidth. This paper tries to analyze the design and implementation complexities involved in designing a 16*16 array of mm wave antennas .The paper tries to analyze the various parameters including substrate ,patch and feeder design of this mm wave array antenna. Power densities have been calculated using the Poynting vector rules. Efforts have been made to comply with DOT and WHO's tower emission standards. Per ICNIRP. Finally ground truth summaries have been referenced to check the dimensions of the 5G Array antennas Designed

Keywords: mm waves, Antenna, LC Oscillator, Massive MIMO

1.0 Introduction

1.1 ELECTROMAGNETIC WAVES

EM waves, also known as electromagnetic waves, are composed of electric and magnetic components oscillating perpendicular to each other and the direction of wave propagation. These waves travel at the speed of light, having no mass or the property to travel in a vacuum, which allows them to achieve the speed of light in the form of photon packets. Classified according to their wavelength and frequency, EM waves span a vast spectrum, ranging from radio waves with long wavelengths and low frequencies to gamma rays with extremely short wavelengths and high frequencies.[1, 2]

The formation of EM waves involves accelerating an electric charge using an external force. For instance, when an electric current flows through an antenna, it generates alternating electric and magnetic fields that radiate away from the antenna in the form of electromagnetic waves. These waves can carry information over long distances, making them crucial for communication technologies such as radio, television, and mobile phones.[4, 5]

1.2 MILLIMETER WAVES

Millimeter waves (mm Waves) are a type of electromagnetic wave with wavelengths ranging from 1 millimeter to 10 millimeters. This corresponds to frequencies between 3 GHz and 300 GHz, positioned between microwaves and infrared waves on the electromagnetic spectrum. The mm Wave spectrum between 3 GHz and 300 GHz is divided into several frequency bands, each with distinct characteristics and applications. These waves have high frequencies, enabling them to transmit large amounts of data. Due to their short wavelengths, mm Waves are often used in applications requiring precise measurements, such as radar systems and 5G networks. Their ability to support high data rates is advantageous for applications like 5G mobile networks, facilitating faster internet speeds and enhanced connectivity. Despite their numerous advantages, including high data transmission capabilities, mm Waves have a limited range. They are best suited for short-range communication because they are more vulnerable to attenuation from atmospheric factors like rain, foliage, and buildings.

1.3 ANTENNA AS AN LC OSCILLATOR

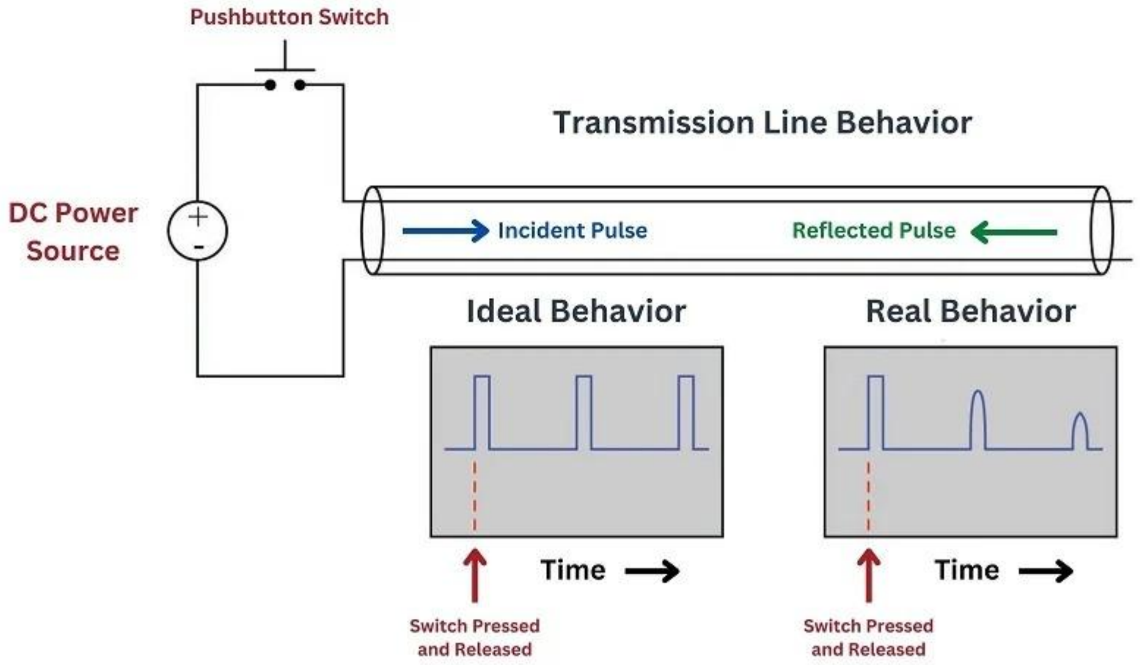
An antenna can be understood as a form of an LC oscillator, where it functions as a resonant circuit composed of inductance (L) and capacitance (C). In an LC oscillator, energy oscillates between the magnetic field of an inductor and the electric field of a capacitor, creating oscillations at a specific resonant frequency. Similarly, an antenna resonates at particular frequencies to efficiently transmit and receive electromagnetic waves.

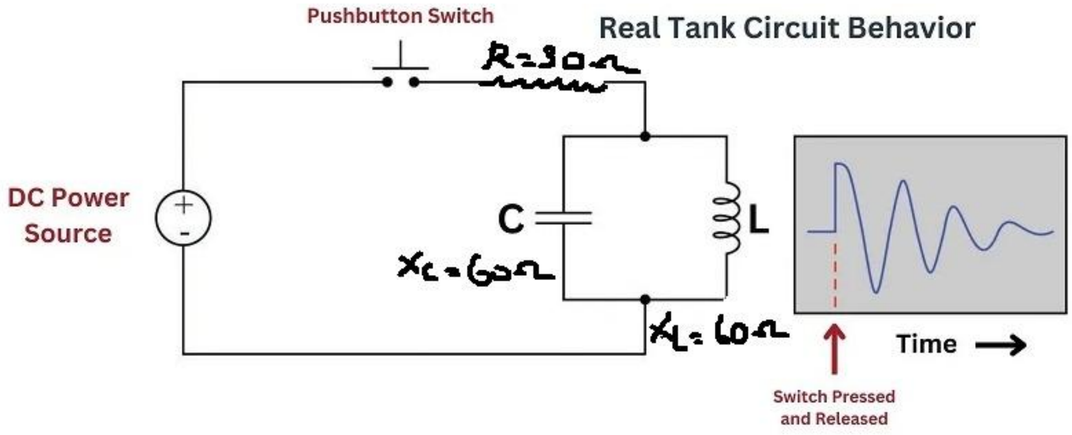
In an antenna, the inductance is provided by its physical structure, such as the length and shape of the conductive elements. The capacitance arises from the spacing between these elements and their interaction with the surrounding environment. This arrangement results in a distributed LC system, with inductive and capacitive components spread along the antenna's length.[6, 7]

At resonance, the antenna achieves maximum efficiency in radiating electromagnetic energy into space or capturing incoming waves. Just as an LC oscillator must be tuned to its resonant frequency for optimal performance, an antenna must be designed and adjusted to resonate at the desired frequency.

This tuning process is essential for applications like radio, television, and wireless networks, where precise frequency matching ensures clear and efficient communication.

Furthermore, both systems benefit from impedance matching to maximize energy transfer and minimize losses. Impedance matching ensures that the impedance of the LC oscillator (source) matches the impedance of the antenna (load). The role of antennas is crucial in ensuring that the transmitted or received signal is efficiently coupled to the rest of the communication system. This is similar to how an LC oscillator's impedance must be matched to the circuit it interacts with. Antenna impedance measurements can be obtained using several methods like vector network analyzer, the impedance bridge method, or the slotted line method. The reflection coefficient is a parameter that describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium. It is equal to the ratio of the amplitude of the reflected wave to the incident wave, with each expressed as phasors & is denoted by the symbol gamma Γ





2.1Antenna Design-Physical Dimensions

Antenna: An antenna is basically a conductor exposed in space. If the length of the conductor is a certain multiple of the wavelength it becomes an antenna. This condition is called resonance as the electrical energy fed into Antenna is radiated into free space. The power Consumed by an LC Circuit is $P=I*V*$ Cosαα is the angle between voltage and current assumed and is equal to ***90^0 which means no power is dissipated in an LC Oscillator***.256 massive multiple-input-multiple-output (mMIMO) antenna system is presented for 5G base stations. The antenna is fed by an antenna feed that has impedance, 50 Ω, [6, 7, and 8]

Feeder has been designed at 0.30 times wavelength=3.46mm.

Specifications and Symbols (mm)

L	Patch Length	2
W_s	Substrate width	6.25
t	Patch thickness	0.035
W	Patch Width	2
Ls	Substrate Length	6
L	Length of Ground	96
w	Width of ground	99.75
W_f	Width of feeder	0.2
L_f	**Length of Feeder**	**3.46**
h	Substrate Height	0.508

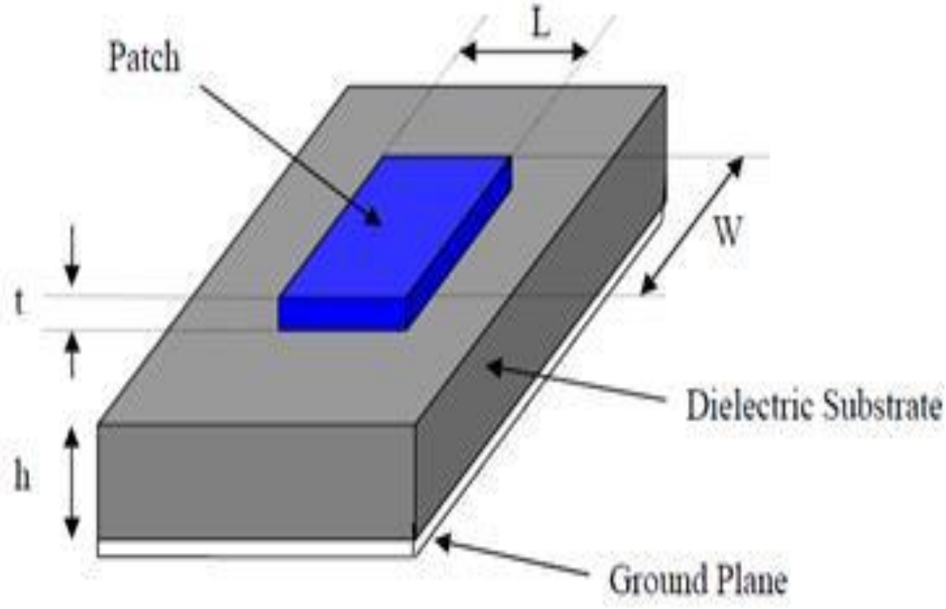


Fig 3: Antenna Design

- Height 76 Cm
- Width 15 Cm
- Weight, 30 kg
- Impedance 60 ohm
- Power 120W (50 dBm).
- Greater than 4G by 500%

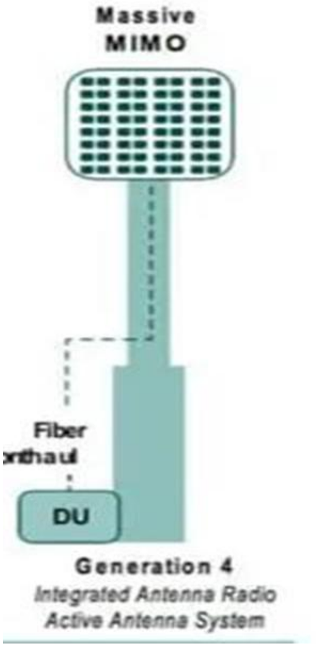


Fig 4: mMIMO Antenna

2.2. Cell Site

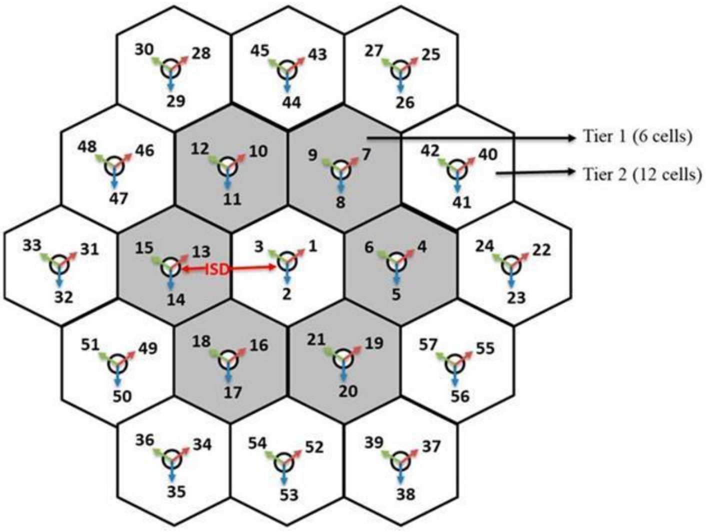


Fig 5: Micro Cell

100 m cell radius, 200 m ISD to avoid out-of-cell interferences

Area of the 5G Cell =**25980.75 m^2**

Intensity =Power Radiated per unit area = **(1/25980.75)=.038 mW/m^2**

Well within .045 W/m2 or 45 mw/m^2 to meet design constraint. (DOT/ICNIRP) [11, 12]

(L) nH	**(C)** pF	**Inductive Impedance** $X_{L(\Omega)}$	**Capacitive Impedance** $X_{C(\Omega)}$	**Resistance (R)** $_{(\Omega)}$	$Z_{(\Omega)}$ **Impedance**	**Reflectivity (%)**
0.32	0.11	60	60	30	60	9.09
0.33	0.11	55.9	53.9	30	57.44	12.95

0.36	0.10	60.85	59.98	30	60	9.09
0.8	0.082	132.8	73.46	30	77.28	21.43

2.3. RF Feeder

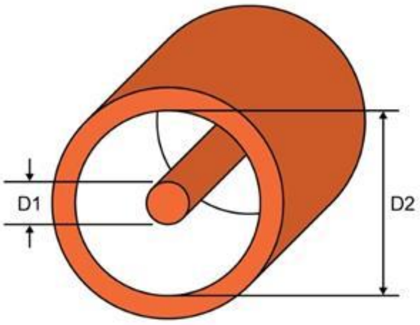


Fig 6:RG11 Co Axial Cable

RG11 is Used where D2=10.30 mm

Reflection Coefficient

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad =(60-50)/(60+50)= 9\%$$

2.4 Cost Considerations

Design Cost Rs 8, 50,000 (USD=10,625)

	BTS(Lakhs)	Mobile Towers(Lakhs)	Tech
2016	17.10	4.61	3G
2017	18.90	4.71	4G
2018	19.26	4.80	4G
2019	21.28	4.92	4G
2020	21.90	5.00	4G
2021	22.75	5.86	4G
2022	23.98	7.4	4G
2023	26.98	10.4	5G
2024	29.98	13.2	5G
2025	32.98	15	5G

Table 3: Projected 5G Tower Trend

If India Implements 1Mn 5G BTS Total Cost=**10 Bn USD** in the period 2023-2025 per TRAI Mandatory rollout.

3.0 RESULTS

3.1 Definition

Multiple-Input Multiple-Output (MIMO) is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time. [8, 14]

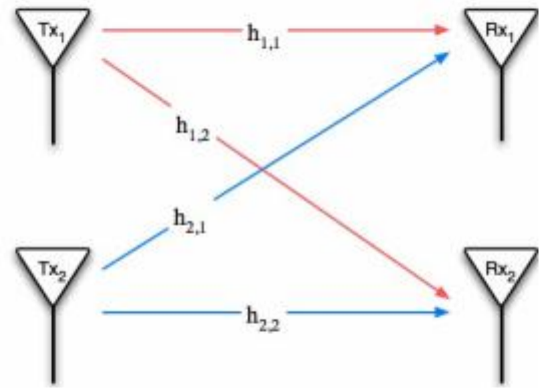


Fig 7: MIMO Basics

MIMO exploits the space dimension to improve wireless systems capacity, range and reliability

MIMO uses multi-paths. It uses multiple antennas to send multiple parallel signals from transmitter Multi-path occurs when the different signals arrive at the receiver at various times. With MIMO, the receiving end uses special signal processing to sort out the multiple signals to produce one signal that has the originally transmitted data. Multiple data streams transmitted in a single channel at the same time multiple radios collect multipath signals Delivers simultaneous speed, coverage, and reliability improvements.

Fig 8: MIMO Transmitter level

4.0 Discussions

The Channel Design Details **(Appendix1)**

Here I have tried to fully utilize the bandwidth for spectrum efficiency and then used the TDD concepts to gather more Antennas on a frequency. This design also permits infrastructure sharing among the players where each of the 4 current TSPs will only conform to the Frequencies and Antennas that has been allotted to them in the Auctions. The Capacitor and the inductor values will accordingly be changed to obtain the Oscillator frequency as the transmission frequency. By using slant polarizations and TDD techniques the required connection density of 26000 devices in the micro cell may be realized. Here I have employed Spatial MIMO techniques and multipolrization characteristics of MIMO to enhance the CPE coverage Due to such high frequencies of mm waves; they are not able to travel through buildings or obstacles and can be absorbed by foliage and rain.

Fig 9 Multi Polarized BEAMS

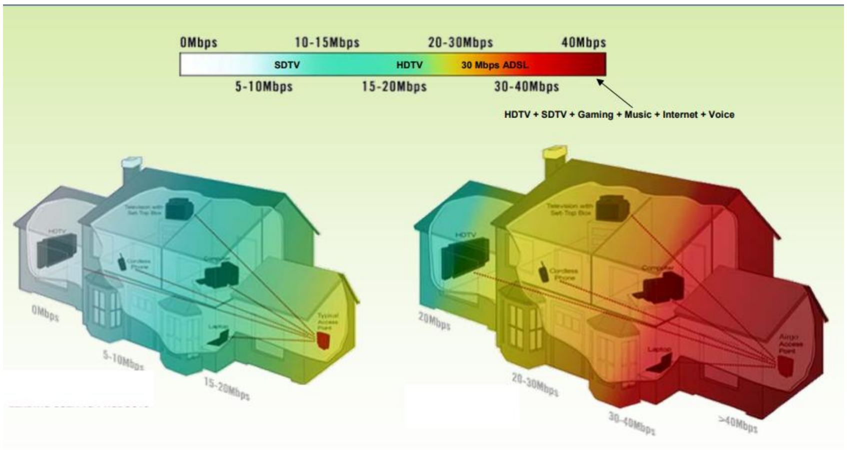


Fig 10: Connectivity Speeds and Multiple Polarizations

Spectrum Band	Block Size (MHz)	Type	Existing (Mhz)	New Entrants (MHz)
600	5	Paired	NA	5.00
700	5	Paired	NA	5.00
800	1	Paired	1.25	5,3.75
900	0	Paired	0.20	5,2.5
1800	0	Paired	0.20	5,0.2
2100	5	Paired	5.00	5.00
2300	10	Unpaired	10.00	10.00
2500	10	Unpaired	10.00	10.00
3500	10	Umpaired	10.00	10.00
26000	50	Unpaired	50.00	50.00

Table 4: India Block Design for mm-waves

1 Mhz price of C-Band 5G=317Cr.1Mhz price of mm Wave 5G=Rs 6.9 Cr. Using a 5G mm wave is 2.2% of the cost of C-Band. However technical efficiency in terms of penetration and coverage also is much lower for mm waves' Bands travel up to 1.92 Km and mm wave is only 300m.Coverage efficiency of Designed mm wave is only **15.63% of C-band**

5.0 Conclusions

- The designed m MIMO Array Antenna satisfies the connectivity constraint but not the coverage constraint.
- **Obtained Connection Density 26,000 Devices Per Cell.**
- Coverage efficiency of Designed mm wave is only **15.63% of C-band**

6.0 References

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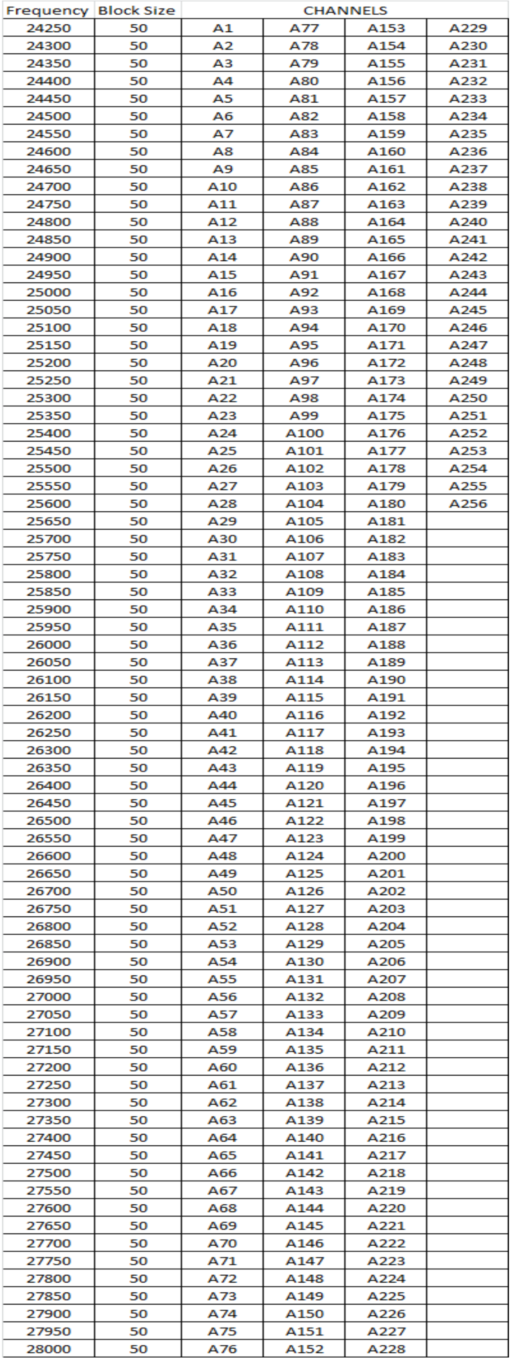
Appendix-1



Frequency	Block Size	CHANNELS			
24250	50	A1	A77	A153	A229
24300	50	A2	A78	A154	A230
24350	50	A3	A79	A155	A231
24400	50	A4	A80	A156	A232
24450	50	A5	A81	A157	A233
24500	50	A6	A82	A158	A234
24550	50	A7	A83	A159	A235
24600	50	A8	A84	A160	A236
24650	50	A9	A85	A161	A237
24700	50	A10	A86	A162	A238
24750	50	A11	A87	A163	A239
24800	50	A12	A88	A164	A240
24850	50	A13	A89	A165	A241
24900	50	A14	A90	A166	A242
24950	50	A15	A91	A167	A243
25000	50	A16	A92	A168	A244
25050	50	A17	A93	A169	A245
25100	50	A18	A94	A170	A246
25150	50	A19	A95	A171	A247
25200	50	A20	A96	A172	A248
25250	50	A21	A97	A173	A249
25300	50	A22	A98	A174	A250
25350	50	A23	A99	A175	A251
25400	50	A24	A100	A176	A252
25450	50	A25	A101	A177	A253
25500	50	A26	A102	A178	A254
25550	50	A27	A103	A179	A255
25600	50	A28	A104	A180	A256
25650	50	A29	A105	A181	
25700	50	A30	A106	A182	
25750	50	A31	A107	A183	
25800	50	A32	A108	A184	
25850	50	A33	A109	A185	
25900	50	A34	A110	A186	
25950	50	A35	A111	A187	
26000	50	A36	A112	A188	
26050	50	A37	A113	A189	
26100	50	A38	A114	A190	
26150	50	A39	A115	A191	
26200	50	A40	A116	A192	
26250	50	A41	A117	A193	
26300	50	A42	A118	A194	
26350	50	A43	A119	A195	
26400	50	A44	A120	A196	
26450	50	A45	A121	A197	
26500	50	A46	A122	A198	
26550	50	A47	A123	A199	
26600	50	A48	A124	A200	
26650	50	A49	A125	A201	
26700	50	A50	A126	A202	
26750	50	A51	A127	A203	
26800	50	A52	A128	A204	
26850	50	A53	A129	A205	
26900	50	A54	A130	A206	
26950	50	A55	A131	A207	
27000	50	A56	A132	A208	
27050	50	A57	A133	A209	
27100	50	A58	A134	A210	
27150	50	A59	A135	A211	
27200	50	A60	A136	A212	
27250	50	A61	A137	A213	
27300	50	A62	A138	A214	
27350	50	A63	A139	A215	
27400	50	A64	A140	A216	
27450	50	A65	A141	A217	
27500	50	A66	A142	A218	
27550	50	A67	A143	A219	
27600	50	A68	A144	A220	
27650	50	A69	A145	A221	
27700	50	A70	A146	A222	
27750	50	A71	A147	A223	
27800	50	A72	A148	A224	
27850	50	A73	A149	A225	
27900	50	A74	A150	A226	
27950	50	A75	A151	A227	
28000	50	A76	A152	A228	

Appendix-2-Derivation of Poynting Vector

$$E_y\,(x,t) = E_0 \cos\,(kx - \omega t) \quad (1)$$

$$B_z\,(x,t) = B_0 \cos\,(kx - \omega t) \quad (2)$$

$$U = U_B + U_E = \frac{1}{2}\left(\frac{1}{\mu_0}B^2 + \epsilon_0 E^2\right) \quad (3)$$

$$c = \frac{\mathrm{E}}{\mathrm{B}} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \quad (4)$$

$$\mathrm{U} = \epsilon_0 E^2 \quad (5)$$

$$\mathrm{U} = \frac{B^2}{\mu_0} \quad (6)$$

$$\vec{S} = \frac{1}{\mu_o}(\vec{E} \times \vec{B}) \quad (7)$$

$$I = S_{\text{avg}} = \tfrac{1}{2} c \epsilon_0 E_0^2 \quad (8)$$

$$I = \frac{c B_0^2}{2\mu_0} \quad (9)$$

$$I = \frac{E_0 B_0}{2\mu_0} \quad (10)$$

$$I = \tfrac{1}{2} c\, U = c\, U_{\text{avg}} \quad (11)$$