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Designing and Analysis of Wideband Antenna for 4G and 5G Applications

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A wideband antenna design for 4G and 5G applications has been analyzed and evaluated in this research. The advanced technology equipment's are getting smaller, which require compact and miniaturized antennas. The antenna designed in this research work is investigated for wideband operations for *time division duplex long term evolution bands* from band number 33 to 43 and for 5G New Radio n78 band. The design is ruled out for size miniaturization and wide bandwidth so that it can be used in any compact radio device. The antenna design is simulated using CST Microwave Studio and is fabricated on low cost easily available FR-4 substrate. The results are simulated and measured for 4G/5G bands for sufficient radiation characteristics, bandwidth, gain and minimum reflected power.

Keywords: Wideband Antenna, Bandwidth, Radiation

Introduction

The 5G New Radio (NR) frequency bands have been defined in the Third Generation Partnership Project (3GPP) release based on the guidance of ITU (International Telecommunication Union). The 5G NR is allocated with two spectrum regime first for sub 6 GHz and second for millimeter wave band.[1] The below 6 GHz 5G NR band is having a good coverage and low path loss in comparison to the mm-wave band. In addition to this, the band is widely been used in the existing 4G LTE (Long Term Evolution) bands and continues to play an essential role in pre 5G implementation.[2,3] The frequency range from 3.3 to 3.8 GHz is been defined as n78 band in 5G NR spectrum allocation. To distinguish the LTE bands they are being allocated numbers. The LTE band number 1 to 32 are for FDD LTE operations and band number 33 to 43 are for TDD LTE operations.[4]

Antenna Designing and result analysis

The design is inspired and derived from the famous cylindrical half wave dipole antenna. The antenna is designed as a patch antenna and consists of three layers. The uppermost layer is for the patch element, the middle one is for the substrate and the lowermost is for the ground element. The antenna is designed on a low cost FR4 (lossy) substrate having dielectric constant ϵ_r= 4.3 with a thickness of 1.574 mm and loss tangent of 0.02. The input resistance of infinitesimally thin dipole (half wave dipole) antenna[5] is given by $R_{in} = 24.7\, G^{2.5}$. Where G is a constant, and can be expressed as product of dipole antenna length (L_d) and half of phase constant β. The input impedance of the antenna is chosen to be 50 Ω for better impedance matching with the feeding port.[6] Then the length of the infinitesimally thin dipole antenna (L_d) is computed as $0.422\,\lambda$. However, thin dipole antenna has narrow bandwidth and thick dipole antenna has wider bandwidth.[7] For thick cylindrical dipole of finite wire diameter (2r), the length can be corrected with the help of correction factor F as

$$L_d = 0.422\,\lambda F \qquad \dots (1)$$

$$F = \frac{L_d/r}{1+L_d/r} = \frac{L_d}{L_d+r} \qquad \dots (2)$$

Thus, the cylindrical dipole antenna length can be retrieved using equations (1) and (2).

$$L_d = 0.422\lambda - r \qquad \dots (3)$$

The width (W_d) of the rectangular dipole can be approximated using the equivalent radius as:

$$W_d = 4r$$

The effect of feed length is not considered in the equation (3) and the same can be corrected by revising the equation for feed length l_f as

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$$L_d + l_f + r = 0.422\lambda$$

However, unlike the case of a wire antenna, the designed antenna has a dielectric substrate, which increases the effective dimension of the antenna. Hence, the equation is modified accordingly using a constant k as:

$$k(L_d + l_f + r) = 0.422\lambda$$

$$L_d = \left(\frac{0.422\lambda}{k}\right) - \frac{W_d}{4} - l_f \quad \dots (4)$$

The constant k is retrieved as 1.15. The initial dimensions of the dipole antenna are calculated using equation (4), for the lowest frequency LTE band no. 35 to resonate at 1.85 GHz. The retrieved value of dipole length for a feed length of 5.7 mm with 4 mm rectangular dipole width is 52.8 mm. The bandwidth enhancement can be obtained by increasing the dipole width, which is analogues to cylindrical dipole radius escalation.

The better tunable results are observed for multiple width dipole elements on the same dipole, one of the possible configurations is represented in fig 1. The resonating frequencies can be controlled with the different dipole lengths and their respective bandwidths can be tuned with their widths. For wide band operations, the bandwidths of different dipole elements should overlap with each other. The same can be achieved with the controlling parameters. Some of the configurations for different controlling parameters are detailed in Table 1 for better understanding. The infinite ground is considered for simulation with width and length of the feed to be fixed as 4.7 mm and 5.6 mm respectively. The substrate is kept with extra spacing in addition to the maximum length and width of the dipole, to accommodate the fringing effects.

Initially, each element of the dipole is considered as monopole antenna for estimation of preliminary dimensions. In configuration 1, all the elements are having a common width of 1 mm. Thus, the configuration is behaving as a single element thin dipole antenna of total length ($L_1 + L_2 + L_3 + L_4 + L_5 + r + l_f$), which is coinciding with the second resonance of dipole (according to the equation (4)) with a resonating frequency of 1.8 GHz. The same kind of resonance behavior with narrow bandwidth is observed in full wave electromagnetic simulation and is illustrated in Fig. 2. The five dipole elements are able to resonate at different frequencies by considering different equivalent length combination, whose bandwidths can be controlled with their respective widths. Configuration 1 is able to resonate for low frequency LTE bands but with narrow bandwidths. The higher frequency bands can also be achieved by wisely choosing the controlling parameters. In configuration 2, the bandwidth has been increased to 420 MHz in comparison to the 350 MHz of configuration 1. The bandwidth improvement has

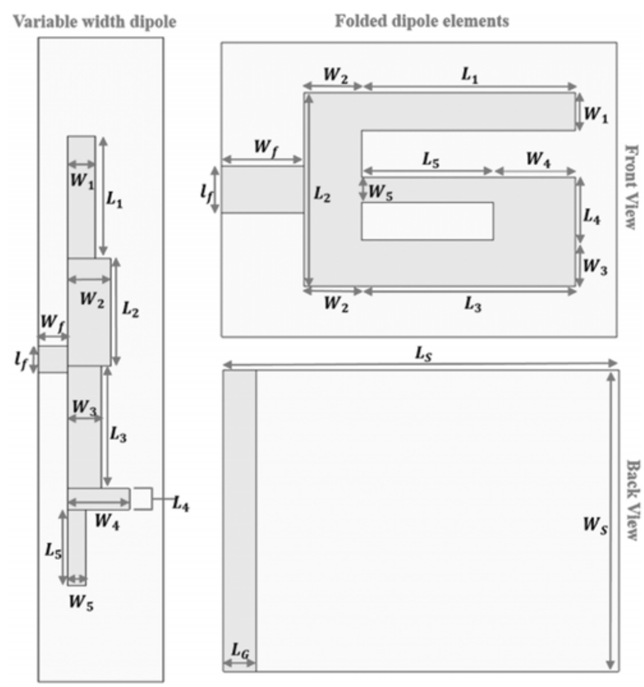

Fig. 1 — Illustration of antenna design

Table 1 — Controlling parameters of dipole elements

Configuration	Controlling parameters in mm: Low frequency elements				Middle frequency elements				High frequency elements		BW $f_L - f_H$ (GHz)
	L_1	W_1	L_3	W_3	L_5	W_5	L_2	W_2	L_4	W_4	
Configuration 1	31	1	30	1	25	1	20	1	10	1	1.7 to 2.05
Configuration 2	29	2	30	3	20	2	21	3	8	5	1.7 to 2.12
Configuration 3	27	3.5	27	4	18	2.5	22	5	7	6	1.7 to 2.5
Configuration 4	27	4	27	5	17	2.5	23	6	4.5	9	1.85 to 2.12 and 2.75 to 3.6
Configuration 5	26	4.5	26	5.5	16	3	23	7	7.5	10	1.85 to 3.8 GHz

been incorporated by increasing the widths of the dipole elements. The lengths are decreased a little bit to include some high-end adjacent frequencies. The configuration 1 and 2 are covering only low frequencies LTE bands, for the inclusion of middle frequencies LTE bands the length and width are further optimized in configuration 3. Two resonating frequencies have been observed in configuration 3, first near to 1.8 GHz and second near to 2.3 GHz. The total length is resonating for low frequency and sub combinations are for high frequency with a total bandwidth of 800 MHz. Although, the high frequency bands are not covered in the first three configurations, the configuration 4 is covering two bandwidths of 270 and 850 MHz respectively. The lower band (1.85 to 2.12 GHz) is resonating for low and middle frequency LTE bands, while the upper band (2.75 to 3.6 GHz) is partially covering the high frequencies LTE and NR band. The required bandwidth can be achieved similarly by optimizing different controlling parameters of dipole elements, but results in a large size antenna. A reduction in size can be achieved by folding the dipole element arms of the antenna, as shown in Figure 1. The folded shape is achieved by folding the dipole elements in the minimum possible substrate area (48×35 mm^2) and the bandwidth depletion occurred in the process is compensated through defected ground structure[8] instead of infinite ground with an optimized length of 4 mm. The optimized width and length of the feed are considered to be 10 mm and 5.6 mm respectively. Further tuning in required operating frequencies is achieved by connecting the dipole element 5 through dipole element 2 in addition to the normal connection via dipole element 4. The dual connection of element 4 helps in further tuning the notch near 2.7 GHz. The scattering plot and optimized dimensions for the folded dipole structure are illustrated in configuration 5. Thus, a wide bandwidth of 1.95 GHz is obtained with two resonating peaks, first for lower and middle LTE frequency bands and second for high frequencies LTE and 5G NR band. The wide bandwidth (1.85 to 3.8 GHz) is capable of covering the entire TDD LTE band from band no. 33 to 43 and 5G NR n78, with a bandwidth percentage of 69.02 % and a minimum scattering of -42 dB. The input impedance observed for the designed antenna is 50.22 Ω.

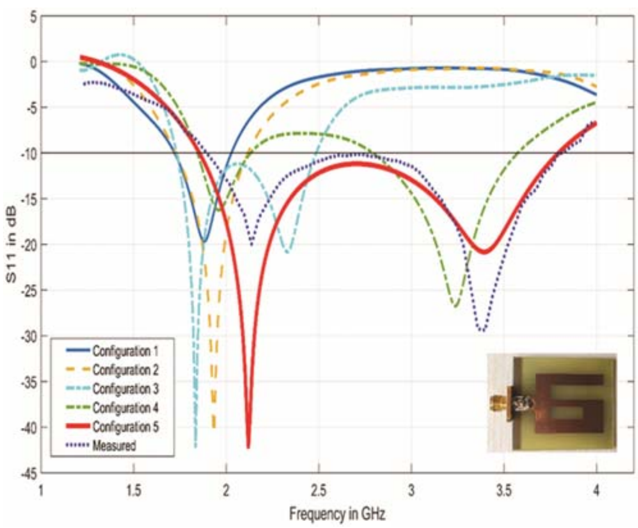

Fig. 2 — Scattering plot for different antenna configurations

The polar plot of the radiation pattern in azimuth and polar plane for all the bands is depicted in Fig. 3.

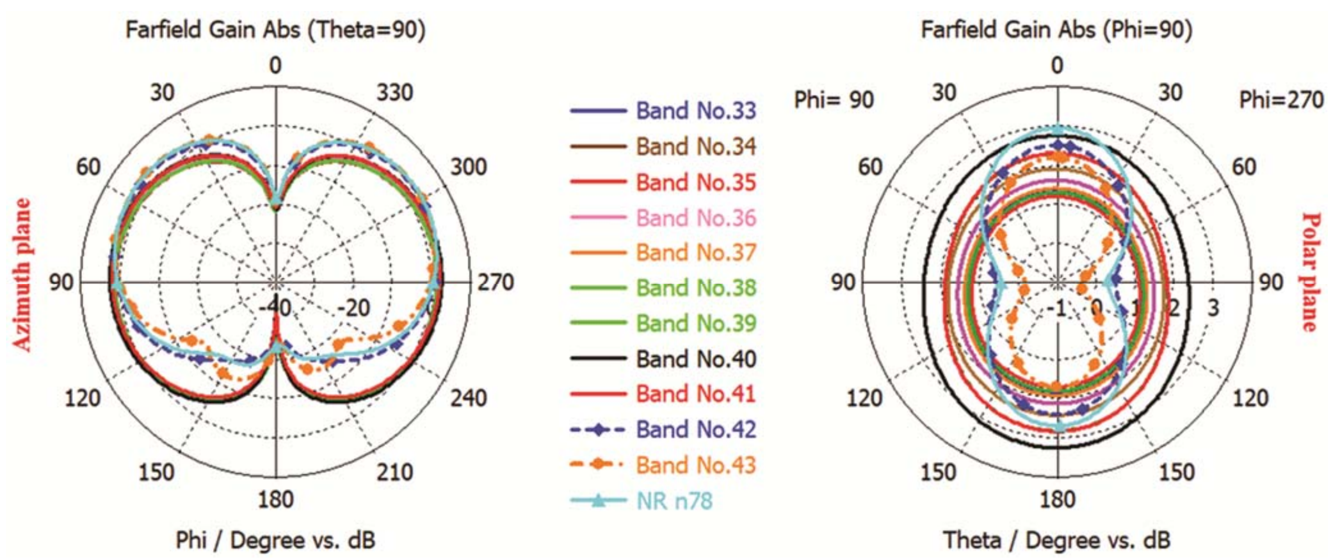

Fig. 3 — Antenna radiation pattern

Table 2 — Gain for all the TDD LTE and NR bands

Band no.	Band name	Allocated frequency (GHz)	Gain (dB)
35	Low frequency LTE bands	1.850 – 1.910	2.735
39		1.880 – 1.920	2.801
33		1.900 – 1.920	2.833
37		1.910 – 1.930	2.865
36		1.930 – 1.990	2.989
34	Middle frequency LTE Bands	2.010 – 2.025	3.150
40		2.300 – 2.400	3.640
41		2.496 – 2.690	3.676
38		2.570 – 2.620	3.677
42	High frequency LTE bands	3.400 – 3.600	4.757
43		3.600 – 3.800	4.926
n78	5G NR sub-6 GHz band	3.300 – 3.800	4.843

Table 3 — Overall size and band no. for different antenna designs

Reference	Band no. covered by the antenna	Overall Size (L×W×H) (mm)
9	33, 34, 35, 36, 37, 38, 39, 44	70 × 120× 0.764
10	33, 34, 35, 36, 37, 38, 39, 40, 41, 44	150 × 75× 7
11	38, 40, 41, 42,n78	49.5× 49.5× 35.2
12	42, n78	150 × 75× 6
13	40, 41, 42, n78	100 × 100× 5.7
This work	33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43	48 × 35 × 1.62

The radiation pattern in the azimuth plane is making an "eight" shape pattern for low and middle frequency LTE bands. On the other hand, for high frequency LTE and NR bands the pattern approximates with "eight" shape, with less radiation in the lower plane. The radiation pattern in the polar plane is making an omni-directional pattern. Thus, the overall radiation pattern of the antenna approximates with the doughnut shape, which is most suitable for the mobile applications.

The gain obtained for all the TDD LTE and NR bands are summarized in Table 2. The performance of the antenna design is verified by fabricating and testing the prototype. The measured and simulated S11 parameters of the fabricated antenna are illustrated in Fig. 2 with fabricated antenna in inset. A good approximation between simulated and measured result is obtained.

The overall dimensions and bands covered by the different reported antennas are summarized in Table 3. The designed antenna is simple in structure and doesn't require any active or complex switch to work. Moreover, the design supports eleven TDD LTE bands and 5G NR sub 6 GHz band to solve the problem of band congestion and is of compact size i.e. 48 × 35 × 1.62 mm^3. Most of the antenna design reported in the literature are small in size but are complex in structure because of the use of infinite ground consideration, active switches or MIMO operations. The overall dimensions of the designed antenna are approximately reduced by 97% in comparison to Zhao *et al.*[11], 96% in comparison to Zhao & Ren[12], 95% in comparison to Jin *et al.*[13] In addition to this, the structure of the designed antenna is planner in nature, which can be embedded in any radio equipment for 4G/5G operations.

Conclusion

The detailed analysis and evaluation of a novel wideband patch antenna have been presented in this research. The antenna design consists of a radiating folded length to miniaturize the antenna dimensions. The radiating elements are capable of shifting their characteristics with the use of controlling parameters. The controlling parameters observed can be engineered to synthesize the antenna to tunable bandwidth according to the application requirements. The designed antenna is capable of operating in the range of 1.85 to 3.8 GHz, covering eleven TDD LTE bands from Band No. 33 to 43 and 5G NR n78 band. A wide bandwidth of 1.95 GHz is obtained with a bandwidth percentage of 69.02 % and a minimum scattering loss of -42 dB. The input impedance of the antenna is 50.22 Ω (≈50 Ω), thus the design does not require any extra impedance matching device. The antenna is radiating approximately in a doughnut pattern, which is most suitable for the mobile applications. Moreover, the design is planner in structure and is compact enough (48 × 35 × 1.62 mm^3) to fit in any radio device. The results are validated by fabricating and testing the performance of the antenna design.

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