LabVIEW model of the Half- Power Beam Width of the Kutunse Antenna

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Abstract

A LabVIEW model to calculate the Half Power Beam Width of the Kutunse antenna was developed. The Kutunse antenna as part of the AVN under the SKA is to do VLBI, to study masers and to train Ghanaians in Astronomy. The model produced an easy-to-use approach in calculating the Half Power Beam Width over the operating frequency range of 5.0 to 6.7 GHz of the antenna. The results indicated an angular width of 0.002249091 radians at 5 GHz and 0.001679611 radians at 6.7 GHz. The sensitive angular width at 6.7 GHz suitable for studying masers is 0.001679611 radians. This model is useful in providing a quick guide to scientists, engineers, technicians and students in using the radio telescope at Kutunse, Ghana.

Keywords: Half power beam width, LabVIEW, Frequency, Kutunse, African VLBI Network (AVN)

1. Background

1.1 The African VLBI Network

The Kutunse antenna in Ghana is part of the African VLBI Network (AVN), which is aimed at training African Scientists, engineers and technicians to be able to perform Very Long Baseline Interferometry (VLBI) experiments and other related astronomy science when the second phase of the Square- Kilometre Array (SKA) is fully operational. The Kutunse antenna is a 32-metre dish telecommunications antenna, which is undergoing modifications; to be able to perform VLBI and other astronomy related science. It will form part of the AVN together with eight other African countries, South- Africa, Botswana, Kenya, Madagascar, Mauritius, Mozambique, Namibia, and Zambia. South- Africa's Hartebeesthoek telescope is currently the only one in the AVN (Nordling, 2012).

Ghana as a country, currently lacked expertise in radio astronomy, and as part of the mandate of the AVN, scientists, engineers and students are to be trained, to be able to man radio telescopes that will be built under the phase two of the SKA. A lot of educational and training programs have to be rolled out thence. User friendly, "one-click", applications to understand some fundamental terms of radio astronomy becomes relevant.

1.2 Radio Astronomy in Ghana

Radio Astronomy is relatively new in Africa especially in Ghana. To be able to make great use of this radio telescope and others that would be built in Ghana in the second phase of the SKA project, a lot of scientists, engineers, technicians and students have to be trained in various aspects of astronomy. A team of seven Ghanaians is currently undergoing training in SKA- South Africa as part of the AVN training scheme of train the trainer's (Joubert, 2013, Gaylard, 2013, Ghanaweb, 2013),

A pedagogic, friendly, easy-to-use computer models of various fundamentals of astronomy are therefore helpful.

A LabVIEW model where users can just key in the parameters of an antenna to calculate the HPBW of a radio telescope is needful. This can then be used to model other features of the antenna.

1.3 The Kutunse Radio Antenna

The 32-m diameter dish at Kutunse in Ghana was commissioned in 1981 as a telecommunication antenna operating at frequency of 3.625- 4.2 GHz. (Ansah-Narh et al, 2013). It was last used as a telecommunicating antenna in the early 2000s. The proposal for converting for its conversion into a fully operational radio telescope instrument was initiated in 2011, by the Ministry of Environment, Science, Technology and Innovation (MESTI) of Ghana and the SKA- Africa group in South Africa. The antenna facility was handed to the Ghana Atomic Energy Commission (GAEC) and then to Ghana Space Science and Technology Institute (GSSTI) to be used as a radio telescope. The GSSTI in collaboration with SKA- South Africa is currently converting this antenna into a functional radio telescope. The conversion process is expected to be completed in 2016 (Madjitey et al, 2013).

After its conversion into a radio telescope, the operating frequency range of the antenna would be 5.0 to 6.7 GHz. It would then be capable of performing VLBI observations and maser studies. A lot of numerical estimations of performance and structural mechanic modifications have to be ascertained (Ansah-Narh et al, 2013).

Figure 1. The Kutunse radio antenna

1.4 Half Power Beam Width of a radio telescope

The beamwidth of an antenna's radiating pattern is the angular separation between two identical points on opposite side of the radiating pattern maximum. The Half Power Beamwidth (HPBW) is one of the most widely used beamwidths of an antenna pattern (Balanis, 2005). The HPBW is defined by IEEE as " in a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one- half value of the beam" (IEEE, 1983). It specifies the angular width within which the antenna is most sensitive. Hence it tells us the minimum angular extent that a source must have, if we want to resolve its structure. Sources smaller than this width - such as the Sun - will fill only part of the antenna beam, and hence the received signal will be less than if the source was extended (Strasbourg, 2011).

A two- dimensional normalized field pattern (linear scale) of a 10-element linear array with a spacing of d= 0.25λ is shown in Figure 2. Another important beamwidth is the angular separation between the first nulls of the pattern and it is referred to as first- Null Beamwidth (FNBW).

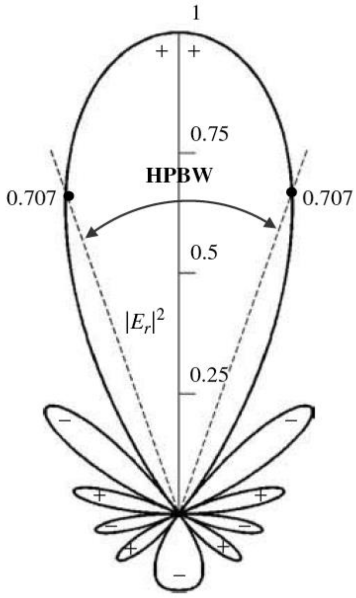


Figure 2. Field pattern (in linear scale) (Balanis 2005)

Other beamwidths are those where the pattern is -10 dB from the maximum, or any other value. In practice however, the term beamwidth, with no other identification, usually refers to HPBW. (Balanis 2005)

The beamwidth of an antenna is a very important figure of antenna performance and often is used as a trade-off between it and the side lobe level; that is, as the beamwidth decreases, the side lobe increases and vice versa. In addition the beamwidth of the antenna is also used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets. The most common resolution criterion states that *the resolution capability of an antenna to distinguish between two sources is equal to half the first-null beamwidth (FNBW/2), which is usually used to approximate the half-power beamwidth (HPBW)* (Kraus, 1988), (Kraus, 1966). That is, two sources separated by angular distances equal or greater than FNBW/2 ≈ HPBW of an antenna with a uniform distribution can be resolved. If the separation is smaller, then the antenna will tend to smooth the angular separation distance (Balanis 2005).

An ideal antenna would produce a beam that captures 100% of the incoming energy in the main beam and would have no side lobes. This antenna would have a main beam efficiency of 1.0. But however, this is not the case, because it is not actually possible to achieve this. Beam efficiencies usually lie between 0.6 and 0.8.

The HPBW is useful in calculating several parameters like radiation pattern, pointing error, and other features of a radio telescope. A model of the HPBW is therefore very expedient as a teaching tutorial in astronomy.

1.5 LabVIEW at School of Nuclear and Allied Sciences

LabVIEW is a computational tool used at the School of Nuclear and Allied Sciences, (SNAS) University of Ghana. Students use LabVIEW to study about mathematical models in various fields. A model of the HPBW would be very useful in mathematical modeling studies.

2. Theory

The beamwidth at the half-power points (HPBW) also called the Full Width at Half Maximum (FWHM) is given by

HPBW= FWHM ~ 1.2λ/ D [radians]……..…………………………………………………………..(1)

HPBW = 1.2λ/ D………………………….……………………………………………… ………………..(2)

where λ is the wavelength and D is the diameter of the dish.

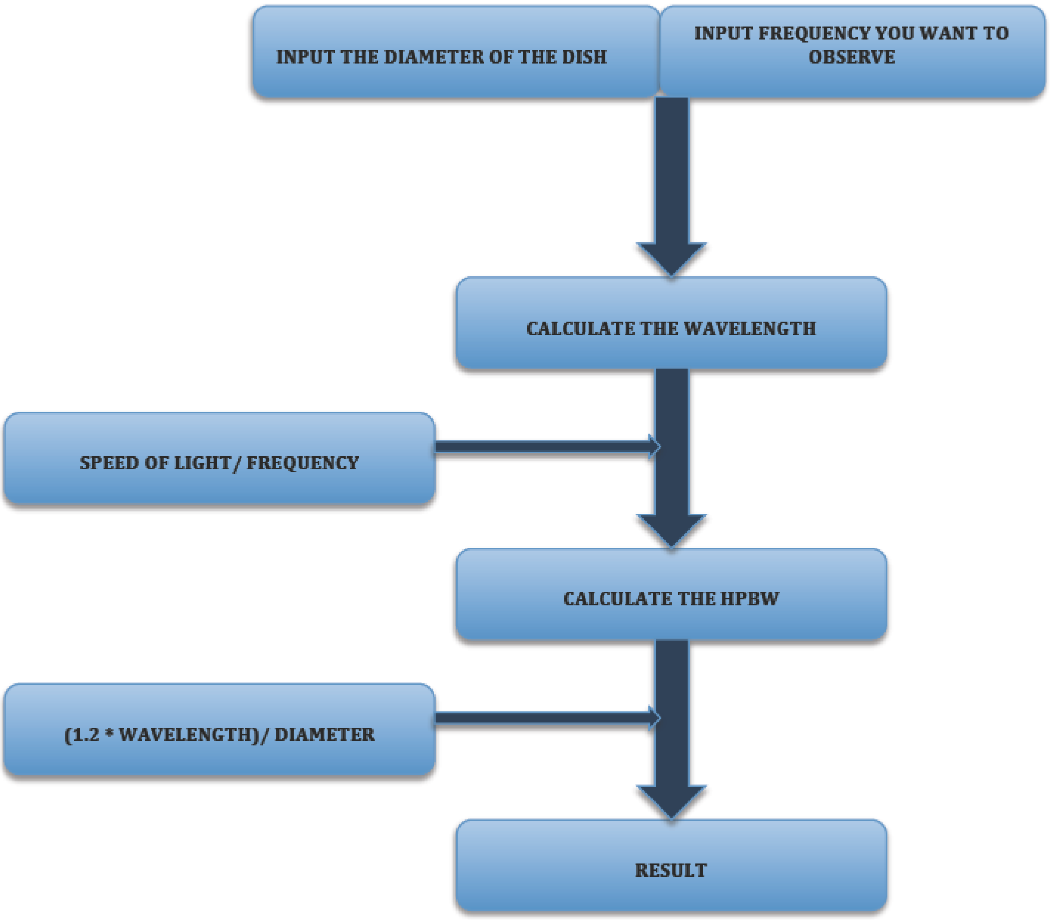
HPBW = (1.2λ/ D) * 57.3 [degrees]……………………………………………………………………..(3)

HPBW = (1.2λ/ D) * 57.3 * 3600 [arc seconds]……..…………………………………………………..(4)

(Gerlard, 2013).

3. Method

A flowchart to implement equation (2) is presented. This flow chart asks the user to input the diameter of the dish and the observing frequency. The LabVIEW program then calculates the wavelength based on speed of light divided by the input observing frequency. The HPBW is then calculated by multiplying the wavelength by 1.2, and dividing by the diameter of the dish. The LabVIEW program was created using drag and drop method as used in LabVIEW. Controls and indicators are dragged and dropped on the front panel. They are then wired in the block diagram pane using equation (2). Lines or wires are connected from controls or indicators through the mathematical operators.



4. Results and Discussions

A front panel of the LabVIEW program is presented in figure 3. It provides a graphical user interface for the user. The user needs to input the observing frequency and the diameter of the dish.

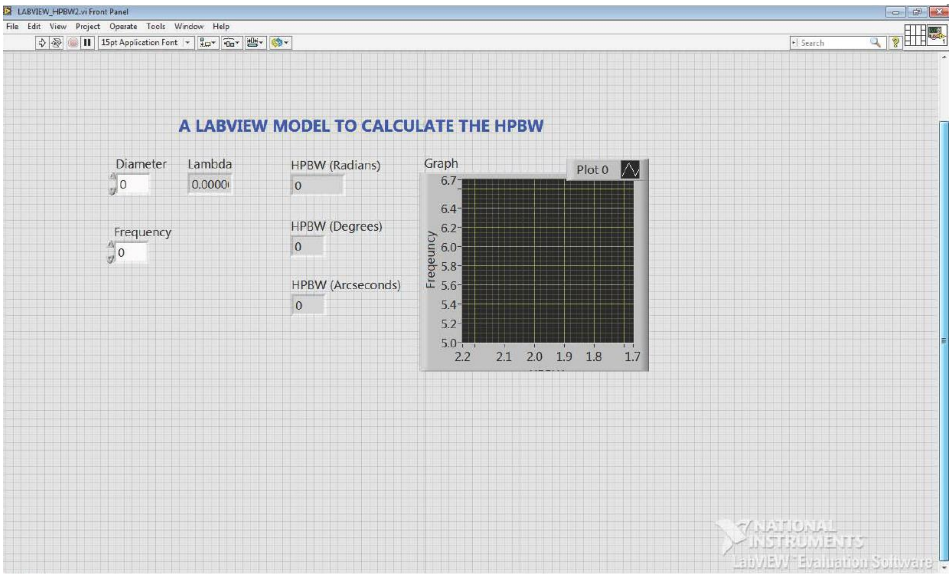


Figure 3. Front panel of the LabVIEW model

The results of the calculation of the HPBW of the frequency range of the Kutunse antenna are presented in table 1.0 in appendix. This serves as a quick reference table of values for the HPBW at a given frequency in radians, degrees and arc seconds. Table 1.0 actually starts from 4.7 GHz to 7.0 GHz to cater for any interpolation studies into the frequency ranges of 4.7 GHz – 5.0 GHz and 6.7 GHz – 7.0 GHz.

Table 2.0 in appendix is the calculated HPBWs of the antenna when its operating frequency was 3.625 GHz – 4.2 GHz.

It is observed from the graph in figure 4 that a linear relationship exists between the wavelength and the HPBW.

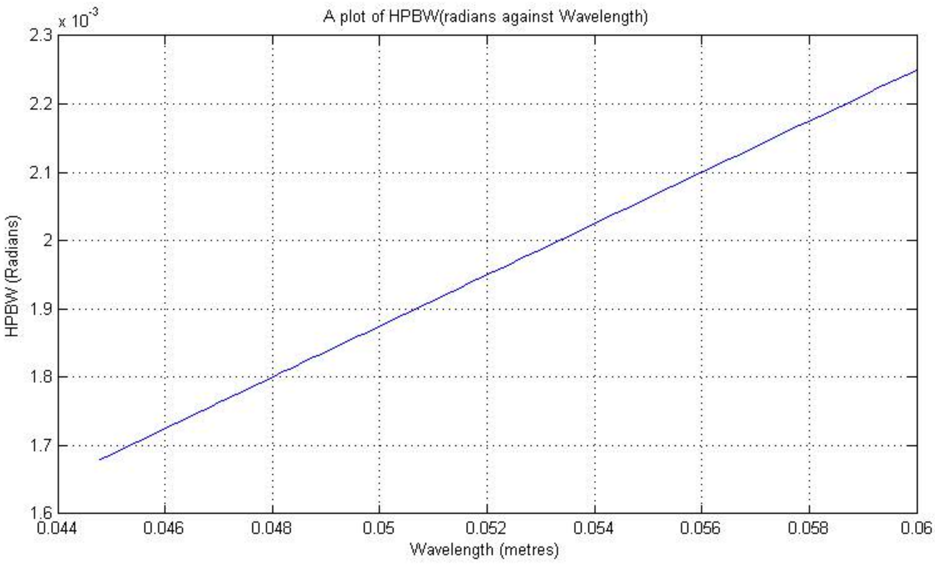


Figure 4. A graph of the HPBW in radians.

5. Conclusion

A LabVIEW model of the HPBW of the Kutunse antenna was developed. The calculated values of the HPBW at a given frequency in radians, degrees and arc seconds, are presented as a quick guide to students, engineers and scientists working on the HPBW of the antenna.

It would be useful in determining the pointing accuracy of the antenna. An ideal pointing accuracy equals HPBW/ 10.

The LabVIEW model generated an easy-to-use approach in calculating the Half Power Beam Width over the operating frequency range of 5.0 to 6.7 GHz of the antenna. The results produced an angular width of 0.002249091 radians at 5 GHz and 0.001679611 radians at 6.7 GHz. As part of the operations of the antenna, much of its time will be spent studying methanol masers; the sensitive angular width at 6.7 GHz suitable for studying masers is 0.001679611 radians. The results of the calculations produced reference values of Half Power Beam Width within any operational frequency of the antenna at Kutunse, Ghana.

The calculated HPBW specifies the angular width within which the antenna is most sensitive for observations at a given frequency within the operating frequency. Hence it reveals the minimum angular extent that a source must have, if we want to resolve its structure. For sources smaller than a given HPBW, it will expected to fill only part of the antenna beam, and hence the received signal will be less than if the source was extended.

6. Future work

The HPBW need to be used to determine the radiating pattern lobes of the Kutunse antenna. The HPBW values need to be used to analyze the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets. The HPBW also need to be used to do drift scans in determining the pointing errors of the antenna.

7. Acknowledgements

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Notes

Appendix

Table 1. Calculated HPBW for frequency range 4.7 – 7.0 GHz

4700000000	0.063829787	0.002393617	0.137154255	493.7553191
4723232323	0.063515825	0.002381843	0.13647963	491.3266681
4746464646	0.063204937	0.002370185	0.135811609	488.9217919
4769696970	0.062897078	0.00235864	0.135150095	486.5403431
4792929293	0.062592202	0.002347208	0.134494995	484.181981
4816161616	0.062290268	0.002335885	0.133846214	481.8463716
4839393939	0.061991234	0.002324671	0.133203663	479.5331872
4862626263	0.061695056	0.002313565	0.132567252	477.2421064
4885858586	0.061401695	0.002302564	0.131936893	474.9728137
4909090909	0.061111111	0.002291667	0.1313125	472.725
4932323232	0.060823264	0.002280872	0.130693989	470.4983617
4955555556	0.060538117	0.002270179	0.130081278	468.2926009
4978787879	0.06025563	0.002259586	0.129474285	466.1074254
5002020202	0.059975767	0.002249091	0.12887293	463.9425485
5025252525	0.059698492	0.002238693	0.128277136	461.7976884
5048484848	0.05942377	0.002228391	0.127686825	459.672569
5071717172	0.059151563	0.002218184	0.127101922	457.5669189
5094949495	0.05888184	0.002208069	0.126522353	455.4804718
5118181818	0.058614565	0.002198046	0.125948046	453.4129663
5141414141	0.058349705	0.002188114	0.125378929	451.3641454
5164646465	0.058087229	0.002178271	0.124814933	449.3337571
5187878788	0.057827103	0.002168516	0.124255987	447.3215537
5211111111	0.057569296	0.002158849	0.123702026	445.3272921
5234343434	0.057313778	0.002149267	0.123152981	443.3507333
5257575758	0.057060519	0.002139769	0.12260879	441.3916427
5280808081	0.056809487	0.002130356	0.122069386	439.4497896
5304040404	0.056560655	0.002121025	0.121534708	437.5249476
5327272727	0.056313993	0.002111775	0.121004693	435.6168942
5350505051	0.056069473	0.002102605	0.120479281	433.7254106
5373737374	0.055827068	0.002093515	0.119958412	431.850282
5396969697	0.055586749	0.002084503	0.119442027	429.991297
5420202020	0.05534849	0.002075568	0.118930069	428.1482482
5443434343	0.055112266	0.00206671	0.118422481	426.3209315
5466666667	0.054878049	0.002057927	0.117919207	424.5091463
5489898990	0.054645814	0.002049218	0.117420193	422.7126955
5513131313	0.054415537	0.002040583	0.116925385	420.9313851
5536363636	0.054187192	0.00203202	0.116434729	419.1650246
5559595960	0.053960756	0.002023528	0.115948174	417.4134266

5582828283	0.053736204	0.002015108	0.115465669	415.6764067
5606060606	0.053513514	0.002006757	0.114987162	413.9537838
5629292929	0.053292661	0.001998475	0.114512605	412.2453795
5652525253	0.053073624	0.001990261	0.11404195	410.5510186
5675757576	0.05285638	0.001982114	0.113575147	408.8705286
5698989899	0.052640907	0.001974034	0.11311215	407.2037398
5722222222	0.052427184	0.001966019	0.112652913	405.5504854
5745454545	0.05221519	0.00195807	0.112197389	403.9106013
5768686869	0.052004903	0.001950184	0.111745535	402.2839258
5791919192	0.051796303	0.001942361	0.111297306	400.6703
5815151515	0.051589369	0.001934601	0.110852658	399.0695675
5838383838	0.051384083	0.001926903	0.110411548	397.4815744
5861616162	0.051180424	0.001919266	0.109973936	395.9061692
5884848485	0.050978373	0.001911689	0.109539779	394.3432029
5908080808	0.050777911	0.001904172	0.109109036	392.7925286
5931313131	0.050579019	0.001896713	0.108681667	391.254002
5954545455	0.050381679	0.001889313	0.108257634	389.7274809
5977777778	0.050185874	0.00188197	0.107836896	388.2128253
6001010101	0.049991584	0.001874684	0.107419416	386.7098973
6024242424	0.049798793	0.001867455	0.107005156	385.2185614
6047474747	0.049607483	0.001860281	0.106594079	383.7386838
6070707071	0.049417637	0.001853161	0.106186148	382.2701331
6093939394	0.049229239	0.001846096	0.105781328	380.8127797
6117171717	0.049042272	0.001839085	0.105379582	379.366496
6140404040	0.04885672	0.001832127	0.104980877	377.9311564
6163636364	0.048672566	0.001825221	0.104585177	376.5066372
6186868687	0.048489796	0.001818367	0.104192449	375.0928163
6210101010	0.048308393	0.001811565	0.103802659	373.6895738
6233333333	0.048128342	0.001804813	0.103415775	372.2967914
6256565657	0.047949629	0.001798111	0.103031765	370.9143526
6279797980	0.047772237	0.001791459	0.102650595	369.5421425
6303030303	0.047596154	0.001784856	0.102272236	368.1800481
6326262626	0.047421364	0.001778301	0.101896655	366.8279578
6349494949	0.047247852	0.001771794	0.101523823	365.485762
6372727273	0.047075606	0.001765335	0.101153709	364.1533524
6395959596	0.046904611	0.001758923	0.100786284	362.8306222
6419191919	0.046734854	0.001752557	0.100421518	361.5174666
6442424242	0.046566322	0.001746237	0.100059384	360.2137817
6465656566	0.046399	0.001739963	0.099699852	358.9194657
6488888889	0.046232877	0.001733733	0.099342894	357.6344178
6512121212	0.046067939	0.001727548	0.098988483	356.3585389
6535353535	0.045904173	0.001721406	0.098636592	355.0917311

6558585859	0.045741568	0.001715309	0.098287194	353.833898
6581818182	0.04558011	0.001709254	0.097940262	352.5849448
6605050505	0.045419789	0.001703242	0.097595772	351.3447775
6628282828	0.045260591	0.001697272	0.097253696	350.1133039
6651515152	0.045102506	0.001691344	0.096914009	348.8904328
6674747475	0.044945521	0.001685457	0.096576687	347.6760745
6697979798	0.044789624	0.001679611	0.096241706	346.4701403
6721212121	0.044634806	0.001673805	0.09590904	345.2725428
6744444444	0.044481054	0.00166804	0.095578666	344.083196
6767676768	0.044328358	0.001662313	0.09525056	342.9020149
6790909091	0.044176707	0.001656627	0.094924699	341.7289157
6814141414	0.04402609	0.001650978	0.09460106	340.5638156
6837373737	0.043876496	0.001645369	0.09427962	339.4066332
6860606061	0.043727915	0.001639797	0.093960358	338.257288
6883838384	0.043580337	0.001634263	0.09364325	337.1157007
6907070707	0.043433753	0.001628766	0.093328276	335.9817929
6930303030	0.04328815	0.001623306	0.093015413	334.8554875
6953535354	0.043143521	0.001617882	0.092704641	333.7367083
6976767677	0.042999855	0.001612495	0.092395939	332.62538
7000000000	0.042857143	0.001607143	0.092089286	331.5214286

Table 2. Calculated HPBW for frequency range 3.625 – 4.2 Ghz

3625000000	0.082758621	0.003103448	0.177827586	640.1793103
3635000000	0.082530949	0.003094911	0.177338377	638.4181568
3645000000	0.082304527	0.00308642	0.176851852	636.6666667
3655000000	0.082079343	0.003077975	0.176367989	634.9247606
3665000000	0.081855389	0.003069577	0.175886767	633.1923602
3675000000	0.081632653	0.003061224	0.175408163	631.4693878
3685000000	0.081411126	0.003052917	0.174932157	629.7557666
3695000000	0.081190798	0.003044655	0.174458728	628.0514208
3705000000	0.08097166	0.003036437	0.173987854	626.3562753
3715000000	0.080753701	0.003028264	0.173519515	624.6702557
3725000000	0.080536913	0.003020134	0.173053691	622.9932886
3735000000	0.080321285	0.003012048	0.172590361	621.3253012
3745000000	0.080106809	0.003004005	0.172129506	619.6662216
3755000000	0.079893475	0.002996005	0.171671105	618.0159787
3765000000	0.079681275	0.002988048	0.171215139	616.374502
3775000000	0.079470199	0.002980132	0.170761589	614.7417219
3785000000	0.079260238	0.002972259	0.170310436	613.1175694
3795000000	0.079051383	0.002964427	0.16986166	611.5019763
3805000000	0.078843627	0.002956636	0.169415243	609.8948752

3815000000	0.078636959	0.002948886	0.168971166	608.2961992
3825000000	0.078431373	0.002941176	0.168529412	606.7058824
3835000000	0.078226858	0.002933507	0.168089961	605.1238592
3845000000	0.078023407	0.002925878	0.167652796	603.550065
3855000000	0.077821012	0.002918288	0.167217899	601.9844358
3865000000	0.077619664	0.002910737	0.166785252	600.4269082
3875000000	0.077419355	0.002903226	0.166354839	598.8774194
3885000000	0.077220077	0.002895753	0.165926641	597.3359073
3895000000	0.077021823	0.002888318	0.165500642	595.8023107
3905000000	0.076824584	0.002880922	0.165076825	594.2765685
3915000000	0.076628352	0.002873563	0.164655172	592.7586207
3925000000	0.076433121	0.002866242	0.164235669	591.2484076
3935000000	0.076238882	0.002858958	0.163818297	589.7458704
3945000000	0.076045627	0.002851711	0.163403042	588.2509506
3955000000	0.07585335	0.002844501	0.162989886	586.7635904
3965000000	0.075662043	0.002837327	0.162578815	585.2837327
3975000000	0.075471698	0.002830189	0.162169811	583.8113208
3985000000	0.075282309	0.002823087	0.161762861	582.3462986
3995000000	0.075093867	0.00281602	0.161357947	580.8886108
4005000000	0.074906367	0.002808989	0.160955056	579.4382022
4015000000	0.074719801	0.002801993	0.160554172	577.9950187
4025000000	0.074534161	0.002795031	0.16015528	576.5590062
4035000000	0.074349442	0.002788104	0.159758364	575.1301115
4045000000	0.074165637	0.002781211	0.159363412	573.7082818
4055000000	0.073982737	0.002774353	0.158970407	572.2934649
4065000000	0.073800738	0.002767528	0.158579336	570.8856089
4075000000	0.073619632	0.002760736	0.158190184	569.4846626
4085000000	0.073439412	0.002753978	0.157802938	568.0905753
4095000000	0.073260073	0.002747253	0.157417582	566.7032967
4105000000	0.073081608	0.00274056	0.157034105	565.3227771
4115000000	0.07290401	0.0027339	0.156652491	563.9489672
4125000000	0.072727273	0.002727273	0.156272727	562.5818182
4135000000	0.072551391	0.002720677	0.1558948	561.2212817
4145000000	0.072376357	0.002714113	0.155518697	559.86731
4155000000	0.072202166	0.002707581	0.155144404	558.5198556
4165000000	0.072028812	0.00270108	0.154771909	557.1788715
4175000000	0.071856287	0.002694611	0.154401198	555.8443114
4185000000	0.071684588	0.002688172	0.154032258	554.516129
4195000000	0.071513707	0.002681764	0.153665077	553.1942789
4205000000	0.071343639	0.002675386	0.153299643	551.8787158
4215000000	0.071174377	0.002669039	0.152935943	550.569395
4225000000	0.071005917	0.002662722	0.152573964	549.2662722

4235000000	0.070838253	0.002656434	0.152213695	547.9693034
4245000000	0.070671378	0.002650177	0.151855124	546.6784452
4255000000	0.070505288	0.002643948	0.151498237	545.3936545
4265000000	0.070339977	0.002637749	0.151143025	544.1148886
4275000000	0.070175439	0.002631579	0.150789474	542.8421053
4285000000	0.070011669	0.002625438	0.150437573	541.5752625
4295000000	0.069848661	0.002619325	0.150087311	540.314319
4305000000	0.069686411	0.00261324	0.149738676	539.0592334