

# Modulation Classification

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# **Modulation Classification**

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**BY**

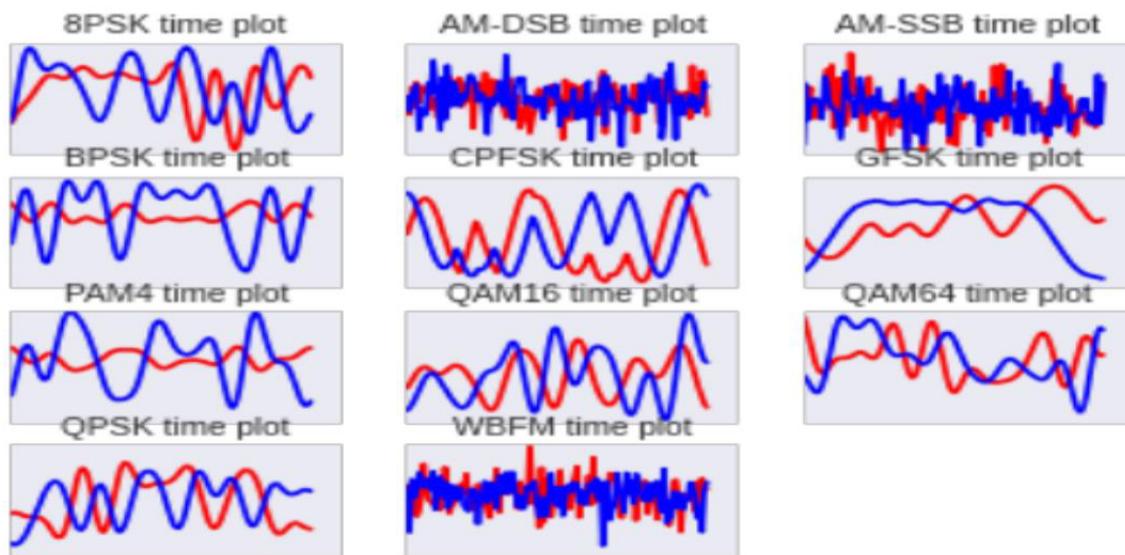
**NADA HASSAN      MARIAM SAEED      MOHAMED METWALLI**

# Preparing data

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# 1 Problem statement

A synthetic dataset, generated with GNU Radio, consisting of 11 modulations. This is a variable-SNR dataset with moderate LO drift, light fading, and numerous different labeled SNR increments for use in measuring performance across different signal and noise power scenarios. It is required to train and compare three different models then try to combine and modify these architectures to obtain better results



## 2 Data Pre-processing

### 2.1 Loading Data

We used google colab to download the data file(.dat) then saved a copy in the drive. After that we used Pickle library to read the data and divide it into samples, labels and snr values.

Data is mostly stored in ‘numpy’ arrays but during processing we kept intermediate results in ‘list’ as it has faster append operation and takes less RAM.

### 2.2 Combining Data

The raw data contained of 2 channels mainly but we could apply derivative or integration on the data to get more channels.

we have tried the following combinations during training:

- Raw data
- Raw data + derivative
- Raw data + Integration

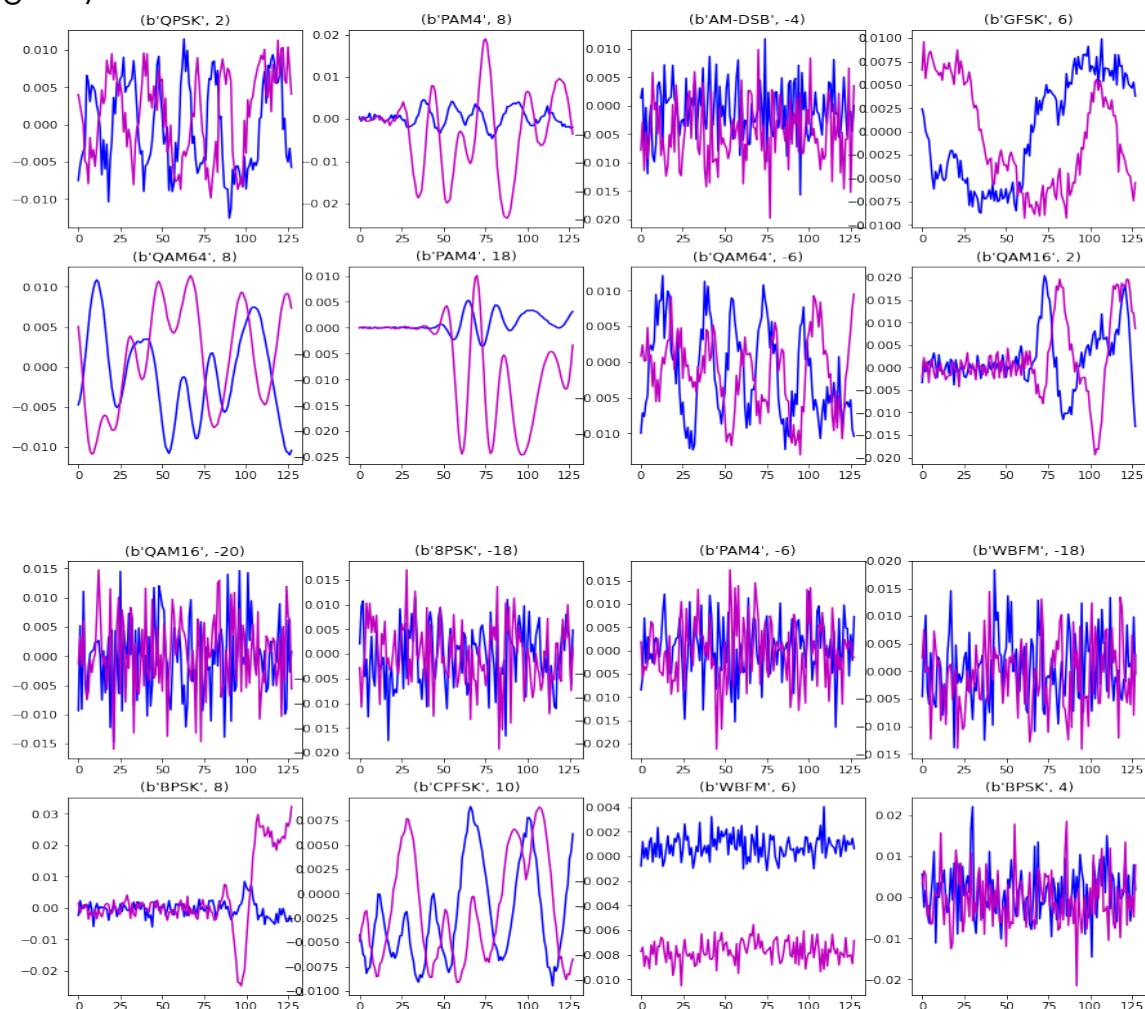
Combining all three together won't fit in RAM because size of data is large.

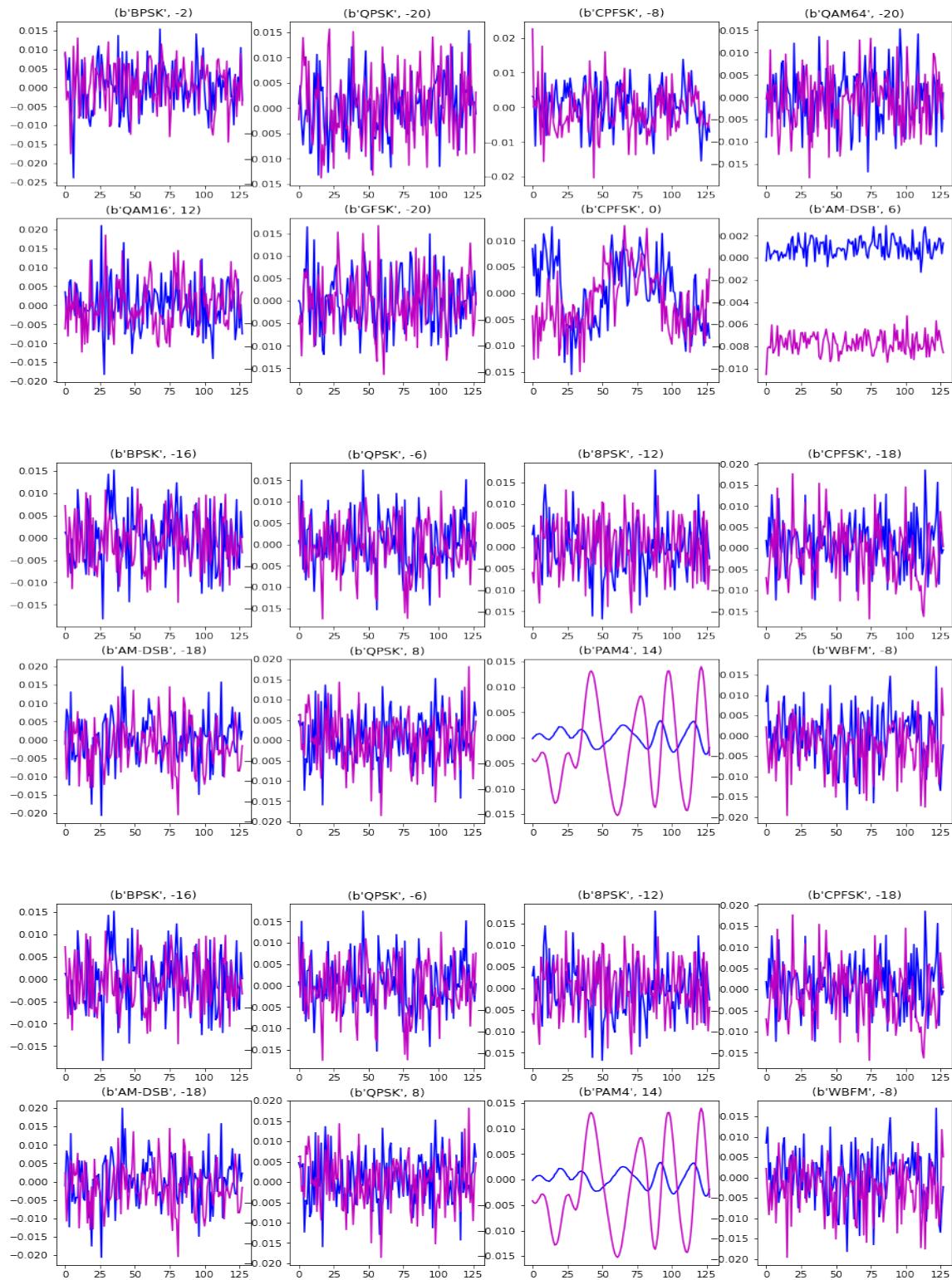
## 2.3 Data explanation

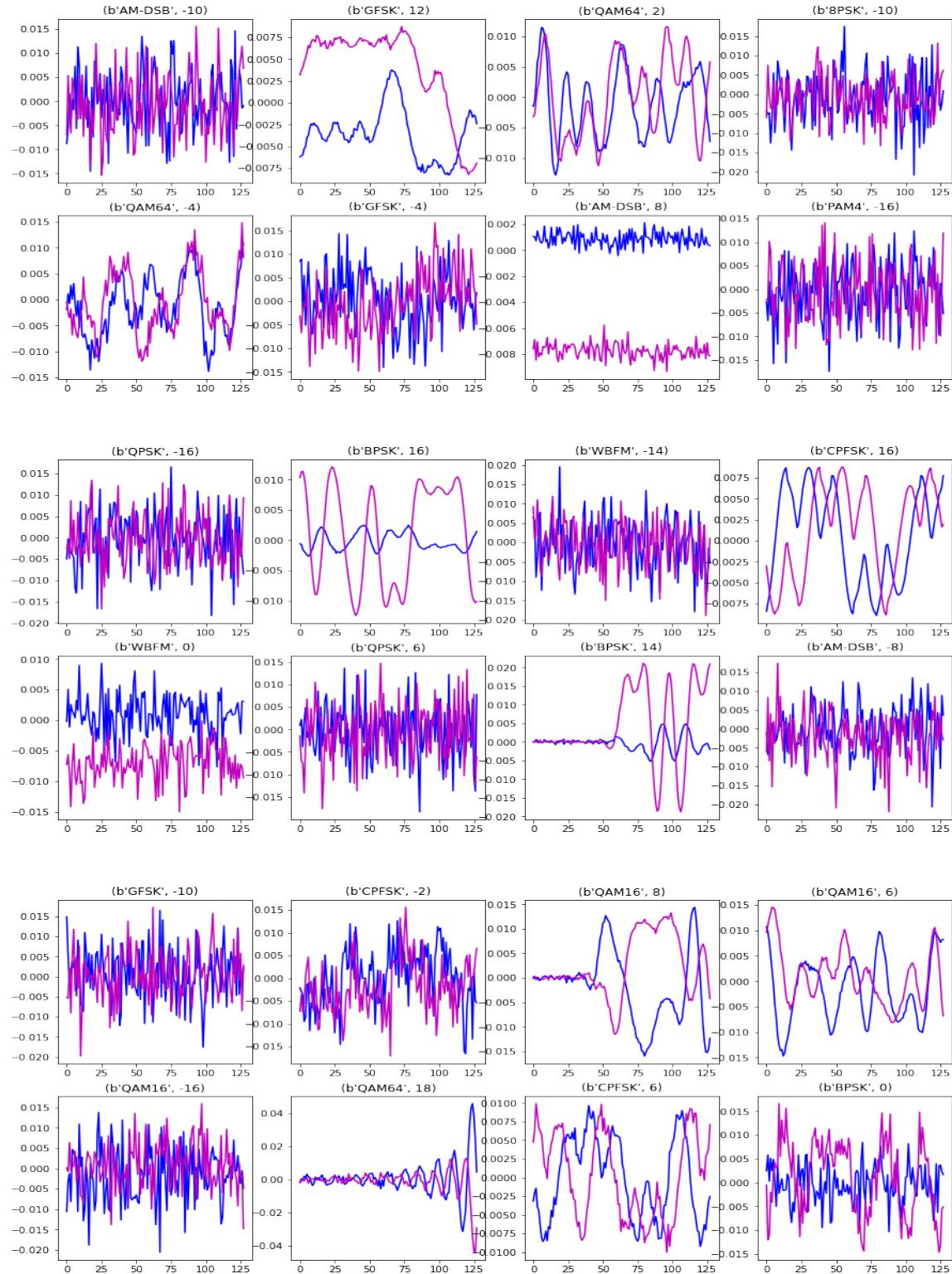
RadioML2016b data set consists of 1,200,000 samples each sample has the shape 128x2 it represents 128 complex time domain samples with 2 vectors to represent the real and imaginary parts of the time samples.

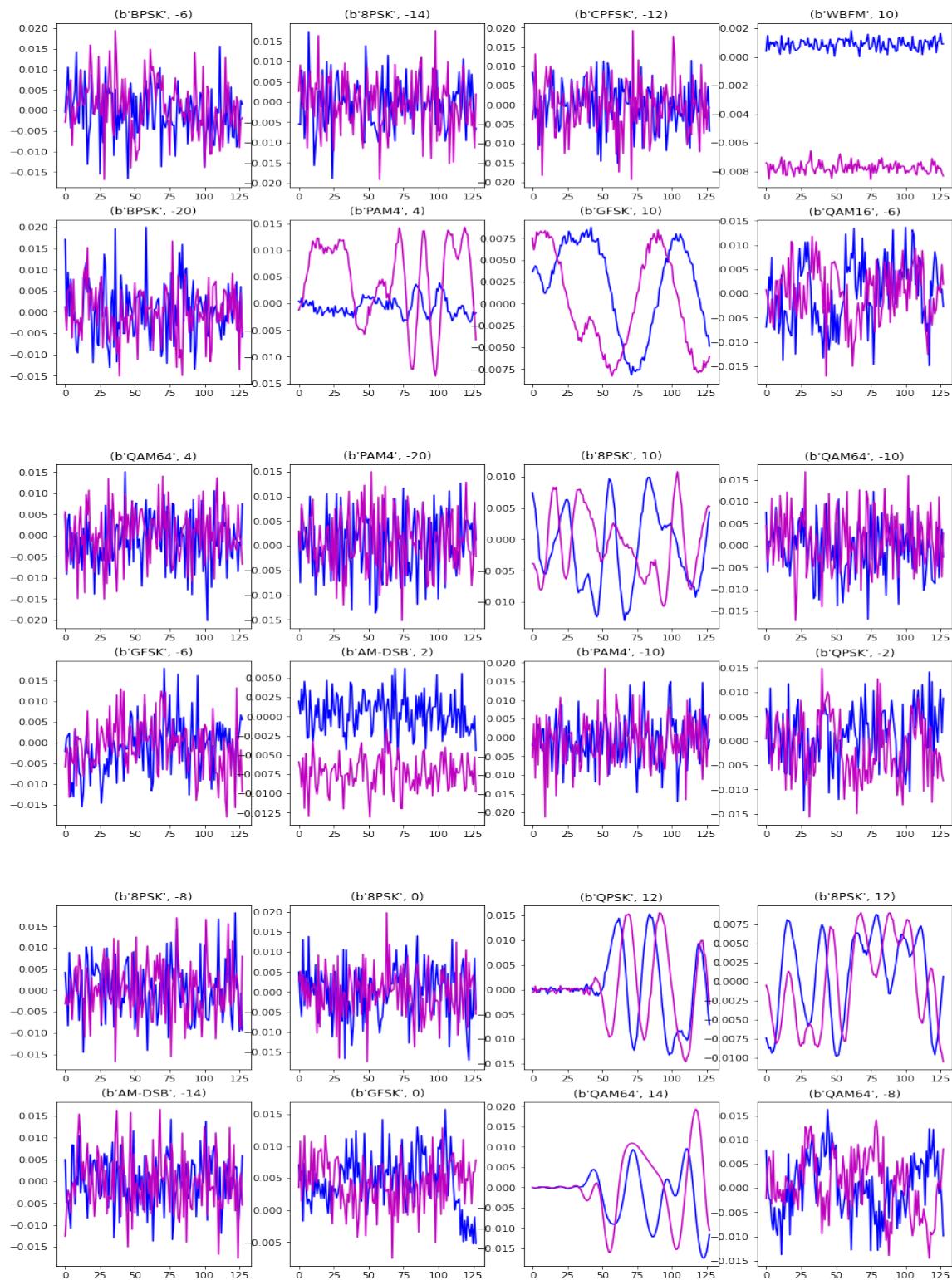
The dataset consists of 10 different signals each one has 20 different level of noise applied to it between -20 and 18 db Here's example of each class with different db levels:

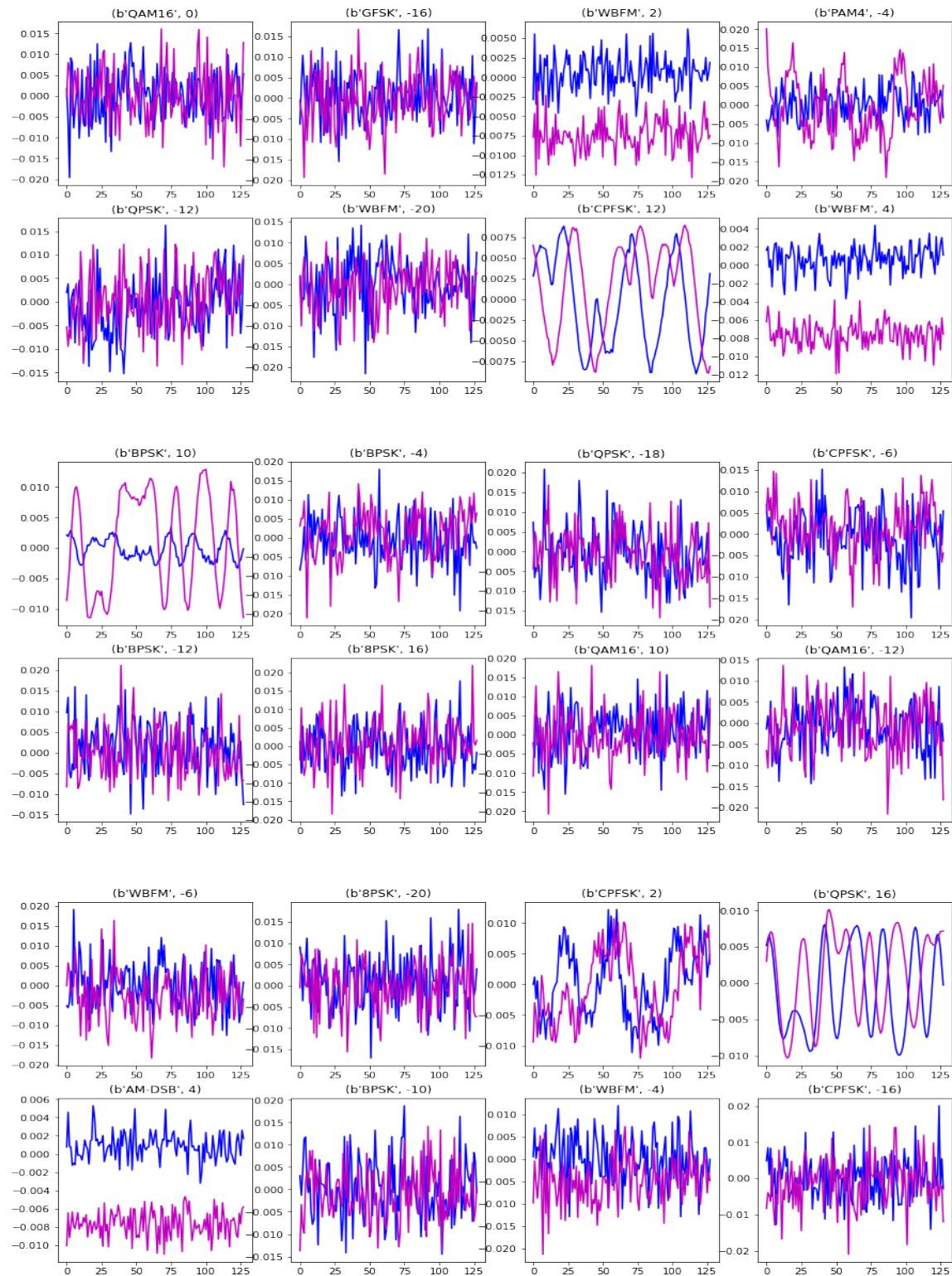
- blue curve represents real values of the signal while magenta represents imaginary values.

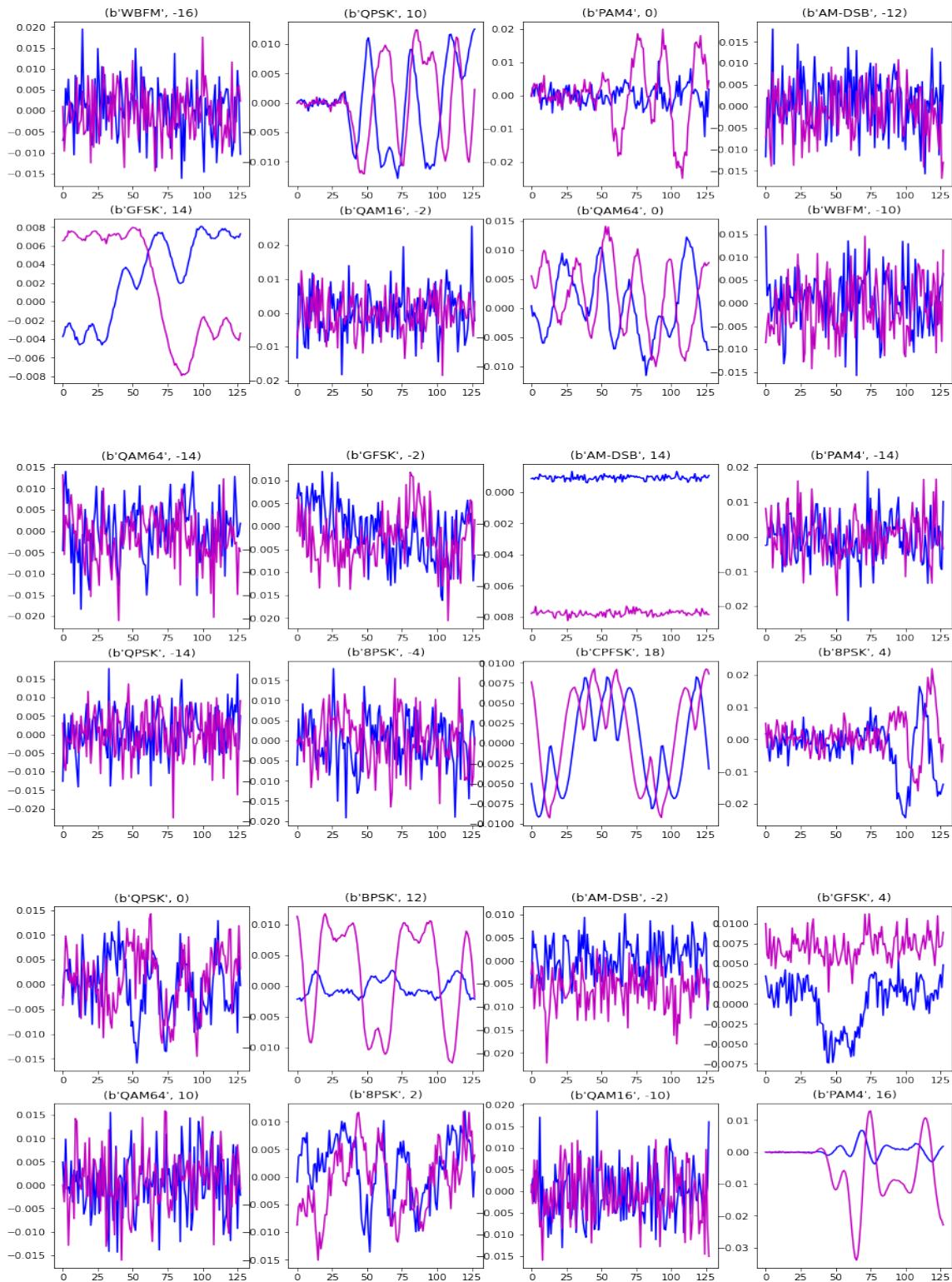


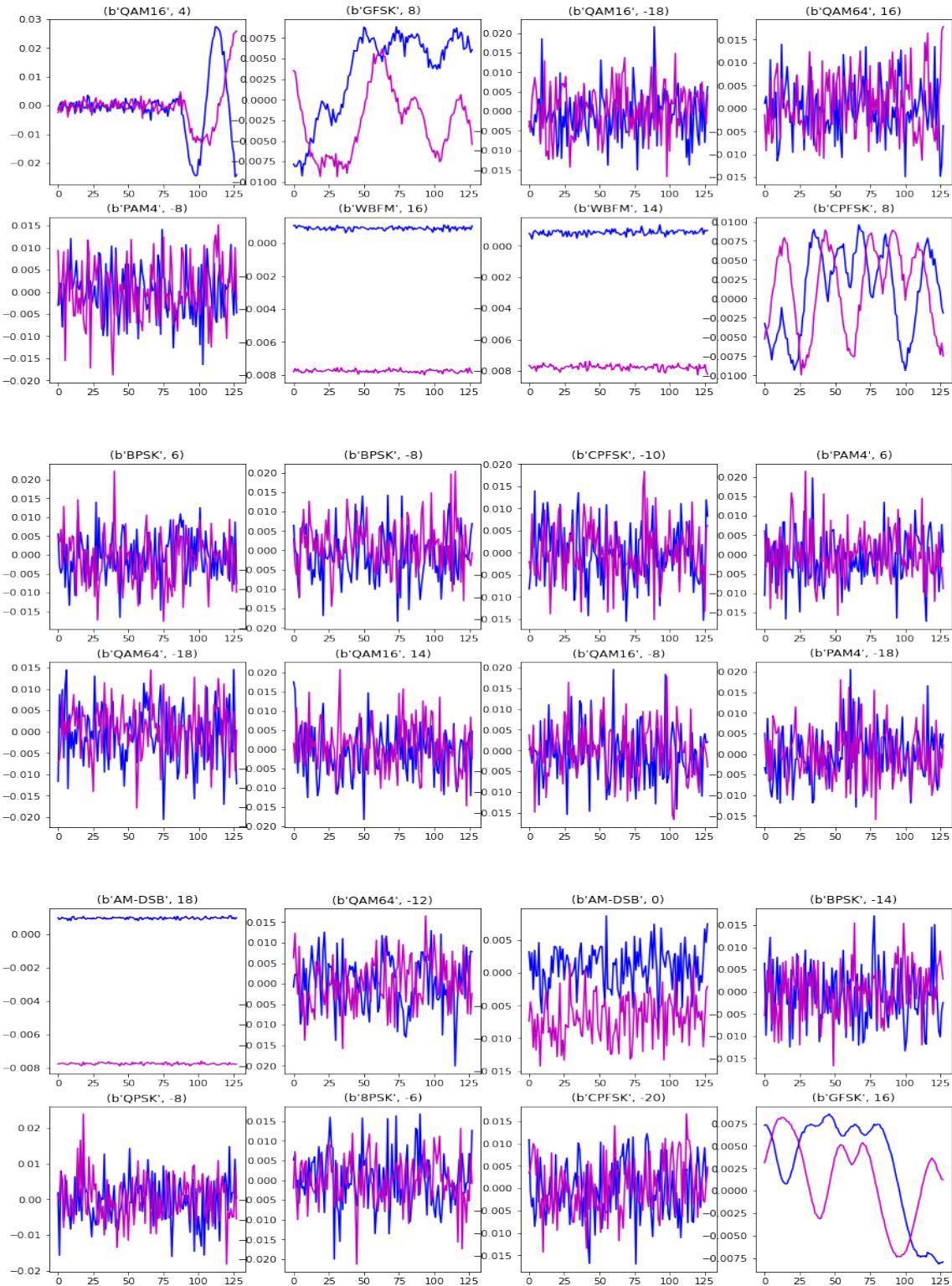


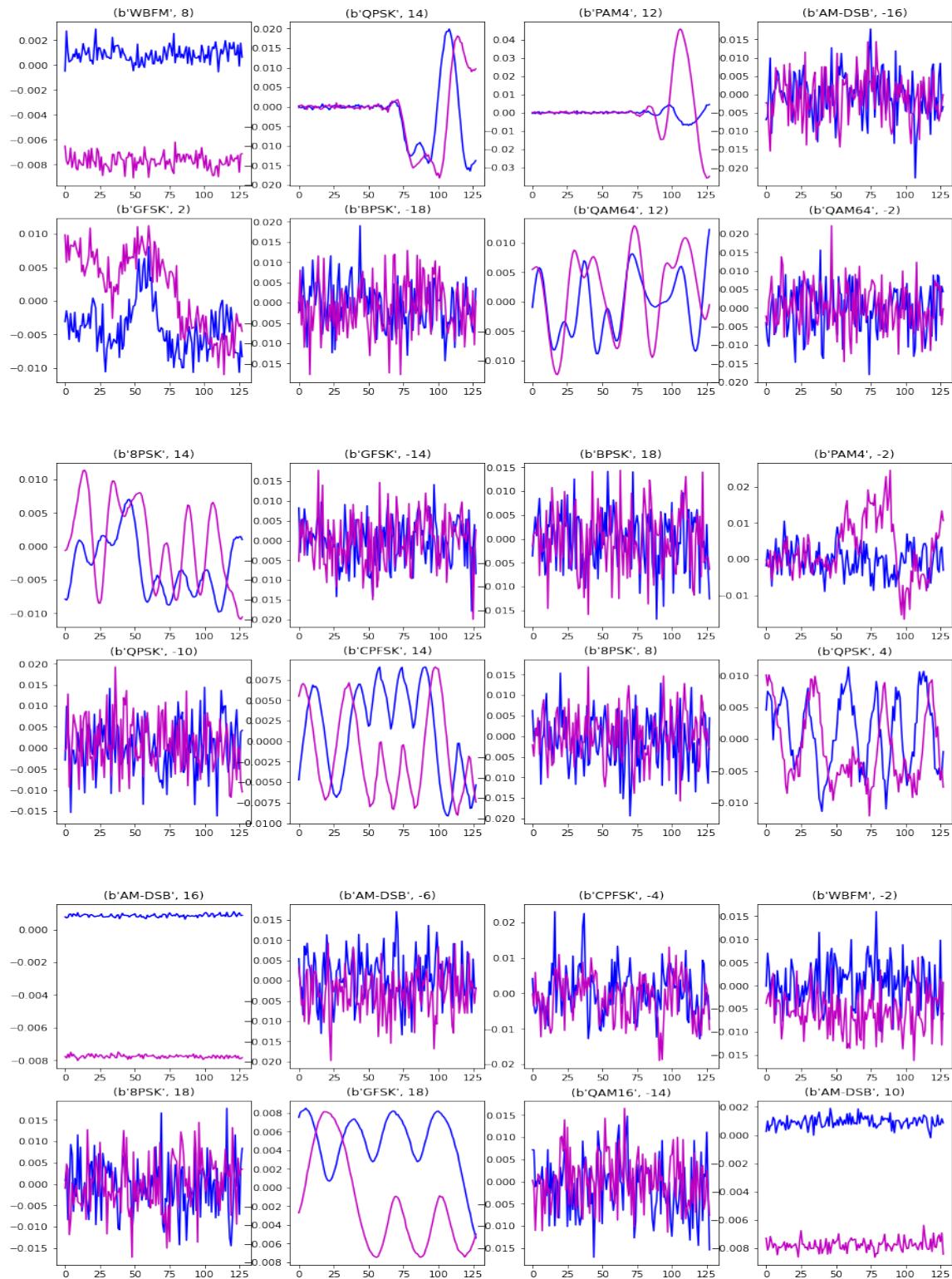


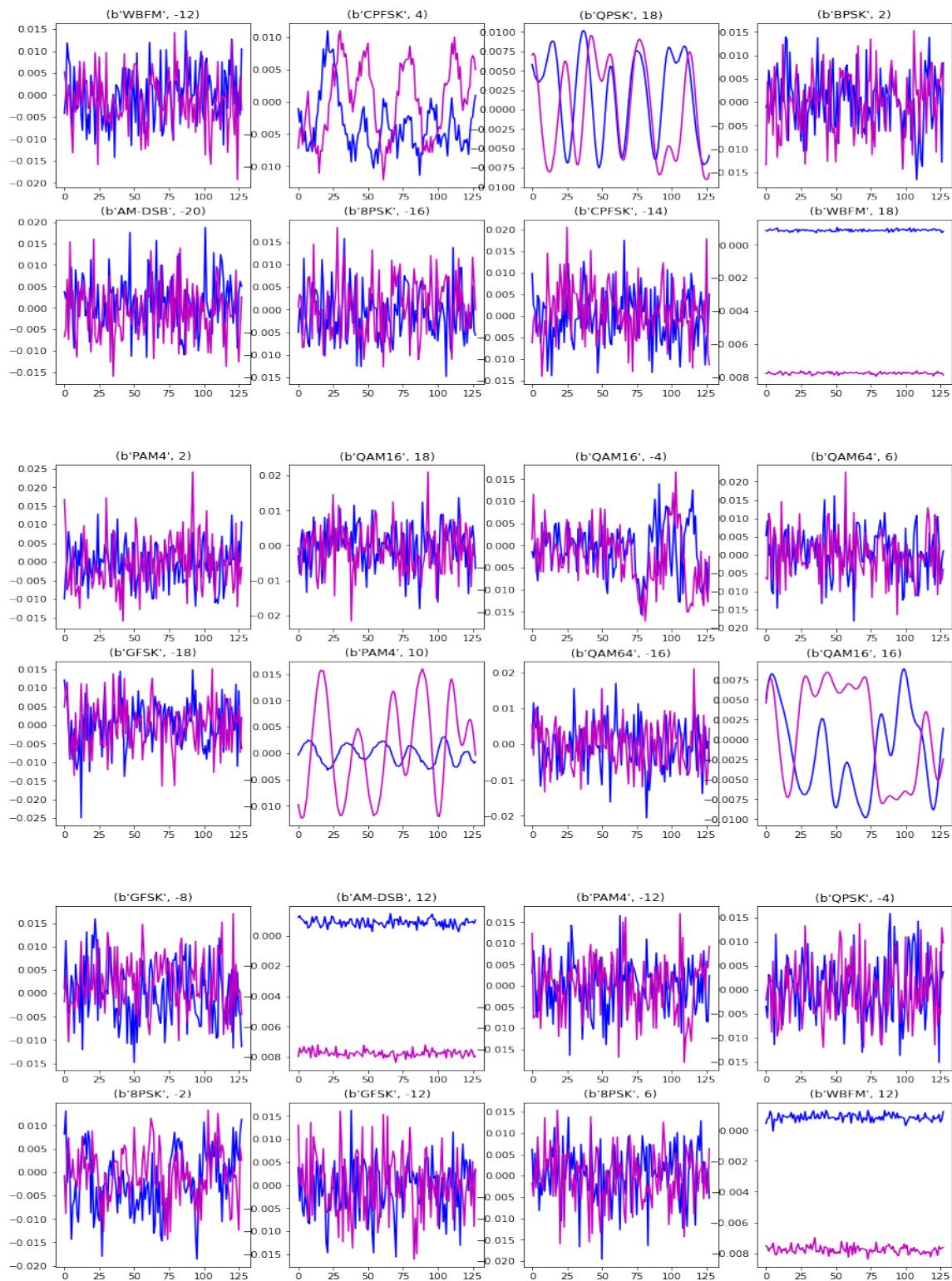












### 3 Different models

We have built 4 models:

- CNN
- Vanilla RNN
- LSTM
- CNN-LSTM which is called CLDNN

### 4 Tuning Techniques

It was required to tune the learning rate of each model so we have tried the most used learning rates:

- 1e-1
- 1e-2
- 1e-3
- 1e-4
- 1e-5
- 1e-6

In most models 1e-4 was the best regarding to accuracy and loss but in LSTM model the default settings of Adam optimizer were better in integral model. We also used some callback function to optimize the tuning process.

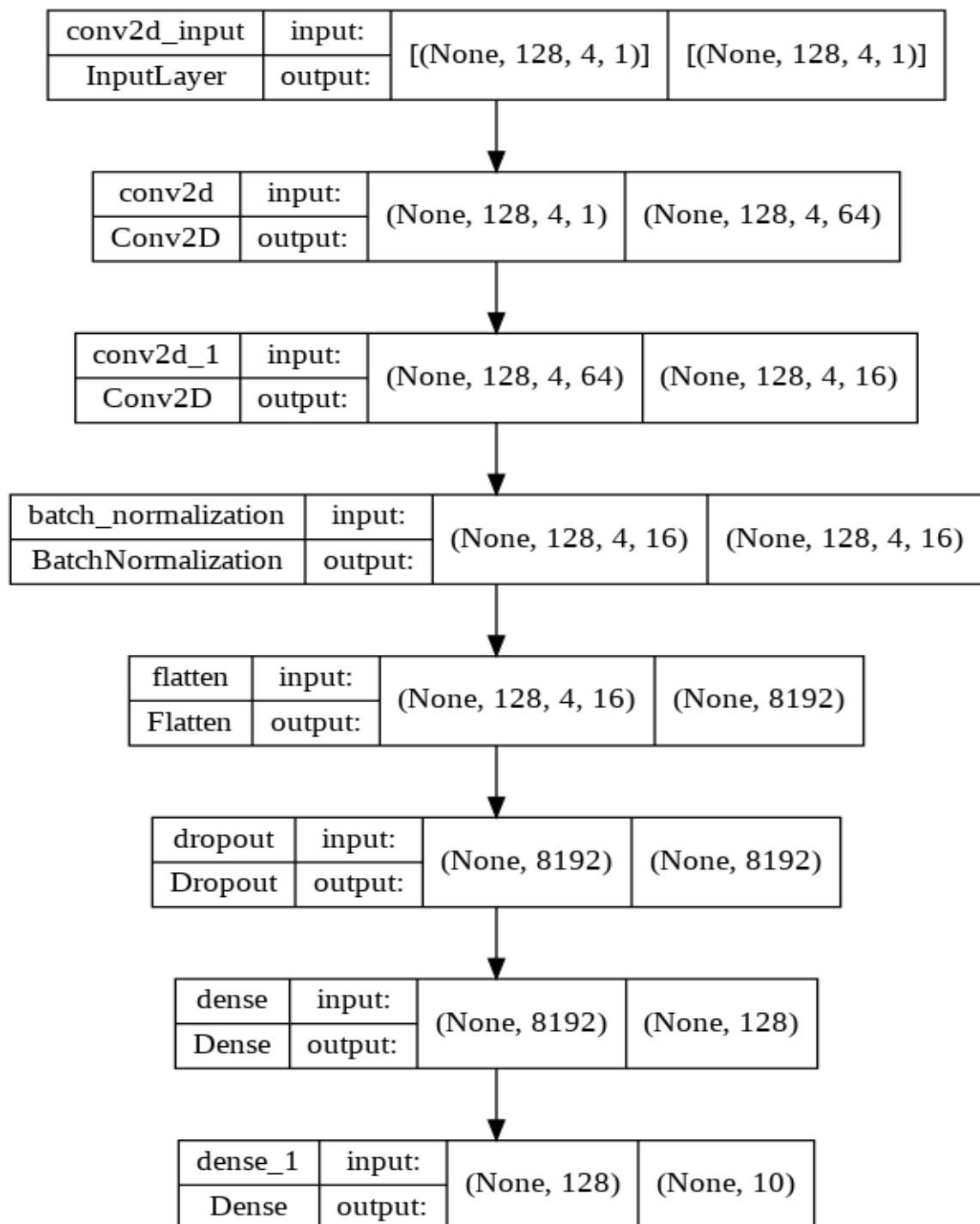
- EarlyStopping to stop training if the model didn't enhance accuracy for 5 epochs
- Save checkpoint which saves a checkpoint only if the model has enhanced its accuracy

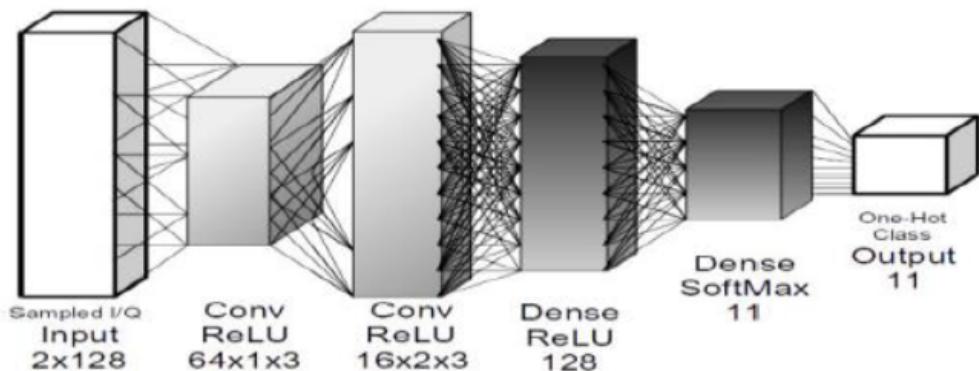
# CNN model

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## 1 Model structure

It processes the data that has a grid pattern, such as images, which is inspired by the organization of animal visual cortex [13, 14] and designed to automatically and adaptively learn spatial hierarchies of features, from low- to high-level patterns.





**Figure 3. CNN Architecture**

## 2 Tuning

	Raw data	Raw data + derivative	Raw data + integration
1e-1	10%	10%	10%
1e-2	10%	10%	10%
1e-3	17%	49.8%	38.80%
1e-4	51%	46.76%	55.54%
1e-5	51.02%	50.13%	49.81%
1e-6	37.5%	41.79%	33.26%

## 3 Models results

### 3.1 (Best model) Integral + Raw model report

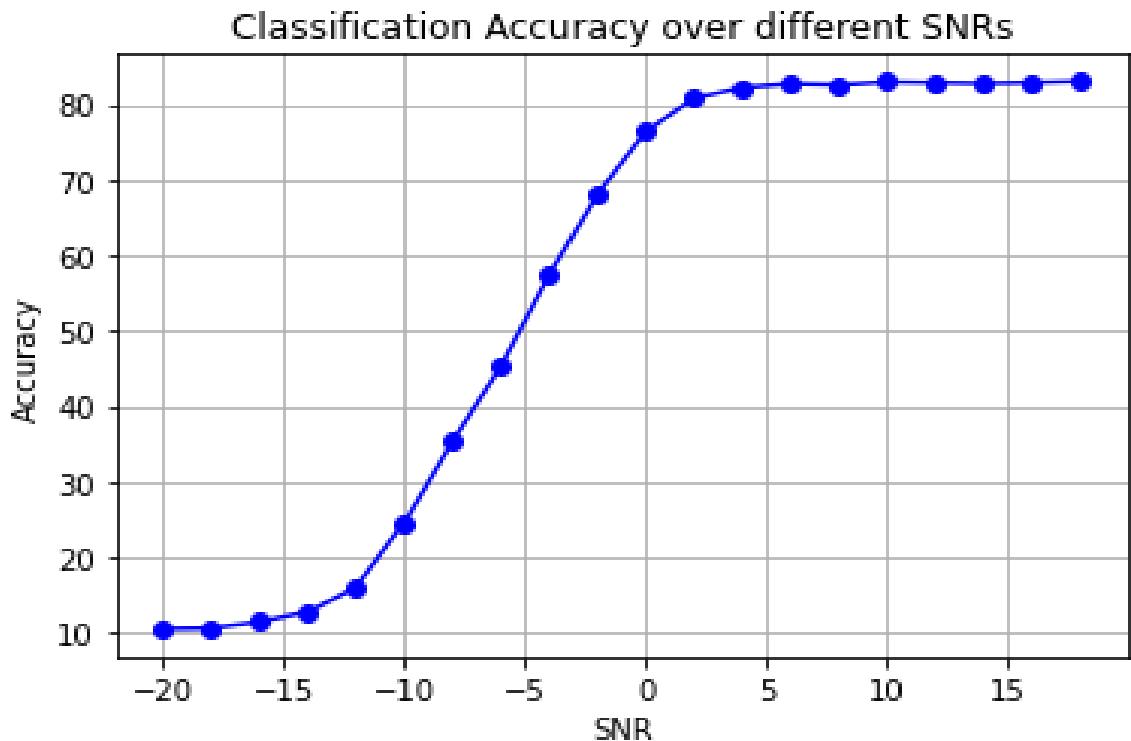
**Testing Accuracy:** 0.5556694269180298

**Precision:** 0.5625580032273572

**Recall:** 0.5556694444444444

**F-score:** 0.5433971659479242

## SNR Plot:



## The Confusion Matrix:

The rows represent the true values or observations

The columns represent the model's predictions

	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	113	267	1562	730	10798	9437	23	10702	25	2343
b'AM-DSB'	0	17480	3577	837	10497	173	0	1	7	3428
b'BPSK'	50	401	4327	751	12848	11738	23	3233	6	2623
b'CPFSK'	95	277	1438	1333	11122	7348	11	12160	20	2196
b'GFSK'	1	649	3472	491	25577	615	47	2332	1	2815
b'PAM4'	100	293	4980	752	8834	16762	11	2533	21	1714
b'QAM16'	337	140	1640	803	7576	11481	33	12700	48	1242
b'QAM64'	297	92	1462	861	5520	12866	50	14001	40	811
b'QPSK'	58	277	1621	728	10606	10339	17	10093	40	2221
b'WBFM'	0	12699	3815	751	12088	219	3	134	5	6286

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.52	10.6	11.43	12.76	15.93	24.53	35.37	45.22	57.3	68.14	76.43	80.81	82.23	82.76	82.6	82.99	82.91	82.81	82.92	83.08

Accuracy of snr at 0db = 76.43%

## Most Confusing Classes:

b'8PSK'	113	267	1562	730	10798	9437	23	10702	25	2343
b'AM-DSB'	0	17480	3577	837	10497	173	0	1	7	3428
b'BPSK'	50	401	4327	751	12848	11738	23	3233	6	2623
b'CPFSK'	95	277	1438	1333	11122	7348	11	12160	20	2196
b'GFSK'	1	649	3472	491	25577	615	47	2332	1	2815
b'PAM4'	100	293	4980	752	8834	16762	11	2533	21	1714
b'QAM16'	337	140	1640	803	7576	11481	33	12700	48	1242
b'QAM64'	297	92	1462	861	5520	12866	50	14001	40	811
b'QPSK'	58	277	1621	728	10606	10339	17	10093	40	2221
b'WBFM'	0	12699	3815	751	12088	219	3	134	5	6286

Most confusing class is QAM16 it confuses it with QAM64(12700 samples), PAM4(11481 samples) and GFSK(7576)

### 3.2 derivative + Raw model report

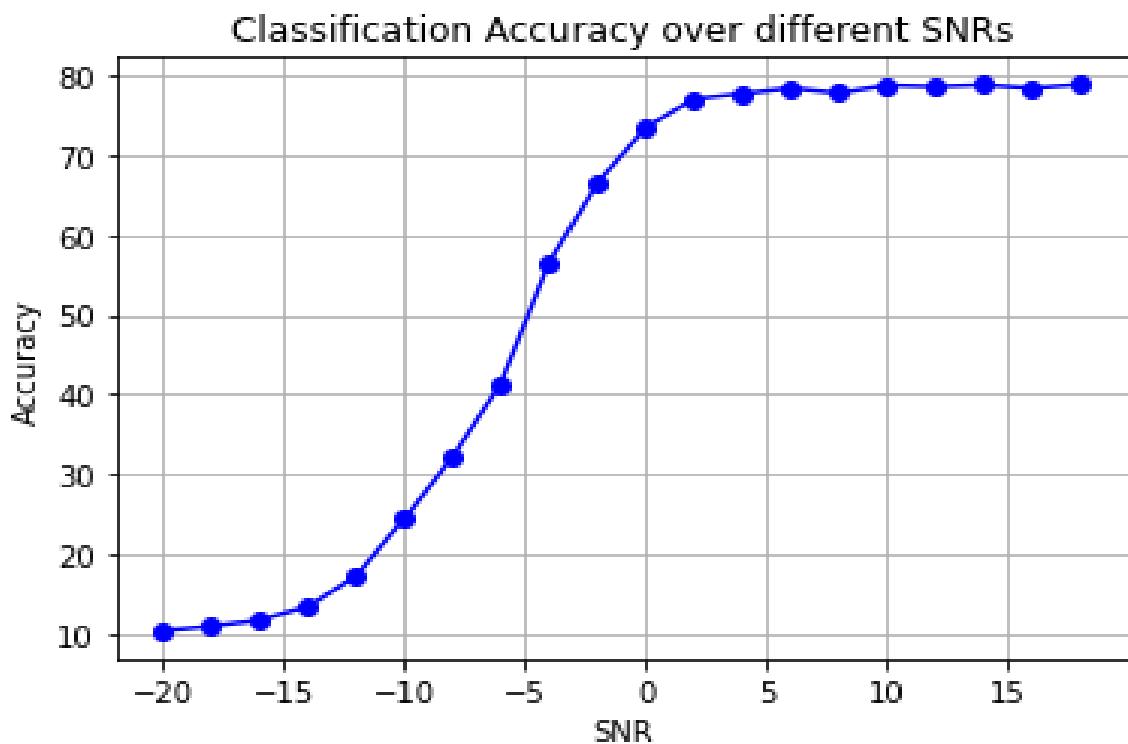
**Testing Accuracy:** 0.5314611196517944

**Precision:** 0.5449455049569323

**Recall:** 0.53146111111112

**F-score:** 0.5263691678808214

### SNR Plot:



### The Confusion Matrix:

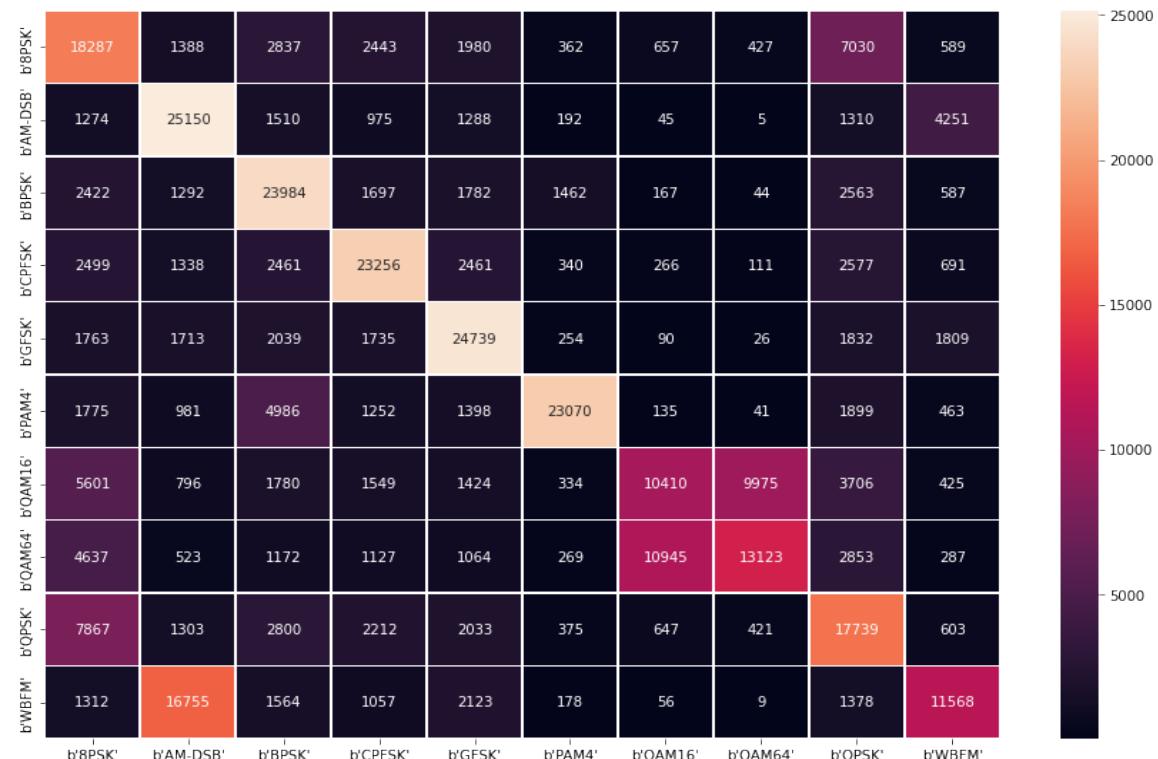
The rows represent the true values or observations The columns represent the model's predictions										
b'8PSK'	18287	1388	2837	2443	1980	362	657	427	7030	589
b'AM-DSB'	1274	25150	1510	975	1288	192	45	5	1310	4251
b'BPSK'	2422	1292	23984	1697	1782	1462	167	44	2563	587
b'CPFSK'	2499	1338	2461	23256	2461	340	266	111	2577	691
b'GFSK'	1763	1713	2039	1735	24739	254	90	26	1832	1809
b'PAM4'	1775	981	4986	1252	1398	23070	135	41	1899	463
b'QAM16'	5601	796	1780	1549	1424	334	10410	9975	3706	425
b'QAM64'	4637	523	1172	1127	1064	269	10945	13123	2853	287
b'QPSK'	7867	1303	2800	2212	2033	375	647	421	17739	603
b'WBFM'	1312	16755	1564	1057	2123	178	56	9	1378	11568

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.29	10.87	11.66	13.34	17.07	24.34	32.17	41.32	56.44	66.63	73.52	77.12	77.81	78.52	77.88	78.87	78.7	78.92	78.48	78.98

Accuracy of snr at 0db = 73.52%

## Most Confusing Classes:



Most confusing class is WBFM it confuses it with AMDSB(16755 samples)

### 3.3 Raw model report

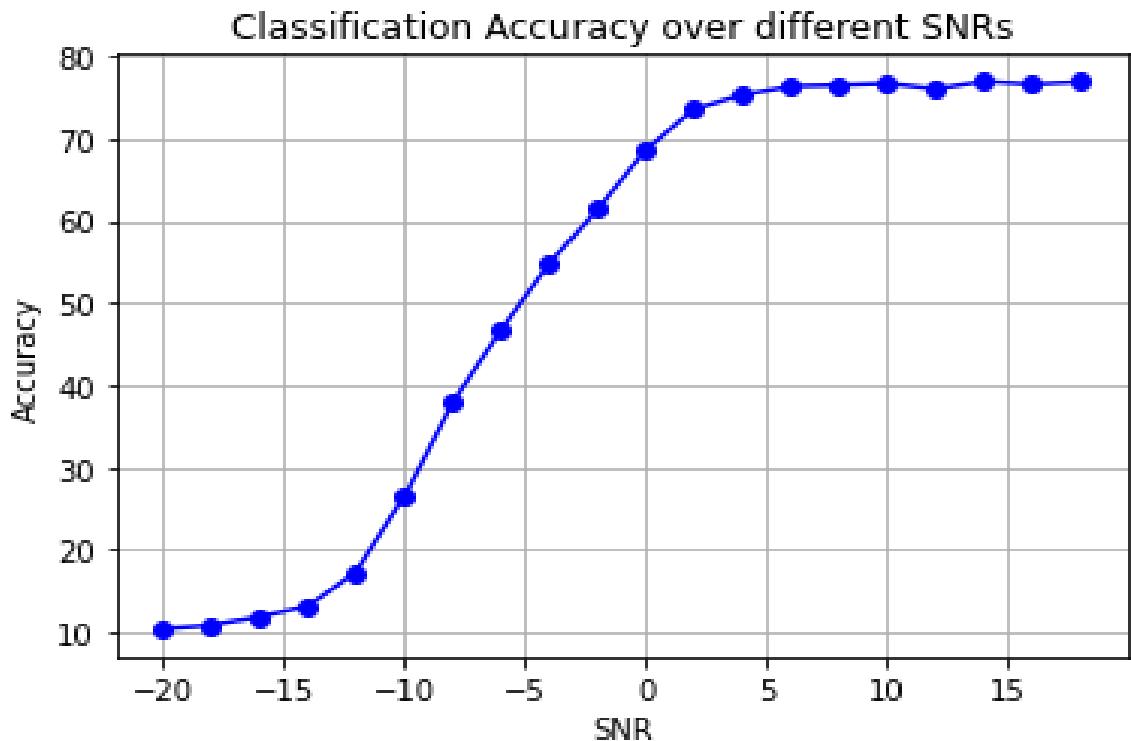
**Testing Accuracy:** 0.5220555663108826

**Precision:** 0.5191220207150733

**Recall:** 0.5220555555555555

**F-score:** 0.5093903981142742

## SNR Plot:



## The Confusion Matrix:

The rows represents the true values or observations  
The columns respresent the model's predictions

	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	16142	1178	1889	2983	2478	325	1656	1900	6308	1141
b'AM-DSB'	1321	22653	917	1302	1483	114	27	5	1124	7054
b'BPSK'	2650	1183	21625	2424	2103	2407	117	42	2328	1121
b'CPFSK'	2512	1181	1592	23674	2852	261	269	189	2251	1219
b'GFSK'	1903	1523	1284	2193	24726	167	54	23	1502	2625
b'PAM4'	1986	844	2768	1932	1619	24100	86	49	1760	856
b'QAM16'	2795	740	1194	2118	1710	349	4040	19758	2576	720
b'QAM64'	2037	477	860	1483	1274	326	3330	23605	2101	507
b'QPSK'	9674	1157	1847	2943	2496	351	1368	1544	13505	1115
b'WBFM'	1377	14994	989	1358	2101	93	35	2	1181	13870

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.42	10.86	11.89	13.16	17.23	26.41	37.9	46.67	54.73	61.4	68.63	73.56	75.31	76.34	76.48	76.69	76.01	76.96	76.59	76.89

Accuracy of snr at 0db = 68.%

## Most Confusing Classes:



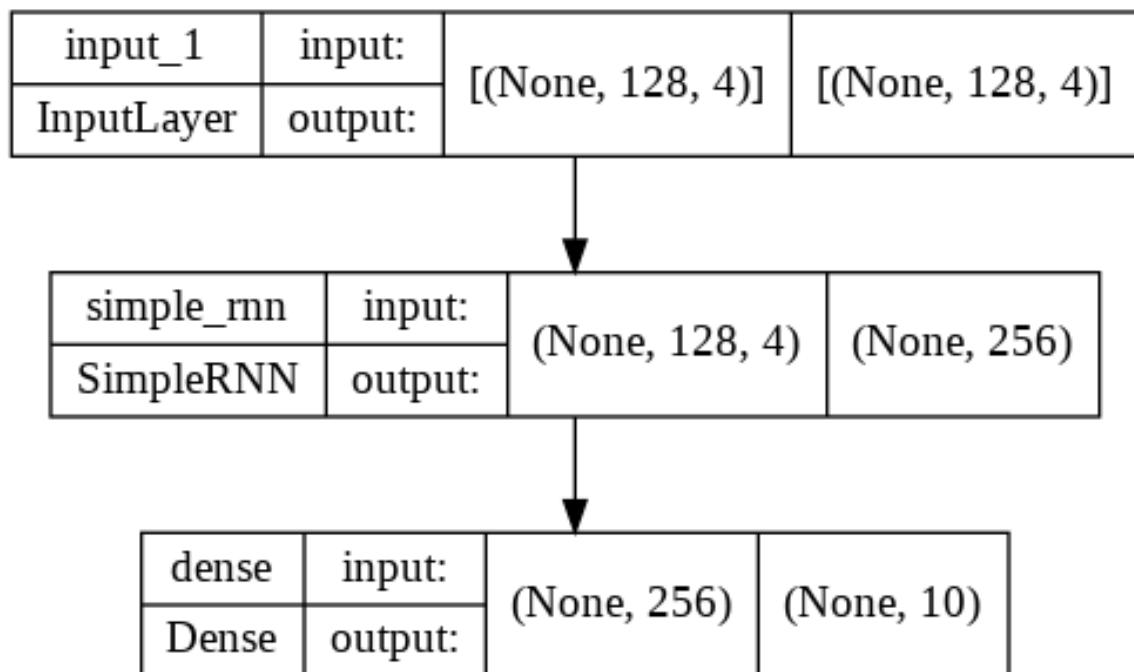
Most confusing class is WBFM it confuses it with AMDSB(14994 samples)

# Vanilla RNN model

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## 1 Model structure

It accepts variable inputs and variable outputs, which contrasts with the vanilla feed-forward neural networks.



## 2 Tuning

We sought to maximize a model's performance as much as possible without over-fitting or creating too high of a variance.

	Raw data	Raw data + derivative	Raw data + integration
1e-1	10%	10%	10%
1e-2	10%	10%	10%
1e-3	10%	10%	10%
1e-4	41.94%	45.26%	47.06
1e-5	20%	32.7%	29.85%

## 3 Models results

### 3.1 (Best model) Integral + Raw model report

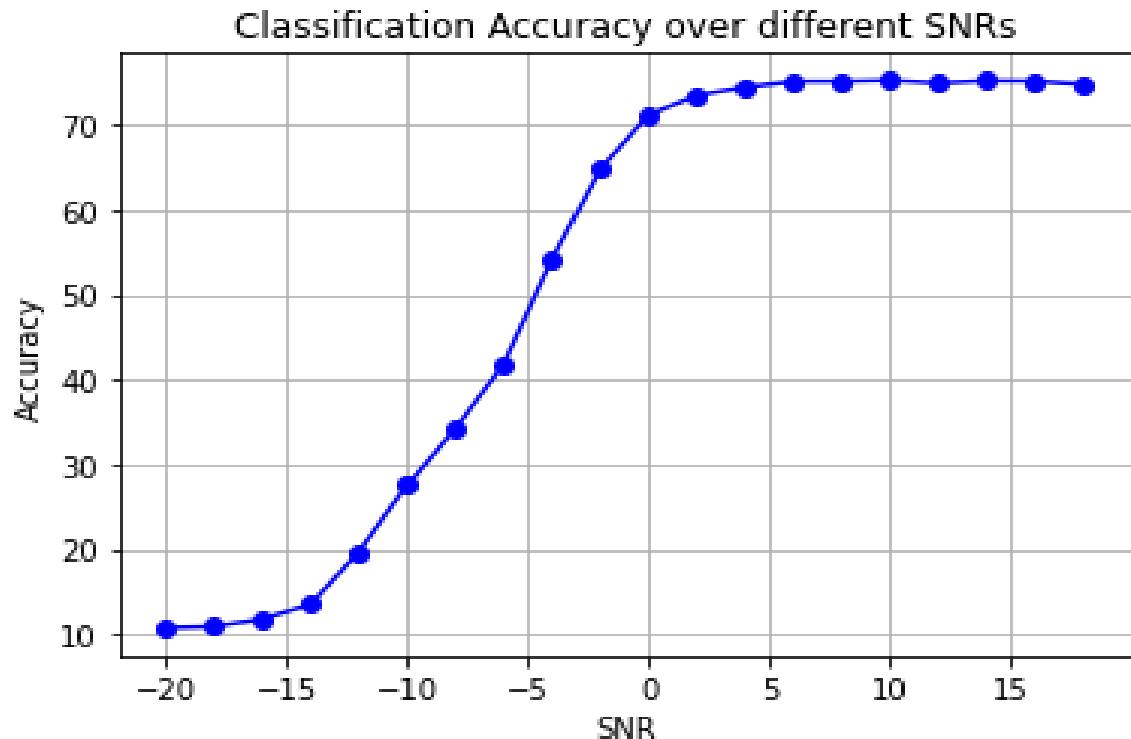
**Testing Accuracy:** 0.516700029373169

**Precision:** 0.49854739189524666

**Recall:** 0.5166999999999999

**F-score:** 0.49371767138430045

### SNR Plot:



### The Confusion Matrix:

The rows represents the true values or observations The columns respresent the model's predictions										
	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	17217	694	4202	2128	1931	1343	1587	1297	5091	510
b'AM-DSB'	1125	22153	2427	897	2075	519	147	14	1042	5601
b'BPSK'	1795	755	24542	1425	1655	2702	492	161	1966	507
b'CPFSK'	1825	784	3776	23173	2336	1050	536	84	1942	494
b'GFSK'	1494	1101	3386	1906	24532	847	319	38	1497	880
b'PAM4'	1190	592	4338	1007	1168	25279	462	268	1318	378
b'QAM16'	2093	455	2802	1400	1304	1311	3333	21034	1941	327
b'QAM64'	1574	303	1943	1034	988	1150	3383	23892	1530	203
b'QPSK'	8021	734	4255	2098	1812	1319	1391	825	15038	507
b'WBFM'	1086	16902	2552	936	5796	582	176	12	1105	6853

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.73	10.88	11.77	13.48	19.61	27.52	34.22	41.77	54.12	64.82	71.18	73.46	74.4	75.11	75.11	75.23	74.91	75.19	75.14	74.75

Accuracy of snr at 0db = 71.18%

## Most Confusing Classes:



Most confusing class is QAM16 it confuses it with QAM64(21034 samples)

## 3.2 derivative + Raw model report

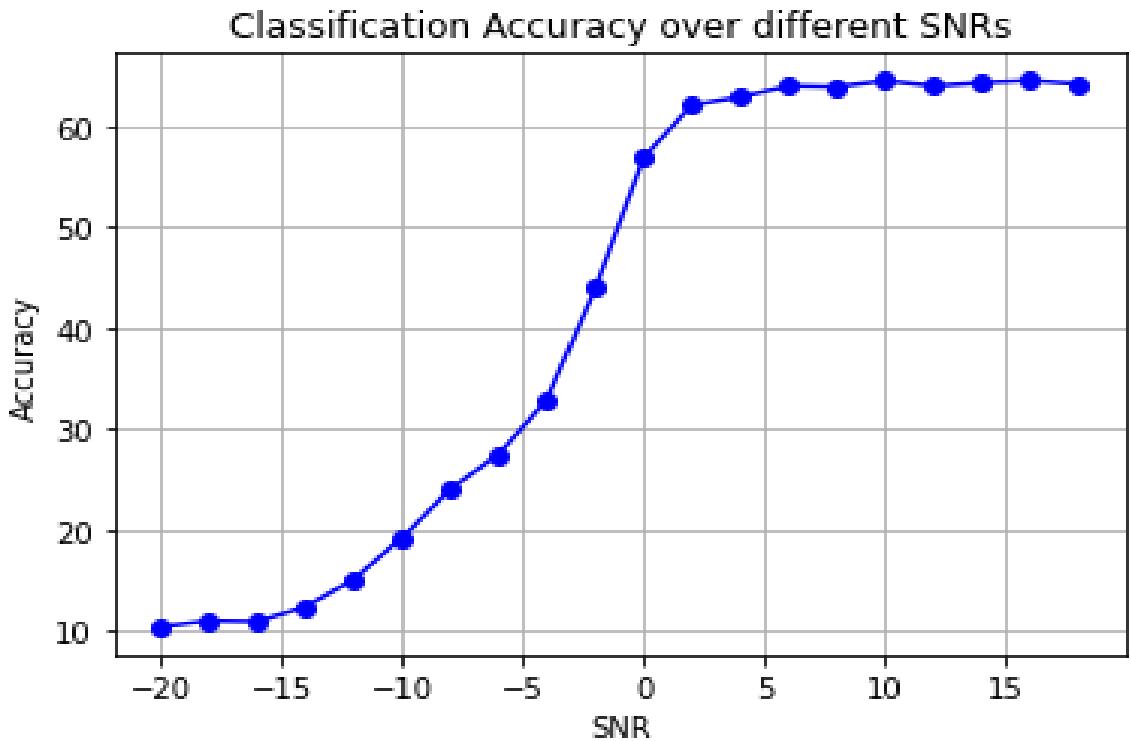
**Testing Accuracy:** 0.4192916750907898

**Precision:** 0.4617040298683916

**Recall:** 0.4192916666666666

**F-score:** 0.39247437062445634

## SNR Plot:



## The Confusion Matrix:

The rows represent the true values or observations  
The columns represent the model's predictions

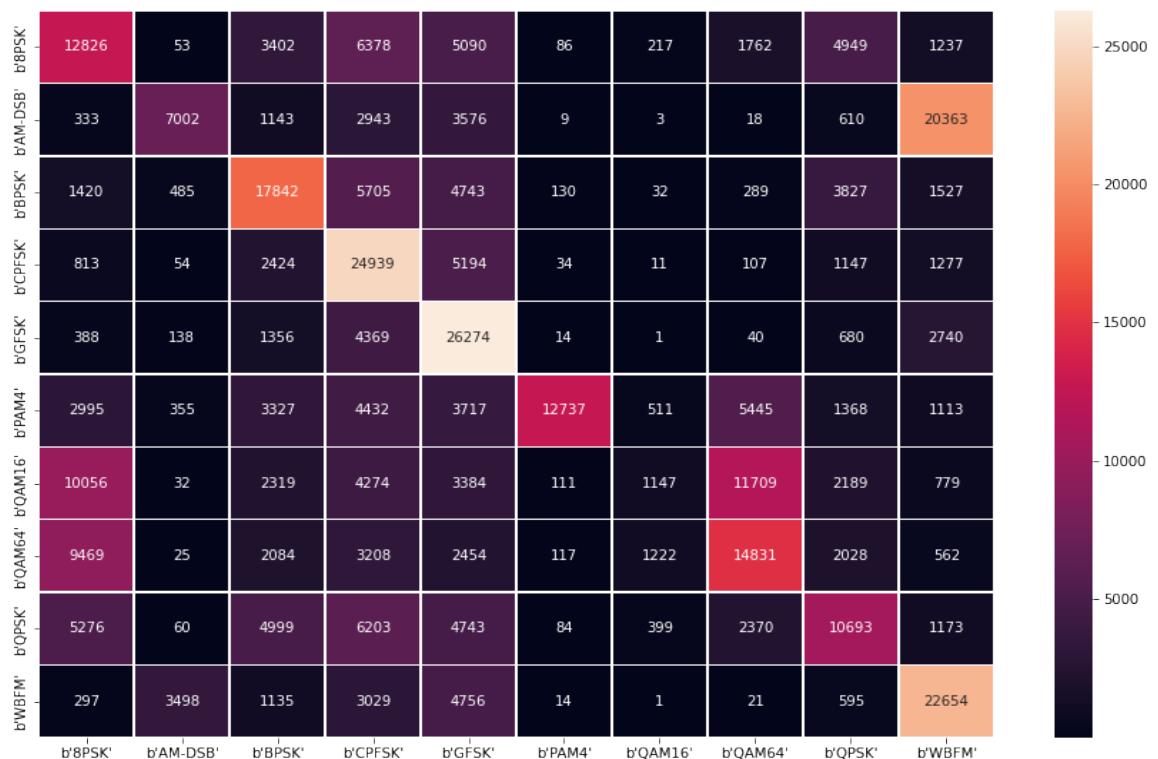
	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	12826	53	3402	6378	5090	86	217	1762	4949	1237
b'AM-DSB'	333	7002	1143	2943	3576	9	3	18	610	20363
b'BPSK'	1420	485	17842	5705	4743	130	32	289	3827	1527
b'CPFSK'	813	54	2424	24939	5194	34	11	107	1147	1277
b'GFSK'	388	138	1356	4369	26274	14	1	40	680	2740
b'PAM4'	2995	355	3327	4432	3717	12737	511	5445	1368	1113
b'QAM16'	10056	32	2319	4274	3384	111	1147	11709	2189	779
b'QAM64'	9469	25	2084	3208	2454	117	1222	14831	2028	562
b'QPSK'	5276	60	4999	6203	4743	84	399	2370	10693	1173
b'WBFM'	297	3498	1135	3029	4756	14	1	21	595	22654

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.34	10.96	10.87	12.36	15.02	19.19	24.05	27.45	32.86	44.01	56.92	62.07	62.91	64.02	63.92	64.54	63.99	64.33	64.57	64.21

Accuracy of snr at 0db = 56.92%

## Most Confusing Classes:



Most confusing class is QAM16 it confuses it with QAM64(11709 samples) and 8PSK(10056 samples)

### 3.3 Raw model report

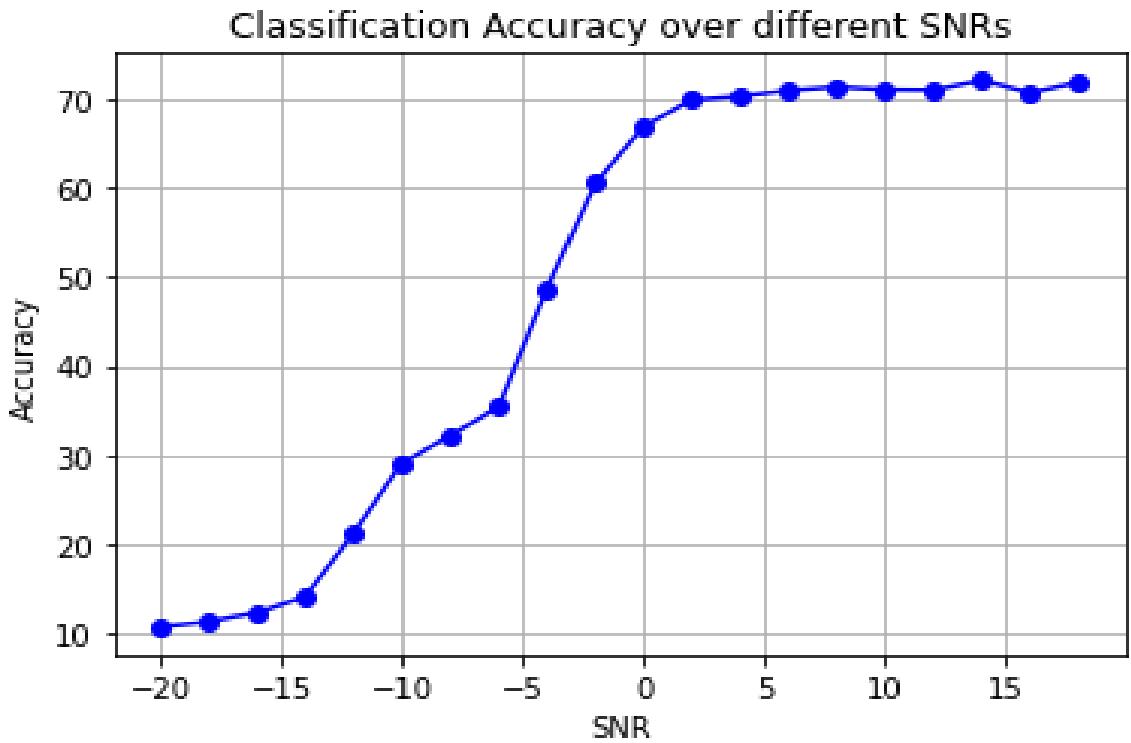
**Testing Accuracy:** 0.4910416603088379

**Precision:** 0.4788510159749351

**Recall:** 0.4910416666666667

**F-score:** 0.47206626498023024

**SNR Plot:**



## The Confusion Matrix:

The rows represents the true values or observations The columns represent the model's predictions										
	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	16918	1700	2511	702	1228	2590	1258	1676	6461	956
b'AM-DSB'	1397	18521	1344	317	1265	942	106	20	1246	10842
b'BPSK'	2518	1625	22511	402	1052	3766	409	242	2503	972
b'CPFSK'	2893	1703	2185	21199	1212	2356	609	331	2496	1016
b'GFSK'	2463	2114	2049	1318	21397	2247	336	104	1960	2012
b'PAM4'	1706	1244	2332	282	733	26476	309	488	1663	767
b'QAM16'	2433	1041	1594	436	682	2449	1601	23067	2113	584
b'QAM64'	1760	663	1089	306	479	2214	1392	26173	1541	383
b'QPSK'	13609	1555	2564	704	1182	2676	1218	1595	9910	987
b'WBFM'	1505	14438	1355	351	3821	974	143	28	1316	12069

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.68	11.26	12.32	14.1	21.18	29.08	32.23	35.38	48.65	60.62	66.95	69.92	70.34	71.0	71.41	71.09	71.04	72.14	70.73	71.93

Accuracy of snr at 0db = 66.95%

## Most Confusing Classes:

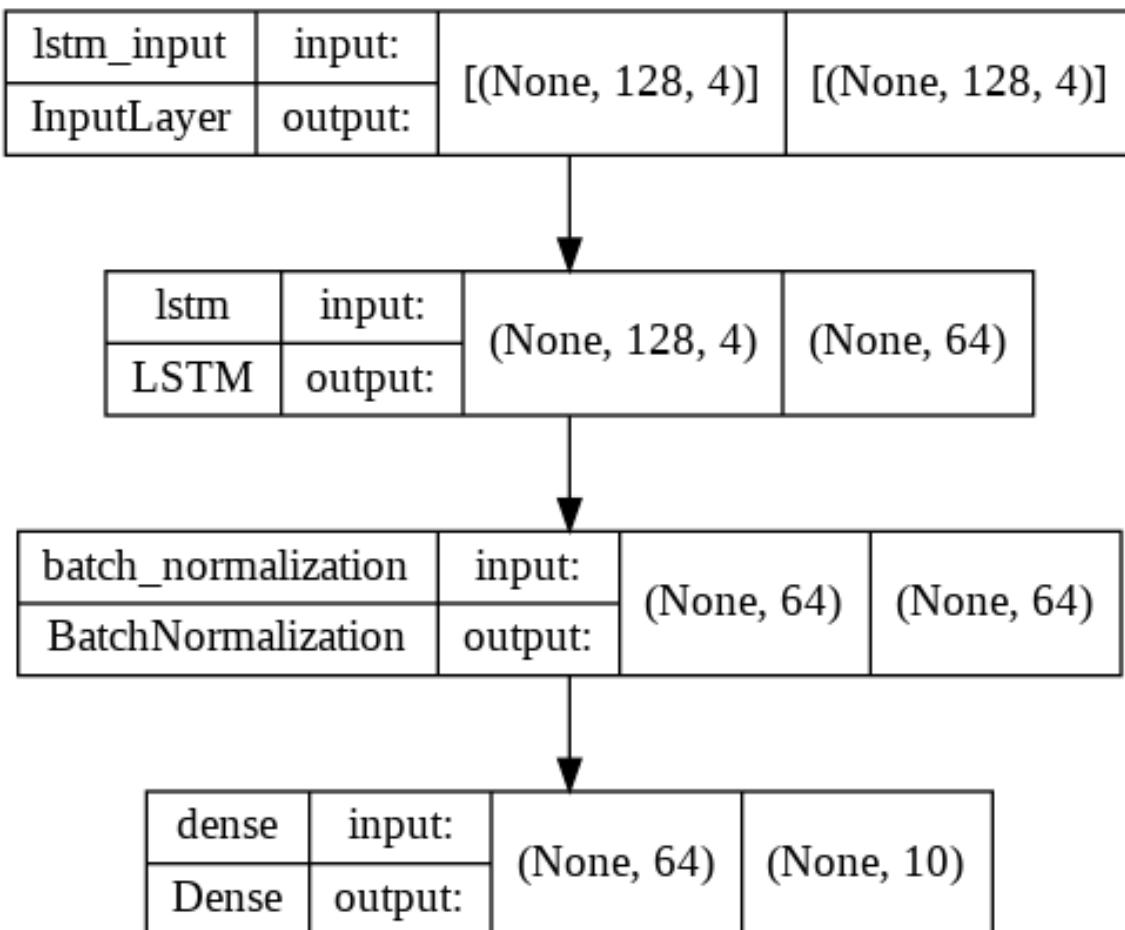


Most confusing class is QAM16 it confuses it with QAM64(23067 samples)

# LSTM model

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3.2	Integral + Raw model report . . . . .	33
3.3	derivative + Raw model report . . . . .	35

## 1 Model structure



## 2 Tuning

	Raw data	Raw data + derivative	Raw data + integration
1e-1	10%	10%	10%
1e-2	10.41%	10%	21.89
1e-3	63.59%	45.65%	41.47
1e-4	57.62%	53%	55%

## 3 Models results

### 3.1 (Best model) Raw model report

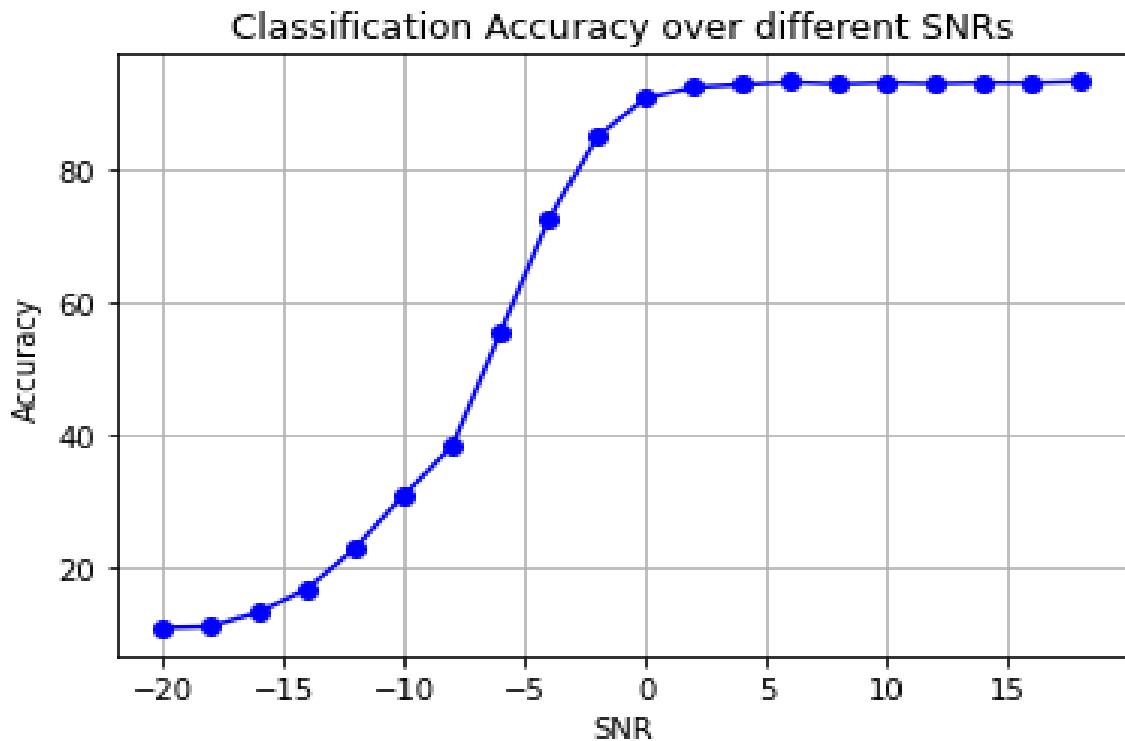
**Testing Accuracy:** 0.6430888772010803

**Precision:** 0.7167638695284315

**Recall:** 0.6430888888888888

**F-score:** 0.6500858349086865

### SNR Plot:



### The Confusion Matrix:

The rows represents the true values or observations The columns respresent the model's predictions										
	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	19178	1827	277	944	3282	703	111	960	7941	777
b'AM-DSB'	0	28563	98	196	2145	276	10	25	2808	1879
b'BPSK'	19	1816	22116	413	3063	1755	47	191	5841	739
b'CPFSK'	32	1770	189	23119	3552	557	45	294	5624	818
b'GFSK'	1	2068	161	602	27413	393	24	78	4065	1195
b'PAM4'	0	1354	1018	303	2256	26167	50	224	4120	508
b'QAM16'	415	1006	180	731	1962	615	21305	3871	5437	478
b'QAM64'	349	668	176	652	1108	511	2023	26129	4091	293
b'QPSK'	424	1773	292	865	3241	625	70	767	27203	740
b'WBFM'	0	19307	97	272	2775	269	15	26	2920	10319

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.82	11.02	13.26	16.73	22.94	30.93	38.39	55.54	72.53	85.16	90.85	92.5	92.91	93.34	93.03	93.24	93.1	93.24	93.19	93.43

Accuracy of snr at 0db = 90.85%

## Most Confusing Classes:



Most confusing class is WBFM it confuses it with AM-DSB(19307 samples)

## 3.2 Integral + Raw model report

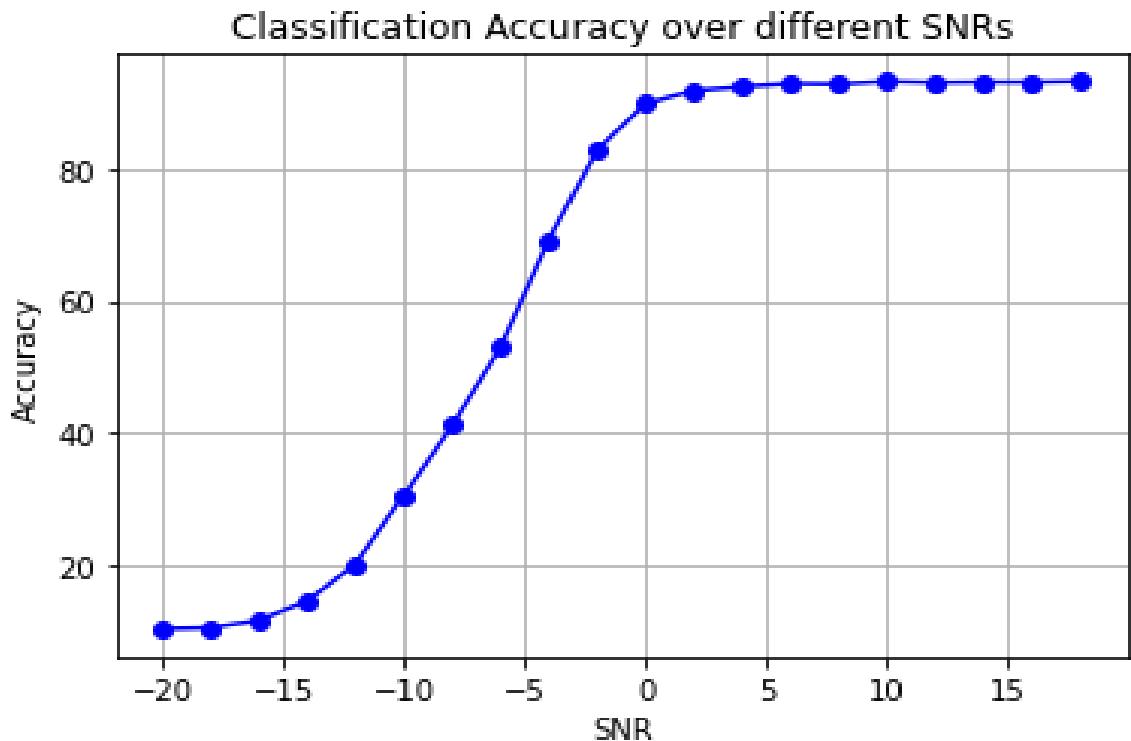
**Testing Accuracy:** 0.6350333094596863

**Precision:** 0.7127499655721209

**Recall:** 0.6350333333333333

**F-score:** 0.6470836058613552

### SNR Plot:



### The Confusion Matrix:

The rows represent the true values or observations The columns represent the model's predictions											
	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'	
b'8PSK'	19566	725	248	3523	7810	370	694	551	1259	1254	
b'AM-DSB'	7	25090	38	1085	5067	93	22	5	122	4471	
b'BPSK'	98	721	21727	2497	7460	1636	115	86	403	1257	
b'CPFSK'	92	712	123	24986	8100	234	107	95	316	1235	
b'GFSK'	18	917	62	1553	31578	153	31	15	147	1526	
b'PAM4'	41	564	698	1860	5392	25984	101	102	296	962	
b'QAM16'	675	370	206	2771	4782	406	21633	3599	767	791	
b'QAM64'	528	252	169	2335	3006	360	2772	25451	611	516	
b'QPSK'	1011	732	243	3569	7641	391	636	362	20229	1186	
b'WBFM'	13	16119	42	1072	6122	100	26	12	126	12368	

### Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.5	10.67	11.78	14.74	20.25	30.68	41.28	53.03	69.22	82.94	89.8	91.79	92.34	92.84	92.77	93.16	92.99	93.06	93.05	93.18

Accuracy of snr at 0db = 89.8%

## Most Confusing Classes:



Most confusing class is WBFM it confuses it with AM-DSB(16119 samples)

### 3.3 derivative + Raw model report

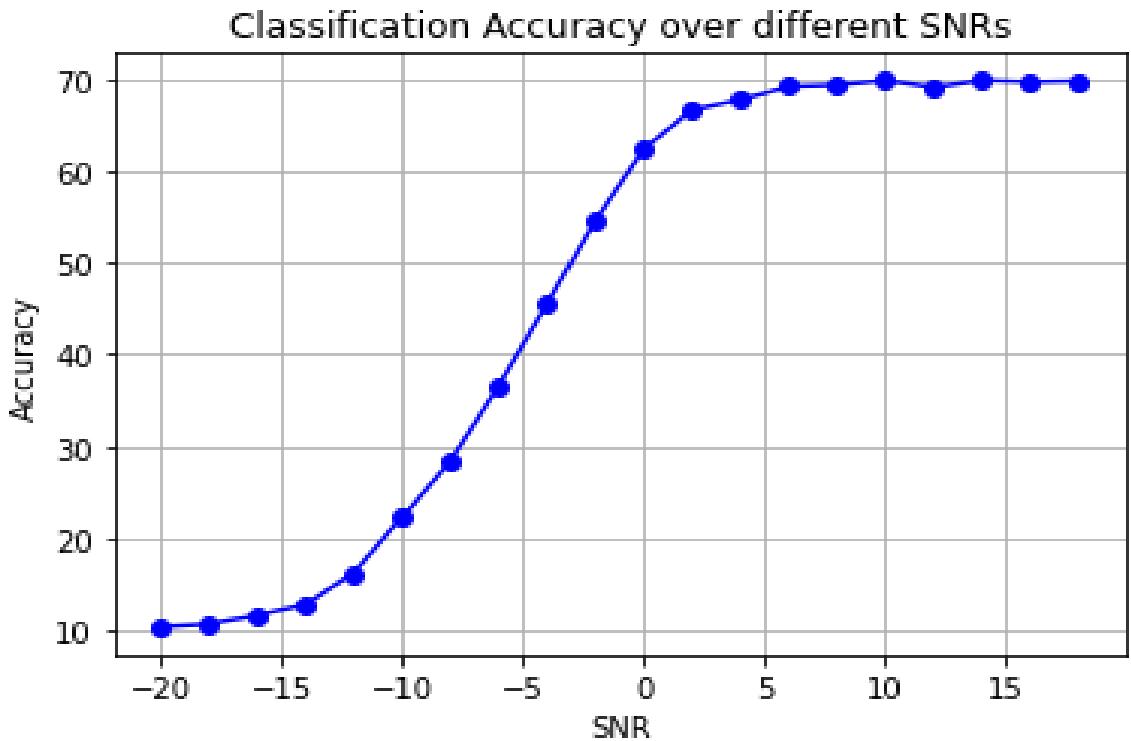
**Testing Accuracy:** 0.4661666750907898

**Precision:** 0.4852865535235294

**Recall:** 0.4661666666666673

**F-score:** 0.44914614283763854

**SNR Plot:**



## The Confusion Matrix:

The rows represents the true values or observations The columns respresent the model's predictions										
	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	13759	986	5343	2320	4917	263	3506	2797	1785	324
b'AM-DSB'	484	25514	2670	456	3451	5	5	7	495	2913
b'BPSK'	2280	985	22276	1812	4499	848	201	215	2569	315
b'CPFSK'	1827	1042	4373	21438	5532	63	224	276	849	376
b'GFSK'	806	1627	3546	981	27200	13	37	51	500	1239
b'PAM4'	2903	739	4512	1663	3548	18457	941	2058	941	238
b'QAM16'	6738	619	3456	1566	3133	1294	4360	13571	1018	245
b'QAM64'	5818	418	2477	1367	2178	1609	4214	16863	866	190
b'QPSK'	6540	988	5412	2686	4808	260	2468	2643	9874	321
b'WBFM'	596	18788	2721	525	4799	9	9	5	469	8079

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.38	10.7	11.67	12.83	16.2	22.31	28.43	36.58	45.46	54.61	62.36	66.56	67.71	69.15	69.31	69.81	69.06	69.83	69.65	69.75

Accuracy of snr at 0db = 62.36%

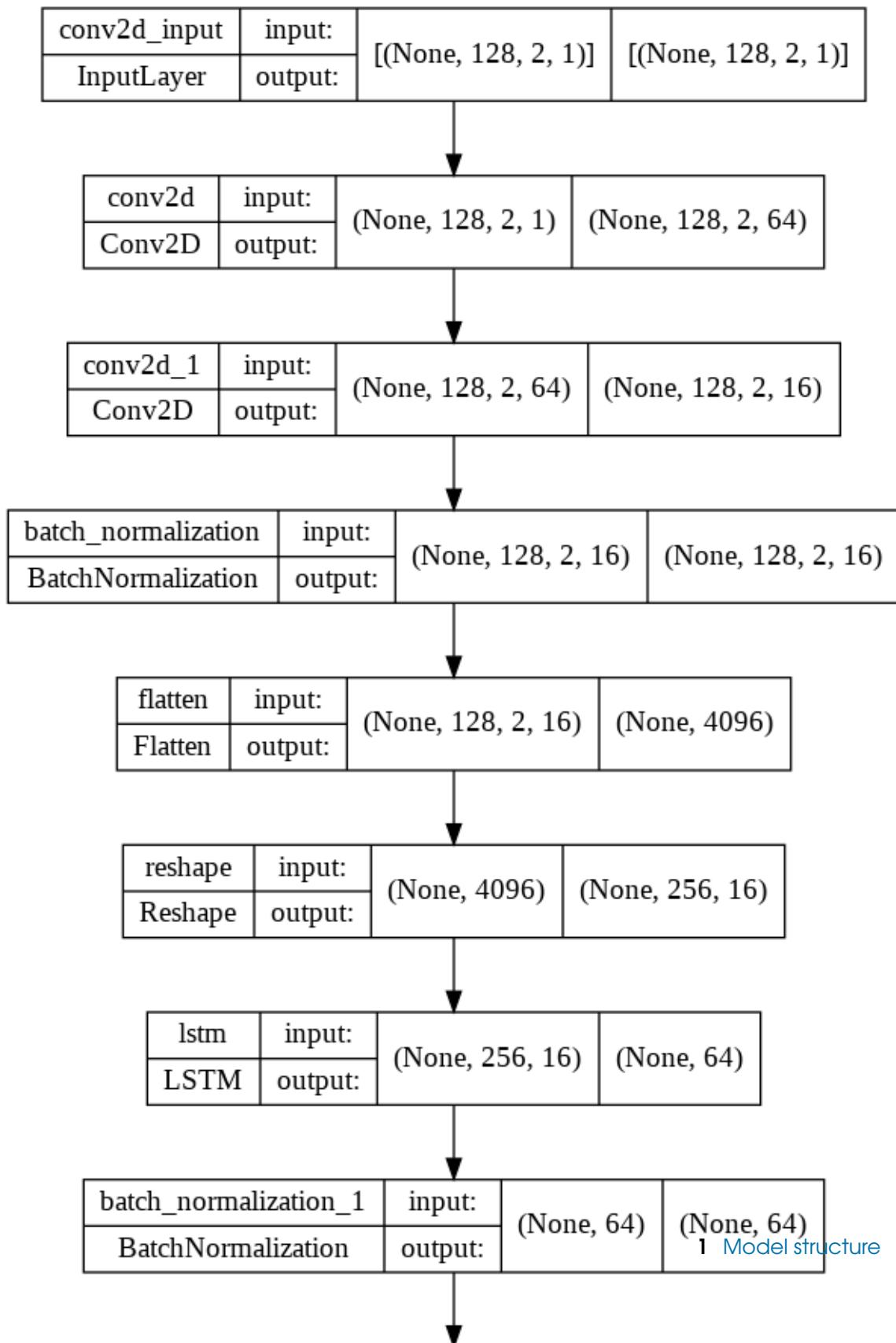
## Most Confusing Classes:



Most confusing class is WBFM it confuses it with AM-DSB(18788 samples)

## CNN-LSTM model

## 1 Model structure



## 2 Tuning

	Raw data	Raw data + derivative	Raw data + integration
e-1	10%	10%	10%
e-2	24.16%	36.12%	10%
e-3	37%	32.71%	55.89%
e-4	51.55%	33.01%	61.31%
e-5	23%	21.78%	29.5%
1e-6			

## 3 Model results

### 3.1 (Best model) Integral + Raw model report

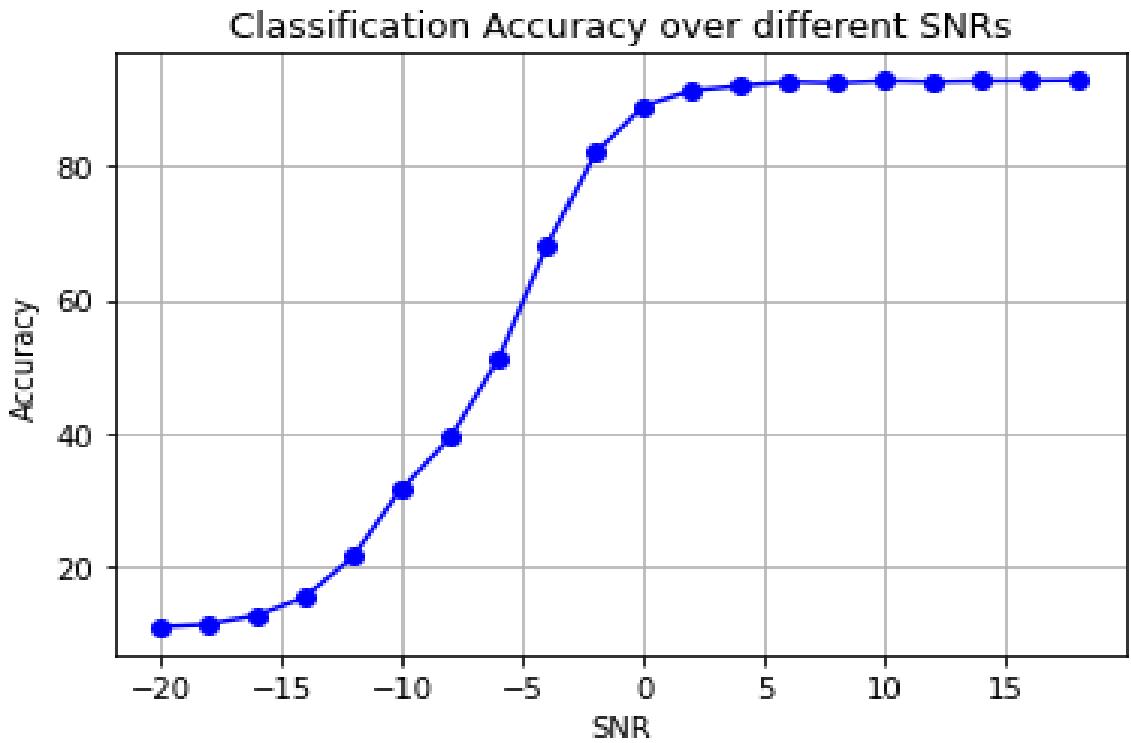
**Testing Accuracy:** 0.63322222328186

**Precision:** 0.6941325702691543

**Recall:** 0.633222222222221

**F-score:** 0.6380697948576479

**SNR Plot:**



## The Confusion Matrix:

The rows represents the true values or observations The columns respresent the model's predictions										
	b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'
b'8PSK'	25066	2356	320	2851	1688	508	1027	488	1470	226
b'AM-DSB'	2935	28227	117	889	1255	188	76	6	81	2226
b'BPSK'	5575	2353	21713	1840	1547	1801	458	110	352	251
b'CPFSK'	5146	2345	225	24797	2026	373	399	106	344	239
b'GFSK'	4099	2564	150	2116	25774	300	161	20	103	713
b'PAM4'	3867	1753	1091	1411	1196	25812	381	128	187	174
b'QAM16'	4510	1324	260	2207	1074	417	21647	3533	875	153
b'QAM64'	3019	837	198	1760	693	342	3658	24568	830	95
b'QPSK'	6592	2303	328	2924	1665	499	991	385	20102	211
b'WBFM'	2983	19144	101	1026	2106	172	116	10	88	10254

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.97	11.37	12.77	15.49	21.54	31.81	39.37	51.17	68.03	82.06	89.04	91.4	92.08	92.71	92.53	92.83	92.69	92.81	92.86	92.92

Accuracy of snr at 0db = 89.04%

## Most Confusing Classes:



Most confusing class is WBFM it confuses it with AM-DSB(19104 samples)

## 3.2 Raw model report

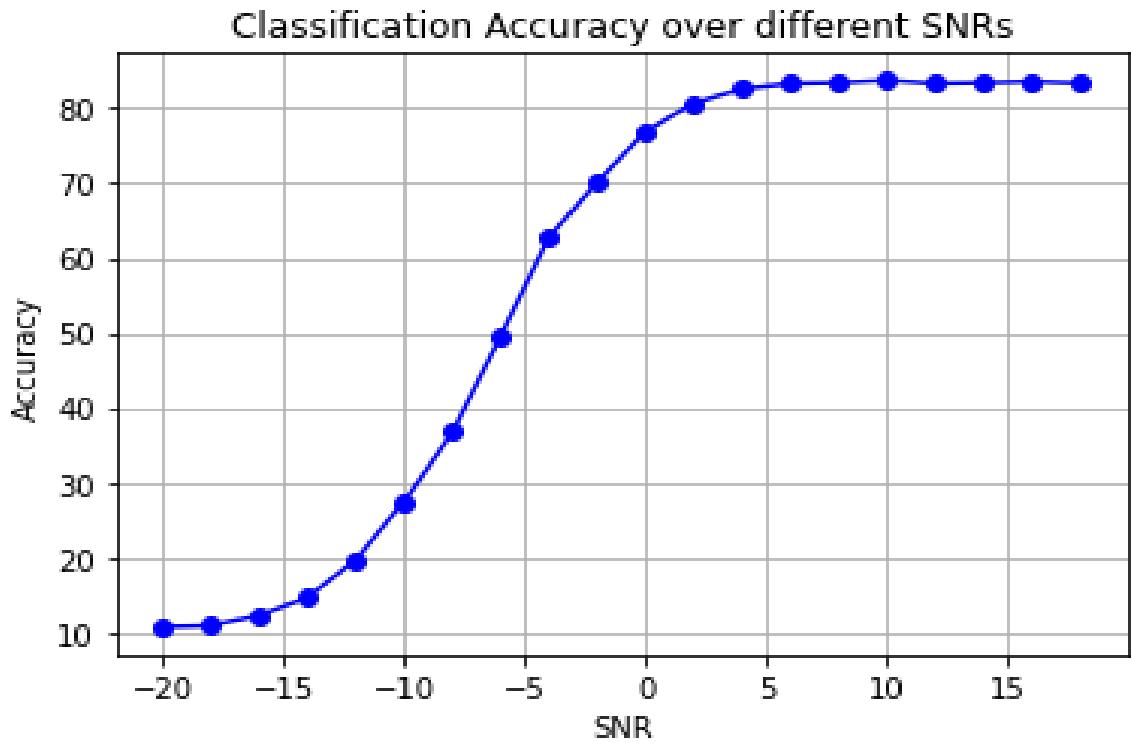
**Testing Accuracy:** 0.5696027874946594

**Precision:** 0.5991327459203615

**Recall:** 0.5696027777777777

**F-score:** 0.5628819483642363

## SNR Plot:



## The Confusion Matrix:

The rows represents the true values or observations The columns represent the model's predictions										
b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'	
25336	413	616	2168	848	371	915	723	3939	671	
4041	24046	345	791	1218	162	21	17	977	4382	
6682	419	22053	1591	795	1461	237	252	1839	671	
6580	394	520	23627	1279	308	167	238	2127	760	
5279	587	399	2163	24698	224	52	39	1239	1320	
4846	329	1935	1282	605	24737	182	351	1225	508	
5663	206	521	1568	595	336	4600	20009	2079	423	
3869	142	374	1294	420	309	3702	23965	1646	279	
9268	391	657	2186	917	400	616	787	20119	659	
4060	15343	356	937	2174	154	30	16	1054	11876	

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.69	10.86	12.26	14.63	19.59	27.43	36.75	49.53	62.71	70.21	76.94	80.69	82.62	83.32	83.44	83.77	83.33	83.43	83.61	83.39

Accuracy of snr at 0db = 76.94%

## Most Confusing Classes:



Most confusing class is QAM16 it confuses it with QAM64(20009 samples)

### 3.3 derivative + Raw model report

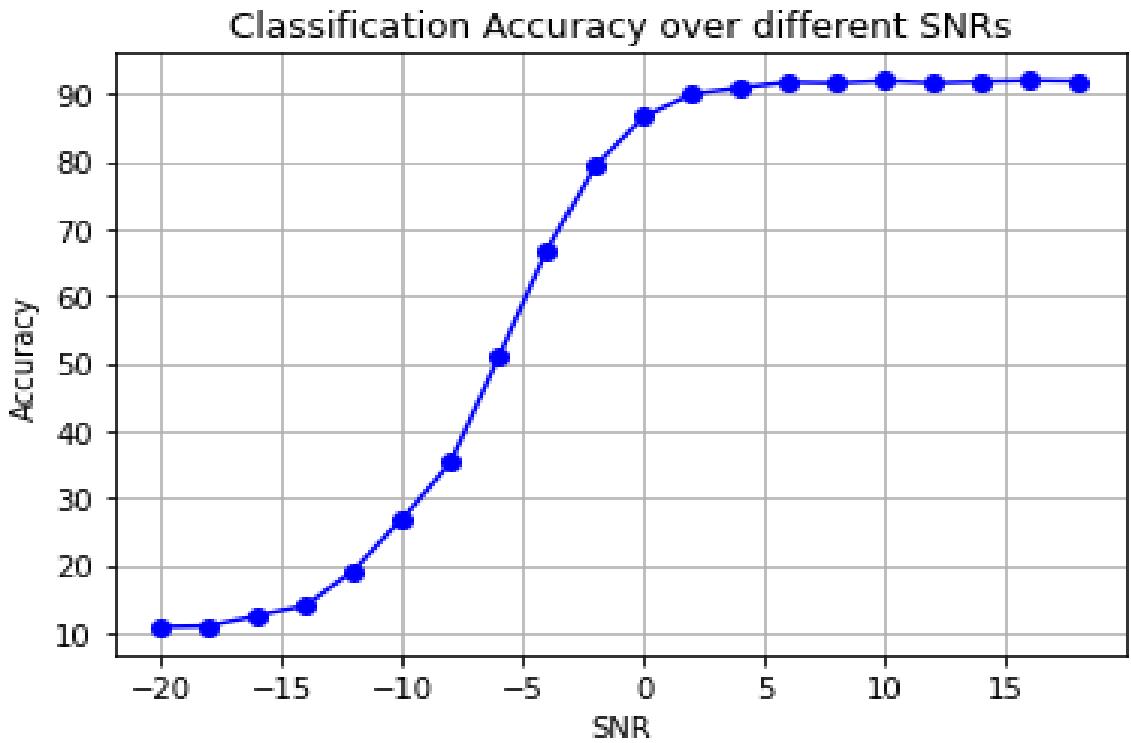
**Testing Accuracy:** 0.6184083223342896

**Precision:** 0.6572071458575122

**Recall:** 0.6184083333333333

**F-score:** 0.6210280509288391

**SNR Plot:**



## The Confusion Matrix:

The rows represents the true values or observations The columns respresent the model's predictions										
b'8PSK'	b'AM-DSB'	b'BPSK'	b'CPFSK'	b'GFSK'	b'PAM4'	b'QAM16'	b'QAM64'	b'QPSK'	b'WBFM'	
24869	879	1790	2643	2732	200	281	328	1429	849	
2590	26147	886	825	2065	105	10	2	250	3120	
4699	933	23401	1732	2492	763	118	144	881	837	
4432	898	1472	24114	3278	180	90	65	632	839	
3250	1167	1101	1722	26344	124	27	15	409	1841	
3157	672	3201	1323	1832	24196	140	316	523	640	
5071	491	1256	2038	1714	200	19755	3906	1053	516	
3642	340	866	1601	1176	179	3748	23188	930	330	
6779	821	1798	2602	2734	204	305	316	19662	779	
2626	17299	868	899	2983	67	19	4	284	10951	

## Classes Accuracy:

	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
accuracy	10.81	10.93	12.5	13.99	19.16	26.87	35.24	50.87	66.75	79.36	86.61	89.98	90.92	91.77	91.64	91.96	91.66	91.86	92.03	91.92

Accuracy of snr at 0db = 86.61%

## Most Confusing Classes:



Most confusing class is WBFM it confuses it with AM-DSB(17299 samples)

## Colab links

## 1 CNN Model

- 1.1 Raw + integral
- 1.2 Raw +derivative
- 1.3 Raw

## 2 RNN Model

- 2.1 Raw + integral
- 2.2 Raw +derivative
- 2.3 Raw

## 3 LTSM Model

- 3.1 Raw + integral
- 3.2 Raw +derivative
- 3.3 Raw

## 4 Bonus Model

- 4.1 Raw + integral
- 4.2 Raw +derivative
- 4.3 Raw