

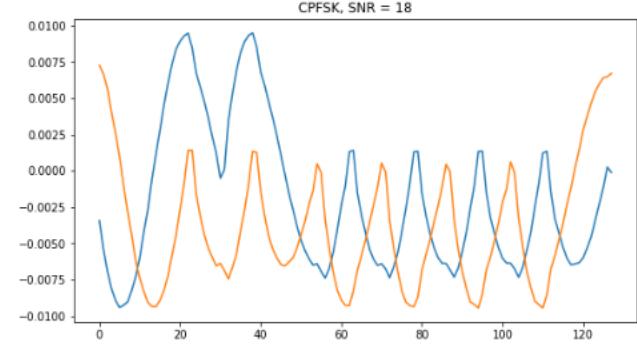
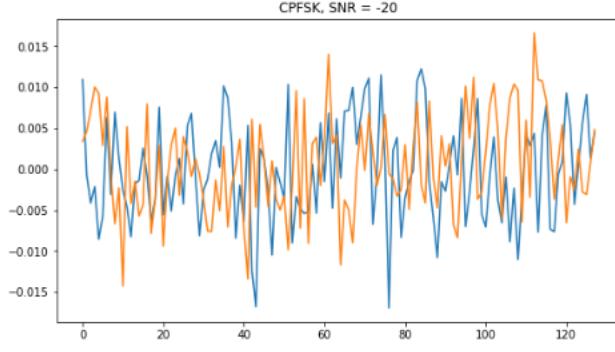
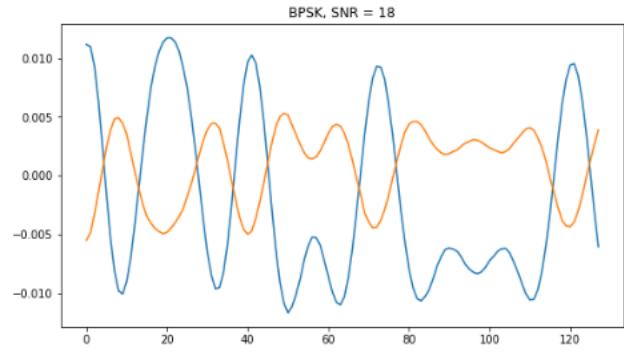
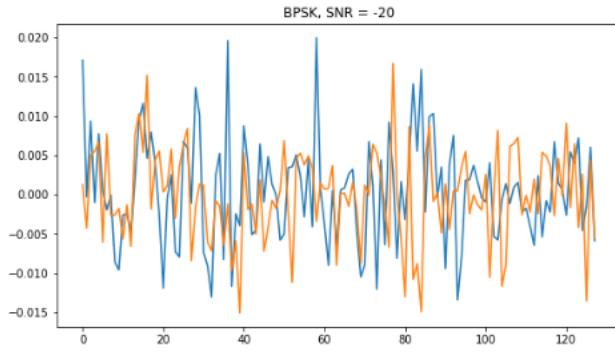
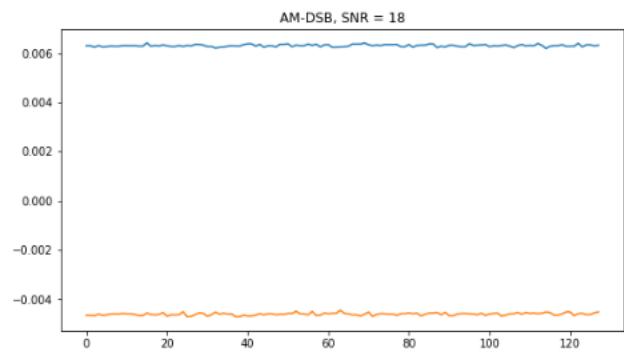
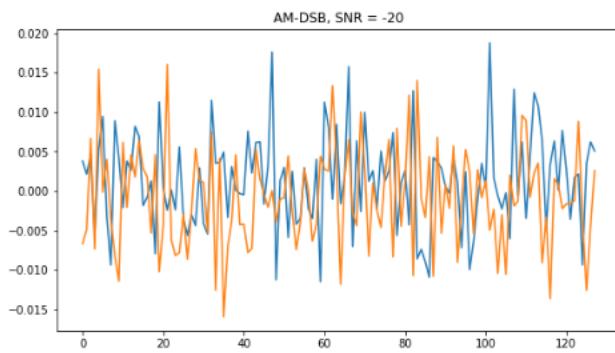
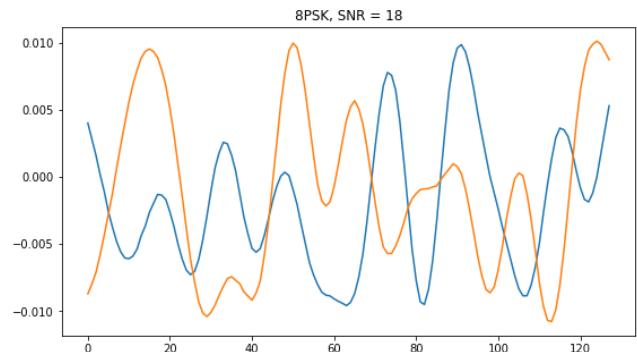
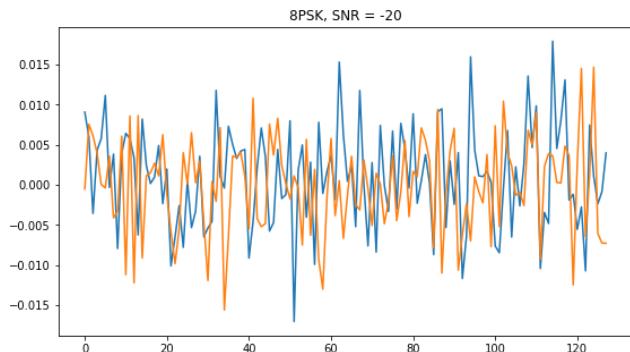
Pattern Recognition **Modulation Classification**

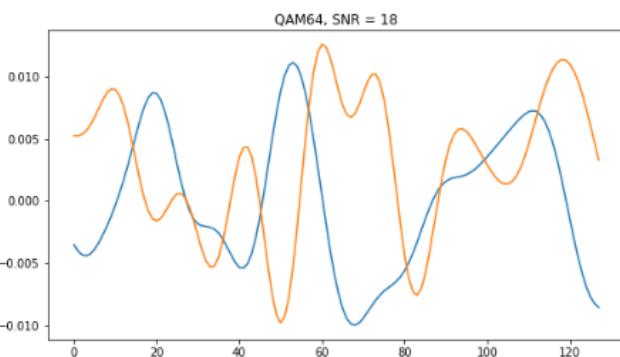
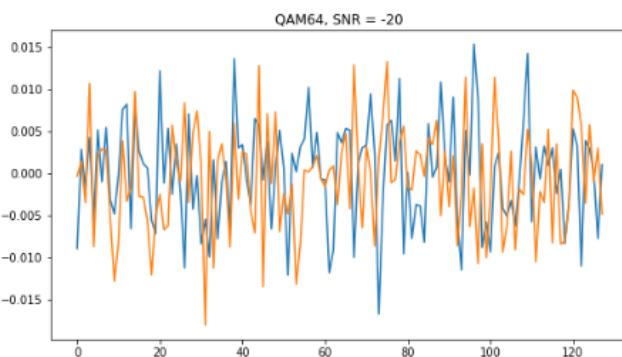
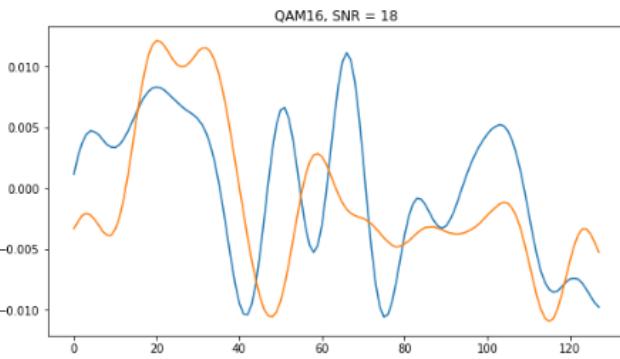
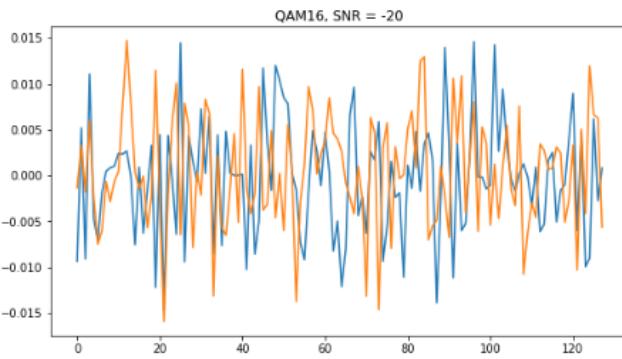
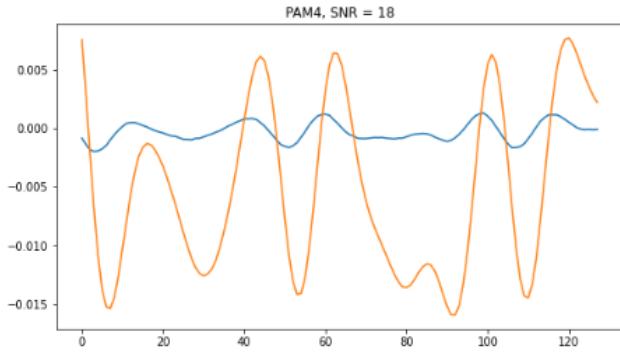
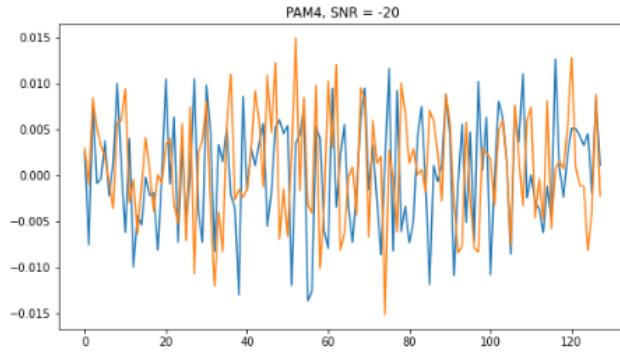
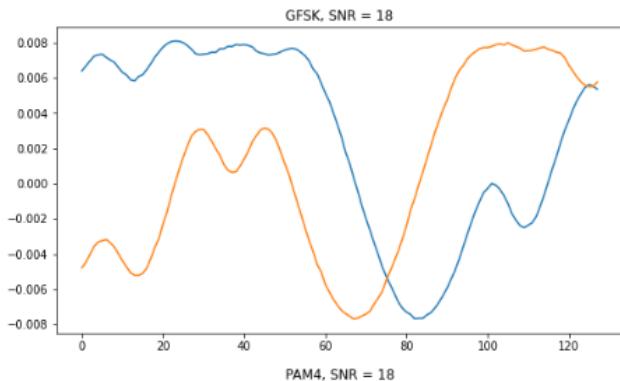
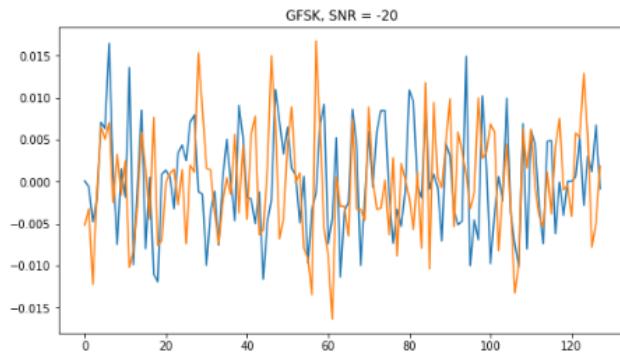
Colab Link

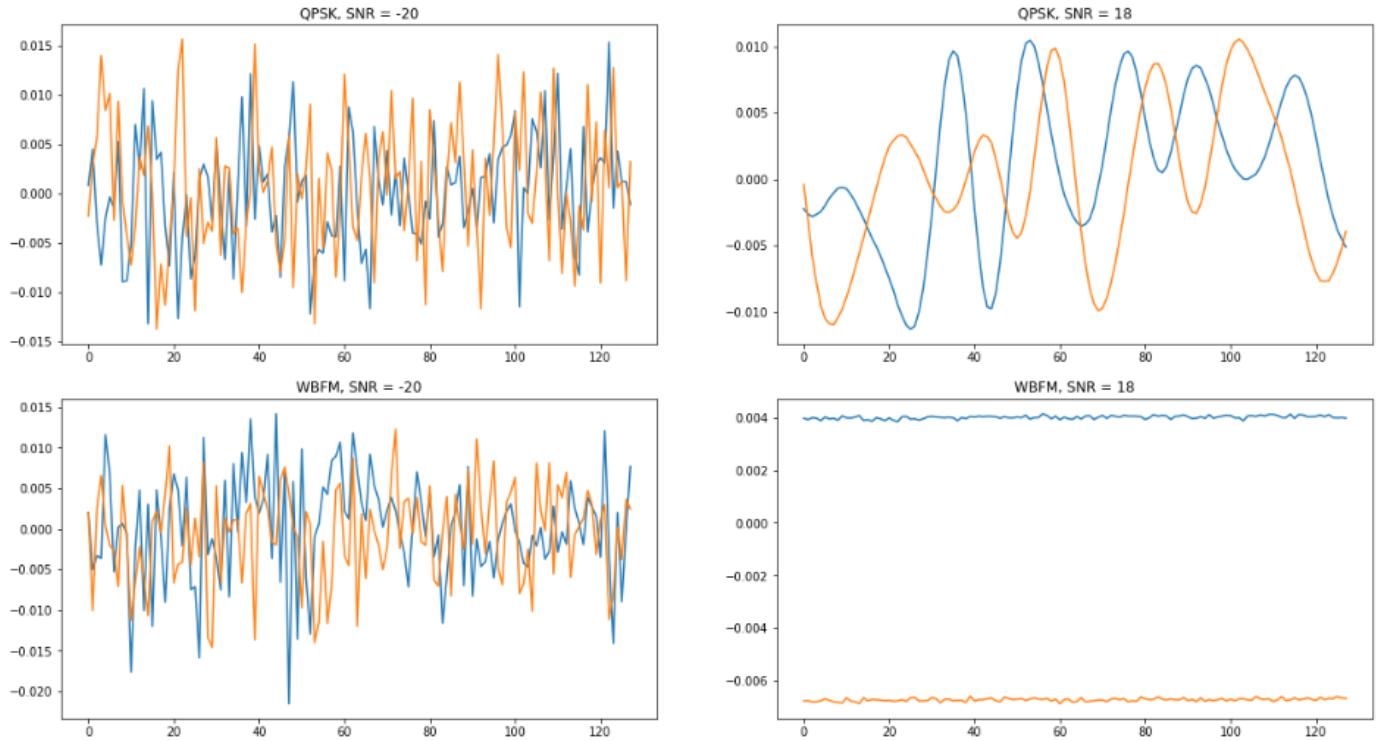
https://colab.research.google.com/drive/1Z_x4DkwAnzvGqillhVa9UYFfluAwJtB?usp=sharing

[0] Data

Visualizing a random data sample:







SNR is a measure of the relative strength of a desired signal compared to the level of background noise. In audio applications, the signal is the audio content being recorded or transmitted, while the noise is any unwanted sound that is present in the signal.

The previous visualization shows the significant difference between modulations as well as showcasing the effect of SNR on each signal. Showing that as SNR increases the signal is more clear and separable from noise.

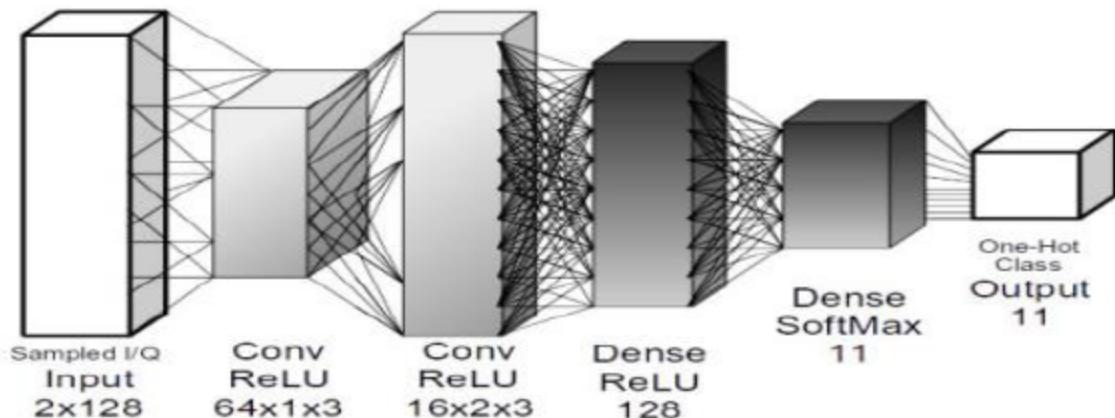
[1] Features

Three types of features were extracted from the data to train the model:

1. Raw time series as given (two channels)
2. Integral in time (two channels)
3. First derivative in time (two channels)

However, the first derivative wasn't added to the results because it delivered far inferior results when compared to the raw data and the integral.

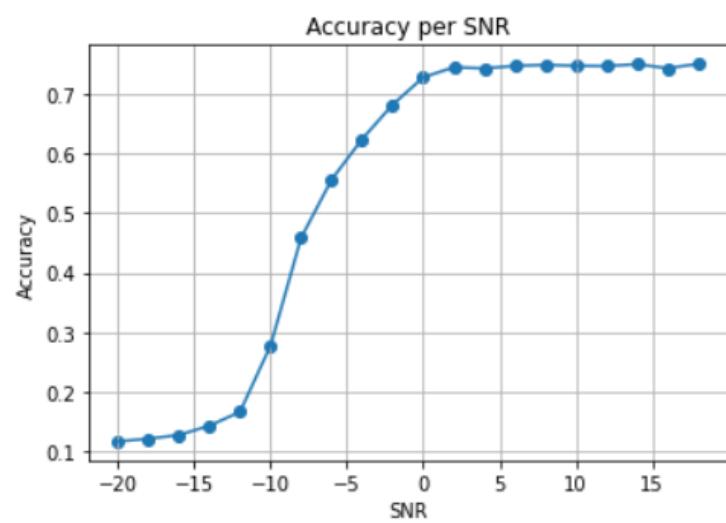
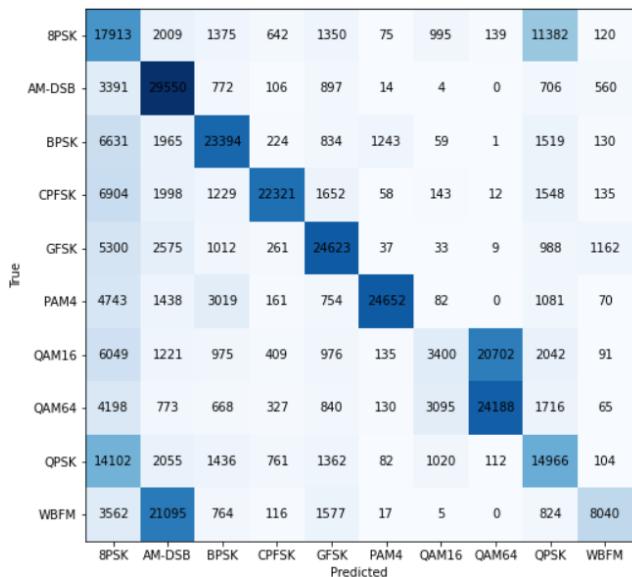
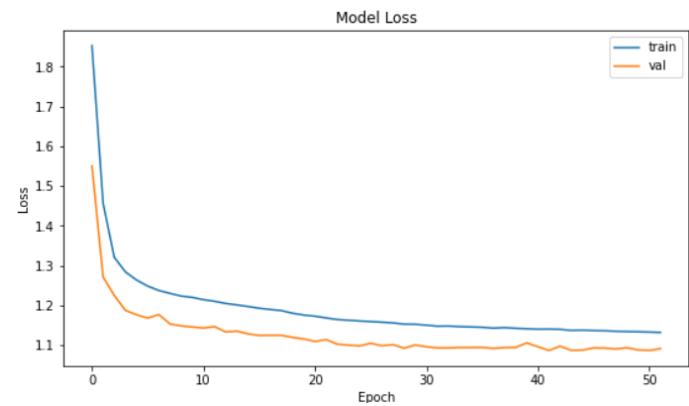
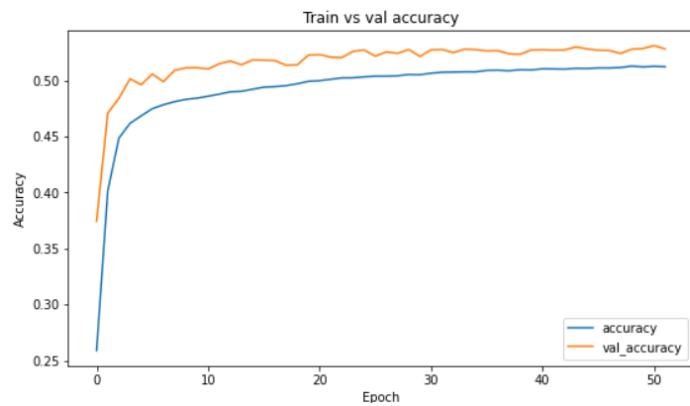
[2] CNN Model



Layer (type)	Output Shape	Param #
=====		
reshape (Reshape)	(None, 2, 128, 1)	0
zero_padding2d (ZeroPadding 2D)	(None, 2, 132, 1)	0
conv1 (Conv2D)	(None, 2, 130, 64)	256
dropout (Dropout)	(None, 2, 130, 64)	0
zero_padding2d_1 (ZeroPaddi ng2D)	(None, 2, 134, 64)	0
conv2 (Conv2D)	(None, 1, 132, 16)	6160
dropout_1 (Dropout)	(None, 1, 132, 16)	0
flatten (Flatten)	(None, 2112)	0
dense1 (Dense)	(None, 128)	270464
dropout_2 (Dropout)	(None, 128)	0
dense2 (Dense)	(None, 10)	1290
activation (Activation)	(None, 10)	0
reshape_1 (Reshape)	(None, 10)	0
=====		
Total params: 278,170		
Trainable params: 278,170		
Non-trainable params: 0		

(a) RAW

(i) Learning Rate = 0.001



SNR	Accuracy
-20	0.12
-18	0.12
-16	0.13
-14	0.14
-12	0.17
-10	0.28
-8	0.46
-6	0.56
-4	0.62
0	0.73
2	0.74
4	0.74
6	0.75
8	0.75
10	0.75
12	0.75
14	0.75
16	0.74
18	0.75

Max Train accuracy = 0.5121654272079468

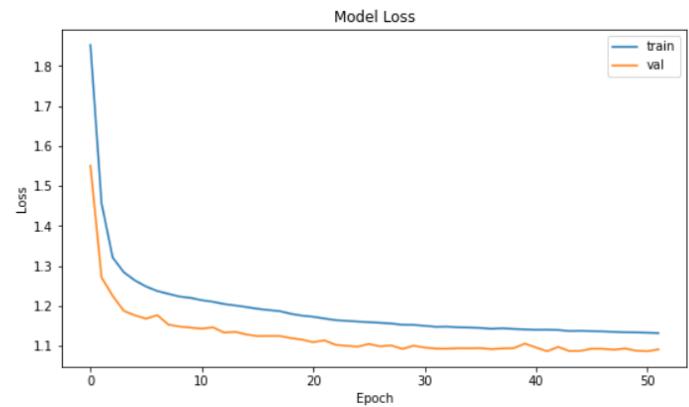
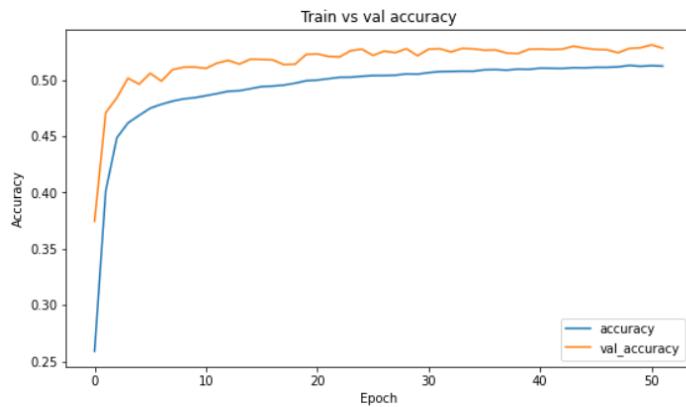
Max Val accuracy = 0.5280476212501526

Max Test accuracy = 0.5362416505813599

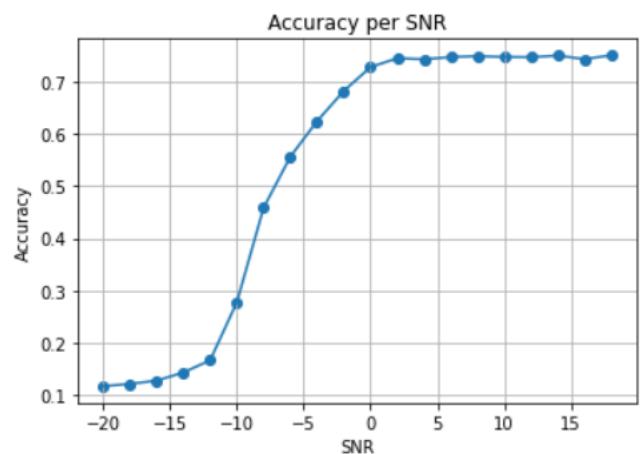
Average Accuracy = 0.5365

Accuracy at SNR=0dB = 0.73

(ii) Learning Rate = 0.0001



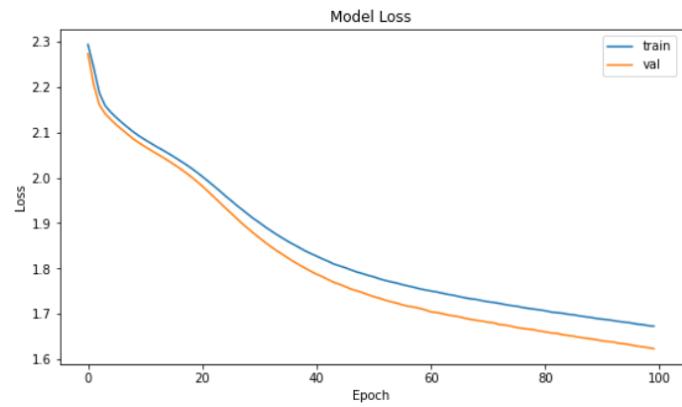
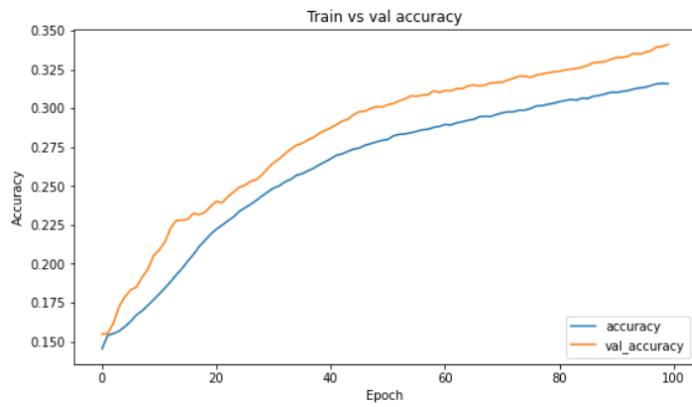
	8PSK	2009	1375	642	1350	75	995	139	11382	120
AM-DSB	3391	29550	772	106	897	14	4	0	706	560
BPSK	6631	1965	23394	224	834	1243	59	1	1519	130
CPFSK	6904	1998	1229	22321	1652	58	143	12	1548	135
GFSK	5300	2575	1012	261	24623	37	33	9	988	1162
PAM4	4743	1438	3019	161	754	24652	82	0	1081	70
QAM16	6049	1221	975	409	976	135	3400	20702	2042	91
QAM64	4198	773	668	327	840	130	3095	24188	1716	65
QPSK	14102	2055	1436	761	1362	82	1020	112	14966	104
WBFM	3562	21095	764	116	1577	17	5	0	824	8040
	8PSK	AM-DSB	BPSK	CPFSK	GFSK	PAM4	QAM16	QAM64	QPSK	WBFM



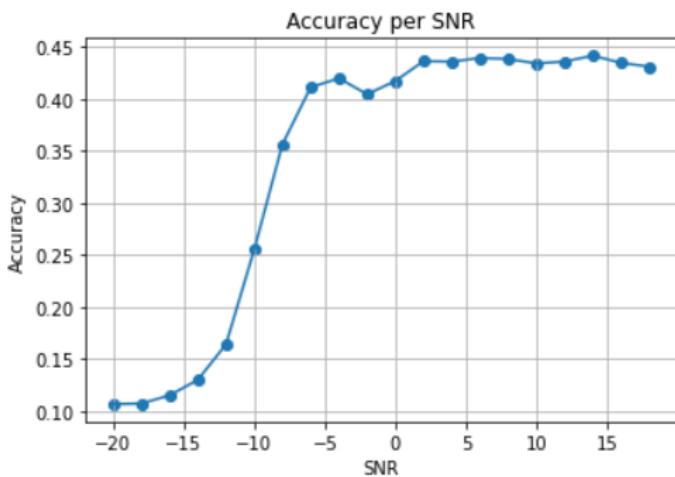
	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
acc	0.11	0.12	0.12	0.13	0.16	0.27	0.42	0.53	0.6	0.77	0.79	0.8	0.8	0.8	0.8	0.81	0.81	0.81	0.8	0.81

Max Train accuracy = 0.5338809490203857
 Max Val accuracy = 0.5525714159011841
 Max Test accuracy = 0.5575249791145325
 Average Accuracy = 0.5575000000000001
 Accuracy at SNR=0dB = 0.77

(iii) Learning Rate = 0.00001



	8PSK	AM-DSB	BPSK	CPFSK	GFSK	PAM4	QAM16	QAM64	QPSK	WBFM
8PSK	3078	1741	1640	5735	2464	189	1876	13163	5563	551
AM-DSB	1108	24954	1251	841	1698	9	25	3	2497	3614
BPSK	2776	1761	8313	2021	1890	10741	568	2772	4613	545
CPFSK	2666	1747	1189	13055	3993	50	1454	5618	5583	645
GFSK	1873	2257	1205	2202	22346	29	101	71	3720	2196
PAM4	2123	1217	5789	1522	1472	17303	556	2264	3322	432
QAM16	2563	1056	1413	5493	1894	320	2337	16731	3794	399
QAM64	2215	638	1221	5552	1632	333	2518	18814	2769	308
QPSK	3187	1723	1651	6264	2306	199	1887	12456	5810	517
WBFM	1215	19291	1102	1064	4046	8	39	3	2642	6590



	-20	-18	-16	-14	-12	-10	-8	-6	-4	0	2	4	6	8	10	12	14	16	18
acc	0.11	0.11	0.12	0.13	0.16	0.25	0.36	0.41	0.42	0.44	0.44	0.44	0.44	0.43	0.44	0.44	0.43	0.43	0.43

Max Train accuracy = 0.31583958864212036

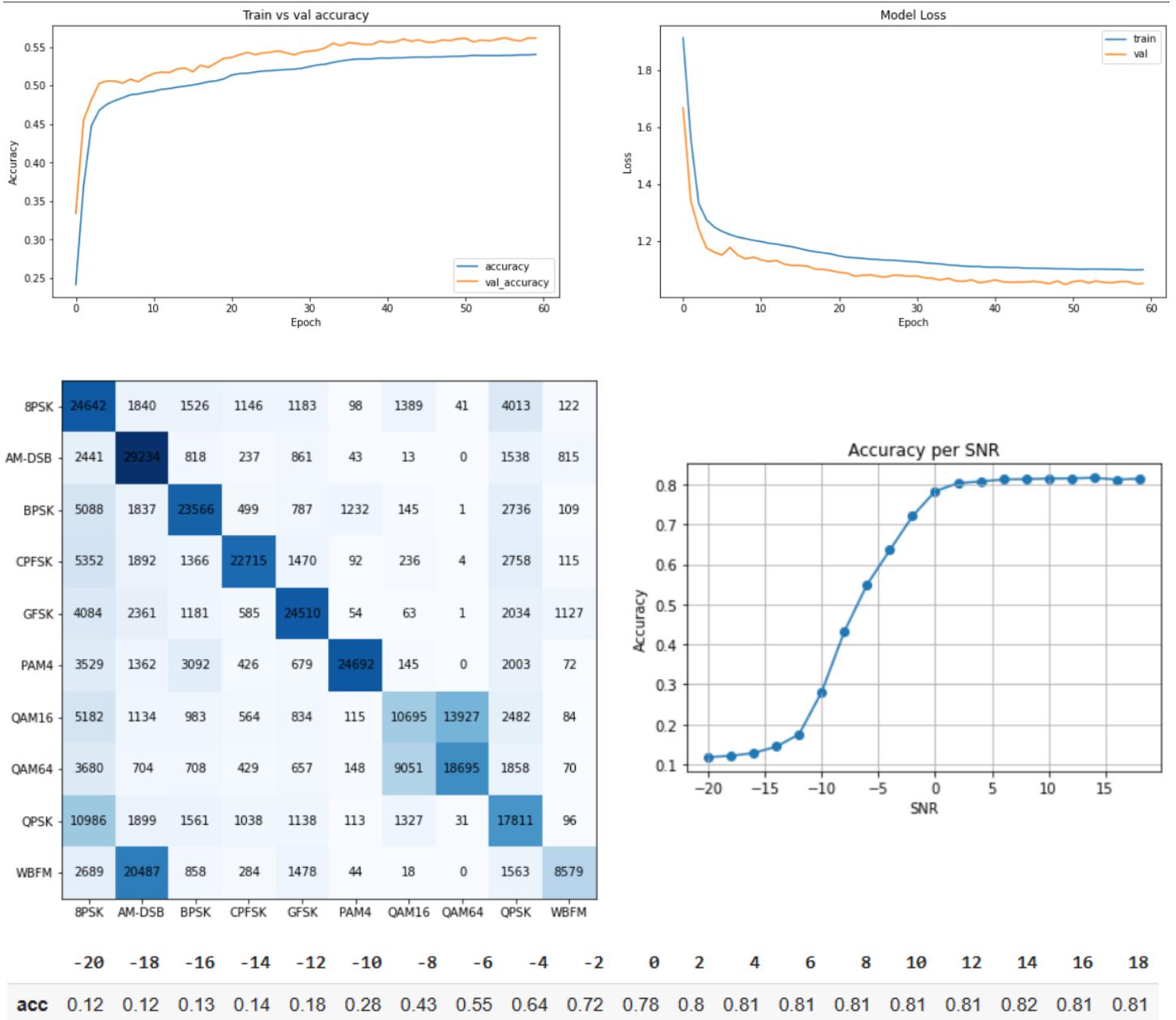
Max Val accuracy = 0.3410952389240265

Max Test accuracy = 0.3405555486679077

Average Accuracy = 0.341

Accuracy at SNR=0dB = 0.42

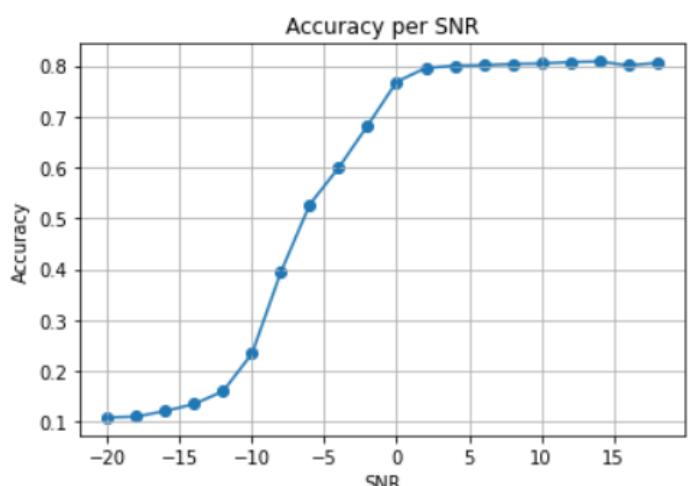
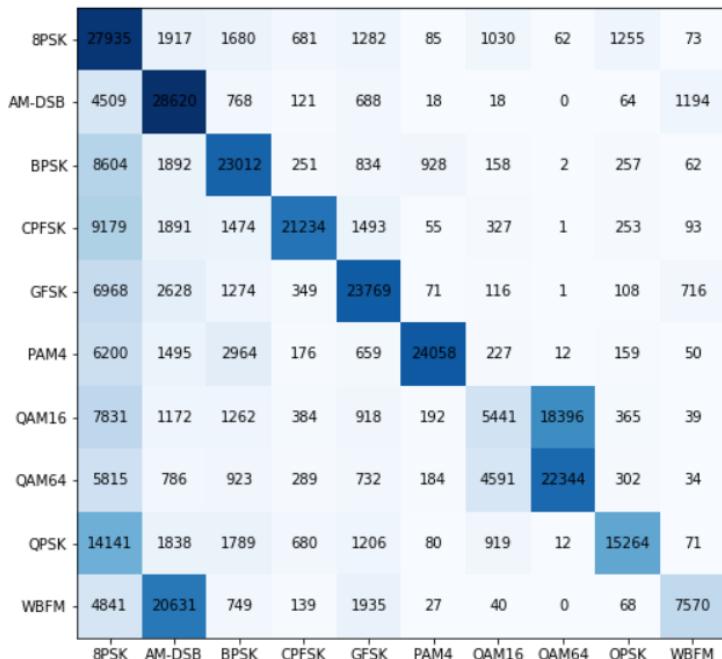
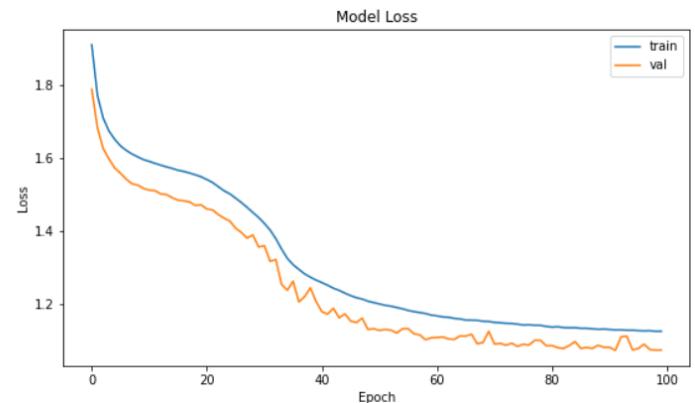
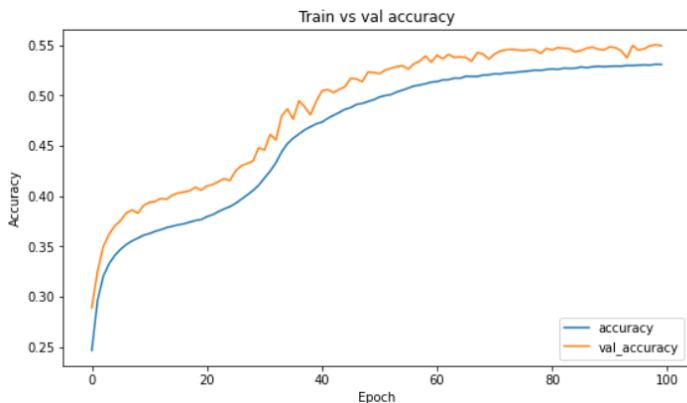
(iv) Learning Rate = 0.001 decaying



Max Train accuracy = 0.5404223203659058
 Max Val accuracy = 0.5616428852081299
 Max Test accuracy = 0.5698305368423462
 Average Accuracy = 0.5690000000000001
 Accuracy at SNR=0dB = 0.78

(b) INTEGRAL

(i) Learning Rate = 0.001



	-20	-18	-16	-14	-12	-10	-8	-6	-4	0	2	4	6	8	10	12	14	16	18
acc	0.11	0.11	0.12	0.14	0.16	0.23	0.39	0.53	0.6	0.77	0.8	0.8	0.8	0.8	0.81	0.81	0.81	0.8	0.81

Max Train accuracy = 0.5306992530822754

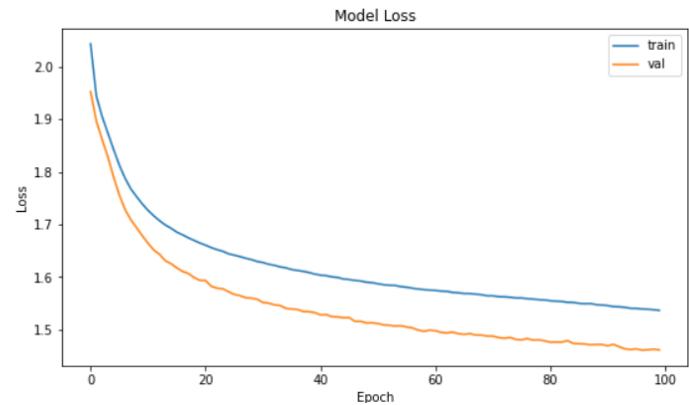
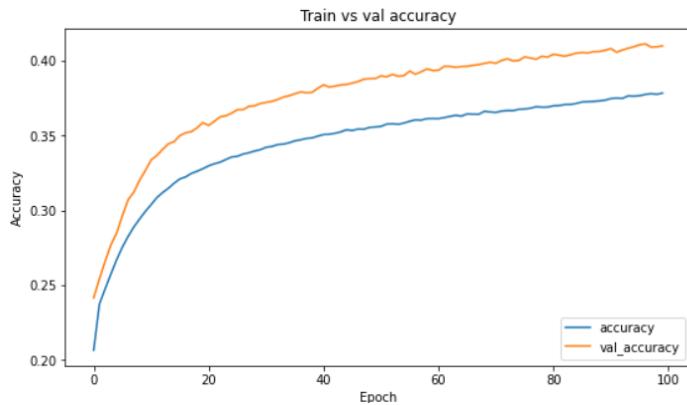
Max Val accuracy = 0.5494047403335571

Max Test accuracy = 0.553463876247406

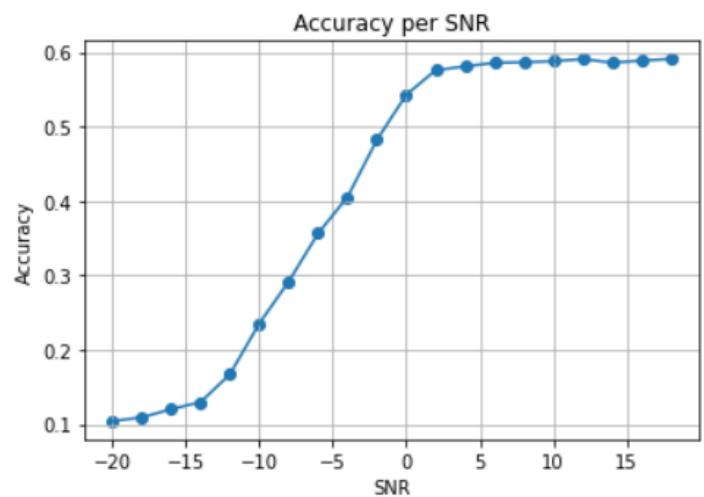
Average Accuracy = 0.5535000000000001

Accuracy at SNR=0dB = 0.77

(ii) Learning Rate = 0.0001



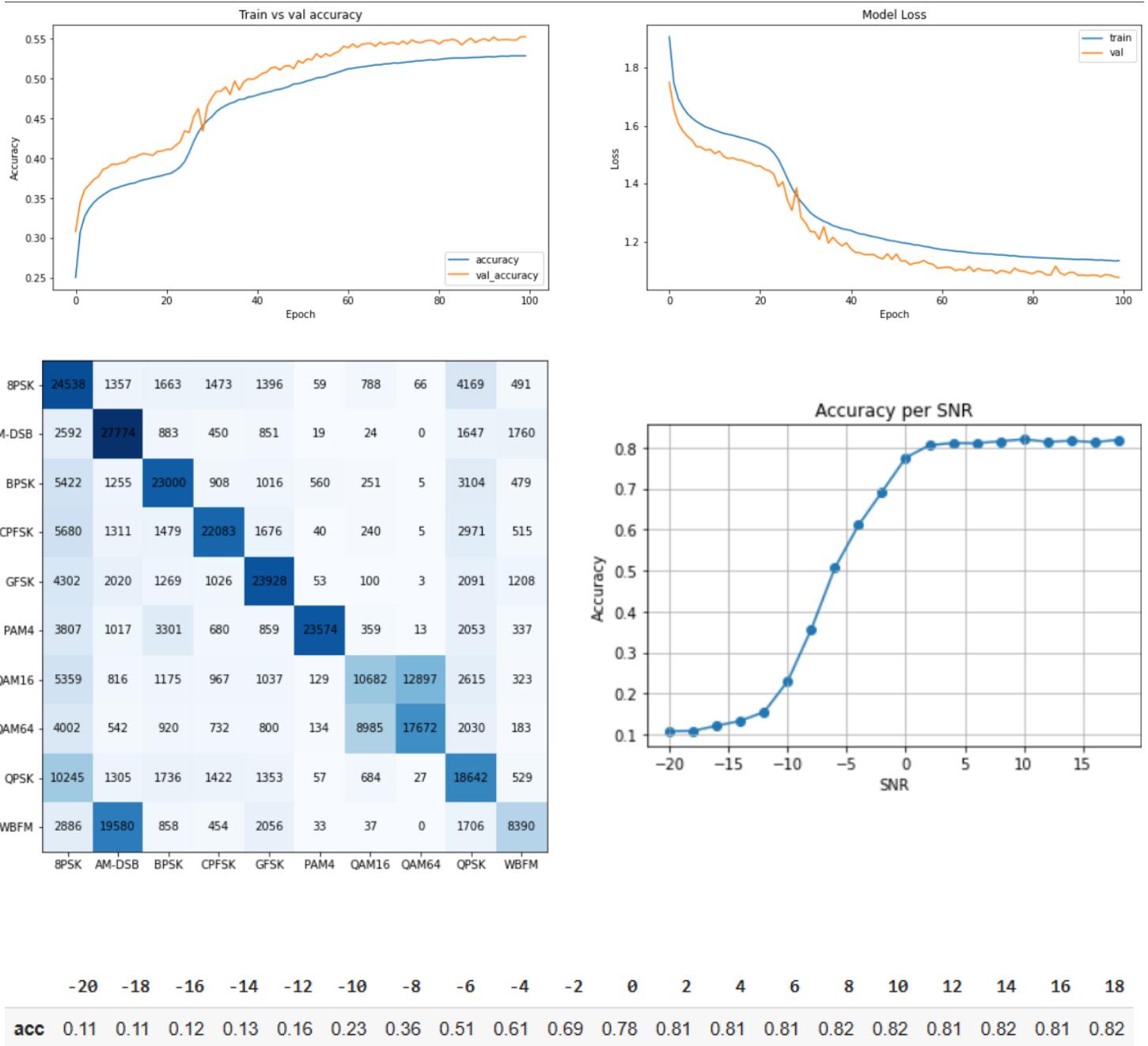
8PSK	14038	1457	2900	4516	1553	312	651	6075	4053	445
AM-DSB	4384	27853	1519	63	483	99	30	16	156	1397
BPSK	8988	1516	18220	305	794	4729	218	227	694	309
CPFSK	9437	1408	2327	17632	2807	202	240	678	766	503
GFSK	6892	1938	1972	1308	21002	169	109	288	388	1934
PAM4	6859	1280	6448	215	618	19318	307	322	400	233
QAM16	9950	973	1990	3169	1426	611	1095	13493	2958	335
QAM64	8707	699	1406	3438	1301	675	1047	15565	2844	318
QPSK	12869	1451	2923	5521	1514	326	525	4058	6395	418
WBFM	4544	20789	1547	180	1725	129	48	34	220	6784
	8PSK	AM-DSB	BPSK	CPFSK	GFSK	PAM4	QAM16	QAM64	QPSK	WBFM



-20	-18	-16	-14	-12	-10	-8	-6	-4	0	2	4	6	8	10	12	14	16	18
acc	0.1	0.11	0.12	0.13	0.17	0.24	0.29	0.36	0.41	0.58	0.58	0.59	0.59	0.59	0.59	0.59	0.59	0.59

Max Train accuracy = 0.3783947229385376
 Max Val accuracy = 0.4099523723125458
 Max Test accuracy = 0.41083890199661255
 Average Accuracy = 0.41200000000000003
 Accuracy at SNR=0dB = 0.54

(iii) Learning Rate = 0.001 decaying



Max Train accuracy = 0.5286390781402588
 Max Val accuracy = 0.5523571372032166
 Max Test accuracy = 0.5563416481018066
 Average Accuracy = 0.557
 Accuracy at SNR=0dB = 0.78

Results

Featuers	LR	Train Acc	Val Acc	Test Acc	Avg Test Acc	At SNR=0	Highest SNR
Raw	0.001	51.2%	52.8%	53.6%	53.7%	73%	75%
Raw	0.0001	53.4%	55.3%	55.8%	55.8%	77%	81%
Raw	0.00001	31.6%	34.1%	34.1%	34.1%	42%	43%
Raw	0.001 + decay	54.0%	56.25%	57.0%	56.9%	78%	81%
Integral	0.001	56.1%	54.9%	55.3%	55.4%	77%	81%
Integral	0.0001	37.8%	41.0%	41.0%	41.2%	54%	59%
Integral	0.001 + decay	52.9%	55.2%	55.6%	55.7%	78%	82%

RAW features

- Highest Test Accuracy at lr = 0.001 with decay factor
 - Accuracy = 57.0%
- Highest Average Test Accuracy at lr = 0.001 with decay factor
 - Accuracy = 56.9%
- Highest Accuracy at SNR = 0 at lr = 0.001 with decay factor
 - Accuracy = 78%

INTEGRAL features:

- Highest Test Accuracy at lr = 0.001 with decay factor
 - Accuracy = 55.6%
- Highest Average Test Accuracy at lr = 0.001 with decay factor
 - Accuracy = 56.7%
- Highest Accuracy at SNR = 0 at lr = 0.001 with decay factor
 - Accuracy = 78%

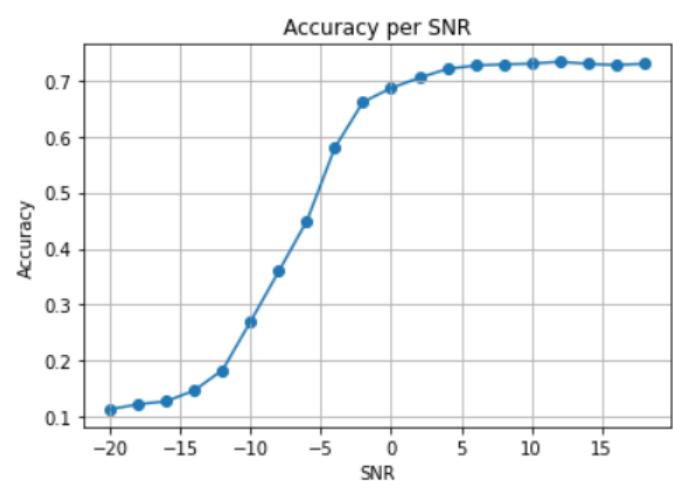
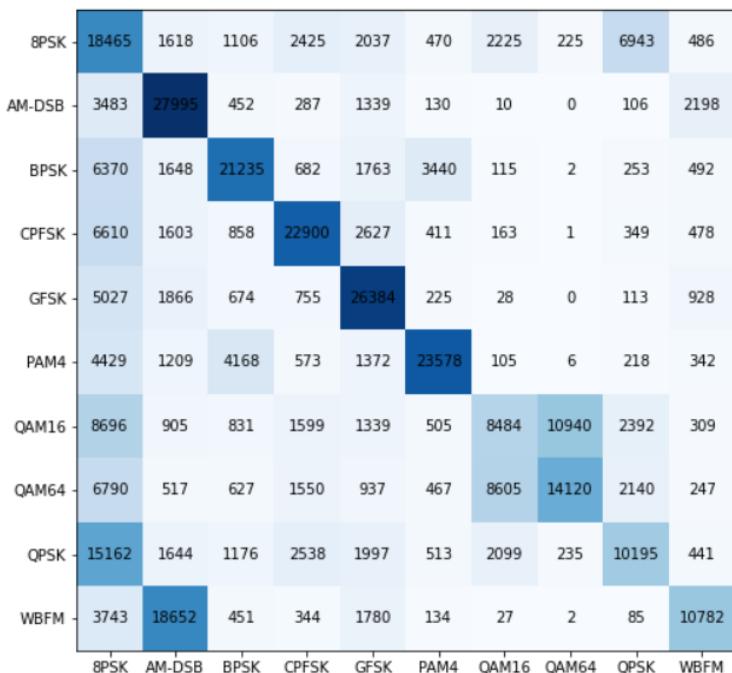
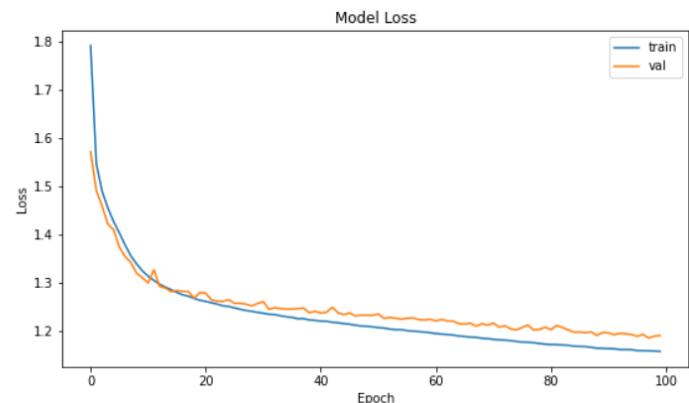
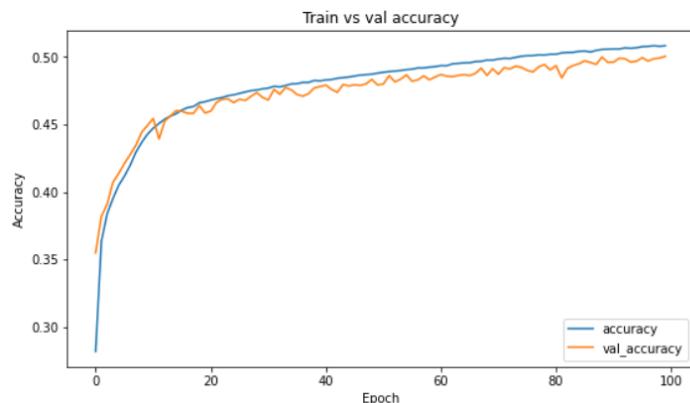
Both **raw** and **integral** features showed similar results with RAW features having a slightly higher test accuracy.

[3] Vanilla RNN Model

Layer (type)	Output Shape	Param #
<hr/>		
simple_rnn (SimpleRNN)	(None, 128)	32896
dense (Dense)	(None, 128)	16512
dropout (Dropout)	(None, 128)	0
dense_1 (Dense)	(None, 64)	8256
dense_2 (Dense)	(None, 10)	650
<hr/>		
Total params: 58,314		
Trainable params: 58,314		
Non-trainable params: 0		

(a) RAW

(i) Learning Rate = 0.001



acc	0.11	0.12	0.13	0.15	0.18	0.27	0.36	0.45	0.58	0.66	0.69	0.7	0.72	0.73	0.73	0.73	0.73	0.73	0.73
-----	------	------	------	------	------	------	------	------	------	------	------	-----	------	------	------	------	------	------	------

Max Train accuracy = 0.508385956287384

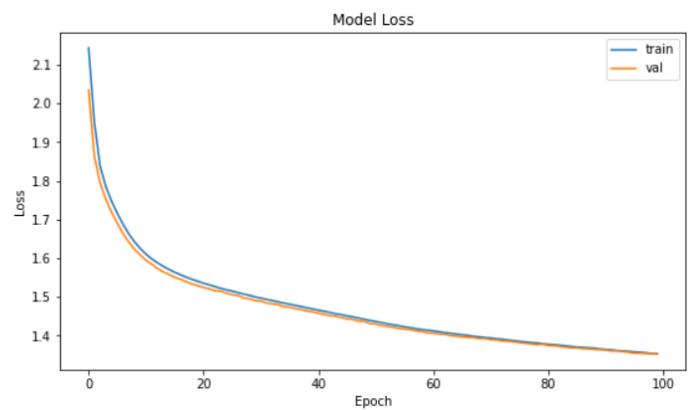
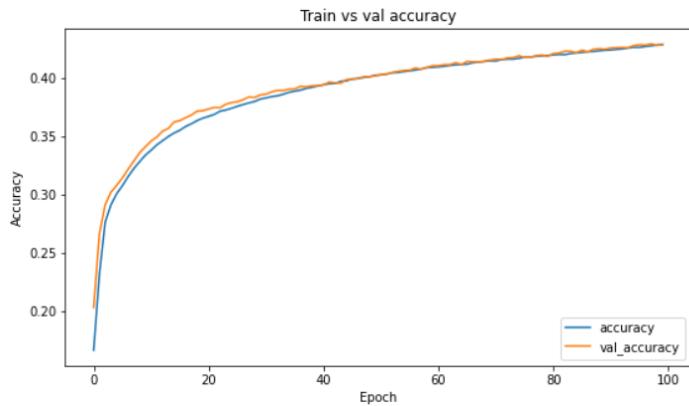
Max Val accuracy = 0.5005714297294617

Max Test accuracy = 0.5114944577217102

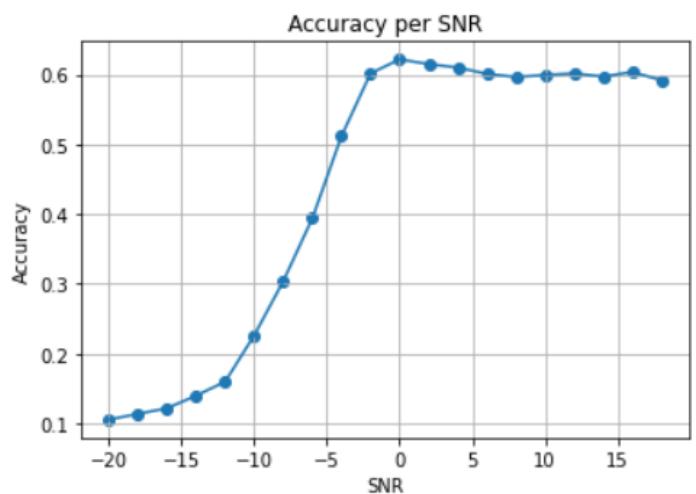
Average Accuracy = 0.5115000000000001

Accuracy at SNR=0dB = 0.69

(ii) Learning Rate = 0.0001



8PSK	6302	1561	2651	4730	1763	137	149	8256	10251	200
AM-DSB	2307	27939	1330	586	1372	19	0	1	872	1574
BPSK	3526	1595	16763	1660	1605	7806	35	187	2623	200
CPFSK	3521	1556	2257	22913	2328	108	71	146	2853	247
GFSK	2920	1895	1799	1599	25634	61	6	2	1335	749
PAM4	2461	1127	9949	1334	1172	17866	34	119	1775	163
QAM16	3850	884	2028	3771	1156	191	166	15900	7920	134
QAM64	2966	543	1542	3460	866	181	168	18559	7599	116
QPSK	5473	1509	2782	4855	1769	151	133	7808	11325	195
WBFM	2315	19200	1362	697	2000	32	1	0	999	9394



	-20	-18	-16	-14	-12	-10	-8	-6	-4	0	2	4	6	8	10	12	14	16	18
acc	0.11	0.11	0.12	0.14	0.16	0.23	0.3	0.39	0.51	0.62	0.61	0.61	0.6	0.6	0.6	0.6	0.6	0.6	0.59

Max Train accuracy = 0.4288797080516815

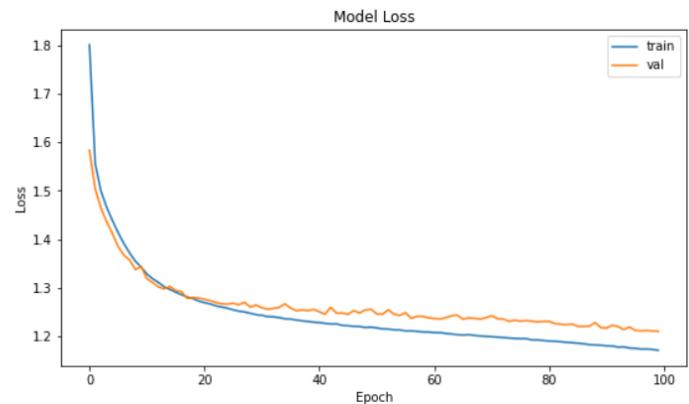
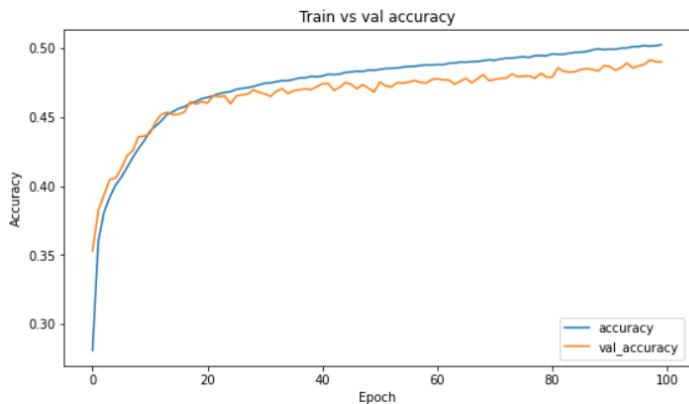
Max Val accuracy = 0.4292857050895691

Max Test accuracy = 0.43572500348091125

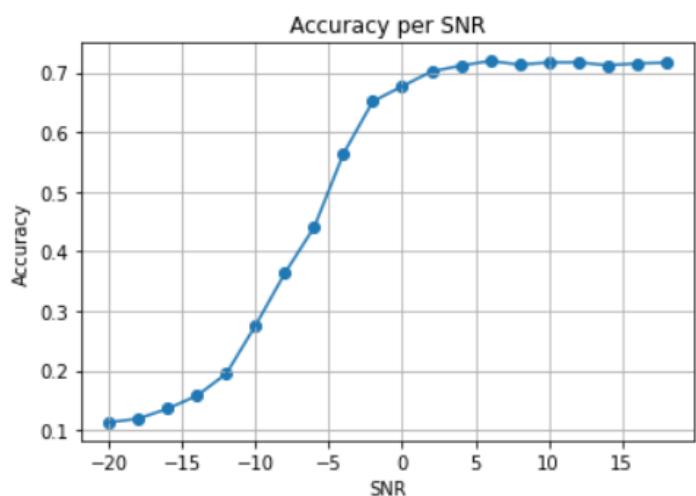
Average Accuracy = 0.43499999999999994

Accuracy at SNR=0dB = 0.62

(iii) Learning Rate = 0.001 decaying



8PSK	12286	1055	4807	2742	1917	391	486	3635	8192	489
AM-DSB	1127	27882	2550	556	1585	100	6	25	631	1538
BPSK	1857	1057	24823	1236	1737	3348	17	265	1176	484
CPFSK	2274	995	4209	23153	2443	322	78	370	1612	544
GFSK	1475	1362	3553	1364	26422	193	12	66	711	842
PAM4	1220	805	7377	910	1320	22920	17	245	890	296
QAM16	4939	618	2979	1990	1268	443	949	18721	3769	324
QAM64	4206	384	1933	1718	852	402	856	22142	3321	186
QPSK	9140	1038	4765	2879	1960	437	441	3362	11480	498
WBFM	1186	18648	2657	691	2063	117	8	44	582	10004

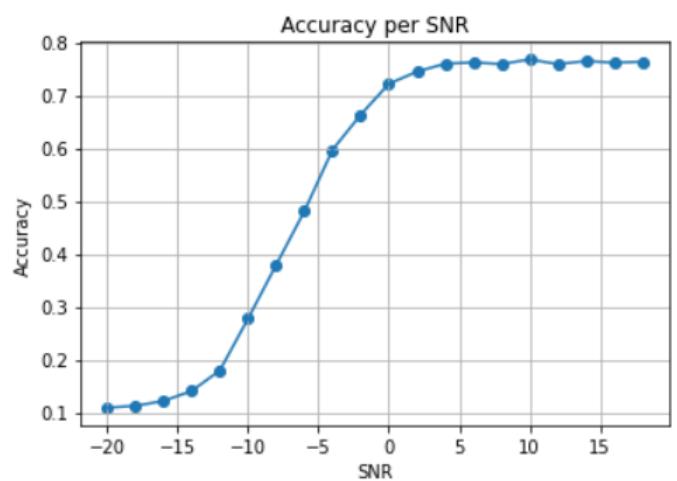
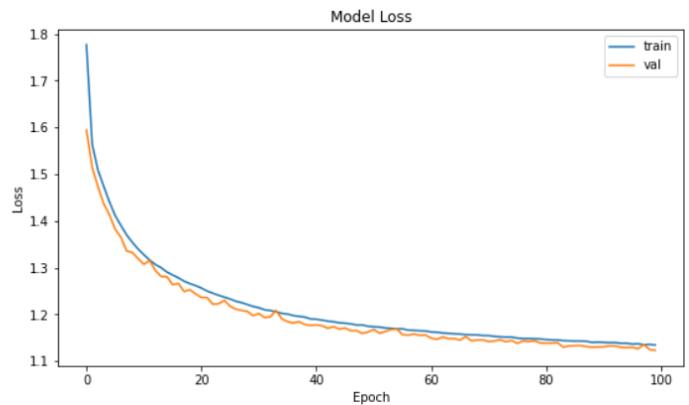
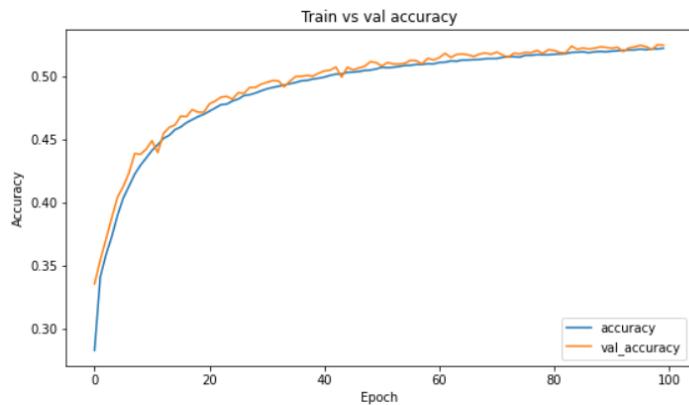


-20	-18	-16	-14	-12	-10	-8	-6	-4	0	2	4	6	8	10	12	14	16	18	
acc	0.11	0.12	0.14	0.16	0.19	0.28	0.36	0.44	0.56	0.65	0.68	0.7	0.71	0.72	0.71	0.72	0.71	0.71	0.72

Max Train accuracy = 0.5023972392082214
 Max Val accuracy = 0.4899761974811554
 Max Test accuracy = 0.5057250261306763
 Average Accuracy = 0.5055000000000001
 Accuracy at SNR=0dB = 0.68

(b) INTEGRAL

(i) Learning Rate = 0.001



acc	-20	-18	-16	-14	-12	-10	-8	-6	-4	0	2	4	6	8	10	12	14	16	18
0.11	0.11	0.11	0.12	0.14	0.18	0.28	0.38	0.48	0.60	0.66	0.72	0.74	0.76	0.76	0.77	0.76	0.76	0.76	0.76

Max Train accuracy = 0.5217919945716858

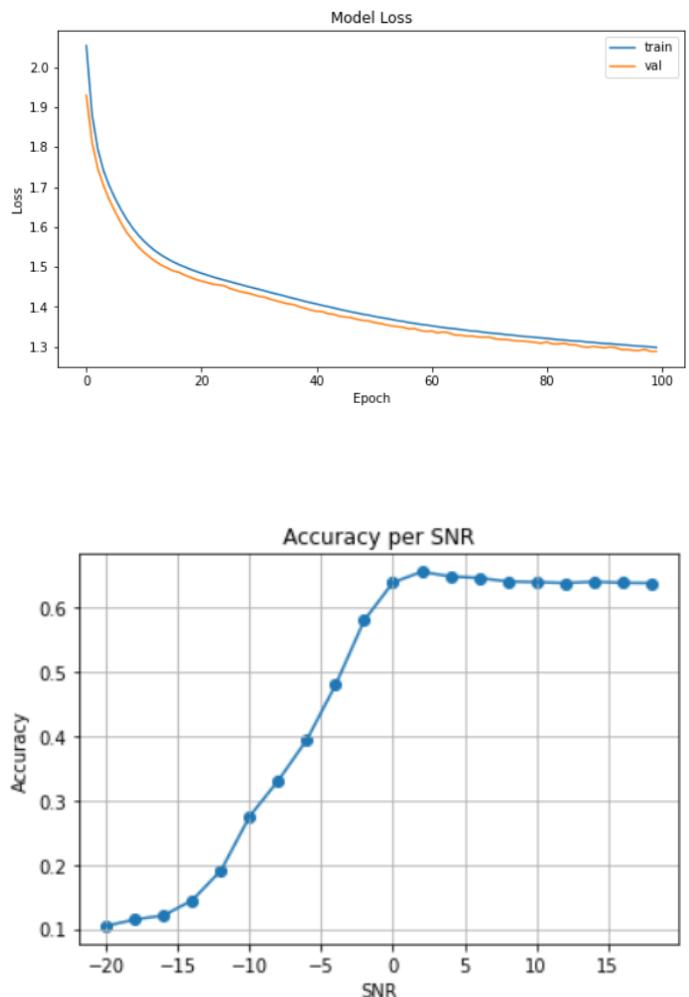
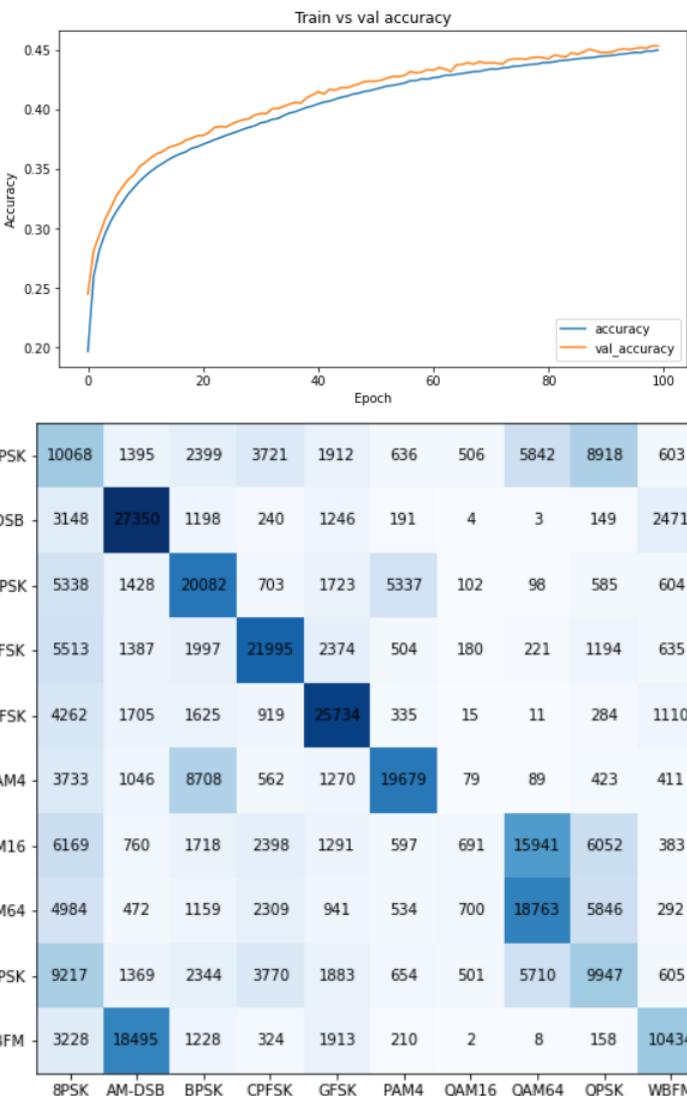
Max Val accuracy = 0.524238109588623

Max Test accuracy = 0.53109444318771362

Average Accuracy = 0.5305

Accuracy at SNR=0dB = 0.72

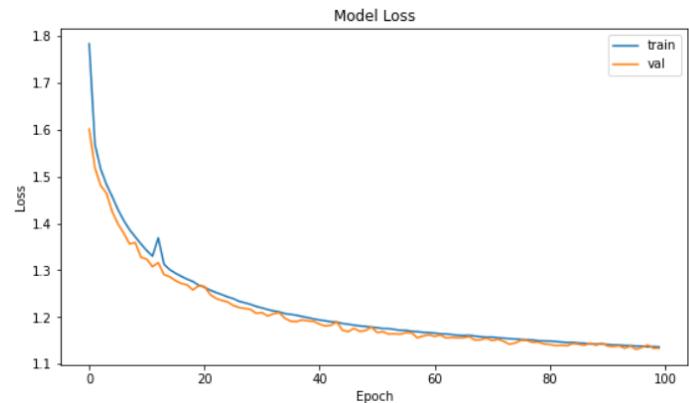
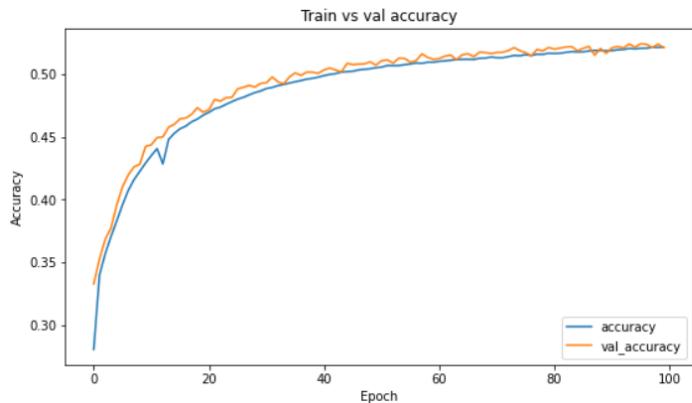
(ii) Learning Rate = 0.0001



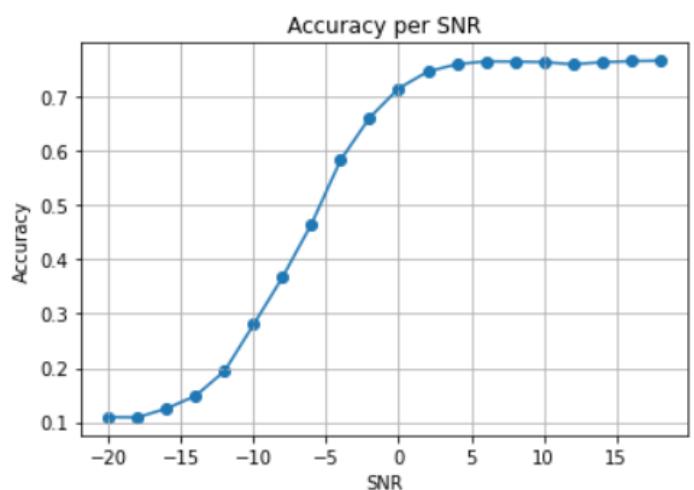
	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
acc	0.1	0.11	0.12	0.14	0.19	0.27	0.33	0.39	0.48	0.58	0.64	0.66	0.65	0.65	0.64	0.64	0.64	0.64	0.64	0.64

Max Train accuracy = 0.45038846135139465
 Max Val accuracy = 0.453809529542923
 Max Test accuracy = 0.45761945843696594
 Average Accuracy = 0.4575
 Accuracy at SNR=0dB = 0.64

(iii) Learning Rate = 0.001 decaying



8PSK	13715	1485	3492	1838	2456	709	1744	425	9919	217
AM-DSB	446	27508	1781	168	1689	266	8	5	2124	2005
BPSK	852	1485	24343	502	2111	2749	52	66	3617	223
CPFSK	1238	1431	3061	22020	3062	546	193	147	4024	278
GFSK	689	1818	2514	566	26557	354	15	19	2751	717
PAM4	545	1026	4801	398	1585	24764	49	80	2581	171
QAM16	3627	811	2318	1230	1607	676	9035	12232	4322	142
QAM64	3247	530	1475	1216	1148	568	8870	15489	3366	91
QPSK	6888	1438	3471	1899	2388	690	1219	389	17390	228
WBFM	443	18450	1897	263	2424	265	13	13	2272	9960



	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
acc	0.11	0.11	0.13	0.15	0.19	0.28	0.37	0.47	0.58	0.66	0.71	0.74	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76

Max Train accuracy = 0.5213608741760254
 Max Val accuracy = 0.5210475921630859
 Max Test accuracy = 0.5299472212791443
 Average Accuracy = 0.5289999999999999
 Accuracy at SNR=0dB = 0.71

Results

Featuers	LR	Train Acc	Val Acc	Test Acc	Avg Test Acc	At SNR=0	Highest SNR
Raw	0.001	50.8%	50.0%	51.1%	51.2%	69%	73%
Raw	0.0001	42.9%	42.9%	43.6%	43.5%	62%	59%
Raw	0.001 + decay	50.2%	49.0%	50.6%	50.6%	68%	72%
Integral	0.001	52.2%	52.4%	53.1%	53.1%	72%	76%
Integral	0.0001	45.0%	45.4%	45.8%	45.8%	64%	64%
Integral	0.001 + decay	52.1%	52.1%	53.0%	52.9%	71%	76%

RAW features

- Highest Test Accuracy at $lr = 0.001$
 - Accuracy = 51.1%
- Highest Average Test Accuracy at $lr = 0.001$
 - Accuracy = 51.2%
- Highest Accuracy at $SNR = 0$ at $lr = 0.001$
 - Accuracy = 69%

INTEGRAL features:

- Highest Test Accuracy at $lr = 0.001$
 - Accuracy = 53.1%
- Highest Average Test Accuracy at $lr = 0.001$
 - Accuracy = 53.1%
- Highest Accuracy at $SNR = 0$ at $lr = 0.001$
 - Accuracy = 72%

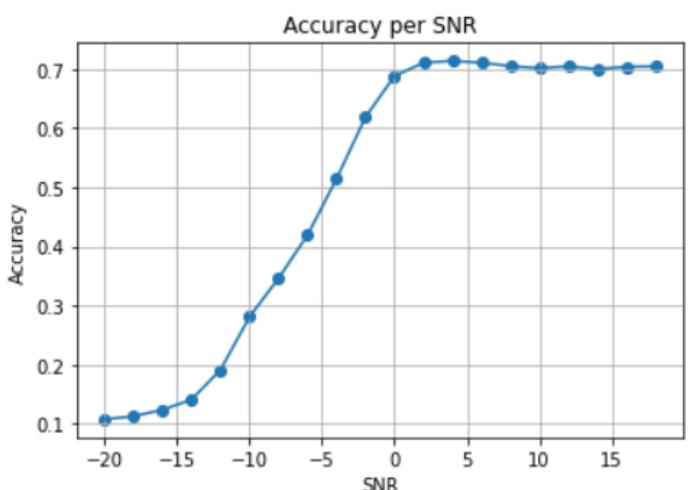
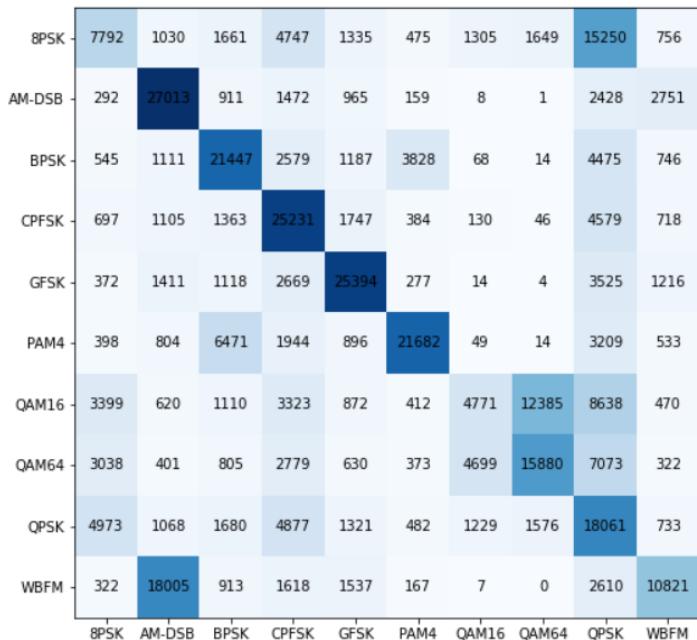
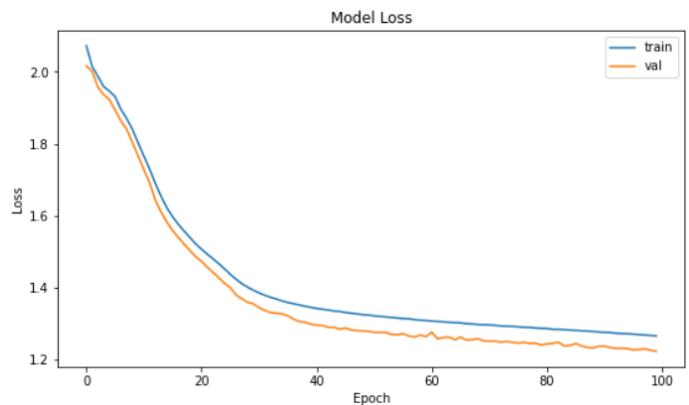
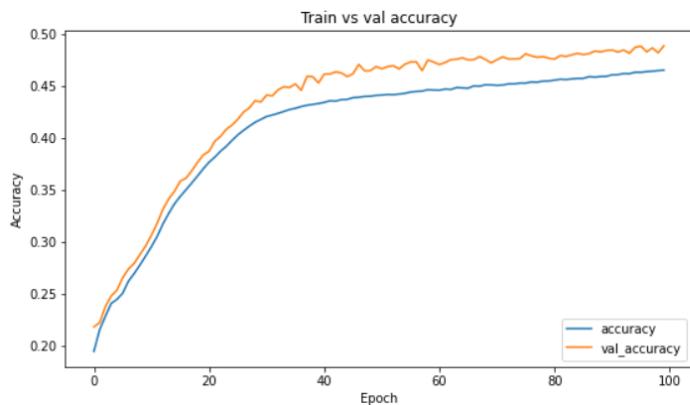
Integral features showed a higher accuracy when compared to the raw features with a consistent 2% higher throughout all the tests.

[4] LSTM Model

Layer (type)	Output Shape	Param #
lstm (LSTM)	(None, 2, 128)	131584
flatten (Flatten)	(None, 256)	0
dense (Dense)	(None, 128)	32896
dense_1 (Dense)	(None, 10)	1290
<hr/>		
Total params: 165,770		
Trainable params: 165,770		
Non-trainable params: 0		

(a) RAW

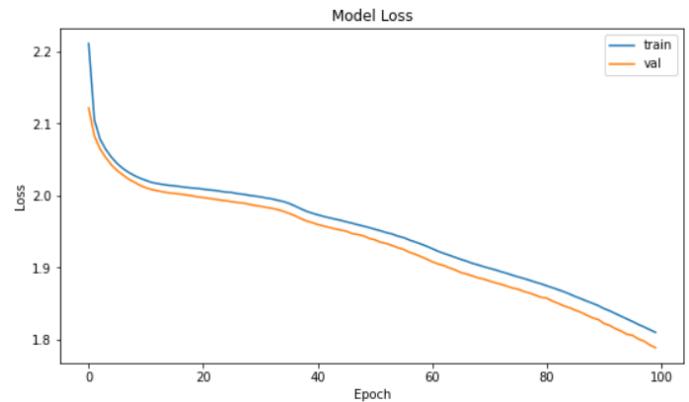
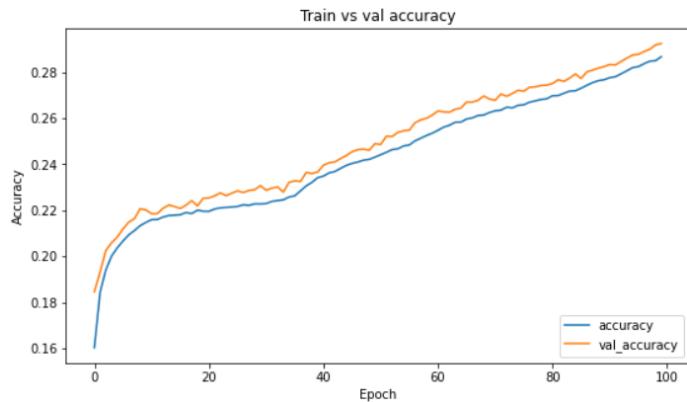
(i) Learning Rate = 0.001



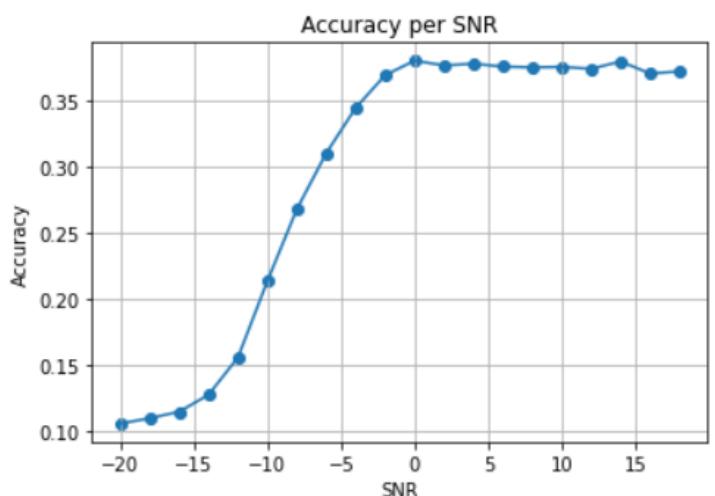
	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
acc	0.11	0.11	0.12	0.14	0.19	0.28	0.35	0.42	0.51	0.62	0.69	0.71	0.71	0.71	0.7	0.7	0.7	0.7	0.7	0.7

Max Train accuracy = 0.4651077687740326
 Max Val accuracy = 0.4886428713798523
 Max Test accuracy = 0.49470001459121704
 Average Accuracy = 0.4934999999999999
 Accuracy at SNR=0dB = 0.69

(ii) Learning Rate = 0.0001



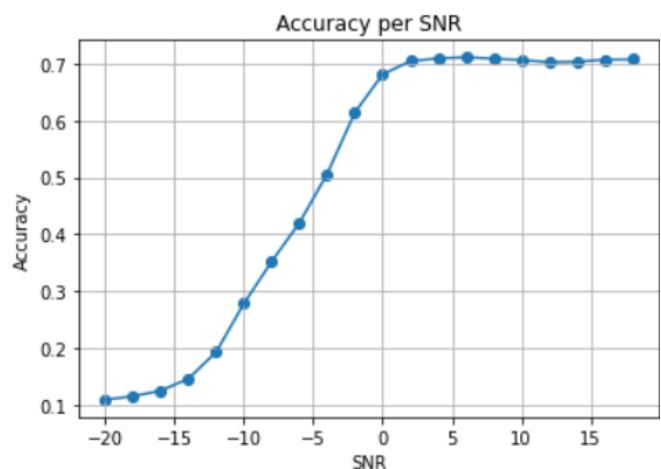
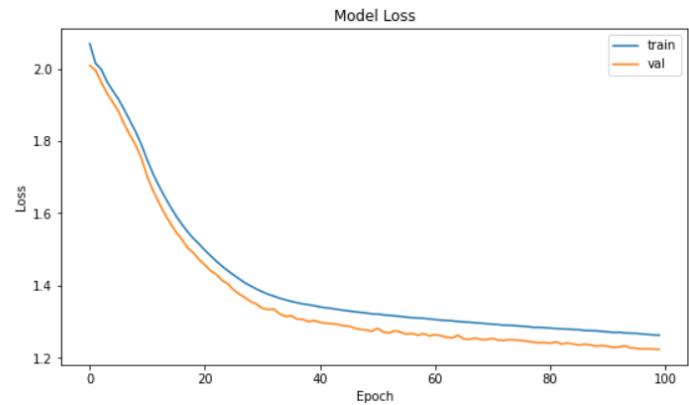
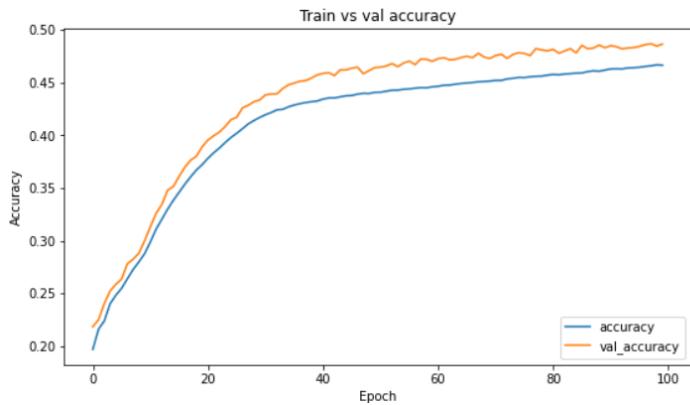
8PSK	6051	1585	7539	2594	611	3780	2368	9563	1611	298
AM-DSB	2073	26105	3651	357	233	539	15	20	534	2473
BPSK	5031	2051	8311	1655	749	10570	1197	4683	1390	363
CPFSK	5020	1575	6448	5199	2234	3364	1543	8840	1306	471
GFSK	3759	1771	4788	3145	18416	1178	102	326	869	1646
PAM4	3483	1656	6263	1314	1037	15891	811	4167	956	422
QAM16	4631	1067	5214	3072	765	4269	2553	12666	1474	289
QAM64	4196	735	3787	3311	830	4406	2567	14546	1377	245
QPSK	5894	1630	7377	2557	534	3725	2306	9951	1750	276
WBFM	2443	19574	3647	607	1482	635	11	33	518	7050
	8PSK	AM-DSB	BPSK	CPFSK	GFSK	PAM4	QAM16	QAM64	QPSK	WBFM



acc	0.11	0.11	0.12	0.13	0.16	0.21	0.27	0.31	0.34	0.37	0.38	0.38	0.38	0.38	0.37	0.38	0.37	0.37
-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

Max Train accuracy = 0.2866804599761963
 Max Val accuracy = 0.29240477085113525
 Max Test accuracy = 0.2940889000892639
 Average Accuracy = 0.29500000000000004
 Accuracy at SNR=0dB = 0.38

(iii) Learning Rate = 0.001 decaying

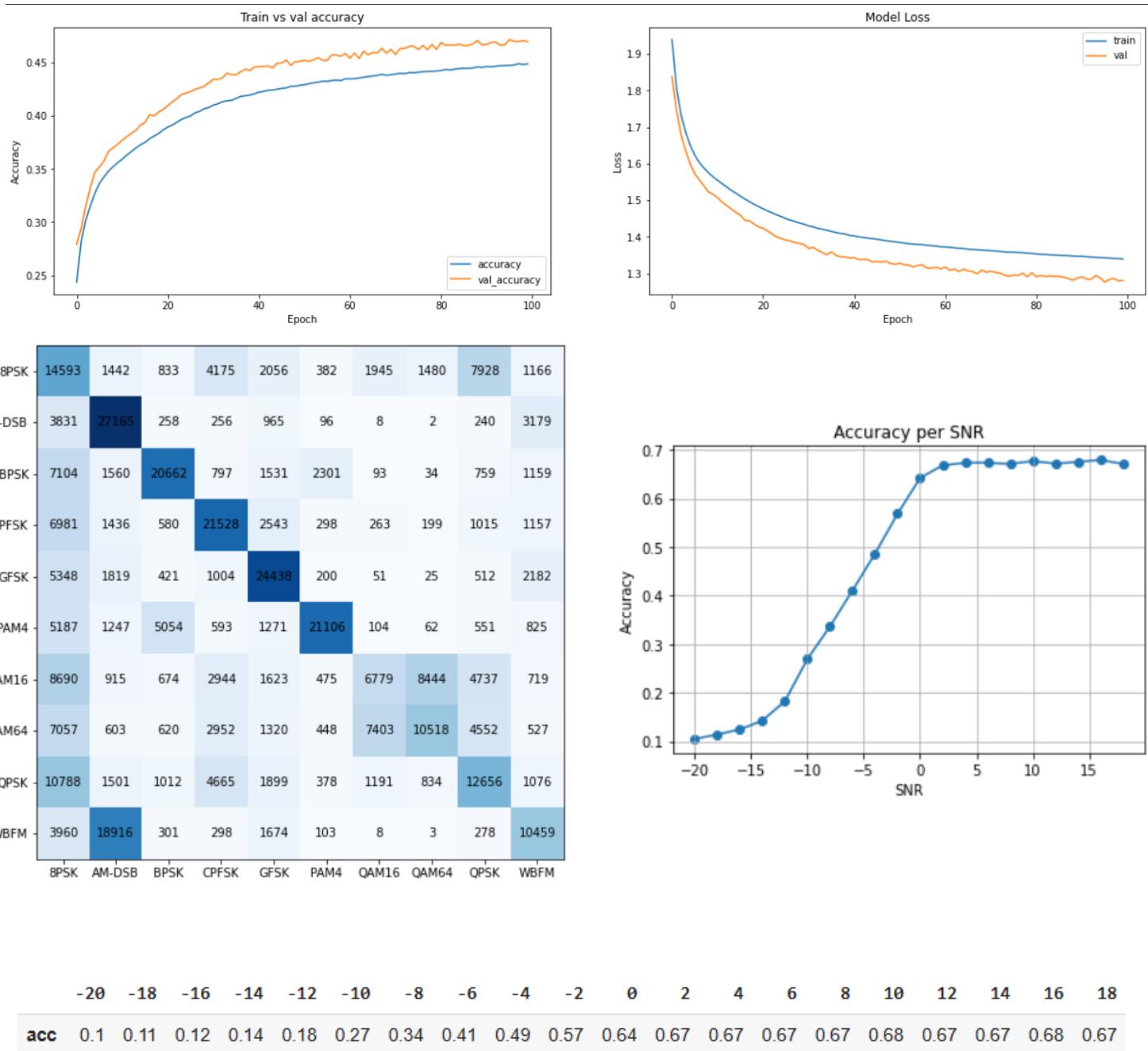


acc	0.11	0.12	0.13	0.15	0.19	0.28	0.35	0.42	0.51	0.61	0.68	0.7	0.71	0.71	0.71	0.71	0.7	0.71	0.71	0.71
-----	------	------	------	------	------	------	------	------	------	------	------	-----	------	------	------	------	-----	------	------	------

Max Train accuracy = 0.46655890345573425
 Max Val accuracy = 0.4865952432155609
 Max Test accuracy = 0.4950944483280182
 Average Accuracy = 0.4955
 Accuracy at SNR=0dB = 0.68

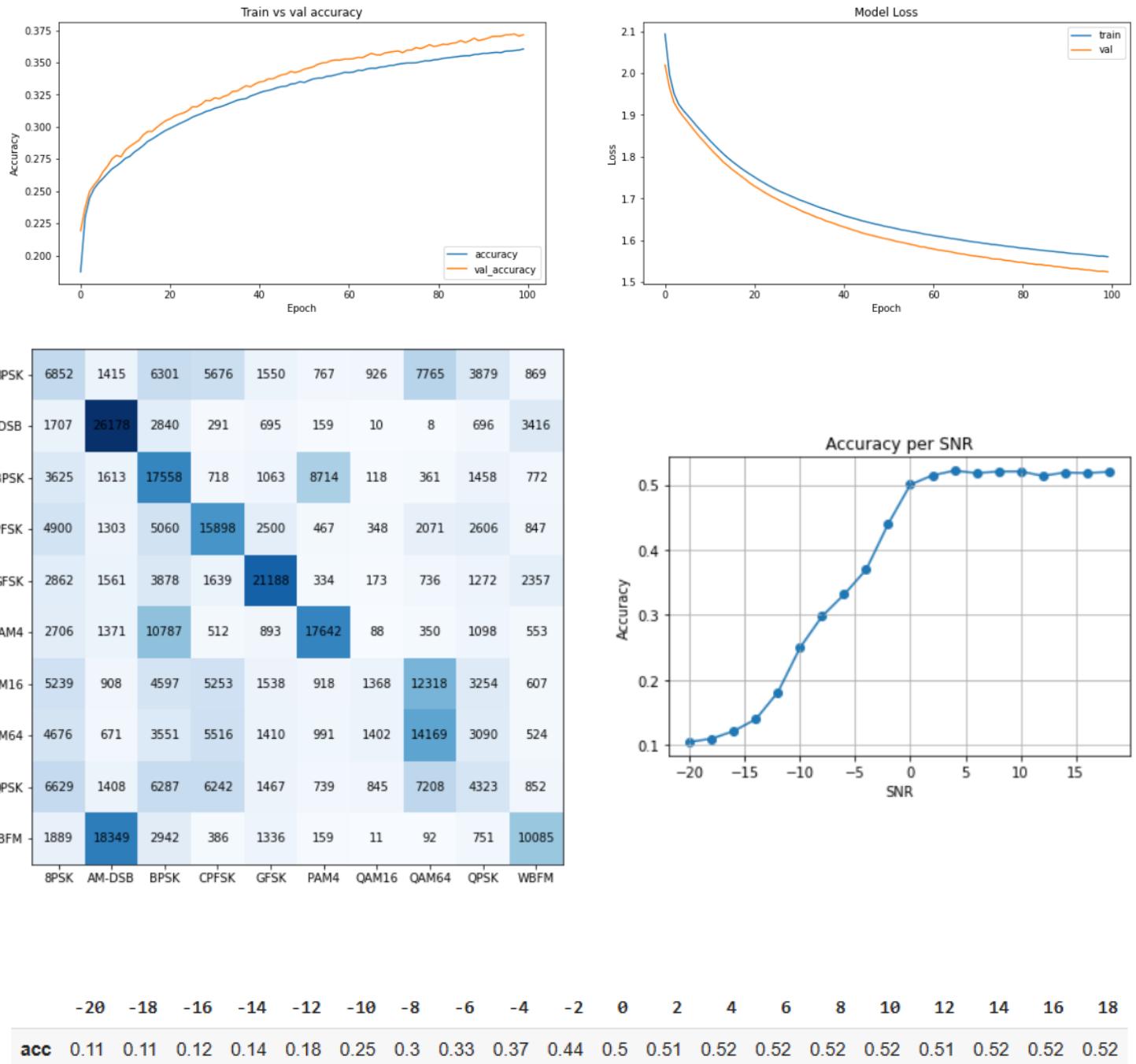
(b) INTEGRAL

(i) Learning Rate = 0.001



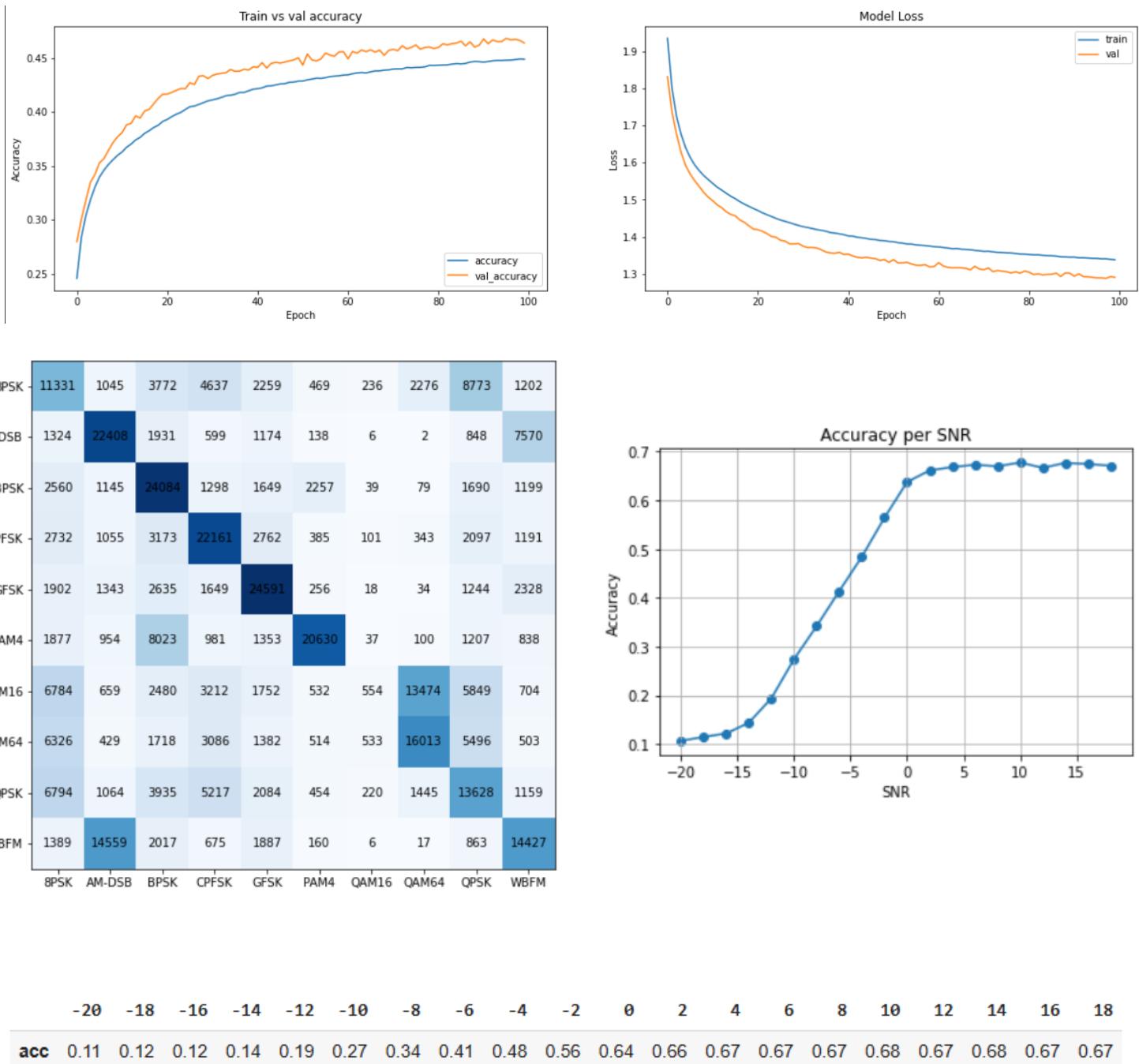
Max Train accuracy = 0.4490087628364563
 Max Val accuracy = 0.46988093852996826
 Max Test accuracy = 0.4719555675983429
 Average Accuracy = 0.471
 Accuracy at SNR=0dB = 0.64

(ii) Learning Rate = 0.0001



Max Train accuracy = 0.36053383350372314
 Max Val accuracy = 0.37157142162323
 Max Test accuracy = 0.37572500109672546
 Average Accuracy = 0.3754999999999999
 Accuracy at SNR=0dB = 0.5

(iii) Learning Rate = 0.001 decaying



Max Train accuracy = 0.44885966181755066
 Max Val accuracy = 0.4638809561729431
 Max Test accuracy = 0.4717416763305664
 Average Accuracy = 0.471
 Accuracy at SNR=0dB = 0.64

Results

Featuers	LR	Train Acc	Val Acc	Test Acc	Avg Test Acc	At SNR=0	Highest SNR
Raw	0.001	46.5%	48.9%	49.5%	49.3%	69%	70%
Raw	0.0001	28.7%	29.2%	29.4%	29.5%	38%	37%
Raw	0.001 + decay	46.7%	48.7%	49.5%	49.6%	68%	71%
Integral	0.001	44.9%	47.0%	47.2%	47.1%	64%	67%
Integral	0.0001	36.1%	37.2%	37.6%	37.5%	50%	52%
Integral	0.001 + decay	44.9%	46.4%	47.2%	47.1%	64%	67%

RAW features

- Highest Test Accuracy at lr = 0.001 with decay factor
 - Accuracy = 49.5%
- Highest Average Test Accuracy at lr = 0.001 with decay factor
 - Accuracy = 49.6%
- Highest Accuracy at SNR = 0 at lr = 0.001
 - Accuracy = 69%

INTEGRAL features:

- Highest Test Accuracy at lr = 0.001
 - Accuracy = 47.2%
- Highest Average Test Accuracy at lr = 0.001
 - Accuracy = 47.1%
- Highest Accuracy at SNR = 0 at lr = 0.001
 - Accuracy = 64%

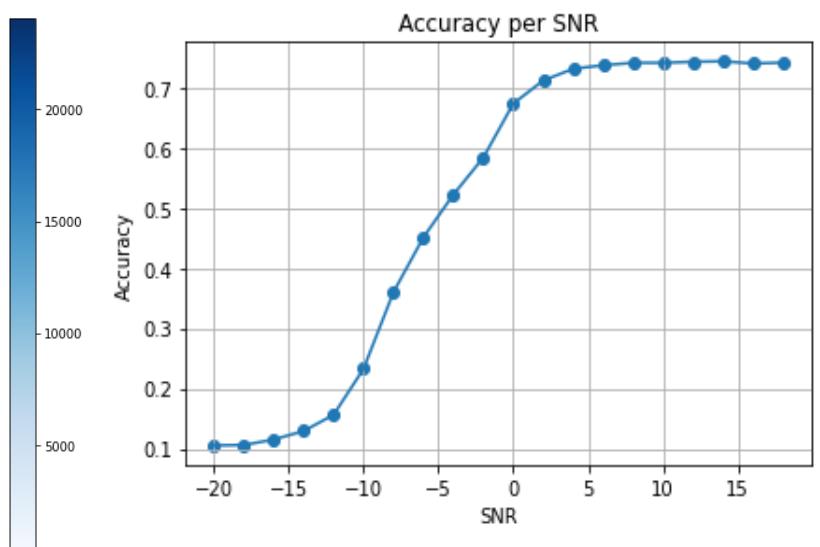
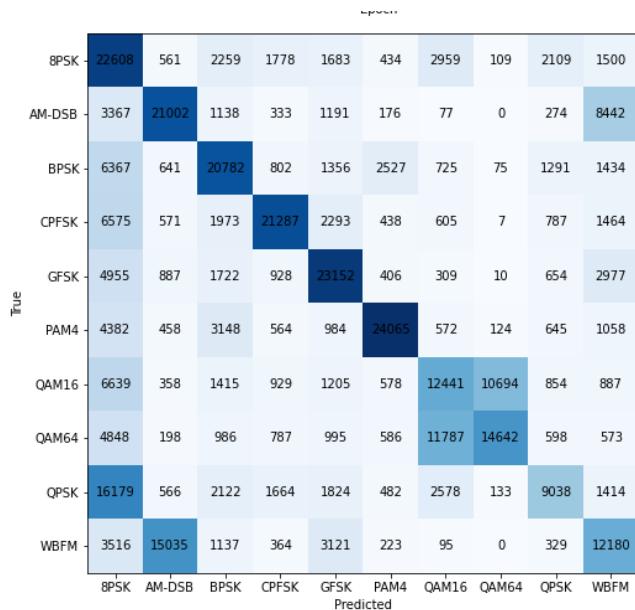
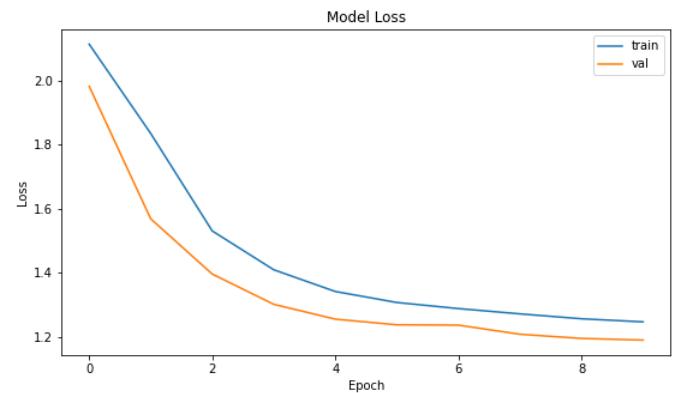
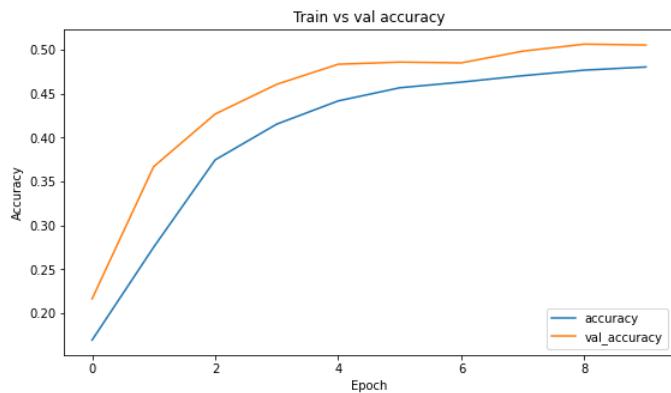
Raw features showed a higher accuracy when compared to the integral features with a consistent 2% higher throughout all the tests.

[5] CONV-LSTM Model

Layer (type)	Output Shape	Param #
=====		
conv_lstm2d_2 (ConvLSTM2D)	(None, 1, 128, 64)	50176
flatten_2 (Flatten)	(None, 8192)	0
dense_6 (Dense)	(None, 256)	2097408
dropout_2 (Dropout)	(None, 256)	0
dense_7 (Dense)	(None, 64)	16448
dense_8 (Dense)	(None, 10)	650
=====		
Total params: 2,164,682		
Trainable params: 2,164,682		
Non-trainable params: 0		

1) RAW

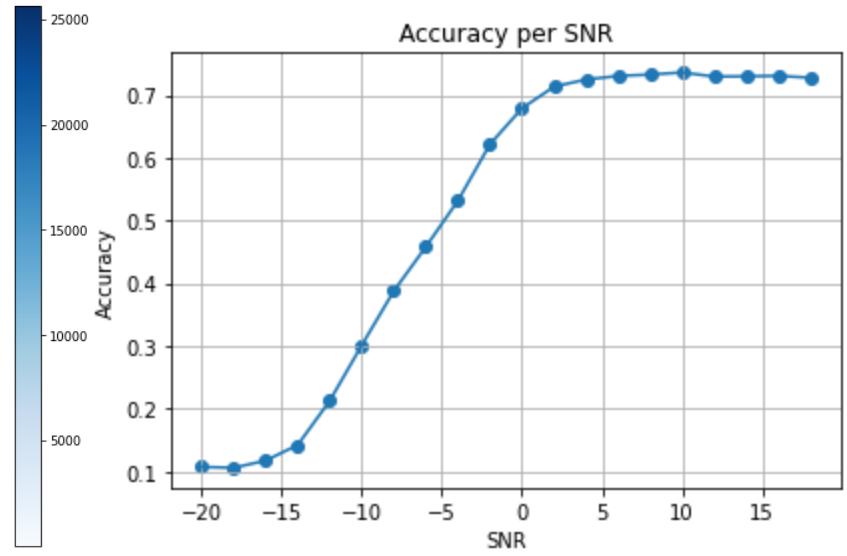
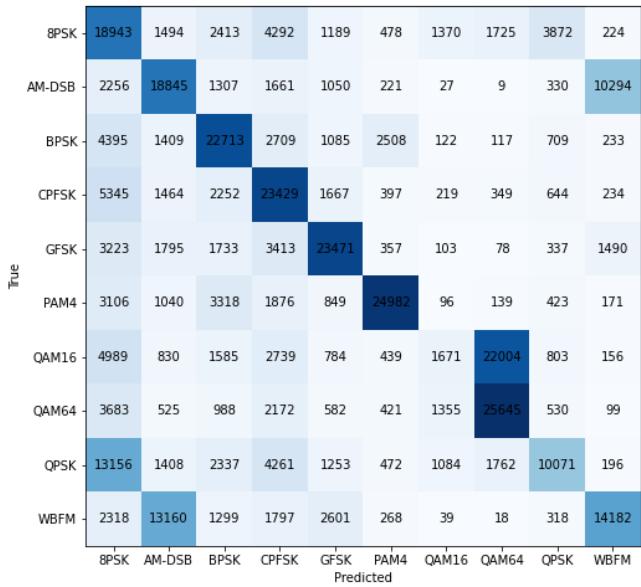
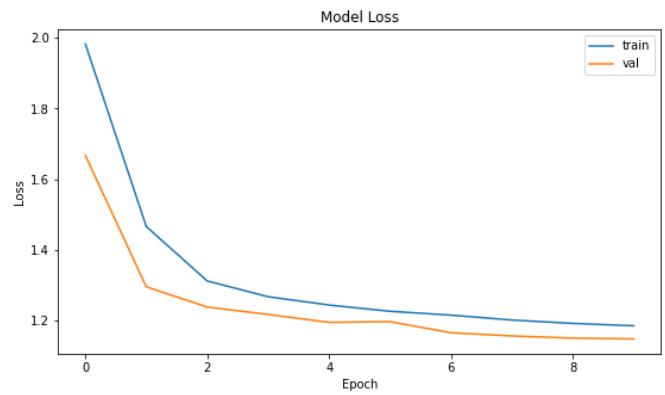
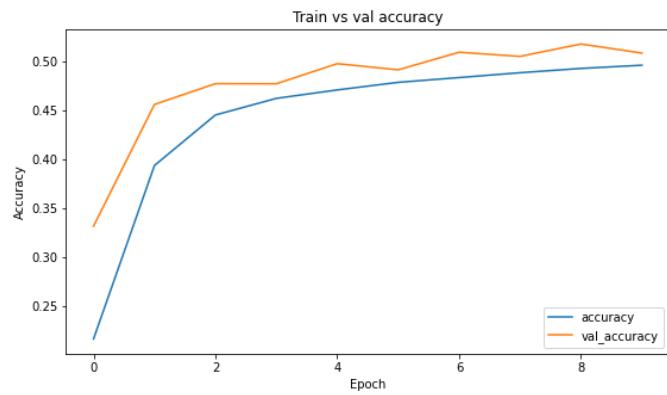
a) Learning Rate = 0.001



	-20	-18	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18
acc	0.11	0.11	0.11	0.13	0.16	0.23	0.36	0.45	0.52	0.58	0.67	0.71	0.73	0.74	0.74	0.74	0.74	0.74	0.74	0.74

Max Train accuracy = 0.48063910007476807
 Max Val accuracy = 0.505642831325531
 Max Test accuracy = 0.5033249855041504
 Average Accuracy = 0.5025000000000001
 Accuracy at SNR=0dB = 0.67

b) Learning Rate = 0.001



[6] Final Results

Model	Feature	LR	Train Acc	Val Acc	Test Acc	Avg Test Acc	At SNR=0	At Highest SNR
CNN	Raw	0.001 + decay	54.0%	56.25%	57.0%	56.9%	78%	81%
CNN	Integral	0.001 + decay	52.9%	55.2%	55.6%	55.7%	78%	82%

The results show that the most confusing classes are QAM16 and WBFM showing the worst results throughout all the models, as well as, in the best model chosen above.

Comparing all the model architectures used, the highest accuracy was obtained using the CNN model trained with the raw data features giving an accuracy of 57.0%. Further investigation showed an accuracy of 78% at SNR=0dB, as well as, 81% at the highest SNR