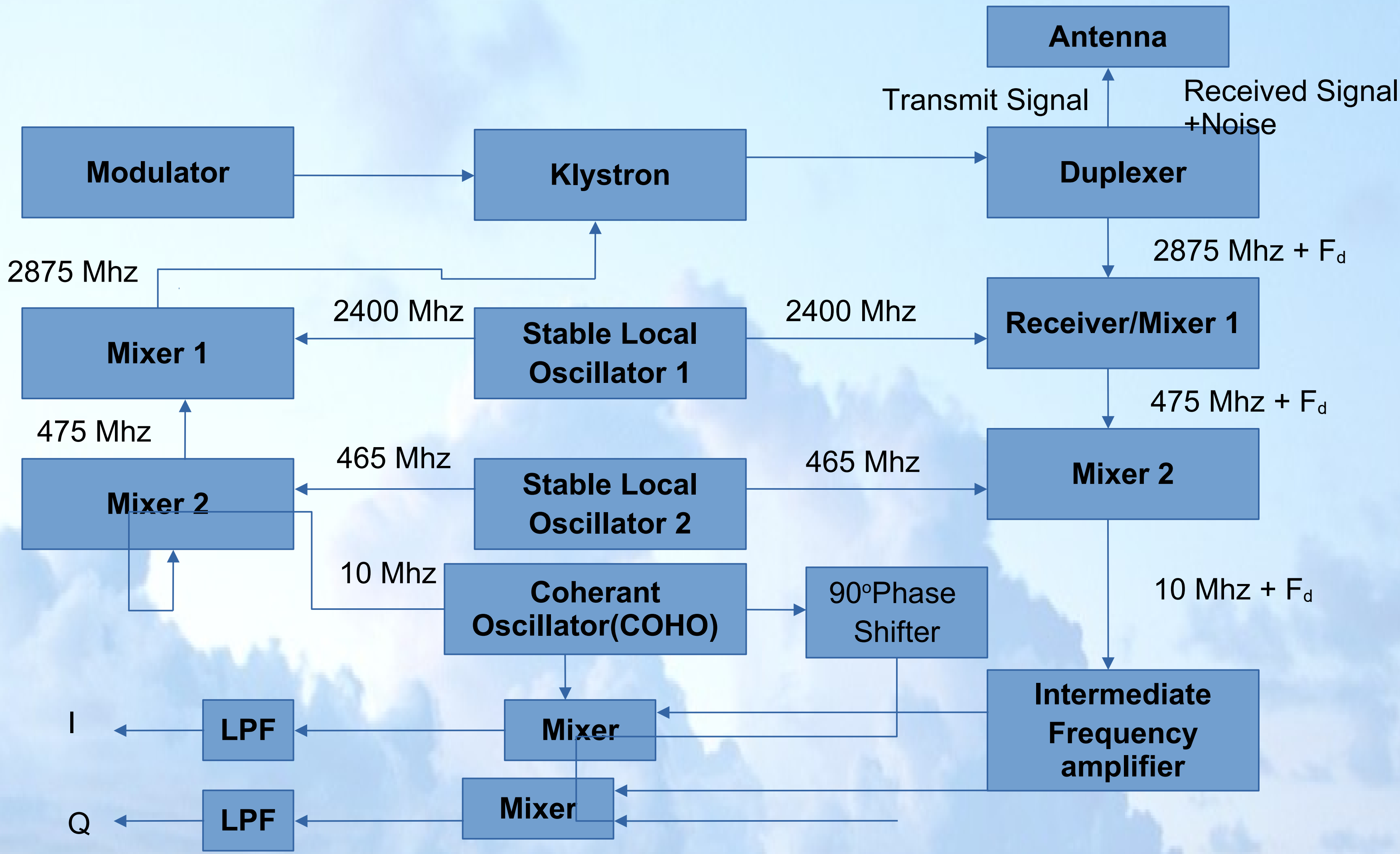
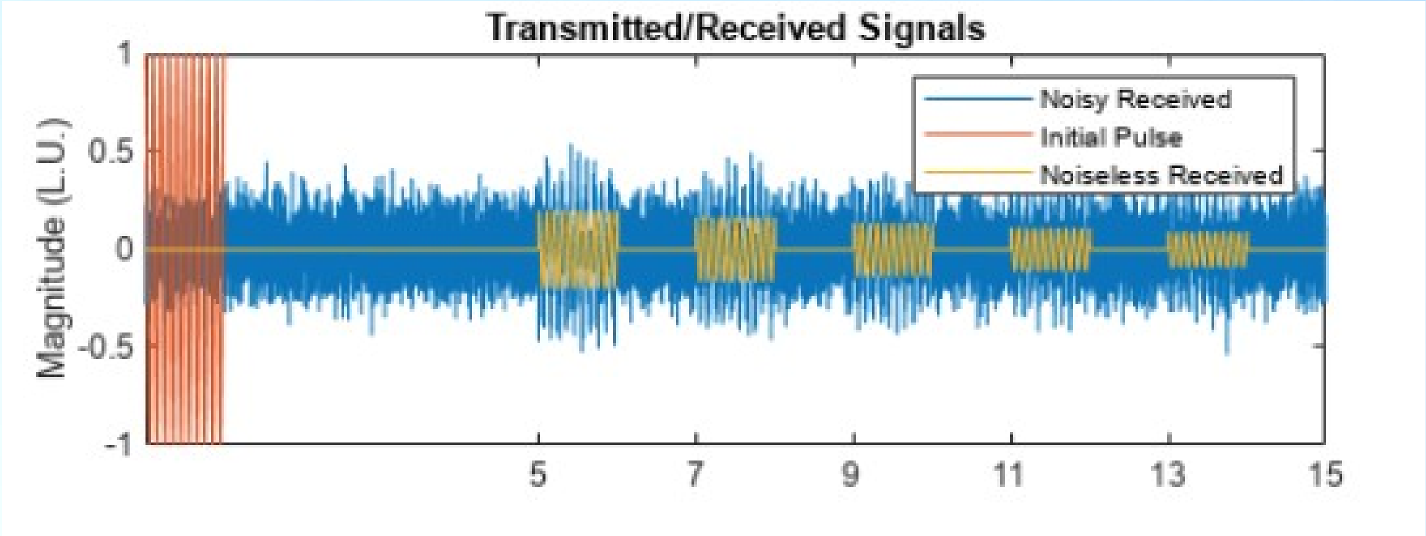
Weather Radar Signal processing – Signals to products

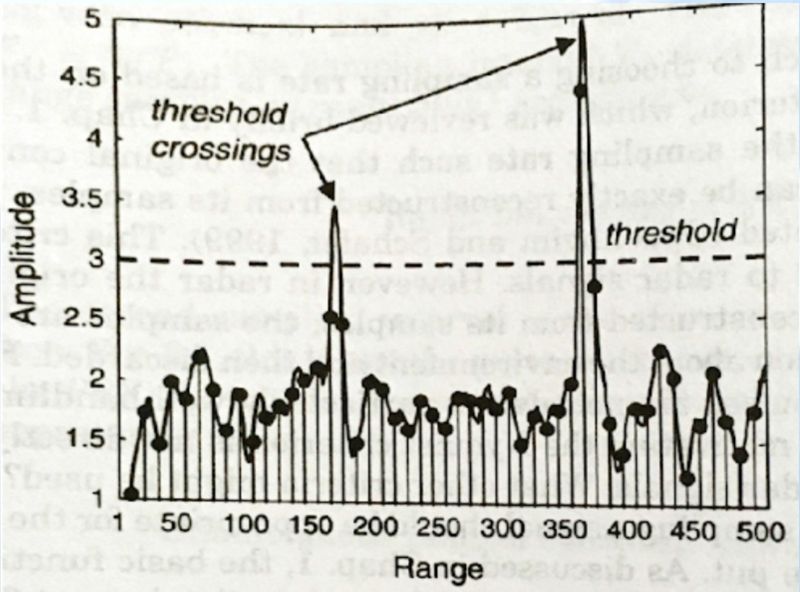
R Bibraj
Scientist
Regional Meteorological Centre, Chennai

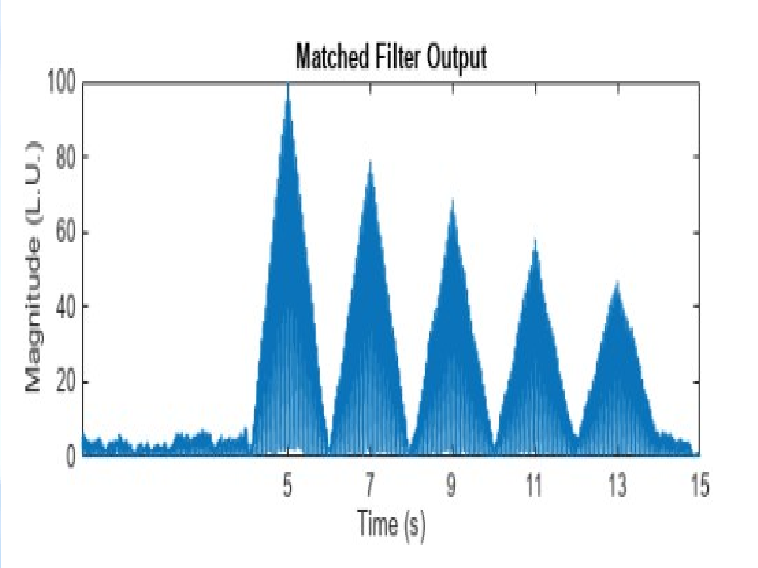
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Block Diagram




Transmitted/Received Signals
Magnitude (L.U.)
1
0.5
0
-0.5
-1
5
7
9
11
13
15
Noisy Received
Initial Pulse
Noiseless Received


Amplitude
5
4.5
4
3.5
3
2.5
2
1.5
1
threshold crossings
threshold
1
50
100
150
200
250
300
350
400
450
500
Range


Matched Filter Output
Magnitude (L.U.)
100
80
60
40
20
0
5
7
9
11
13
15
Time (s)

Ray Data synchronization

Angle Coverage synchronization

$$V = \frac{Resolution * f(PRF)}{sampling} \qquad sampling = \frac{Resolution * f(PRF)}{V}$$

Resolution= 0.7°

Min speed= 6 deg/sec

PRF= 1500 Hz

Sample=?

$$\text{Sampling} = \frac{0.7}{6} * 1500 = 175$$

Ray Data synchronization

Pulse Number synchronization

$$\text{Beam spacing (Resolution)} = \frac{Nsamp}{PRF} * Ant.speed$$

No of Samples = 80   PRF = 1000Hz and Antenna speed is 20 deg/sec

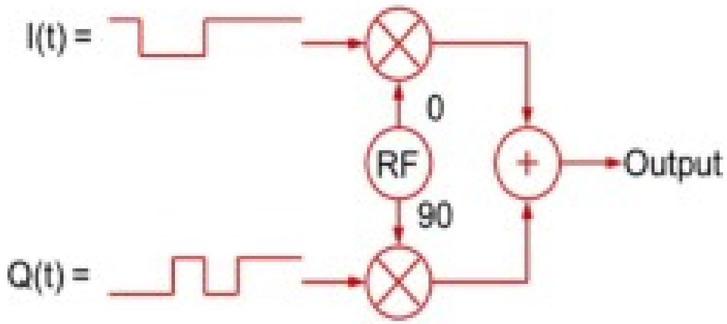
Then the resolution is 1.6 Deg

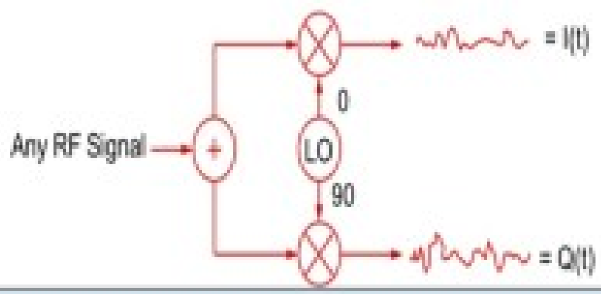
Samples to Integrate

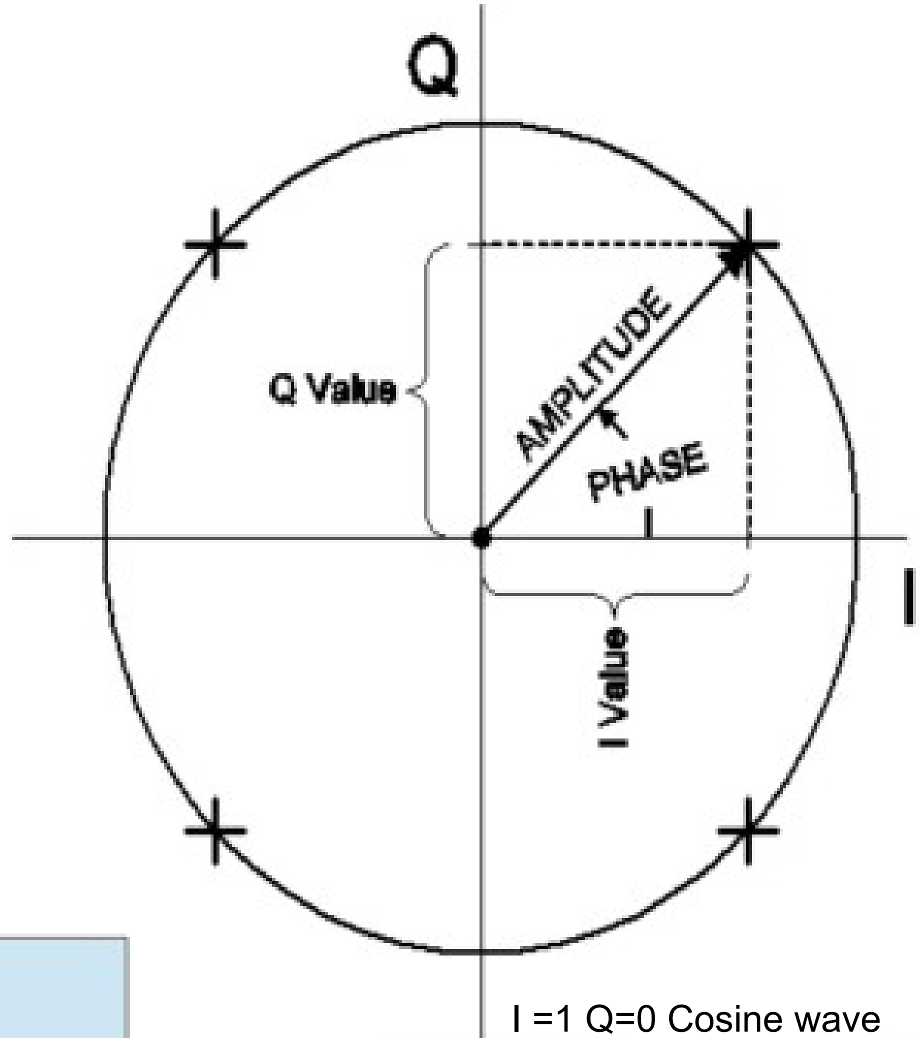
Antenna Beam width = 1 Degree

PRF	Antenna speed	Dwell time(sec)	Samples
180	6 Deg/Sec	1/6	30
180	3 Deg/sec	1/3	60
180	18 Deg/Sec	1/18	10
300	6 Deg/Sec	1/6	50
300	3 Deg/sec	1/3	100
300	18 Deg/Sec	1/18	17
600	6 Deg/Sec	1/6	100
600	3 Deg/sec	1/3	200
600	18 Deg/Sec	1/18	33

- I=+1 & Q=+1 results in 45 degree phase
- I=-1 & Q=+1 results in 135 degree phase
- I=-1 & Q=-1 results in 225 degree phase
- I=+1 & Q=-1 results in 315 degree phase





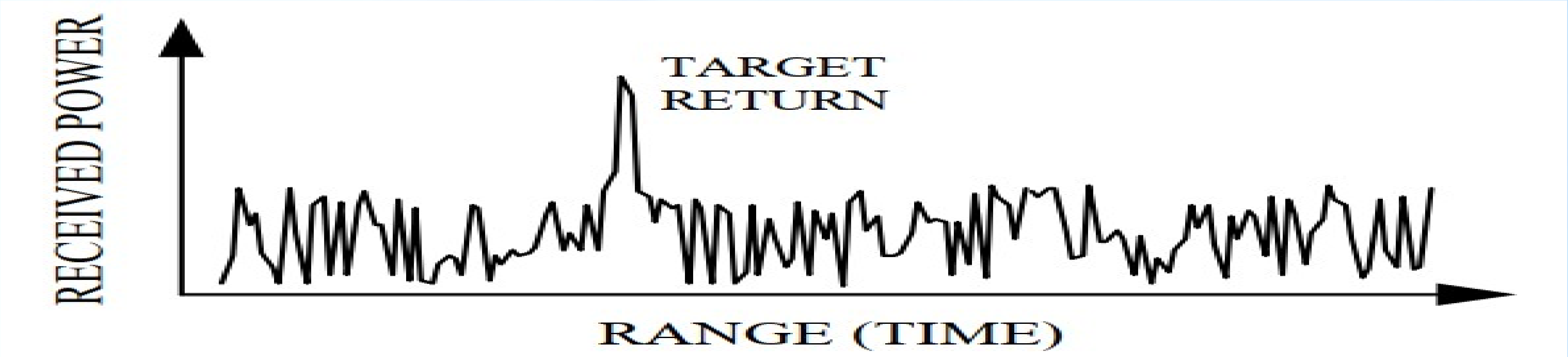


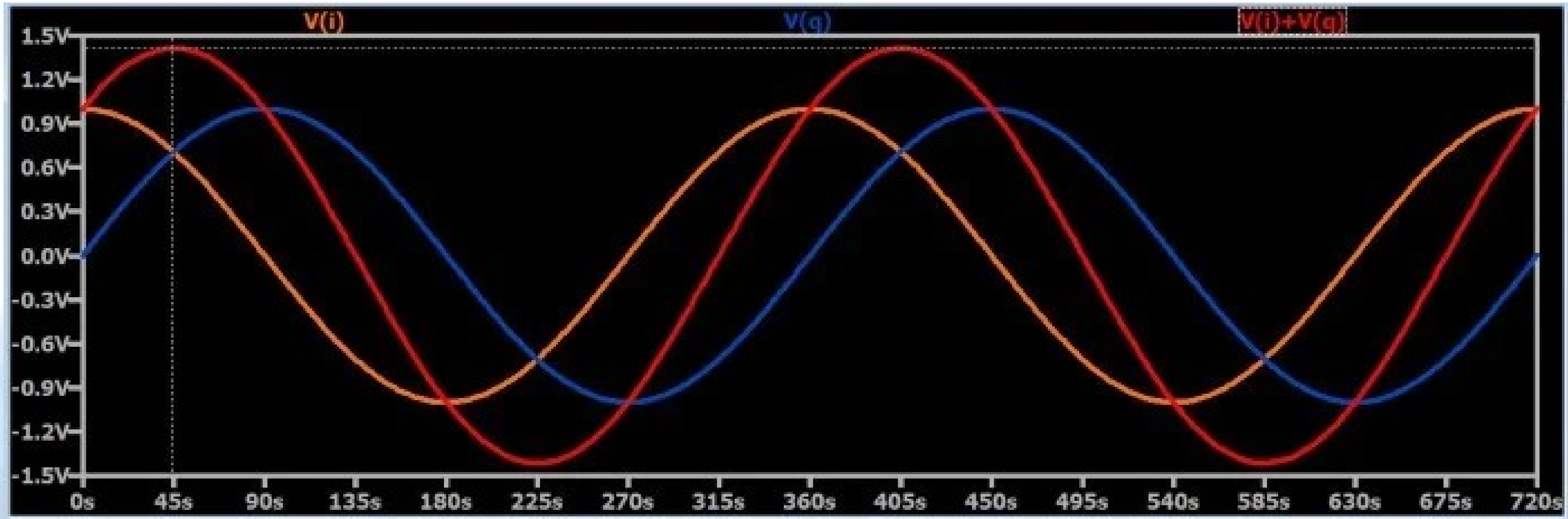
$$s = I + jQ$$

PHASOR

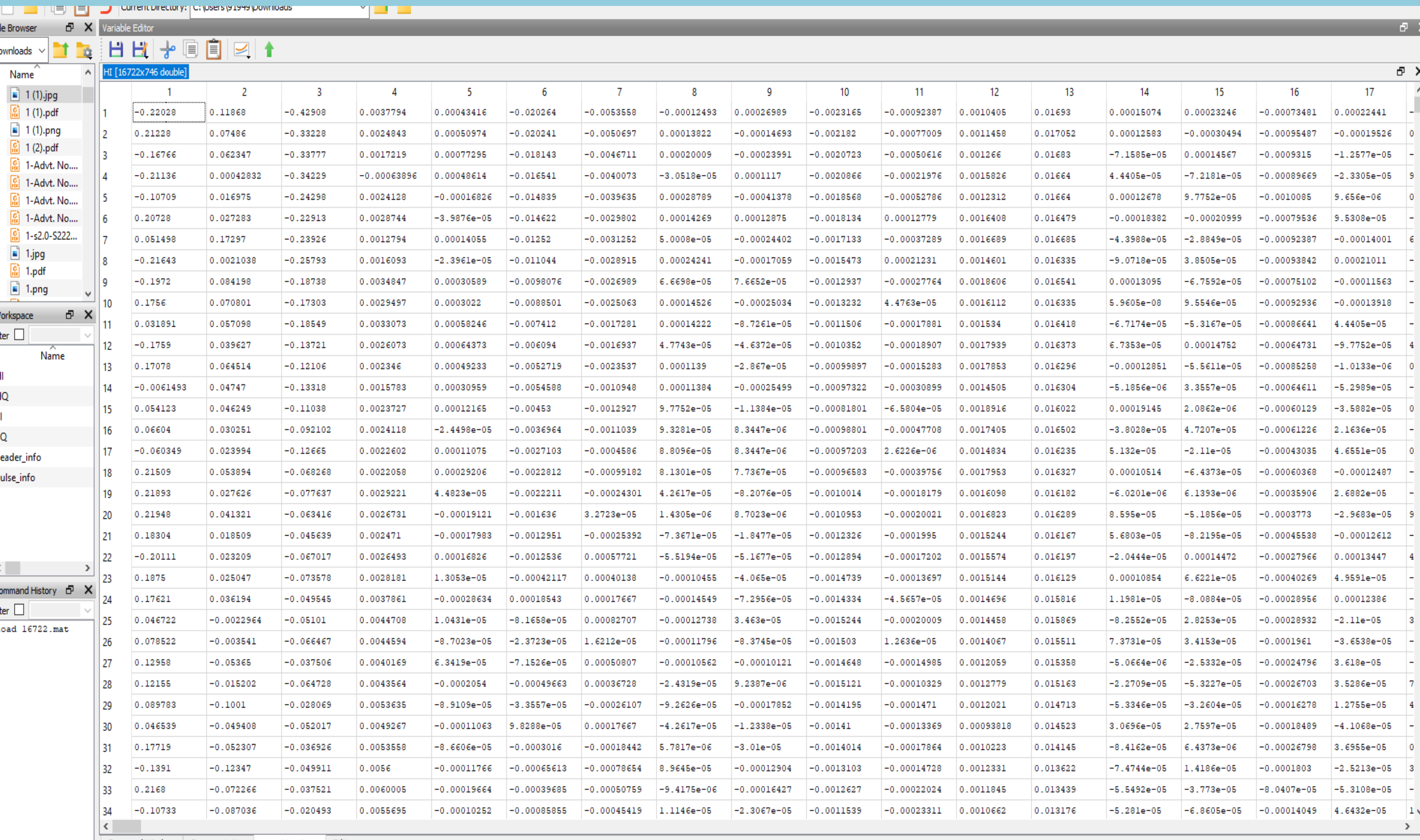
I =1 Q=0 Cosine wave
I=0 Q=1 Sine wave

Mixing of signals





I components



HI [16722x746 double]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	-0.22028	0.11868	-0.42908	0.0037794	0.00043416	-0.020264	-0.0053558	-0.00012493	0.00026989	-0.0023165	-0.00092387	0.0010405	0.01693	0.00015074	0.00023246	-0.00073481	0.00022441
2	0.21228	0.07486	-0.33228	0.0024843	0.00050974	-0.020241	-0.0050697	0.00013822	-0.00014693	-0.002182	-0.00077009	0.0011458	0.017052	0.00012583	-0.00030494	-0.00095487	-0.00019526
3	-0.16766	0.062347	-0.33777	0.0017219	0.00077295	-0.018143	-0.0046711	0.00020009	-0.00023991	-0.0020723	-0.00050616	0.001266	0.01683	-7.1585e-05	0.00014567	-0.0009315	-1.2577e-05
4	-0.21136	0.00042832	-0.34229	-0.00063896	0.00048614	-0.016541	-0.0040073	-3.0518e-05	0.0001117	-0.0020866	-0.00021976	0.0015826	0.01664	4.4405e-05	-7.2181e-05	-0.00089669	-2.3305e-05
5	-0.10709	0.016975	-0.24298	0.0024128	-0.00016826	-0.014839	-0.0039635	0.00028789	-0.00041378	-0.0018568	-0.00052786	0.0012312	0.01664	0.00012678	9.7752e-05	-0.0010085	9.656e-06
6	0.20728	0.027283	-0.22913	0.0028744	-3.9876e-05	-0.014622	-0.0029802	0.00014269	0.00012875	-0.0018134	0.00012779	0.0016408	0.016479	-0.00018382	-0.00020999	-0.00079536	9.5308e-05
7	0.051498	0.17297	-0.23926	0.0012794	0.00014055	-0.01252	-0.0031252	5.0008e-05	-0.00024402	-0.0017133	-0.00037289	0.0016689	0.016685	-4.3988e-05	-2.8849e-05	-0.00092387	-0.00014001
8	-0.21643	0.0021038	-0.25793	0.0016093	-2.3961e-05	-0.011044	-0.0028915	0.00024241	-0.00017059	-0.0015473	0.00021231	0.0014601	0.016335	-9.0718e-05	3.8505e-05	-0.00093842	0.00021011
9	-0.1972	0.084198	-0.18738	0.0034847	0.00030589	-0.0098076	-0.0026989	6.6698e-05	7.6652e-05	-0.0012937	-0.00027764	0.0018606	0.016541	0.00013095	-6.7592e-05	-0.00075102	-0.00011563
10	0.1756	0.070801	-0.17303	0.0029497	0.0003022	-0.0088501	-0.0025063	0.00014526	-0.00025034	-0.0013232	4.4763e-05	0.0016112	0.016335	5.9605e-08	9.5546e-05	-0.00092936	-0.00013918
11	0.031891	0.057098	-0.18549	0.0033073	0.00058246	-0.007412	-0.0017281	0.00014222	-8.7261e-05	-0.0011506	-0.00017881	0.001534	0.016418	-6.7174e-05	-5.3167e-05	-0.00086641	4.4405e-05
12	-0.1759	0.039627	-0.13721	0.0026073	0.00064373	-0.006094	-0.0016937	4.7743e-05	-4.6372e-05	-0.0010352	-0.00018907	0.0017939	0.016373	6.7353e-05	0.00014752	-0.00064731	-9.7752e-05
13	0.17078	0.064514	-0.12106	0.002346	0.00049233	-0.0052719	-0.0023537	0.0001139	-2.867e-05	-0.00099897	-0.00015283	0.0017853	0.016296	-0.00012851	-5.5611e-05	-0.00085258	-1.0133e-06
14	-0.0061493	0.04747	-0.13318	0.0015783	0.00030959	-0.0054588	-0.0010948	0.00011384	-0.00025499	-0.00097322	-0.00030899	0.0014505	0.016304	-5.1856e-06	3.3557e-05	-0.00064611	-5.2989e-05
15	0.054123	0.046249	-0.11038	0.0023727	0.00012165	-0.00453	-0.0012927	9.7752e-05	-1.1384e-05	-0.00081801	-6.5804e-05	0.0018916	0.016022	0.00019145	2.0862e-06	-0.00060129	-3.5882e-05
16	0.06604	0.030251	-0.092102	0.0024118	-2.4498e-05	-0.0036964	-0.0011039	9.3281e-05	8.3447e-06	-0.00098801	-0.00047708	0.0017405	0.016502	-3.8028e-05	4.7207e-05	-0.00061226	2.1636e-05
17	-0.060349	0.023994	-0.12665	0.0022602	0.00011075	-0.0027103	-0.0004586	8.8096e-05	8.3447e-06	-0.00097203	2.6226e-06	0.0014834	0.016235	5.132e-05	-2.11e-05	-0.00043035	4.6551e-05
18	0.21509	0.053894	-0.068268	0.0022058	0.00029206	-0.0022812	-0.00099182	8.1301e-05	7.7367e-05	-0.00096583	-0.00039756	0.0017953	0.016327	0.00010514	-6.4373e-05	-0.00060368	-0.00012487
19	0.21893	0.027626	-0.077637	0.0029221	4.4823e-05	-0.0022211	-0.00024301	4.2617e-05	-8.2076e-05	-0.0010014	-0.00018179	0.0016098	0.016182	-6.0201e-06	6.1393e-06	-0.00035906	2.6882e-05
20	0.21948	0.041321	-0.063416	0.0026731	-0.00019121	-0.001636	3.2723e-05	1.4305e-06	8.7023e-06	-0.0010953	-0.00020021	0.0016823	0.016289	8.595e-05	-5.1856e-05	-0.0003773	-2.9683e-05
21	0.18304	0.018509	-0.045639	0.002471	-0.00017983	-0.0012951	-0.00025392	-7.3671e-05	-1.8477e-05	-0.0012326	-0.0001995	0.0015244	0.016167	5.6803e-05	-8.2195e-05	-0.00045538	-0.00012612
22	-0.20111	0.023209	-0.067017	0.0026493	0.00016826	-0.0012536	0.00057721	-5.5194e-05	-5.1677e-05	-0.0012894	-0.00017202	0.0015574	0.016197	-2.0444e-05	0.00014472	-0.00027966	0.00013447
23	0.1875	0.025047	-0.073578	0.0028181	1.3053e-05	-0.00042117	0.00040138	-0.00010455	-4.065e-05	-0.0014739	-0.00013697	0.0015144	0.016129	0.00010854	6.6221e-05	-0.00040269	4.9591e-05
24	0.17621	0.036194	-0.049545	0.0037861	-0.00028634	0.00018543	0.00017667	-0.00014549	-7.2956e-05	-0.0014334	-4.5657e-05	0.0014696	0.015816	1.1981e-05	-8.0884e-05	-0.00028956	0.00012386
25	0.046722	-0.0022964	-0.05101	0.0044708	1.0431e-05	-8.1658e-05	0.00082707	-0.00012738	3.463e-05	-0.0015244	-0.00020009	0.0014458	0.015869	-8.2552e-05	2.8253e-05	-0.00028932	-2.11e-05
26	0.078522	-0.003541	-0.066467	0.0044594	-8.7023e-05	-2.3723e-05	1.6212e-05	-0.00011796	-8.3745e-05	-0.001503	1.2636e-05	0.0014067	0.015511	7.3731e-05	3.4153e-05	-0.0001961	-3.6538e-05
27	0.12958	-0.05365	-0.037506	0.0040169	6.3419e-05	-7.1526e-05	0.00050807	-0.00010562	-0.00010121	-0.0014648	-0.00014985	0.0012059	0.015358	-5.0664e-06	-2.5332e-05	-0.00024796	3.618e-05
28	0.12155	-0.015202	-0.064728	0.0043564	-0.0002054	-0.00049663	0.00036728	-2.4319e-05	9.2387e-06	-0.0015121	-0.00010329	0.0012779	0.015163	-2.2709e-05	-5.3227e-05	-0.00026703	3.5286e-05
29	0.089783	-0.1001	-0.028069	0.0053635	-8.9109e-05	-3.3557e-05	-0.00026107	-9.2626e-05	-0.00017852	-0.0014195	-0.0001471	0.0012021	0.014713	-5.3346e-05	-3.2604e-05	-0.00016278	1.2755e-05
30	0.046539	-0.049408	-0.052017	0.0049267	-0.00011063	9.8288e-05	0.00017667	-4.2617e-05	-1.2338e-05	-0.00141	-0.00013369	0.00093818	0.014523	3.0696e-05	2.7597e-05	-0.00018489	-4.1068e-05
31	0.17719	-0.052307	-0.036926	0.0053558	-8.6606e-05	-0.0003016	-0.00018442	5.7817e-06	-3.01e-05	-0.0014014	-0.00017864	0.0010223	0.014145	-8.4162e-05	6.4373e-06	-0.00026798	3.6955e-05
32	-0.1391	-0.12347	-0.049911	0.0056	-0.00011766	-0.00065613	-0.00078654	8.9645e-05	-0.00012904	-0.0013103	-0.00014728	0.0012331	0.013622	-7.4744e-05	1.4186e-05	-0.0001803	-2.5213e-05
33	0.2168	-0.072266	-0.037521	0.0060005	-0.00019664	-0.00039685	-0.00050759	-9.4175e-06	-0.00016427	-0.0012627	-0.00022024	0.0011845	0.013439	-5.5492e-05	-3.773e-05	-8.0407e-05	-5.3108e-05
34	-0.10733	-0.087036	-0.020493	0.0055695	-0.00010252	-0.00085855	-0.00045419	1.1146e-05	-2.3067e-05	-0.0011539	-0.00023311	0.0010662	0.013176	-5.281e-05	-6.8605e-05	-0.00014049	4.6432e-05

Q components

Current Directory: C:\Users\91949\Downloads

Variable Editor

HQ [16722x746 double]

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1	0.0046711	0.34631	-0.13641	0.00077653	5.9128e-05	-0.014587	-0.0065613	-4.9531e-05	0.00032055	-0.0015125	-0.0017242	-0.00018579	0.0091133	0.00013953	-0.00025463	0.0015016	-2.4438e-06
2	0.054596	0.30847	-0.10718	0.0022335	0.00085592	-0.013313	-0.0068169	0.00037158	-0.00039852	-0.0015125	-0.0018549	-0.00020838	0.0093994	-2.1935e-05	0.00010449	0.0012331	5.4777e-05
3	0.13794	0.22095	-0.11829	0.002985	0.00076509	-0.012527	-0.0066128	-4.7326e-05	0.00031507	-0.0017886	-0.001317	-0.00032759	0.0087585	1.7822e-05	1.3709e-05	0.0014033	7.3314e-06
4	-0.062073	0.41333	-0.14484	0.0055065	0.00031042	-0.011925	-0.0071278	0.00015652	-0.00024134	-0.0019088	-0.0017571	-0.00076461	0.0090752	0.00015813	3.9458e-05	0.0010443	0.00019592
5	0.18909	0.44287	-0.15192	0.0072651	0.00068283	-0.013004	-0.0058861	0.00018001	-3.1769e-05	-0.0019131	-0.0011959	-0.0007484	0.0081902	-0.0002045	-7.7546e-05	0.00098276	-4.524e-05
6	-0.070251	0.30981	-0.15796	0.0061455	0.00048828	-0.010727	-0.0060463	-0.00016385	0.00012171	-0.0020971	-0.0012426	-0.00078917	0.008255	-9.9182e-05	-0.00010788	0.00094748	2.9802e-05
7	0.2121	0.29175	-0.15704	0.0060787	0.00034392	-0.010674	-0.0058765	0.00022042	-0.0002358	-0.0021162	-0.001245	-0.00095582	0.0073204	7.8022e-05	0.0001328	0.00068355	6.6459e-05
8	0.037216	0.26721	-0.17053	0.0075722	9.7752e-05	-0.0096741	-0.0046215	6.9261e-05	0.00019878	-0.0020294	-0.00095797	-0.00098181	0.007164	5.3108e-05	-5.0545e-05	0.00072145	0.00015801
9	-0.09729	0.1485	-0.15228	0.0067482	-7.7069e-05	-0.0087547	-0.0045643	0.00012589	-0.00014061	-0.0020151	-0.0011339	-0.0008707	0.0061836	0.000117	0.00010383	0.00053549	-0.00019109
10	-0.12854	0.22711	-0.1441	0.0065117	0.00014704	-0.0071449	-0.0032387	0.00014454	1.2636e-05	-0.0021296	-0.0006218	-0.0010691	0.0057297	-7.1526e-05	-2.8193e-05	0.00029337	6.9976e-05
11	-0.21552	0.1853	-0.14459	0.005291	-4.9889e-05	-0.006052	-0.0026016	9.4593e-05	0.00011307	-0.001996	-0.00096011	-0.00088382	0.0054054	-2.4498e-05	7.3731e-05	0.00052428	4.8041e-05
12	0.1286	0.11752	-0.13776	0.0053024	5.3823e-05	-0.0048065	-0.0030537	0.00011963	8.9765e-05	-0.0018859	-0.00037026	-0.00062656	0.0046844	4.9889e-05	-2.0206e-05	0.00024676	-4.7505e-05
13	0.13824	0.13458	-0.12338	0.0055199	-0.00014728	-0.0042706	-0.0013142	7.6592e-05	-1.4424e-05	-0.0019627	-0.00054526	-0.0010014	0.0045395	-0.00012916	-7.2837e-05	0.00022972	3.5584e-05
14	0.21777	0.10641	-0.13782	0.0054722	1.1086e-05	-0.003603	-0.0010266	0.00013697	0.00015223	-0.0017638	-8.5533e-05	-0.00055385	0.003912	0.00012118	2.3901e-05	0.0002324	-8.6606e-05
15	-0.21027	0.026306	-0.12946	0.0060863	4.0829e-05	-0.0014887	-0.0011849	-9.7573e-05	3.2783e-05	-0.0016351	-0.00028801	-0.00048423	0.0036898	-1.651e-05	-4.4525e-05	6.5506e-05	-5.0843e-05
16	0.20825	0.0034094	-0.13477	0.0055809	0.00022805	-0.0014024	-1.5378e-05	6.2883e-05	-8.9407e-06	-0.0017643	0.00020862	-0.00062466	0.0032663	-0.00012237	-3.8326e-05	0.00011396	-8.3447e-07
17	0.2088	-0.014061	-0.13068	0.0053253	7.5221e-05	-0.00072169	-0.00039482	3.8743e-06	-8.9407e-06	-0.0015626	0.00021195	-0.00019932	0.0026312	7.2956e-05	-4.8757e-05	6.7413e-05	-6.6936e-05
18	0.053543	-0.058395	-0.11166	0.0053635	-9.1136e-05	-0.00029182	-5.0724e-05	3.9637e-05	3.9816e-05	-0.0015054	0.00029624	-0.00023419	0.0026655	-9.1791e-05	6.6638e-05	1.812e-05	-7.4983e-05
19	0.023956	-0.098389	-0.10626	0.0045891	-0.00044012	-0.00032067	0.00061202	-3.3498e-05	6.2823e-05	-0.001411	0.0007565	-5.9605e-05	0.0025005	5.4896e-05	3.5763e-06	7.7069e-05	2.1279e-05
20	0.0078163	-0.096954	-0.050827	0.0038567	-0.00036156	0.00015426	5.0902e-05	3.7074e-05	0.00016242	-0.0013266	0.00063872	6.2406e-05	0.0024223	-7.7486e-07	-2.5988e-05	-9.5844e-05	-0.00013816
21	0.12189	-0.11438	-0.085724	0.0039978	-0.00010359	0.00045955	0.00045025	6.5565e-07	8.4877e-05	-0.001265	0.0010209	0.00023293	0.0025167	-9.9897e-05	8.8632e-05	5.5611e-05	0.0001058
22	0.08609	-0.1463	-0.045181	0.0035334	-8.7023e-05	0.00062585	0.00072074	8.285e-06	0.00011688	-0.0011973	0.00092149	0.00035381	0.0024529	-6.938e-05	8.3506e-05	-4.7684e-07	-5.3525e-05
23	0.11502	-0.17053	-0.071747	0.0043411	-0.0002625	0.0013576	-4.9829e-05	7.987e-06	3.3677e-05	-0.0011201	0.0012803	0.00045872	0.0023861	-4.4107e-06	-6.9857e-05	-4.2856e-05	-3.8803e-05
24	0.12982	-0.22449	-0.078125	0.0041656	0.00010693	0.0011163	0.00084257	-6.7174e-05	4.6074e-05	-0.00095963	0.0010481	0.00062442	0.0028982	-0.00021011	-3.5167e-06	5.9009e-06	1.1563e-05
25	0.21301	-0.24072	-0.032181	0.0032091	7.0632e-05	0.00088787	0.00053287	3.9935e-05	-9.8348e-06	-0.00099897	0.0013547	0.00075746	0.003006	-0.00014144	4.0412e-05	-1.1206e-05	-6.8307e-05
26	-0.20197	-0.26721	-0.066559	0.0025988	-1.2696e-05	0.0011997	0.00029683	1.0192e-05	8.4043e-06	-0.00092173	0.0014634	0.00087094	0.0031767	-0.00011152	-5.1558e-05	1.3053e-05	5.728e-05
27	0.17657	-0.2088	-0.07843	0.0020618	-5.4717e-05	0.0016026	0.0011129	5.3644e-06	1.2994e-05	-0.00091648	0.0014367	0.0010376	0.0034342	-0.00010544	-5.2512e-05	-5.3644e-06	2.4736e-05
28	0.18127	-0.29834	-0.049286	0.0028305	-0.00023985	0.0017266	0.00030422	4.1723e-07	3.8385e-05	-0.00083756	0.0015469	0.0013084	0.0037098	-0.00019145	7.9274e-06	-9.1672e-05	2.4855e-05
29	-0.19824	-0.41638	-0.053207	0.0021887	2.5094e-05	0.0024977	0.0007503	3.8922e-05	-4.9949e-05	-0.00092769	0.0016794	0.001255	0.0038538	1.049e-05	1.6928e-05	7.1824e-05	-3.7611e-05
30	-0.21277	-0.31677	-0.045929	0.0015588	-0.00015688	0.0022316	0.0010548	9.2447e-05	-3.9339e-06	-0.00099993	0.0016508	0.0015516	0.0040817	-0.000135	4.0114e-05	-5.1856e-06	3.6538e-05
31	-0.12622	-0.42896	-0.034729	0.0018196	-0.00013047	0.0020084	0.00049567	8.4281e-05	-6.1035e-05	-0.00084805	0.0016775	0.0016403	0.0039654	-0.00013393	-2.7537e-05	-3.8147e-06	3.8147e-06
32	-0.16827	-0.39893	-0.016304	0.0015855	-0.00012052	0.0024462	0.0008409	-7.2539e-05	-0.00010163	-0.0009203	0.0015755	0.0016227	0.0045834	-4.9293e-05	-4.9055e-05	6.4552e-05	-4.2737e-05
33	0.030243	-0.3761	-0.039688	0.0011239	-9.6858e-05	0.0024986	0.0011749	-5.1022e-05	2.8312e-05	-0.0008986	0.0017486	0.0015841	0.0045033	9.1791e-06	1.6689e-05	2.8491e-05	7.2479e-05
34	-0.19043	-0.37708	-0.013412	0.00015843	2.5332e-05	0.0023413	0.0009923	4.7386e-05	3.2961e-05	-0.0010486	0.001873	0.0016894	0.004612	1.2755e-05	5.7638e-05	-5.6446e-05	0.00014204

Number of samples

header_info [1x16722 struct]

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1	0	22859	86	746	746	2	2	1	0 0	0 0	0.220307	59672	0.217851	59566	0	0	0
2	0	22863	86	746	746	2	2	2	0 0	0 0	0.21921	29921	0.217928	29931	0	0	0
3	0	22869	86	746	746	2	2	3	0 0	0 0	0.21714	42575	0.219834	42672	0	0	0
4	0	22875	86	746	746	2	2	4	0 0	0 0	0.22028	55375	0.217829	55179	0	0	0
5	0	22881	86	746	746	2	2	5	0 0	0 0	0.217314	13989	0.2198	14139	0	0	0
6	0	22886	86	746	746	2	2	6	0 0	0 0	0.218856	25166	0.216565	25160	0	0	0
7	0	22892	86	746	746	2	2	7	0 0	0 0	0.218252	48229	0.220421	48086	0	0	0
8	0	22906	86	746	746	2	2	8	0 0	0 0	0.219584	48444	0.217057	48558	0	0	0
9	0	22910	86	746	746	2	2	9	0 0	0 0	0.219909	58979	0.218763	58911	0	0	0
10	0	22916	86	746	746	2	2	10	0 0	0 0	0.217609	44138	0.21754	44281	0	0	0
11	0	22922	86	746	746	2	2	11	0 0	0 0	0.217837	8262	0.220479	8156	0	0	0
12	0	22929	86	746	746	2	2	12	0 0	0 0	0.217895	24500	0.217895	24606	0	0	0
13	0	22935	86	746	746	2	2	13	0 0	0 0	0.219716	19085	0.219001	18864	0	0	0
14	0	22941	86	746	746	2	2	14	0 0	0 0	0.217877	55957	0.220657	56037	0	0	0
15	0	22946	86	746	746	2	2	15	0 0	0 0	0.217138	30435	0.220526	30468	0	0	0
16	0	22952	86	746	746	2	2	16	0 0	0 0	0.218487	38599	0.22042	38507	0	0	0
17	0	22958	86	746	746	2	2	17	0 0	0 0	0.217329	59398	0.221033	59489	0	0	0
18	0	22964	86	746	746	2	2	18	0 0	0 0	0.221632	16774	0.218995	16697	0	0	0
19	0	22970	86	746	746	2	2	19	0 0	0 0	0.220238	1408	0.21768	1456	0	0	0
20	0	22976	86	746	746	2	2	20	0 0	0 0	0.219599	766	0.21719	790	0	0	0
21	0	22982	86	746	746	2	2	21	0 0	0 0	0.219929	59780	0.218787	59677	0	0	0
22	0	22987	86	746	746	2	2	22	0 0	0 0	0.218759	43114	0.217055	43304	0	0	0
23	0	22993	86	746	746	2	2	23	0 0	0 0	0.219957	22810	0.218641	22621	0	0	0
24	0	22999	86	746	746	2	2	24	0 0	0 0	0.218857	64653	0.21793	64647	0	0	0
25	0	23006	86	746	746	2	2	25	0 0	0 0	0.218087	58028	0.220294	58066	0	0	0
26	0	23012	86	746	746	2	2	26	0 0	0 0	0.216677	26647	0.218773	26779	0	0	0
27	0	23018	86	746	746	2	2	27	0 0	0 0	0.219045	43239	0.21954	43067	0	0	0
28	0	23022	86	746	746	2	2	28	0 0	0 0	0.218252	65093	0.218945	65094	0	0	0
29	0	23030	86	746	746	2	2	29	0 0	0 0	0.2176	22171	0.219438	22355	0	0	0
30	2	23035	86	746	746	2	2	0	0 0	0 0	0.217793	2190	0.220326	2142	0	0	0
31	2	23039	86	746	746	2	0	1	0 0	0 0	0.217535	57854	0.218222	57944	0	0	0
32	2	23042	86	746	746	2	0	2	0 0	0 0	0.21831	17134	0.218533	16906	0	0	0
33	2	23047	86	746	746	2	0	3	0 0	0 0	0.218911	40500	0.216526	40592	0	0	0
34	2	23052	86	746	746	2	0	4	0 0	0 0	0.218572	23184	0.219623	23098	0	0	0

Correlation processing

S = I + jQ

$$|s| = \sqrt{Real\{s\}^2 + Imag\{s\}^2}$$

$$\measuredangle = Arg\{s\} = \arctan\left[\frac{Imag\{s\}}{Real\{s\}}\right]$$

$$s^* = Real\{s\} - j\,Imag\{s\}.$$

Correlation processing

$$T_0 = \frac{1}{M}\sum_{n=1}^{M} s_n{}^* s_n$$

$$R_0 = \frac{1}{M}\sum_{n=1}^{M} s'_n{}^* s'_n$$

$$R_1 = \frac{1}{M-1}\sum_{n=1}^{M-1} s'_n{}^* s'_{n+1}$$

$$R_2 = \frac{1}{M-2}\sum_{n=1}^{M-2} s'_n{}^* s'_{n+2}$$

$$s = I + jQ$$

s' denotes the clutter-filtered time series, s denotes the original unfiltered time series and the * denotes a complex conjugate

Correlation processing

$$\mathbf{Lag\ [0]} = (I + jQ) \text{ x conj } (I + jQ)$$

$$= (I + jQ) \text{ x } (I - jQ)$$

$$= (0.707 + j0.707) \text{ x } (0.707 - j0.707)$$

$$= 0.707\text{x}0.707 - i(0.707\text{x}0.707) + i(0.707\text{x}0.707) - j^2(0.707\text{x}0.707)$$

$$= 0.5 - j0.5 + j0.5 - j^2(0.5)$$

$$= 0.5 + j0 + 0.5$$

$$= 1 + j0$$

R0 has only magnitude, phase will always be zero

Correlation processing

Stationary target:

I&Q samples for PRF_2 will ideally have exactly the same phase and magnitude as I&Q samples taken at PRF_1.eg. $PRF_1 = 0.707 + j0.707$ & $PRF_2 = 0.707 + j0.707$

Calculating the auto-correlation of the first lag will provide the phase difference between PRF_1 and PRF_2.

The phase of the resultant vector provides the phase difference between PRF_1 & PRF_2.

$$
\begin{aligned}
\text{Lag }[1] &= (I_2 + jQ_2) \text{ x conj}(I_1 + jQ_1) \\
&= (I_2 + jQ_2) \text{ x } (I_1 - jQ_1) \\
&= (0.707 + j0.707) \text{ x } (0.707 - j0.707) \\
&= 0.707\text{x}0.707 - j(0.707\text{x}0.707) + j(0.707\text{x}0.707) - j^2(0.707\text{x}0.707) \\
&= 0.5 + j0 - j^2(0.5) \\
&= 0.5 + j0 + 0.5 \\
&= 1 + j0 \qquad \Rightarrow \text{Phase difference} = 0 \text{ deg}
\end{aligned}
$$

Correlation processing

Moving target: $PRF_1 = 0.707 + j0.707$

$PRF_2 = 1 + j0$

$$\begin{aligned}
\text{Lag [1]} &= (I_2 + jQ_2) \text{ x conj } (I_1 + jQ_1) \\
&= (I_2 + jQ_2) \text{ x } (I_1 - jQ_1) \\
&= (1 + j0) \text{ x } (0.707 - j0.707) \\
&= (1\text{x}0.707) - j(1\text{x}0.707) + j(0\text{x}0.707) - j^2(0 \text{ x}0.707) \\
&= 0.707 - j0.707 + j0 - j^2(0) \\
&= 0.707 - j0.707
\end{aligned}$$

Phase = -45deg. or $-\pi/4$

Phase value from R1 for velocity measurement

Reflectivity

Reflectivity

$$dBZ = 10\log\left[\frac{T_0 - N}{N}\right] + dBZ_0 + 20\log r + ar + CCOR$$

1st Term : $10\log\left[\frac{T_0 - N}{N}\right]$ Signal to Noise Ratio

2rd Term: dBZ_0: Calibration Reflectivity (

3th Term: $20\log r$: Range Normalization

4th Term: ar: Gaseous Attenuation Correction

5th Term: CCOR: Clutter Correction

Velocity

Velocity

$$V = \frac{\lambda}{4\pi\tau_s}\theta_1 \text{ where } \theta_1 = \arg\{R_1\}.$$

λ is the radar wavelength, is the sampling time (1/PRF). θ1 is constrained to be on the interval [-π, π]

Spectrum Width

Spectrum Width

R_0, R_1 "fast" algorithm valid when SNR >> 10 dB

$$Variance = 2\ln\left[\frac{R_0}{|R_1|}\right]$$

R_0, R_1, R_2 "accurate" algorithm for SNR >> 0 to 5 dB

$$Variance = \frac{2}{3}\ln\left[\frac{|R_1|}{|R_2|}\right]$$

$$W = \frac{\sqrt{Variance}}{\pi}$$

Width is normalized to the Nyquist Interval [-1, 1],
To obtain the width in meters per second, one multiplies
The output width by *V*u

Range Averaging

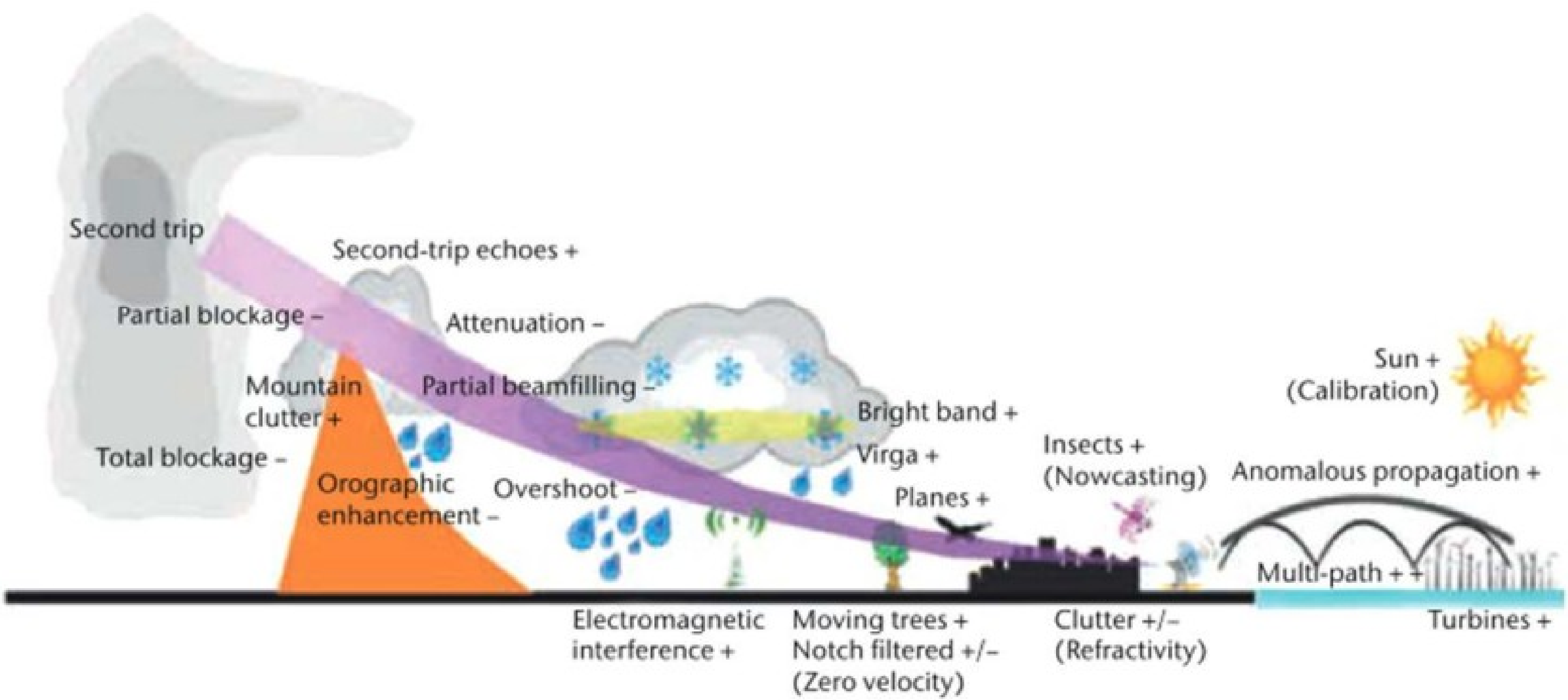
It can be performed over 2, 3, ..., 16 bins. This is accomplished by simply averaging the $T0$, $R0$, $R1$ and $R2$ values.

Thresholds can be applied on the bins to exclude the bins which does not satisfy the quality criteria

Bin size is determined by the pulse width

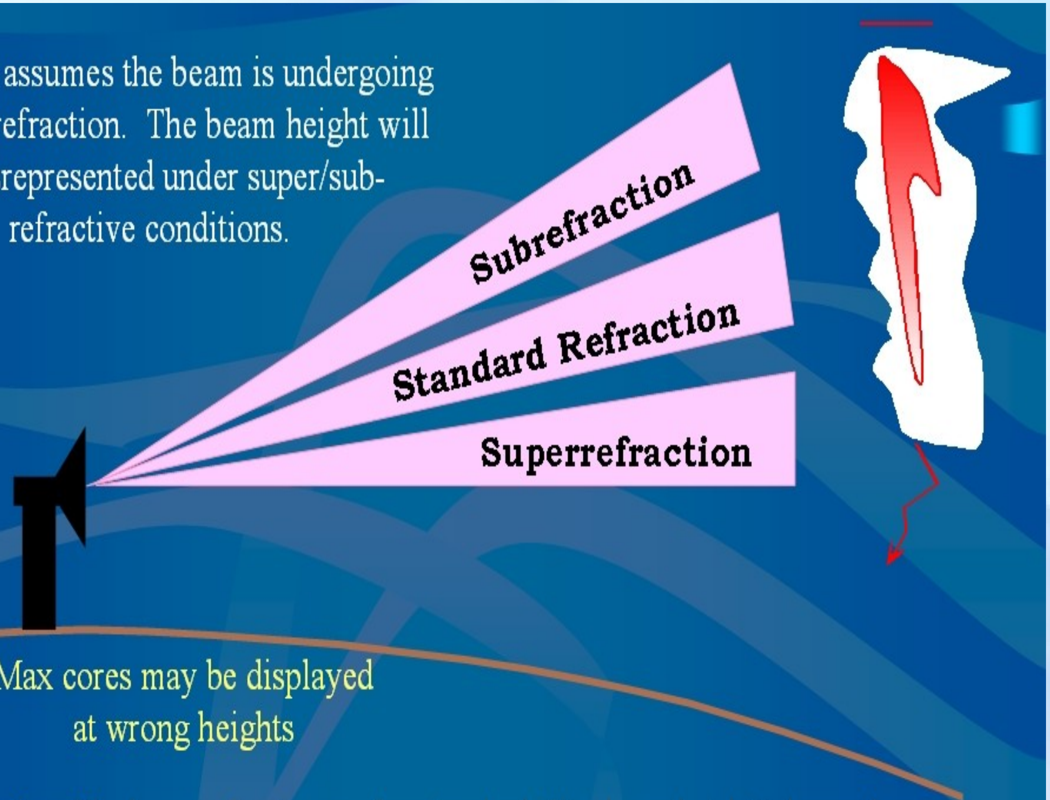
Factors affecting radar data

Error sources on weather radar observation



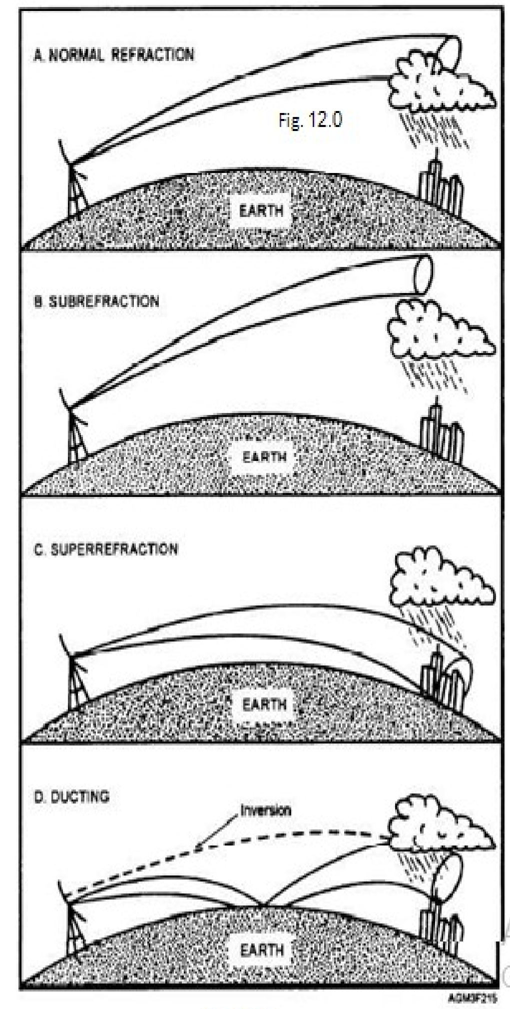
Factors affecting radar data

The radar assumes the beam is undergoing standard refraction. The beam height will be misrepresented under super/sub-refractive conditions.

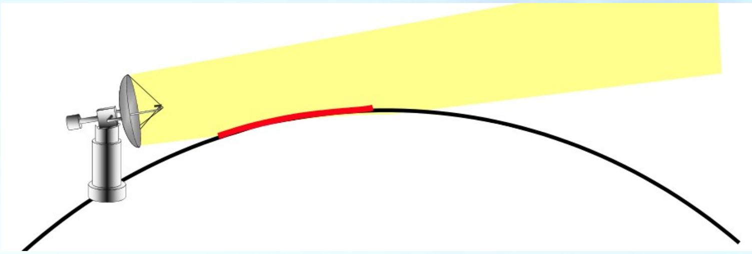


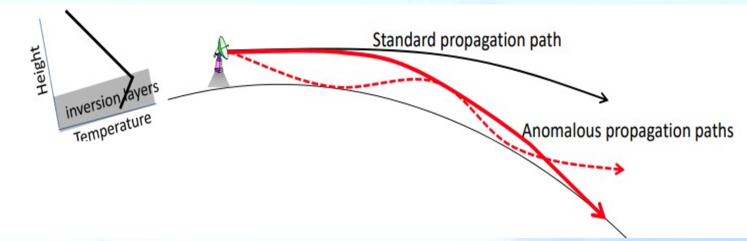
Superrefraction: The beam refracts more than standard. The beam height is lower than the radar indicates.

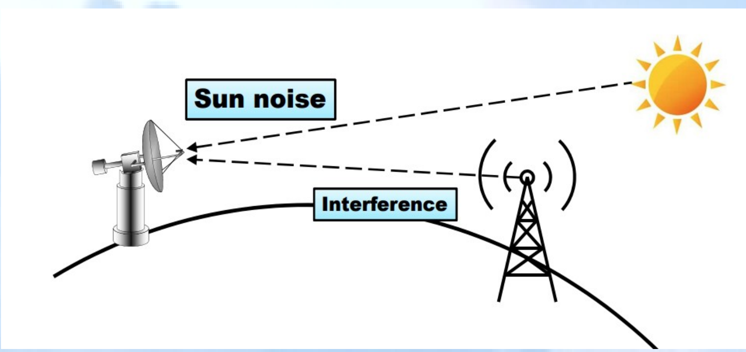
Subrefraction: The beam refracts less than standard. The beam height is higher than the radar indicates. Beam can overshoot developing storms.

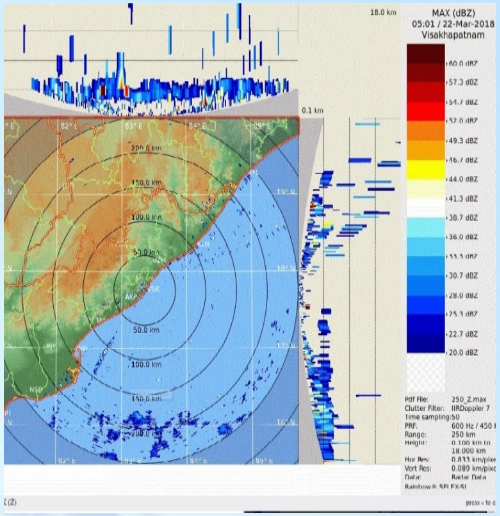


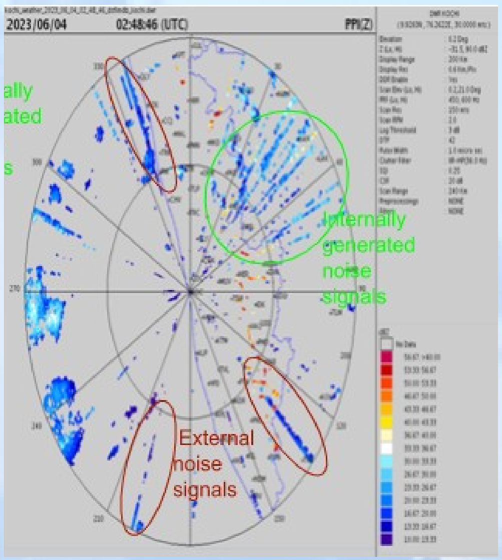
Factors affecting radar data



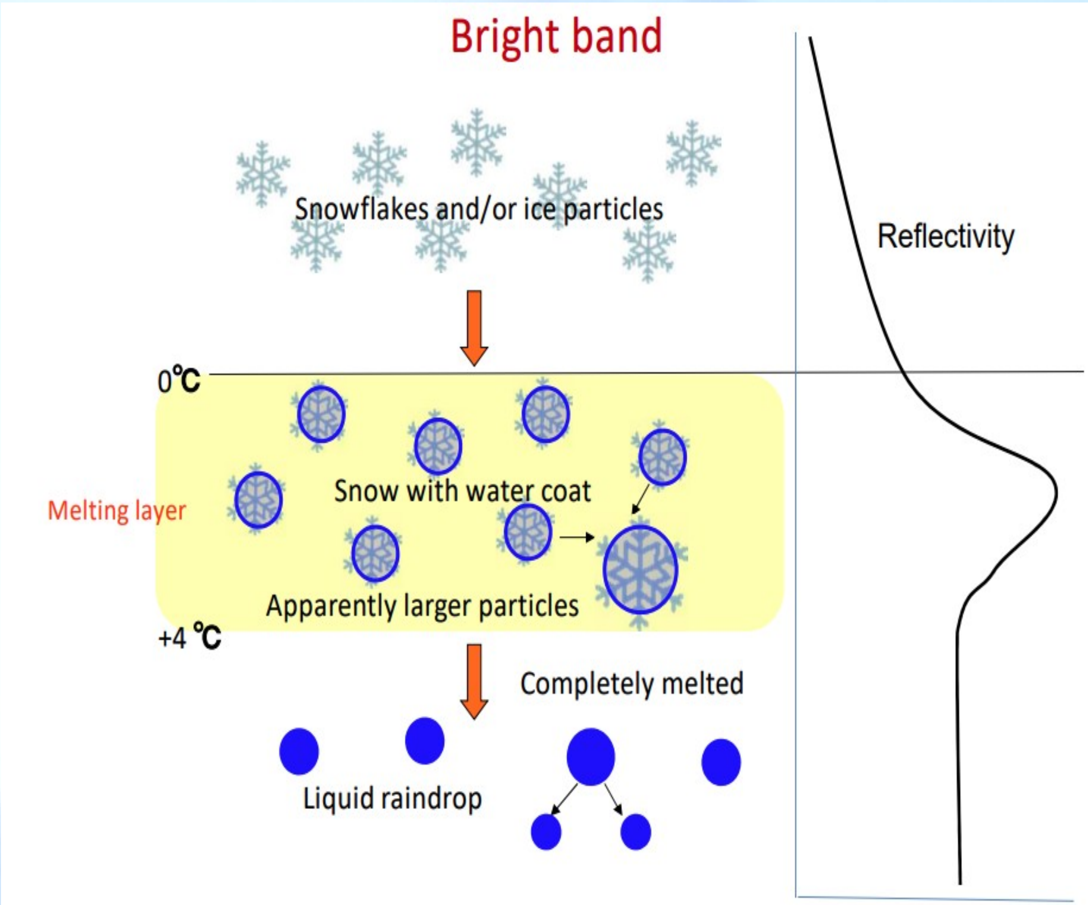


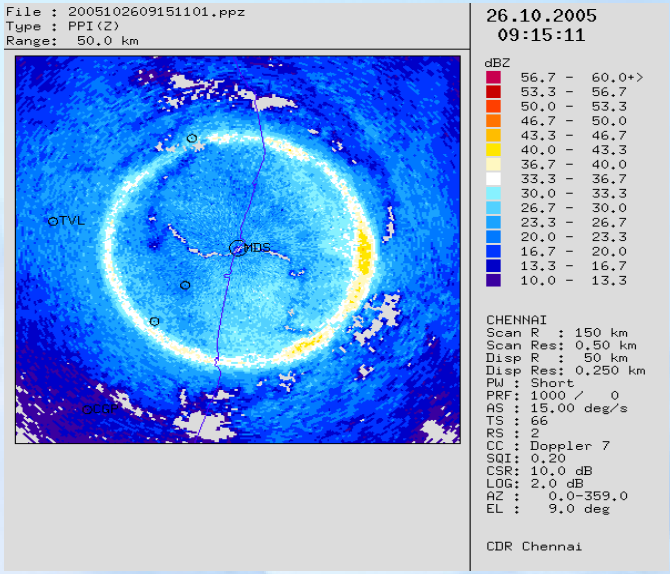




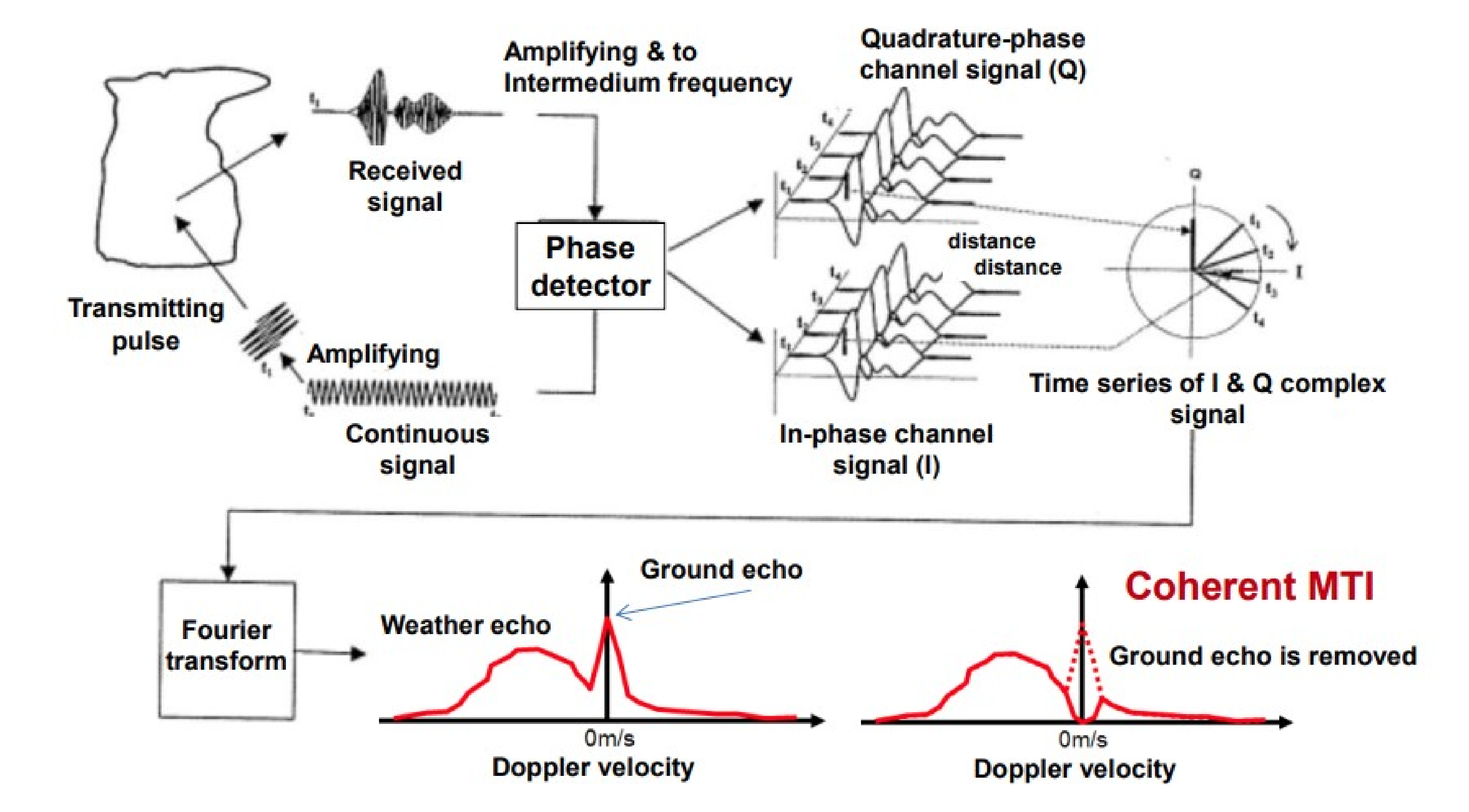


Bright band


Bright band
Snowflakes and/or ice particles
Reflectivity
0°C
Melting layer
Snow with water coat
Apparently larger particles
+4 °C
Completely melted
Liquid raindrop


File : 2005102609151101.ppz
Type : PPI(Z)
Range: 50.0 km
26.10.2005
09:15:11
dBZ
56.7 - 60.0+>
53.3 - 56.7
50.0 - 53.3
46.7 - 50.0
43.3 - 46.7
40.0 - 43.3
36.7 - 40.0
33.3 - 36.7
30.0 - 33.3
26.7 - 30.0
23.3 - 26.7
20.0 - 23.3
16.7 - 20.0
13.3 - 16.7
10.0 - 13.3
TVL
MDS
CGP
CHENNAI
Scan R : 150 km
Scan Res: 0.50 km
Disp R : 50 km
Disp Res: 0.250 km
PW : Short
PRF: 1000 / 0
AS : 15.00 deg/s
TS : 66
RS : 2
CC : Doppler 7
SQI: 0.20
CSR: 10.0 dB
LOG: 2.0 dB
AZ : 0.0-359.0
EL : 9.0 deg
CDR Chennai

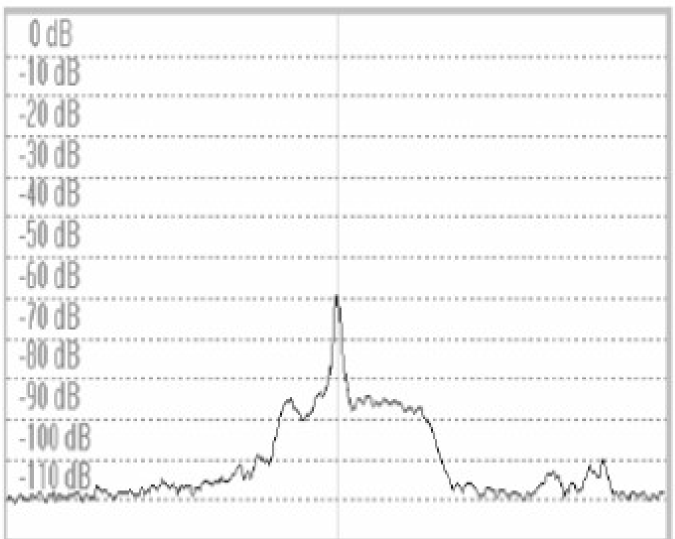
Removing clutter

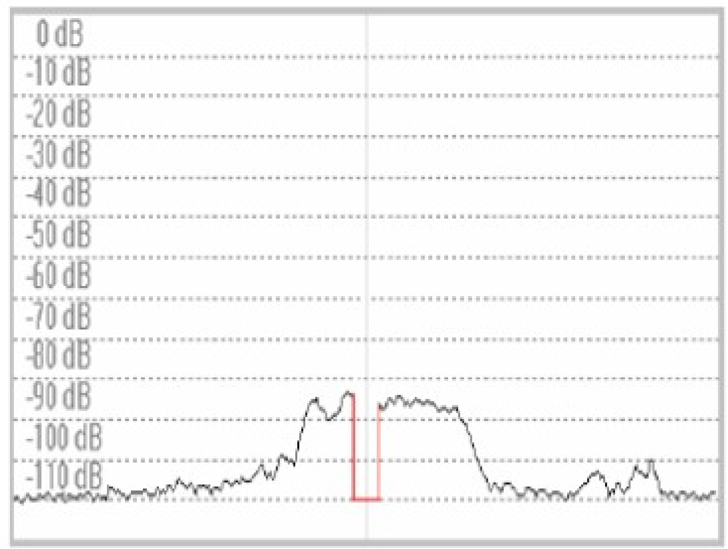


Clutter Filter

Time series mode – IIR Filter (velocity

Weather Data with zero velocity (tangetial elements will also be removed)

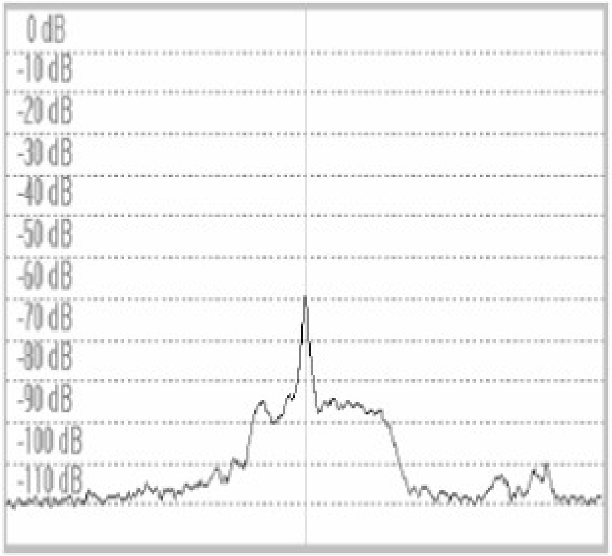


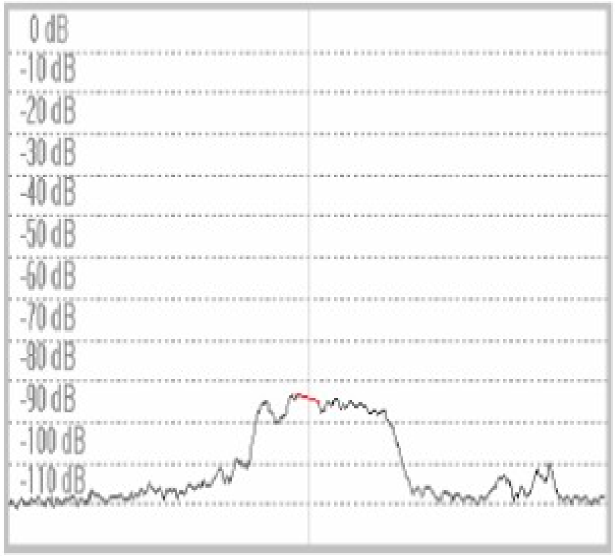


Clutter Filter

Frequency domain – by FFT

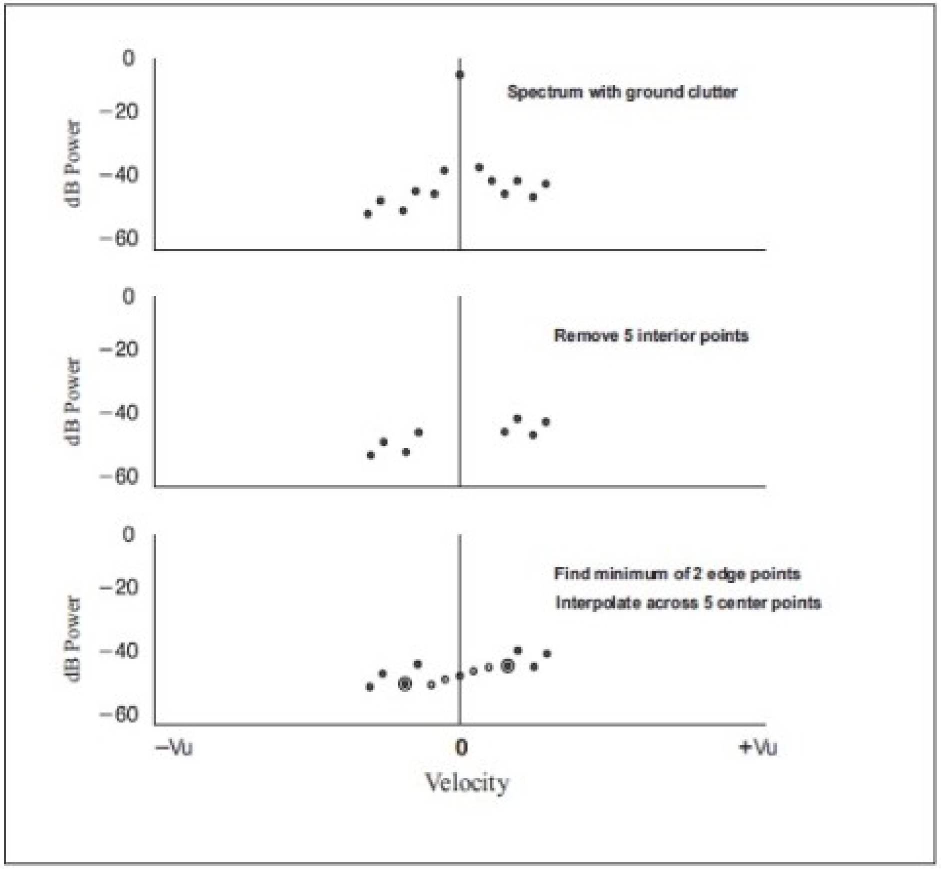
Interpolation across 0 Hz region





Clutter Filter

Frequency domain – by FFT



Thresholding

Signal quality Index (SQI)

The signals which are very weak to be of any use or the spectrum width is too high to justify further analysis

SQI = f(SNR, SW)

$$SQI = \frac{|R_1|}{R_0}$$

$$SQI = \frac{SNR}{SNR+1} e^{\frac{-\pi^2 W^2}{2}}$$

The SQI is the normalized magnitude of the autocorrelation at lag 1 and varies between 0 for an uncorrelated signal (white noise) to 1 for a noise-free zero-width signal (pure tone). Mean velocity estimates are degraded when the spectrum, width is large or when the signal-to-noise ratio is weak.

For very large SNR's the SQI is a function of the spectrum width only.
For a zero-width pure tone (W=0),the SQI is a function of the SNR only
(for example, for W=0, an SNR of 1corresponds to SQI=0.5).
The SQI threshold is typically set to a value of 0.4 to 0.5.

Thresholding

Clutter correction Threshold (CCOR)

T0 is the total unfiltered power. By comparing the total filtered and unfiltered powers at each range bin, a clutter power, and hence a clutter correction, for that bin can be derived

$$CCOR_{est} = 10\log\frac{S}{C+S} = 10\log\frac{1}{CSR+1}$$

The clutter power is computed from:

$$C = T_0 - R_0 = [C+S+N] - [S+N]$$

The signal power S is then computed from:

$$S = |R_1|\exp\frac{\pi^2 W^2}{2}$$

The default threshold is set to -18db

Thresholding

LOG

A threshold parameter called LOG is also calculated to provide a signal strength estimate that is useful for qualifying reflectivity.It is the ratio of Signal plus Noise to Noise, which always has a positive representation in dB

$$LOG = 10\log\left[\frac{R_0}{N}\right] \; (when\ applied\ to\ the\ other\ parameter)$$

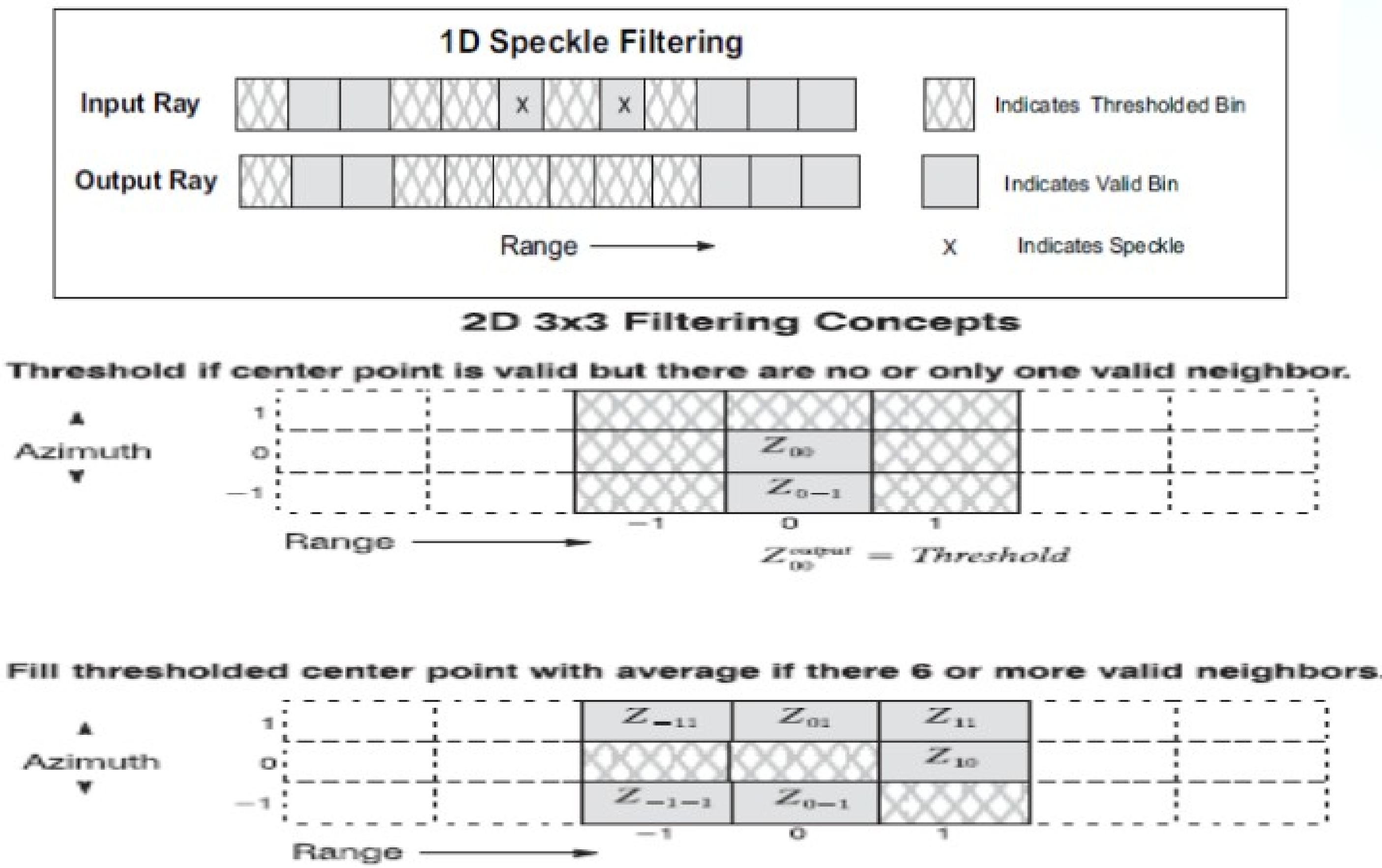
The default threshold is set to 0.75db

Thresholds

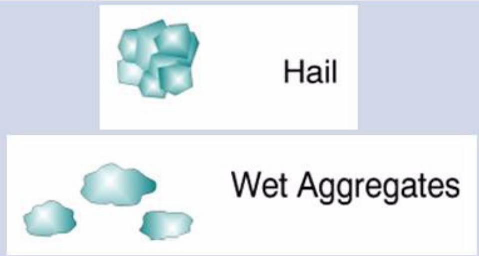
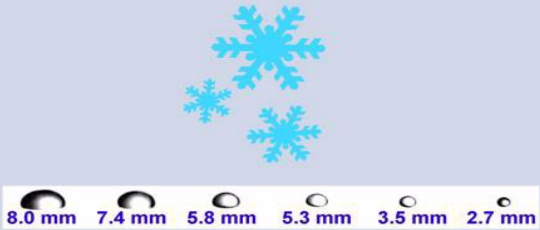
ID	Criterion Name	Pass Criterion
LOG	(Signal+Noise)-to-Noise Ratio	LOG > threshold
SQI	Signal Quality Index	SQI > threshold
CCOR	Clutter Correction	CCOR > threshold
SIG	Weather Signal Power	SIG > threshold
PMI	Polarimetric Meteo Index	PMI > threshold

Speckle Filter

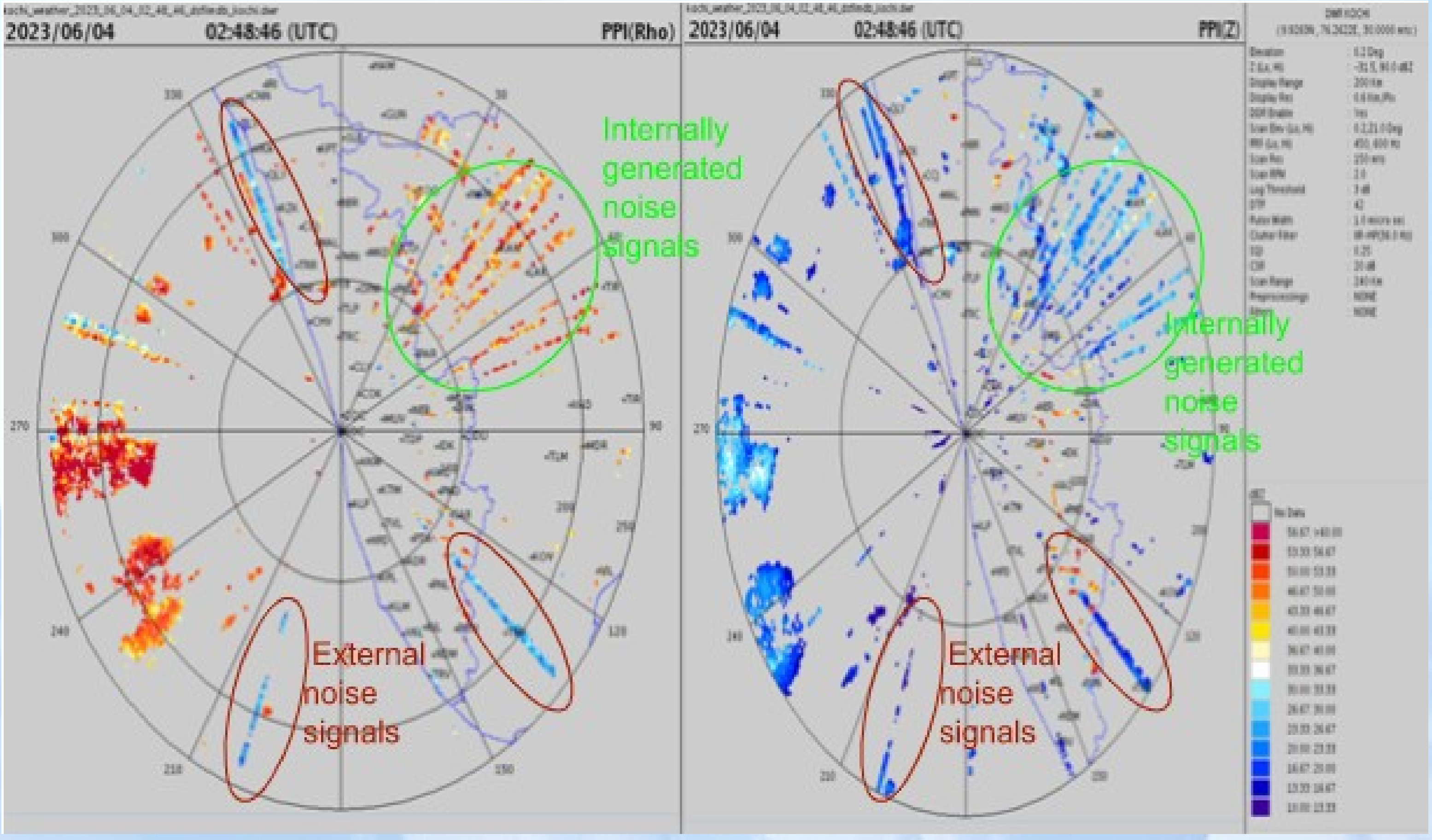
A speckle filter is a final pass over each output ray, in which isolated bins are removed.Speckle filters remove isolated data points that are likely to be noise, interference, aircraft, birds, or other point targets. Meteorological targets typically occupy multiple range bins, so they are not affected by the speckle filters



Post processing

Non-Meteorological (birds, insects, etc.)	**Metr (Non-Uniform)** (hail, melting snow, etc.)	**Metr (Uniform)** (rain, snow, etc.)
		
Complex scattering from pulse-to-pulse. Horizontal and vertical pulses change in different manners from pulse-to-pulse	Somewhat complex scattering from pulse-to-pulse. Moderate differences from pulse-to-pulse for the horizontal and vertical pulses	Well-behaved scattering from pulse-to-pulse. Little differences from pulse-to-pulse for the horizontal and vertical pulses
Low CC (< 0.7)	Moderate CC (0.80 to 0.97)	High CC (> 0.97)

Post processing



Thank you
Any Questions?
bibraj.r@imd.gov.in