Pattern Recognition
Assignment 3
Modulation Classification

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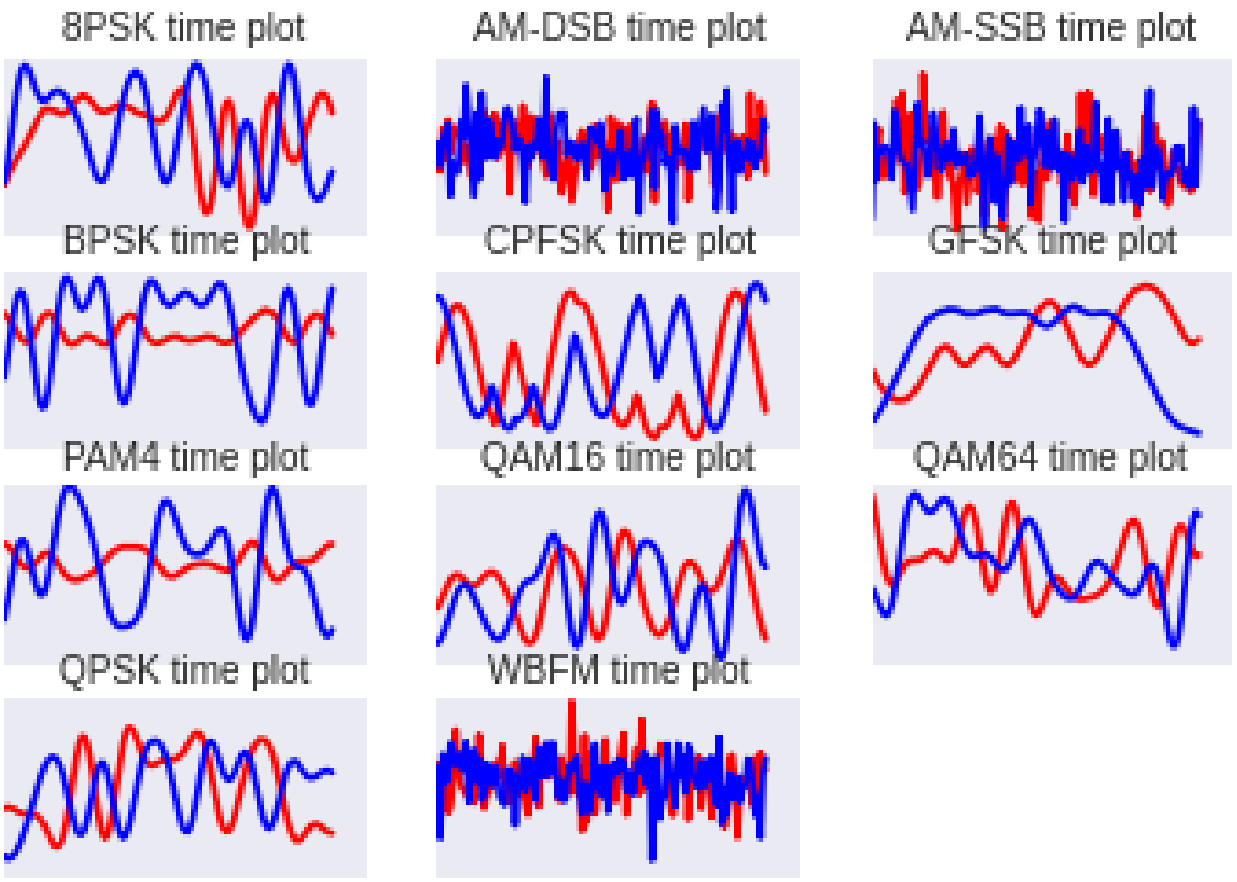
Problem Statement

A synthetic dataset, generated with GNU Radio, consisting of 10 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.

DeepSig Dataset: RadioML 2016.04C
Link: http://opendata.deepsig.io/datasets/2016.10/RML2016.10b.tar.bz2
1.2M samples, each represented using two vectors each of them has 128 elements
Shape: (1200000 , 2 , 128)

Signals Modulations:



Note:

- We created 3 new feature spaces, the derivative in time, the integral in time and the combination of the raw time series, derivative and integrals. So we had to work with 4 datasets each having a 3.5 GBs size.
- Due to RAM/CPU limitations we had to run the notebook with one dataset at a time, and tabulate the results in this report
- The results left in the notebook are the results of the original Dataset which is the raw time series
- Some changes will be made in case of the combined dataset as it will has different dimensions
- We must flatten the 2x128 vectors in case of Logistic Regression, Decision Trees and Random Forests
- We must use a Labelbinarizer/ OneHot Encoder to transform the labels to a 10 elements 1/0 target as we are dealing with a multi-label output

Performance Analysis

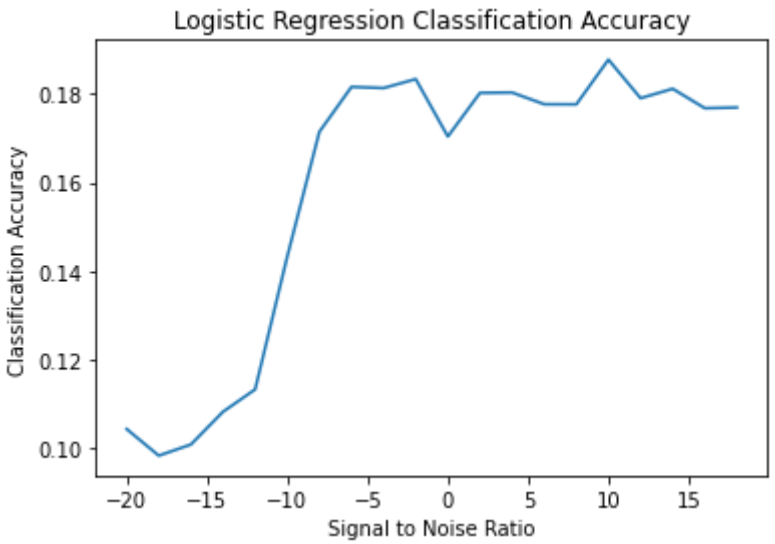
1.Raw time series

Logistic regression

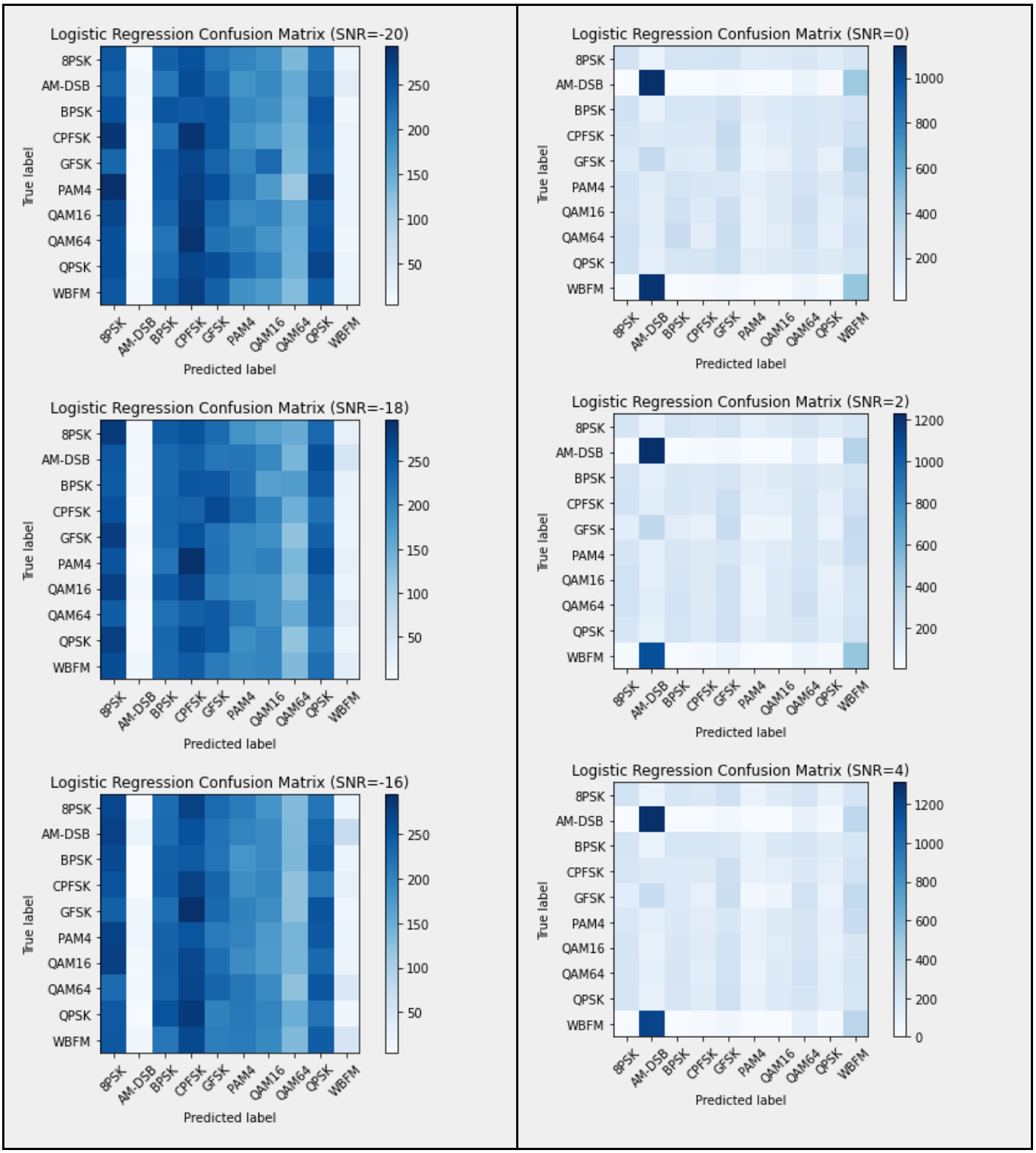
- Accuracies

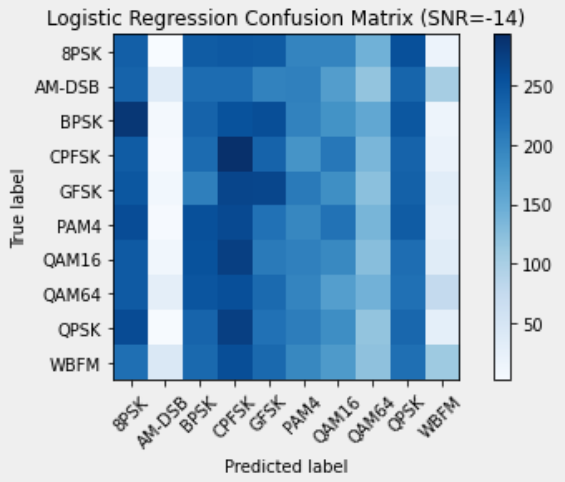
SNR = -20 Accuracy = 0.10433769691590859 SNR = -18 Accuracy = 0.0983295156153975 SNR = -16 Accuracy = 0.10084693476919625 SNR = -14 Accuracy = 0.10824197228560298 SNR = -12 Accuracy = 0.11329429150019156 SNR = -10 Accuracy = 0.14329523278505715 SNR = -8 Accuracy = 0.1714740948299544 SNR = -6 Accuracy = 0.1816216815385468 SNR = -4 Accuracy = 0.1813581002168956 SNR = -2 Accuracy = 0.18338488731771985	SNR = 0 Accuracy = 0.17041002152199106 SNR = 2 Accuracy = 0.1802660753880266 SNR = 4 Accuracy = 0.1803480499132673 SNR = 6 Accuracy = 0.17770849571317227 SNR = 8 Accuracy = 0.17767514328640588 SNR = 10 Accuracy = 0.18778305534077103 SNR = 12 Accuracy = 0.17906886410299094 SNR = 14 Accuracy = 0.18119610570236439 SNR = 16 Accuracy = 0.17680916457110926 SNR = 18 Accuracy = 0.17696028799640004

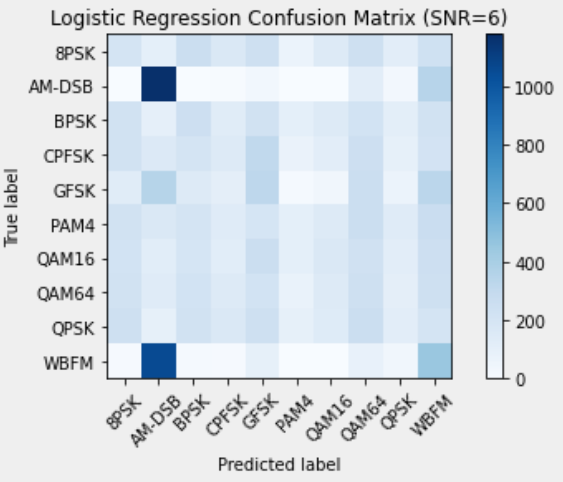
- Accuracy Against SNR

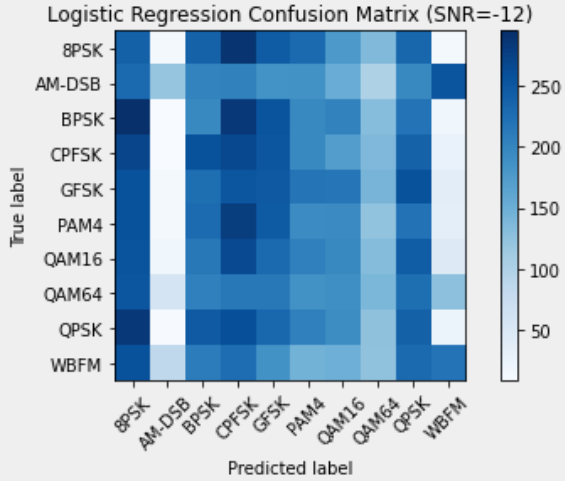


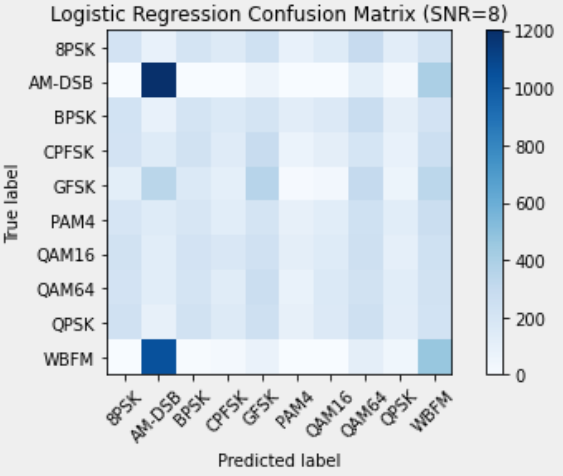
- Confusion Matrices

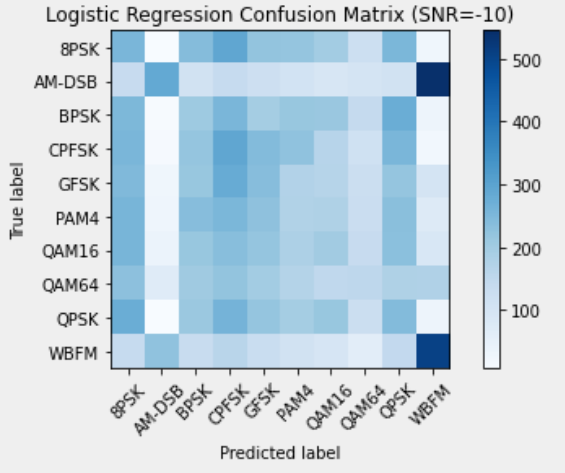


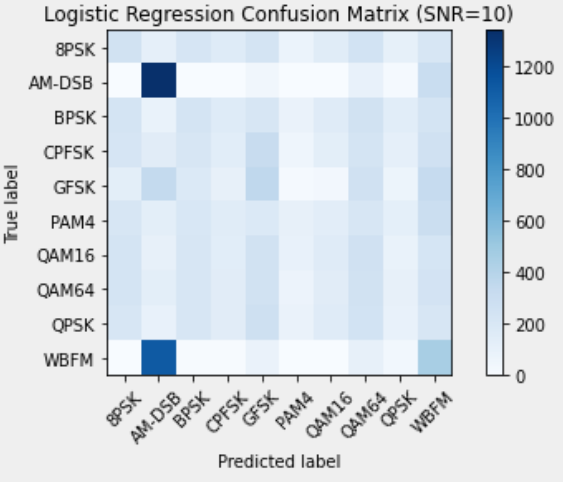

Logistic Regression Confusion Matrix (SNR=-14)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
250
200
150
100
50

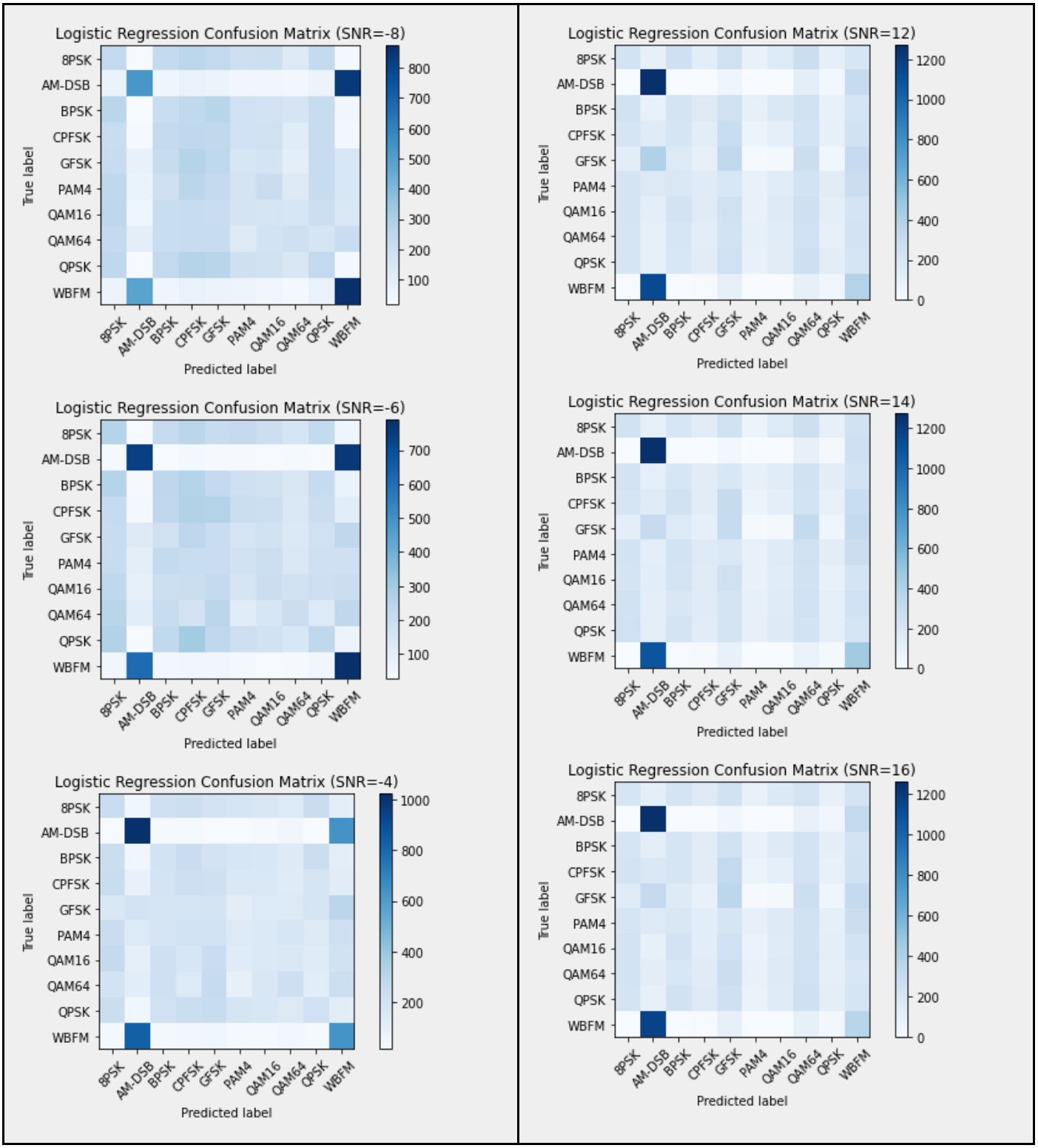

Logistic Regression Confusion Matrix (SNR=6)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1000
800
600
400
200
0

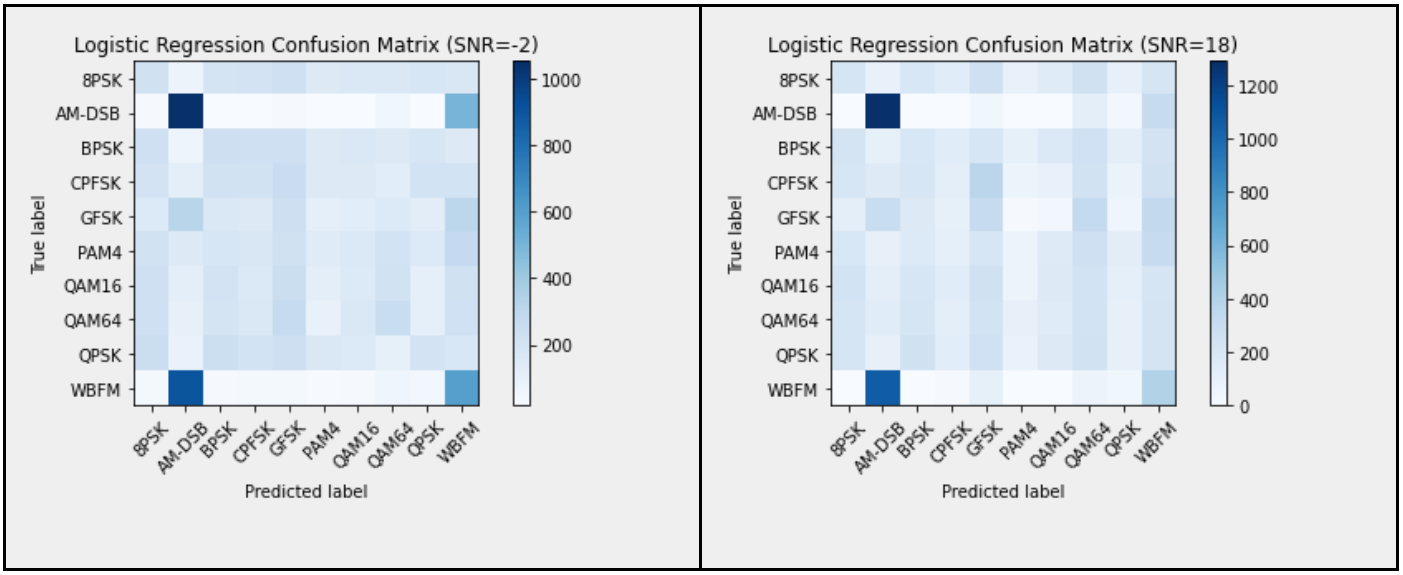

Logistic Regression Confusion Matrix (SNR=-12)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
250
200
150
100
50


Logistic Regression Confusion Matrix (SNR=8)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1200
1000
800
600
400
200
0


Logistic Regression Confusion Matrix (SNR=-10)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
500
400
300
200
100


Logistic Regression Confusion Matrix (SNR=10)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1200
1000
800
600
400
200
0


Logistic Regression Confusion Matrix (SNR=-8)
Logistic Regression Confusion Matrix (SNR=-6)
Logistic Regression Confusion Matrix (SNR=-4)
Logistic Regression Confusion Matrix (SNR=12)
Logistic Regression Confusion Matrix (SNR=14)
Logistic Regression Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM

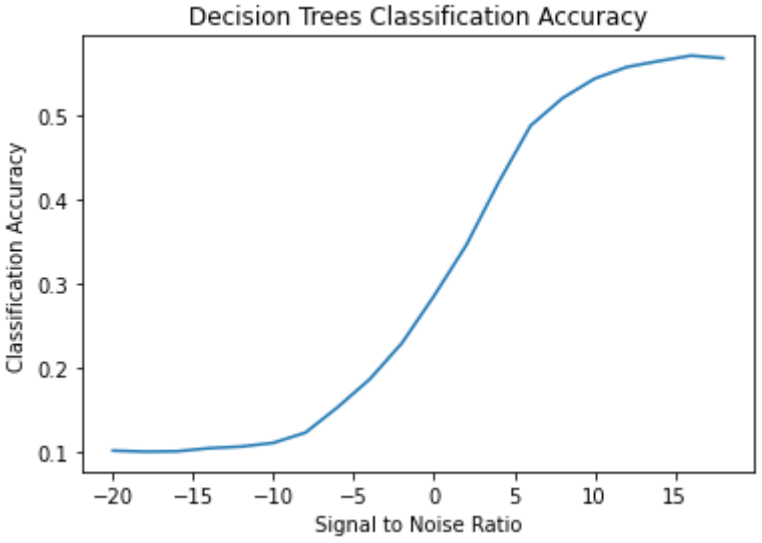

Logistic Regression Confusion Matrix (SNR=-2)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1000
800
600
400
200
Logistic Regression Confusion Matrix (SNR=18)
1200
1000
800
600
400
200
0

Decision Trees

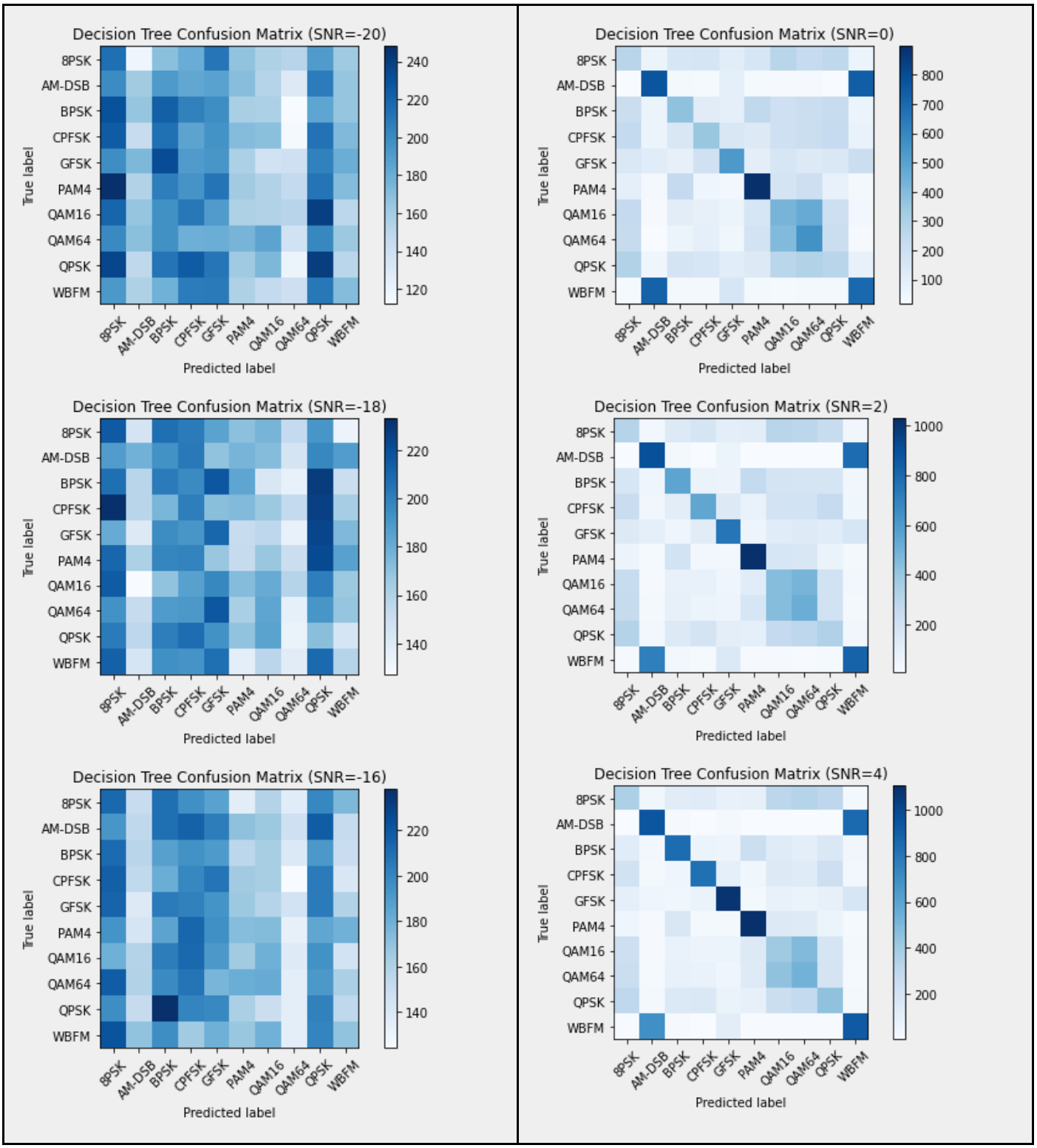
- Accuracies

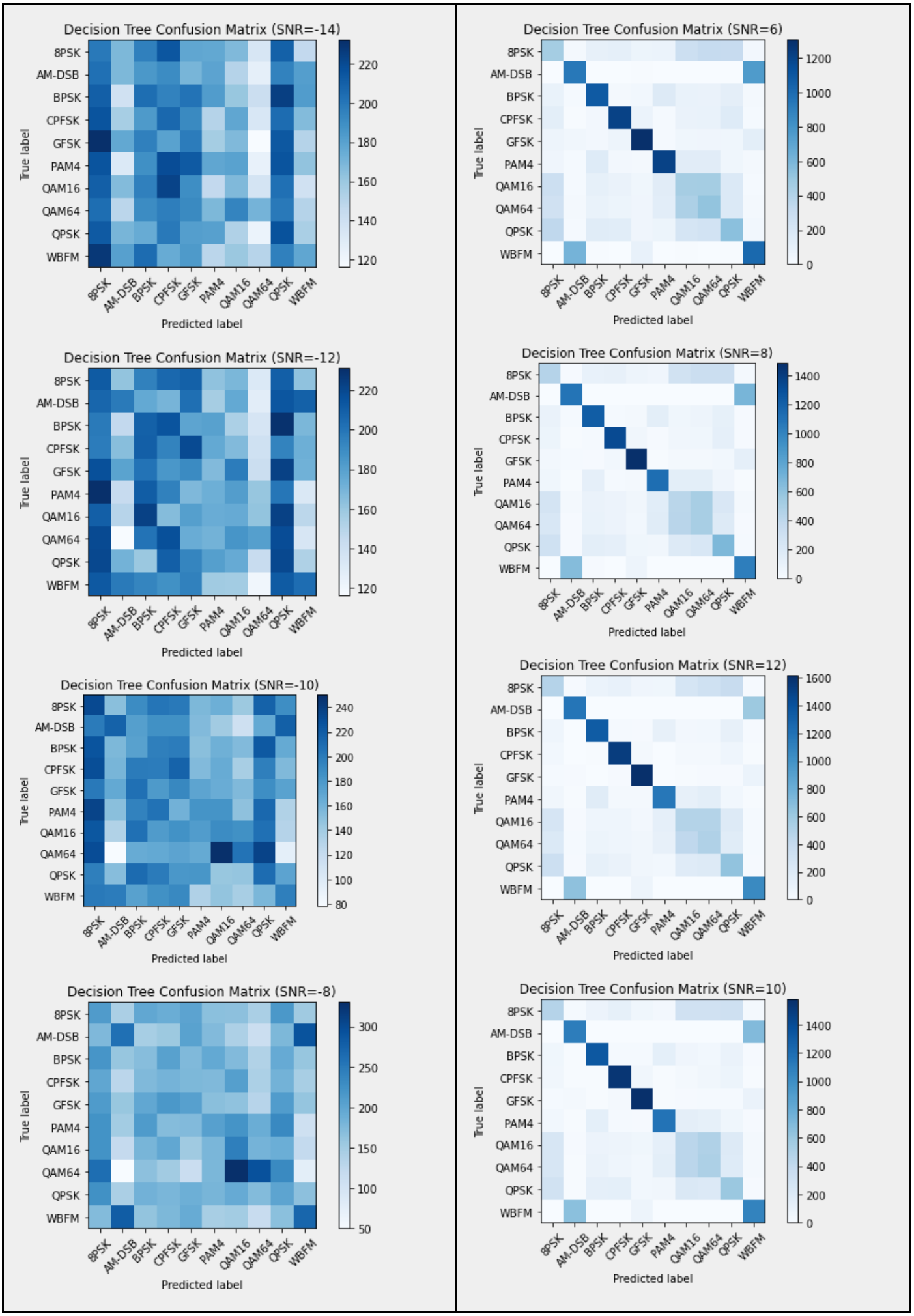
SNR = -20 Accuracy = 0.10228533392500555 SNR = -18 Accuracy = 0.10106709872059892 SNR = -16 Accuracy = 0.10151999551292837 SNR = -14 Accuracy = 0.10512549390617174 SNR = -12 Accuracy = 0.10710962727820043 SNR = -10 Accuracy = 0.1115137998327293 SNR = -8 Accuracy = 0.12372946541398824 SNR = -6 Accuracy = 0.15385468048550685 SNR = -4 Accuracy = 0.1870863689449975 SNR = -2 Accuracy = 0.22983870967741934	SNR = 0 Accuracy = 0.28585618895204457 SNR = 2 Accuracy = 0.3457871396895787 SNR = 4 Accuracy = 0.4197302892955067 SNR = 6 Accuracy = 0.487473555283376 SNR = 8 Accuracy = 0.5202270324411552 SNR = 10 Accuracy = 0.5433557936595603 SNR = 12 Accuracy = 0.5570723045335997 SNR = 14 Accuracy = 0.564172461752434 SNR = 16 Accuracy = 0.5706063146130204 SNR = 18 Accuracy = 0.5675554055574306

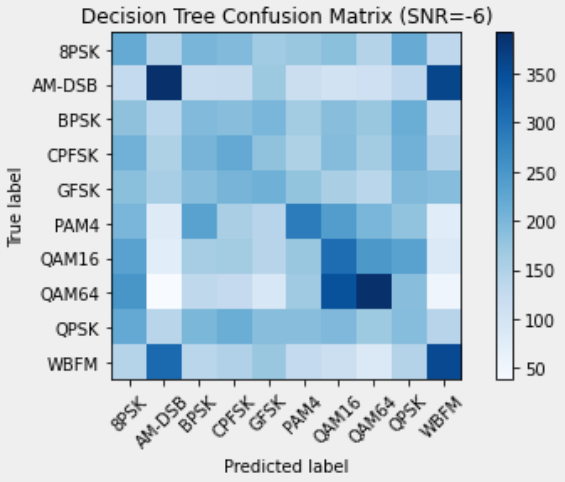
- Accuracy against SNR

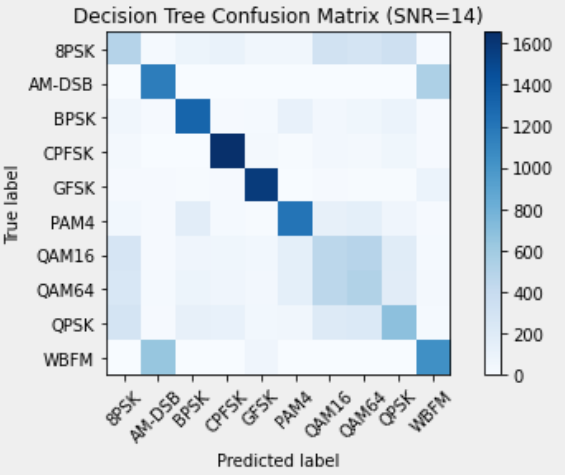


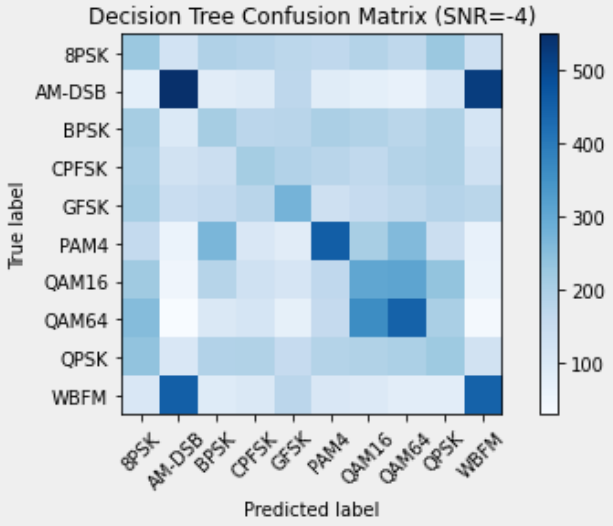
- Confusion matrices

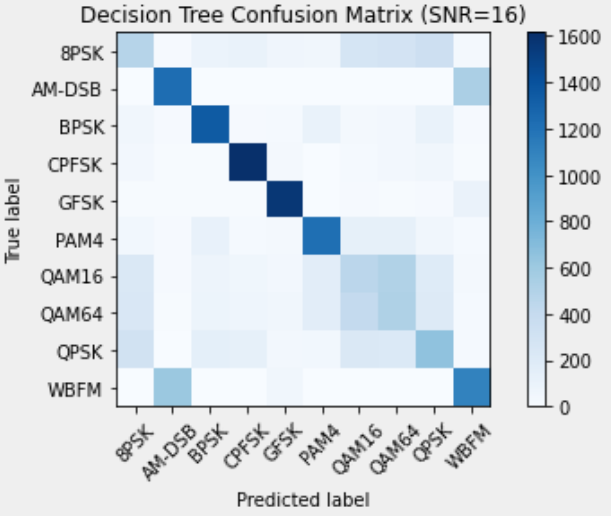


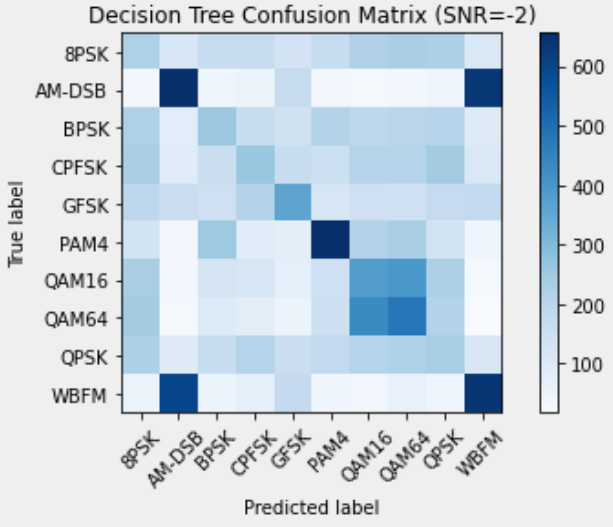

Decision Tree Confusion Matrix (SNR=-14)
Decision Tree Confusion Matrix (SNR=6)
Decision Tree Confusion Matrix (SNR=-12)
Decision Tree Confusion Matrix (SNR=8)
Decision Tree Confusion Matrix (SNR=-10)
Decision Tree Confusion Matrix (SNR=12)
Decision Tree Confusion Matrix (SNR=-8)
Decision Tree Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM

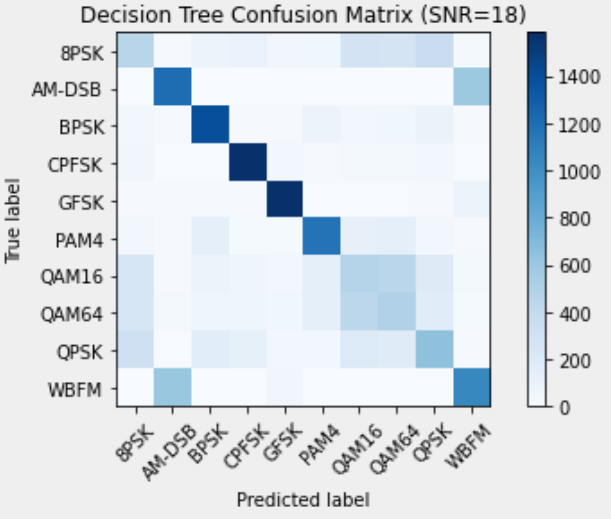

Decision Tree Confusion Matrix (SNR=-6)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
350
300
250
200
150
100
50


Decision Tree Confusion Matrix (SNR=14)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1600
1400
1200
1000
800
600
400
200
0


Decision Tree Confusion Matrix (SNR=-4)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
500
400
300
200
100


Decision Tree Confusion Matrix (SNR=16)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1600
1400
1200
1000
800
600
400
200
0


Decision Tree Confusion Matrix (SNR=-2)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
600
500
400
300
200
100

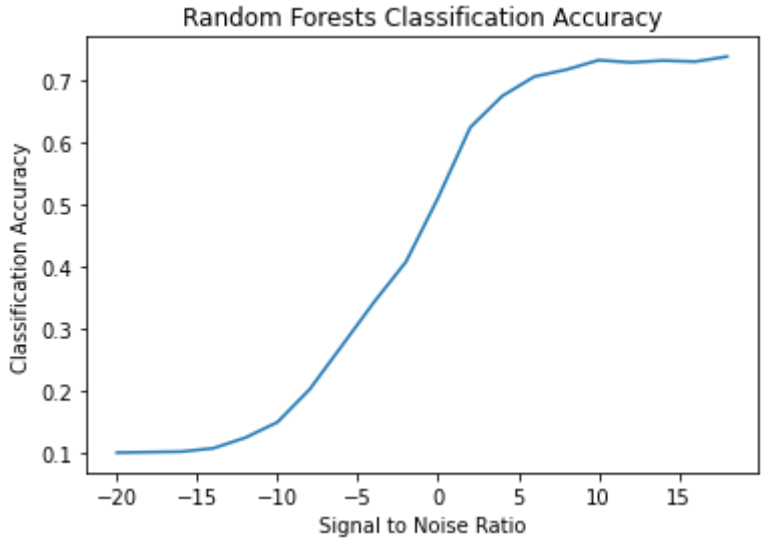

Decision Tree Confusion Matrix (SNR=18)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1400
1200
1000
800
600
400
200
0

Random Forests

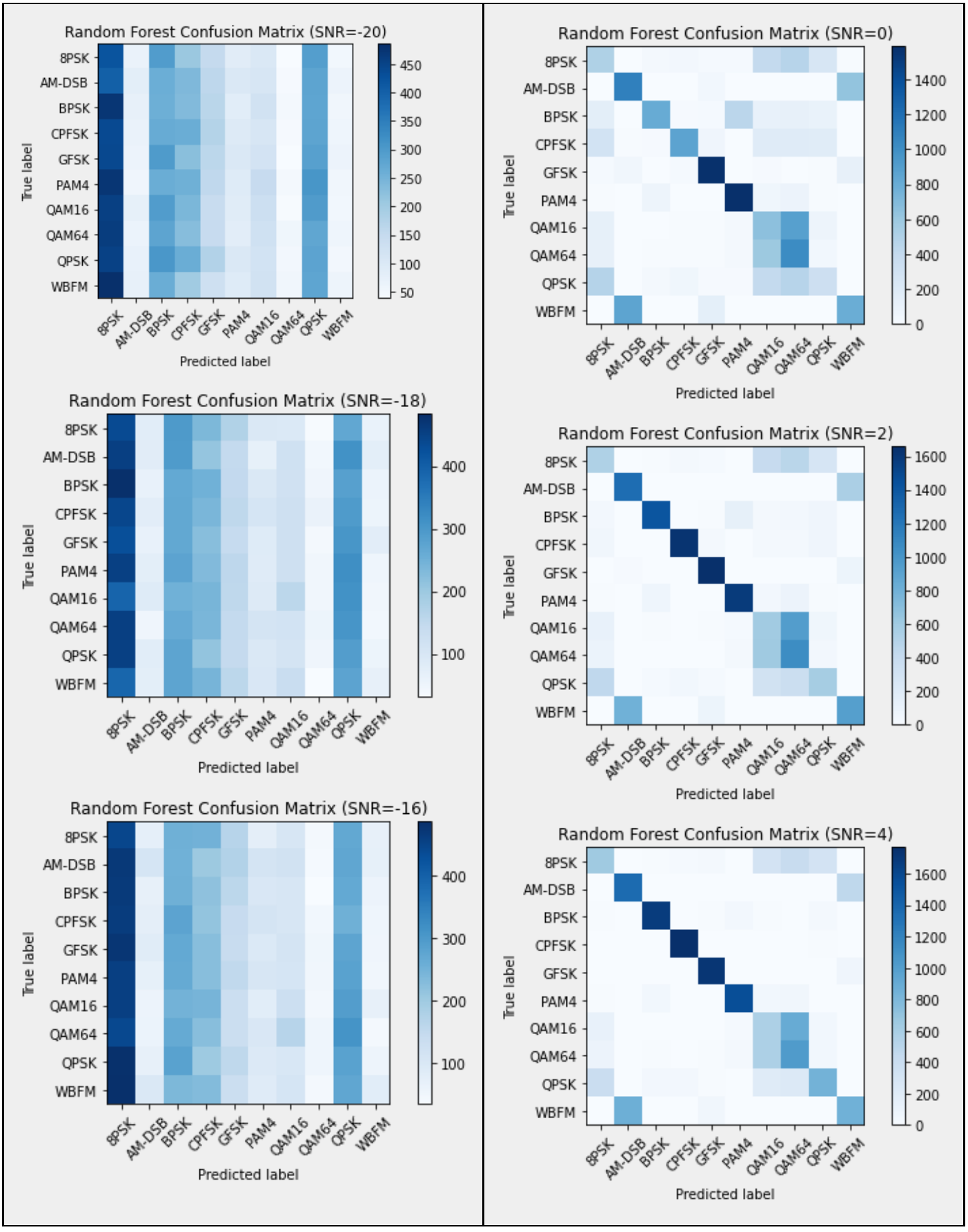
- Accuracies

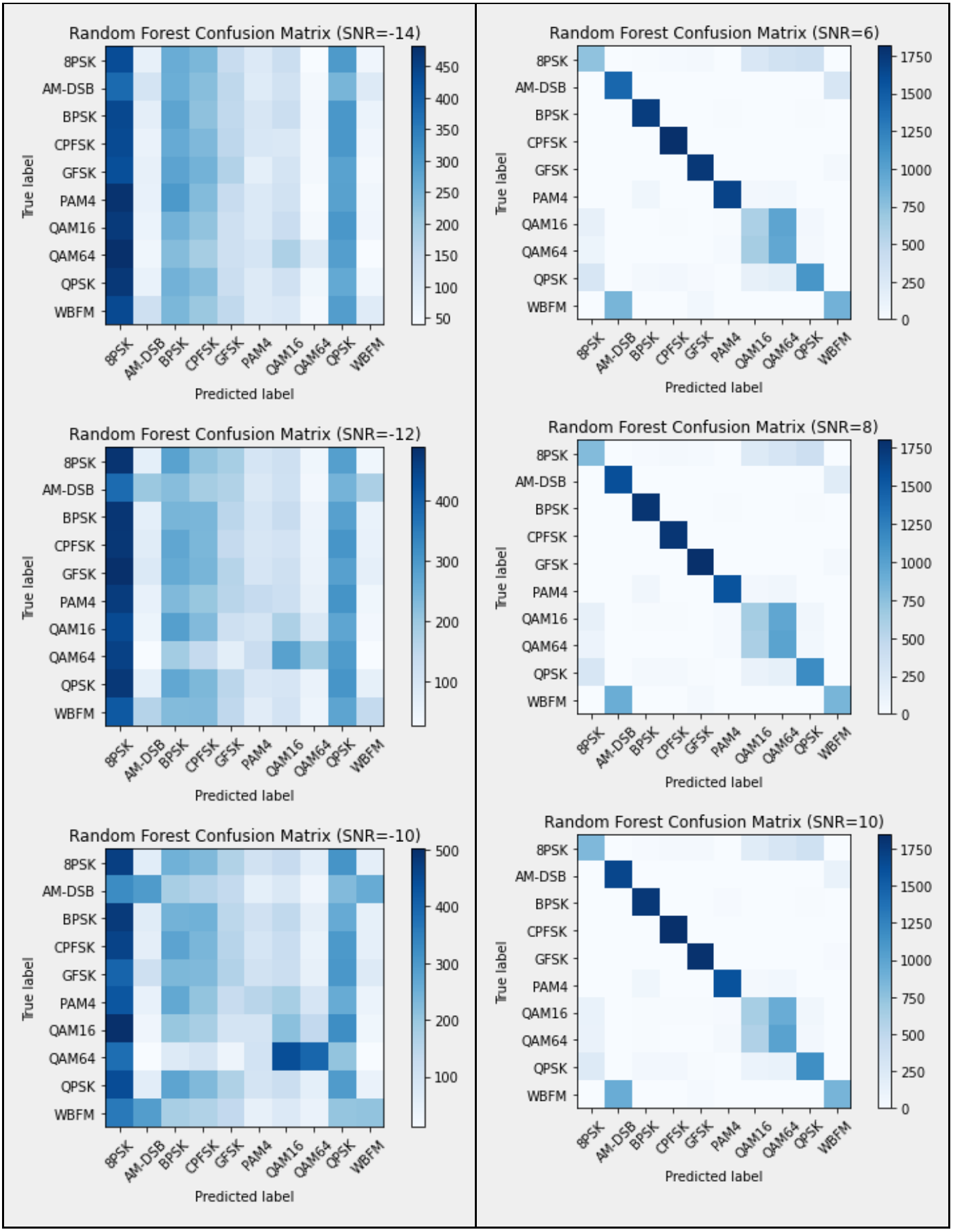
SNR = -20 Accuracy = 0.10089860217439539 SNR = -18 Accuracy = 0.10173752723615845 SNR = -16 Accuracy = 0.10252958662852656 SNR = -14 Accuracy = 0.10790806388780678 SNR = -12 Accuracy = 0.12495210990093591 SNR = -10 Accuracy = 0.1499860607750209 SNR = -8 Accuracy = 0.2026262293280589 SNR = -6 Accuracy = 0.2725156570415119 SNR = -4 Accuracy = 0.34275068127467884 SNR = -2 Accuracy = 0.40797613787008397	SNR = 0 Accuracy = 0.5110645107885878 SNR = 2 Accuracy = 0.6243348115299335 SNR = 4 Accuracy = 0.6749482401656315 SNR = 6 Accuracy = 0.7062131165794455 SNR = 8 Accuracy = 0.7173779978854822 SNR = 10 Accuracy = 0.7325748370705844 SNR = 12 Accuracy = 0.7289273625215027 SNR = 14 Accuracy = 0.7319054242002782 SNR = 16 Accuracy = 0.730203967588712 SNR = 18 Accuracy = 0.73827202159973

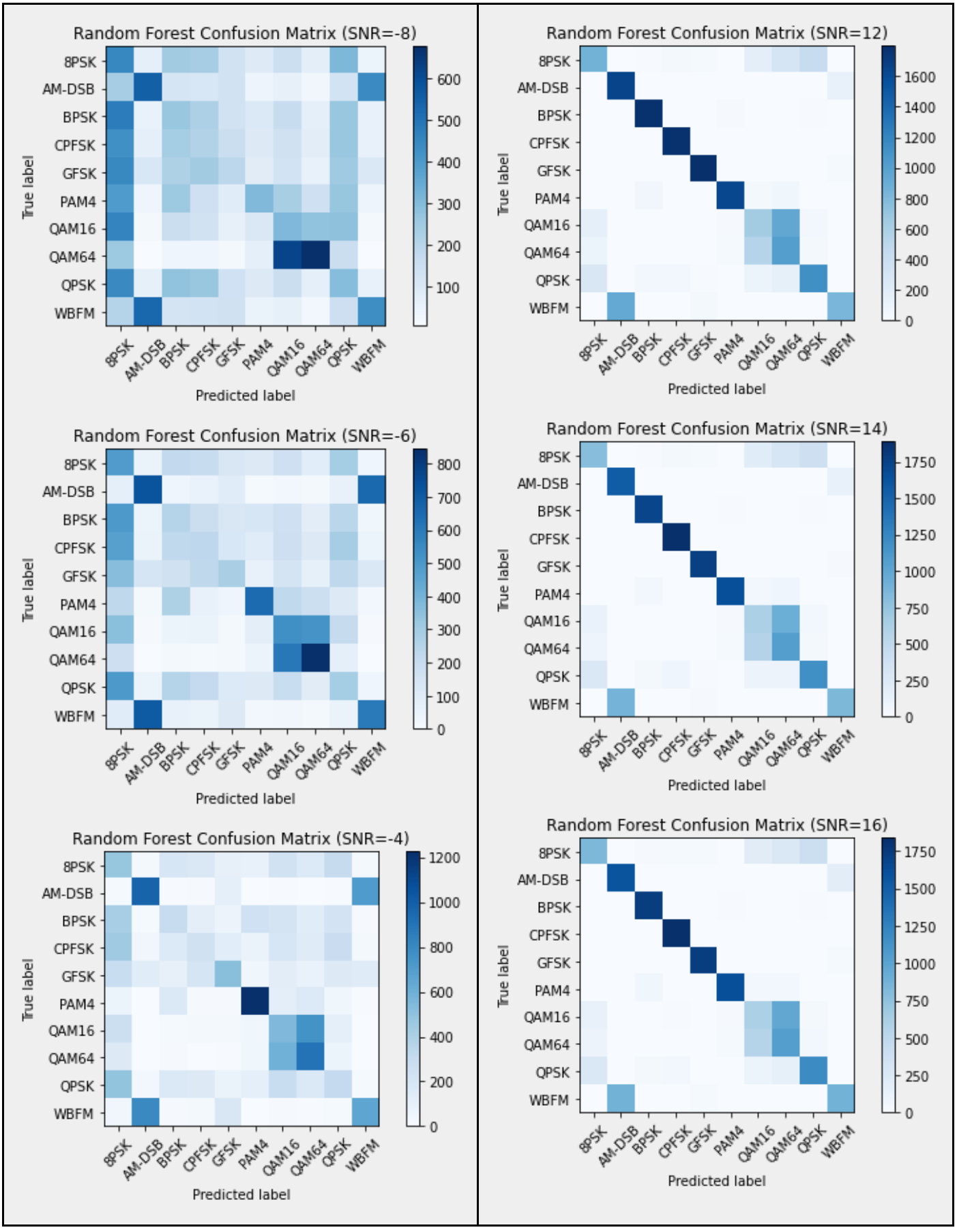
- Accuracy Against SNR

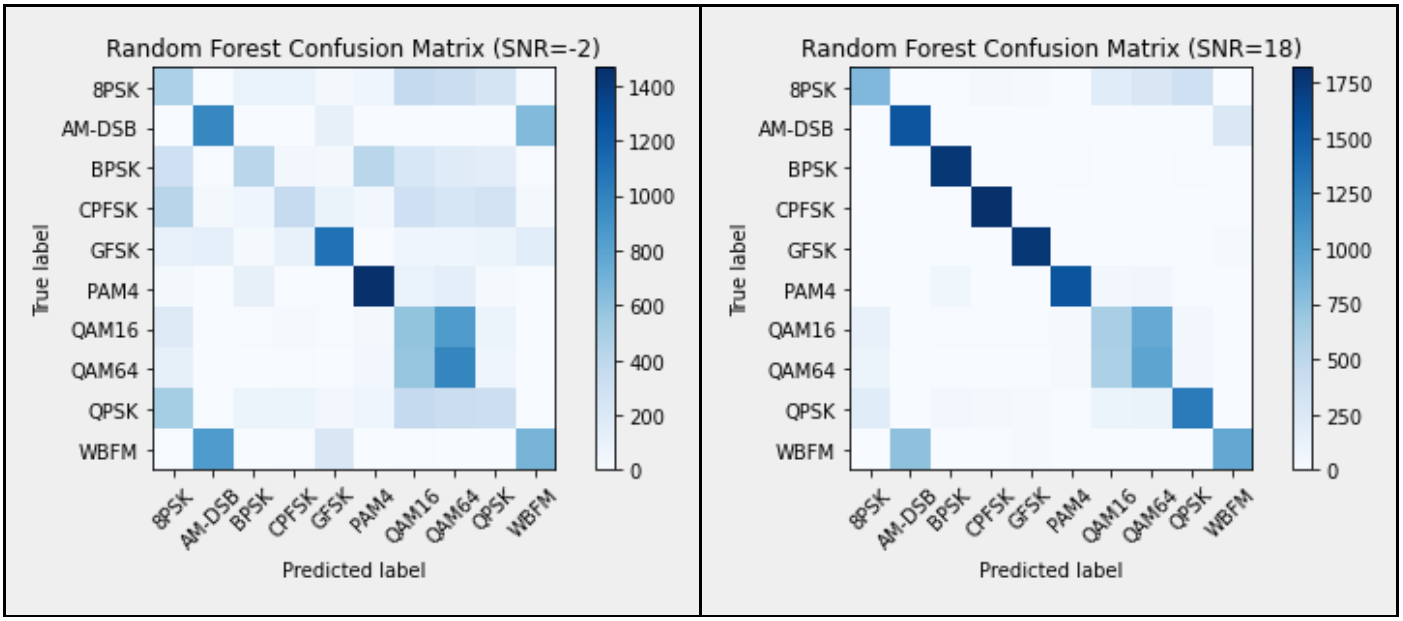


- Confusion Matrices




Random Forest Confusion Matrix (SNR=-14)
Random Forest Confusion Matrix (SNR=6)
Random Forest Confusion Matrix (SNR=-12)
Random Forest Confusion Matrix (SNR=8)
Random Forest Confusion Matrix (SNR=-10)
Random Forest Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


Random Forest Confusion Matrix (SNR=-8)
Random Forest Confusion Matrix (SNR=12)
Random Forest Confusion Matrix (SNR=-6)
Random Forest Confusion Matrix (SNR=14)
Random Forest Confusion Matrix (SNR=-4)
Random Forest Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


Random Forest Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1400
1200
1000
800
600
400
200
0
Random Forest Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1750
1500
1250
1000
750
500
250
0

Dense layer NN:

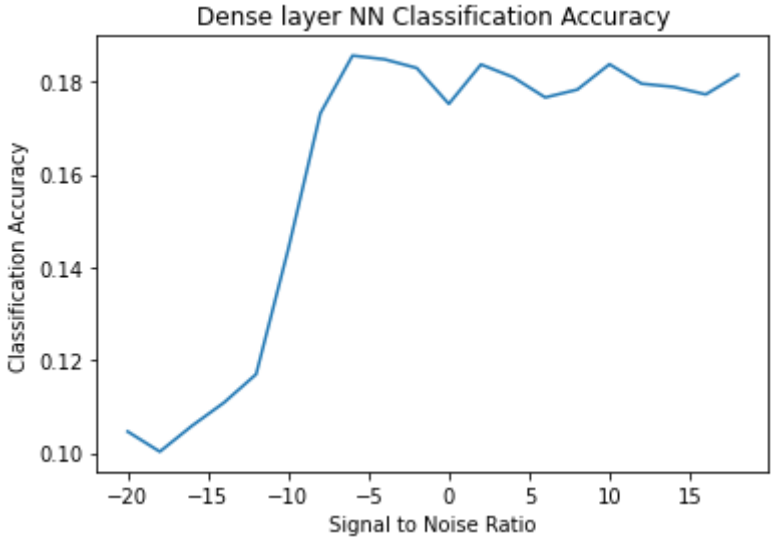
- Epochs

```
Train on 798000 samples, validate on 42000 samples
Epoch 1/100
 - 2s - loss: 2.2481 - val_loss: 2.1627
Epoch 2/100
 - 2s - loss: 2.1628 - val_loss: 2.1611
Epoch 3/100
 - 2s - loss: 2.1628 - val_loss: 2.1619
Epoch 4/100
 - 2s - loss: 2.1629 - val_loss: 2.1615
Epoch 5/100
 - 2s - loss: 2.1630 - val_loss: 2.1612
Epoch 6/100
 - 2s - loss: 2.1628 - val_loss: 2.1628
Epoch 7/100
 - 2s - loss: 2.1629 - val_loss: 2.1617
```

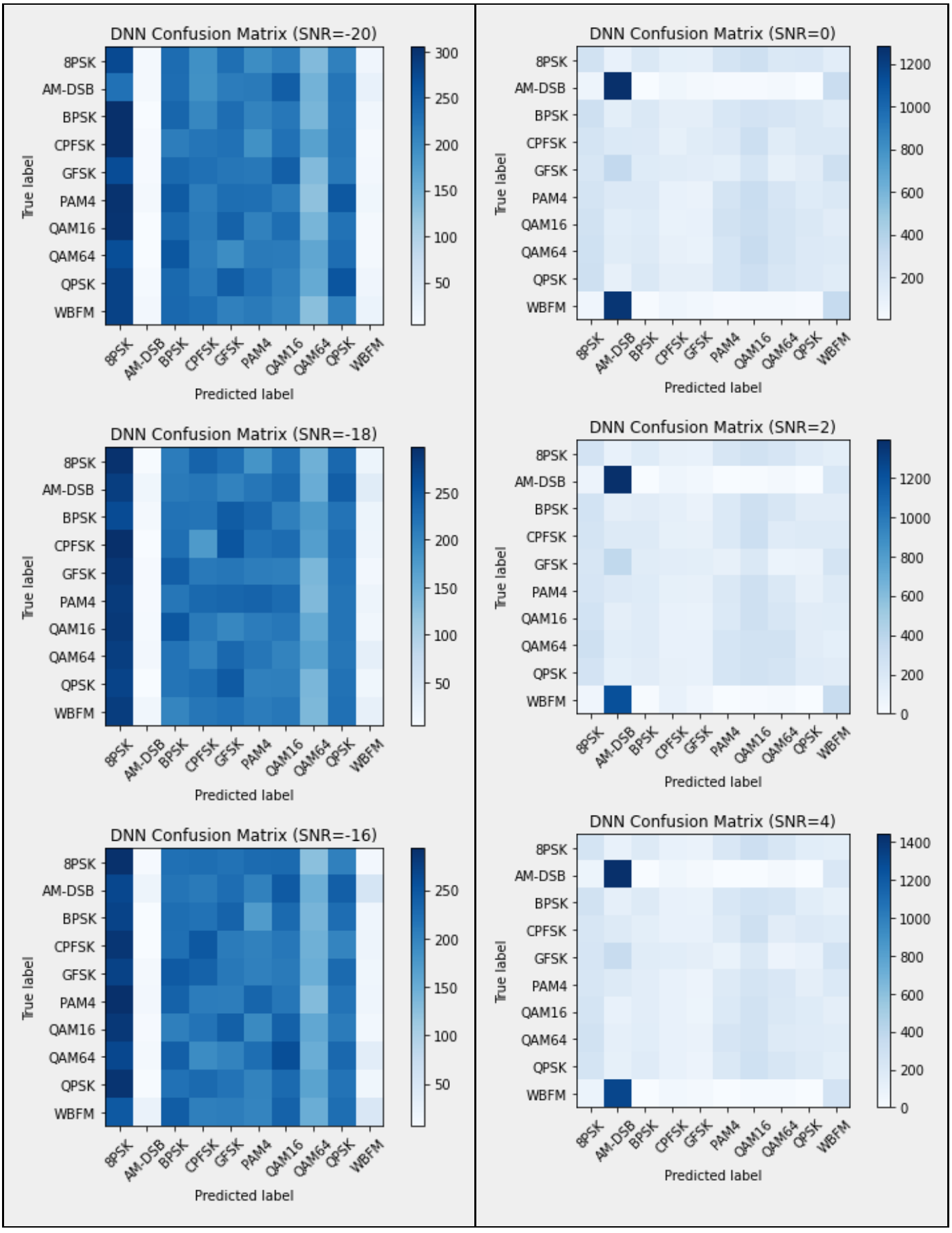
- Accuracies

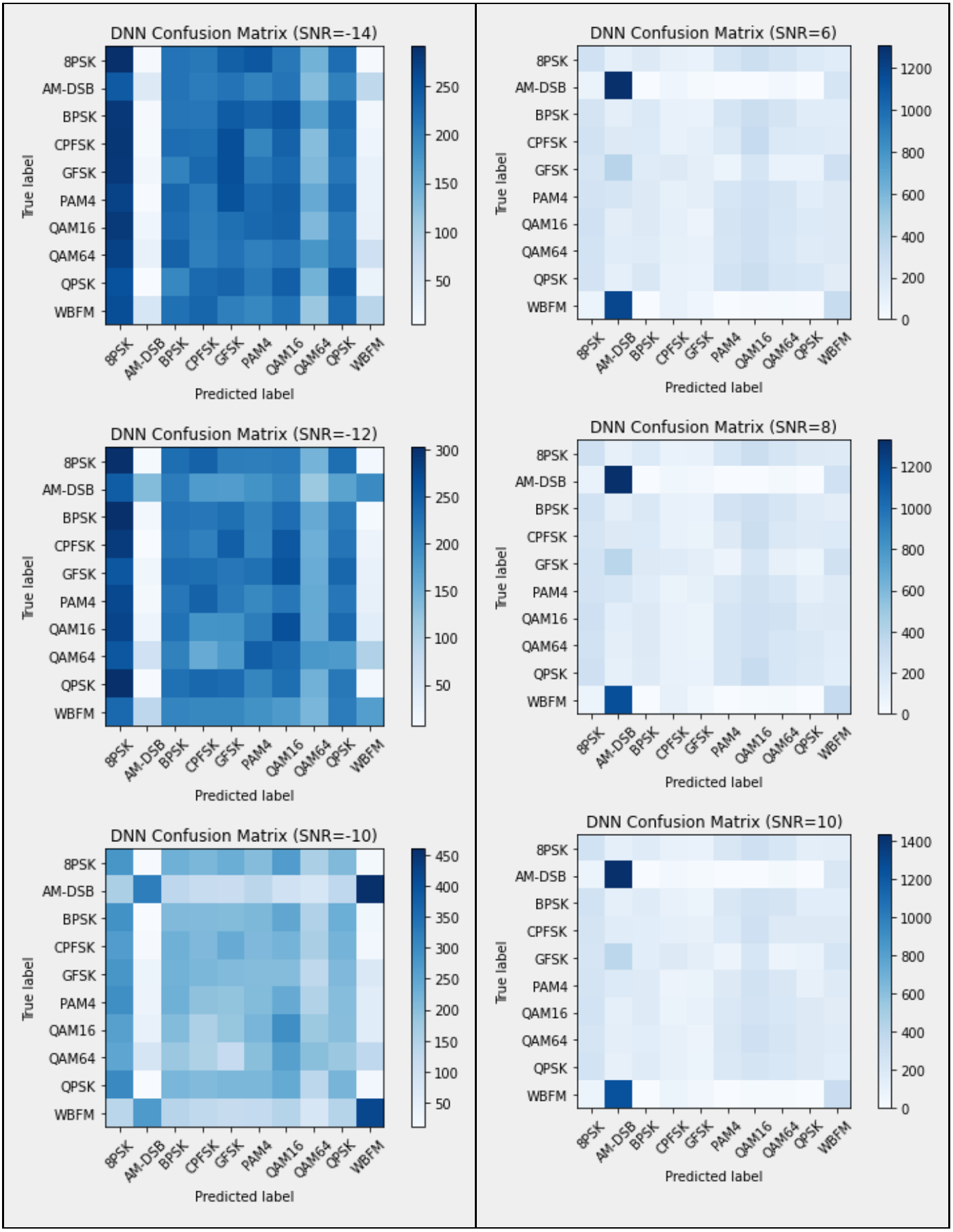
Accuracy = 0.10461504326603062	Accuracy = 0.1752110810661663
Accuracy = 0.1002849321191128	Accuracy = 0.1837028824833703
Accuracy = 0.10583880195187616	Accuracy = 0.1809635722679201
Accuracy = 0.11085758806833992	Accuracy = 0.17659503396058346
Accuracy = 0.11696130479995621	Accuracy = 0.17828724055422626
Accuracy = 0.14390855868413716	Accuracy = 0.18375124268198387
Accuracy = 0.17317729795066206	Accuracy = 0.1795682814494201
Accuracy = 0.18561214875575016	Accuracy = 0.1788595271210014
Accuracy = 0.18480618430565596	Accuracy = 0.17725621682034087
Accuracy = 0.18294299602297834	Accuracy = 0.18146023174710316

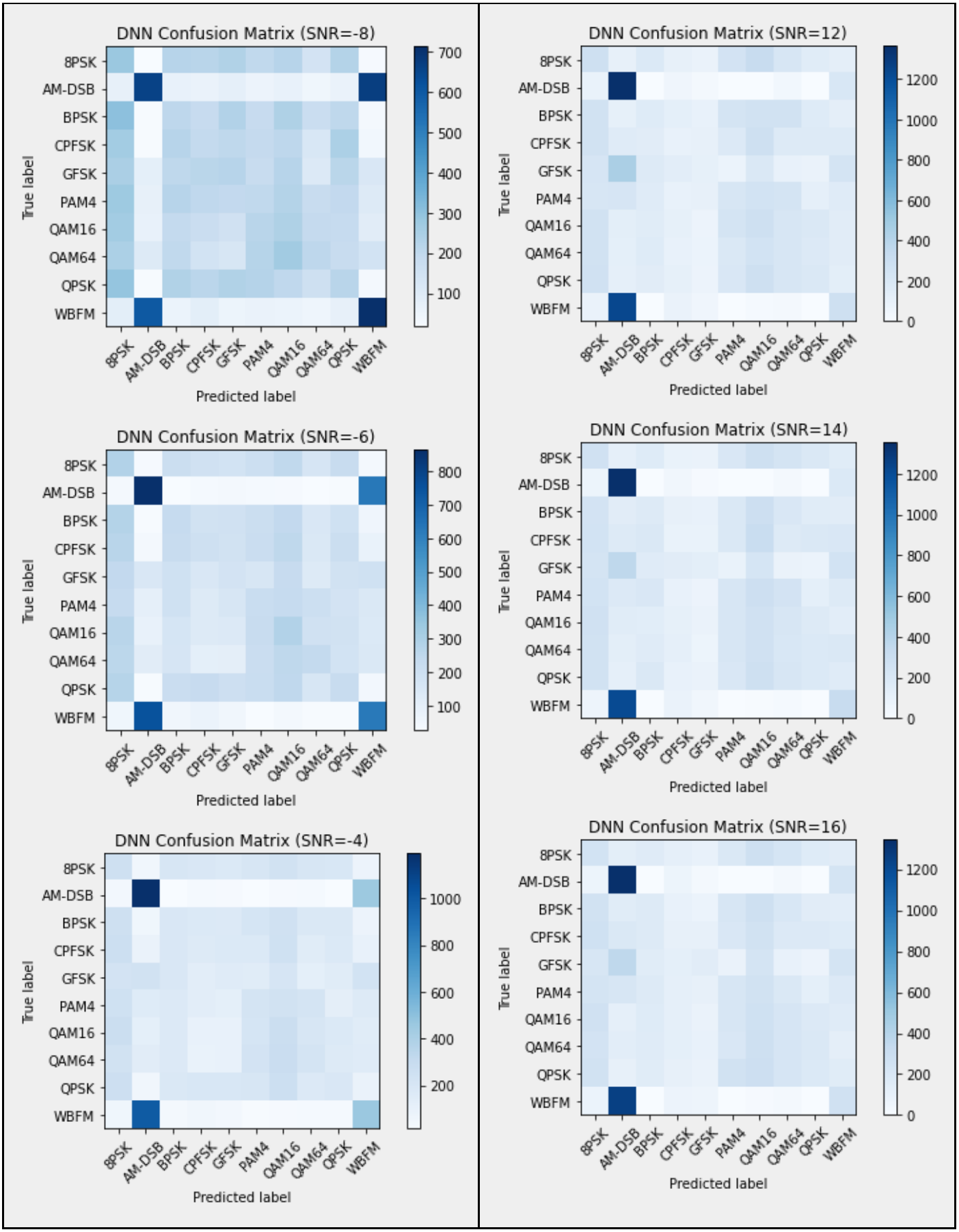
- Accuracies Against SNR

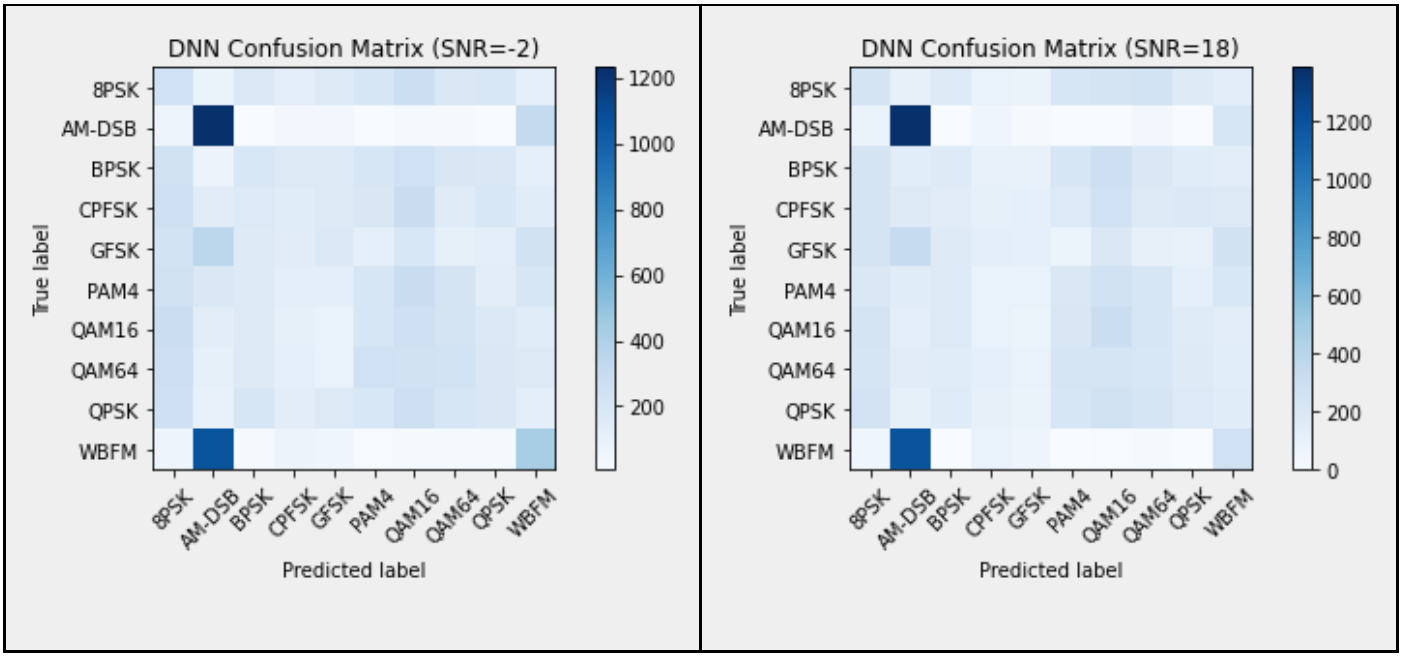


- Confusion Matrices




DNN Confusion Matrix (SNR=-14)
DNN Confusion Matrix (SNR=6)
DNN Confusion Matrix (SNR=-12)
DNN Confusion Matrix (SNR=8)
DNN Confusion Matrix (SNR=-10)
DNN Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


DNN Confusion Matrix (SNR=-8)
DNN Confusion Matrix (SNR=12)
DNN Confusion Matrix (SNR=-6)
DNN Confusion Matrix (SNR=14)
DNN Confusion Matrix (SNR=-4)
DNN Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


DNN Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1200
1000
800
600
400
200
DNN Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1200
1000
800
600
400
200
0

CNN

- Epochs

Train on 798000 samples, validate on 42000 samples

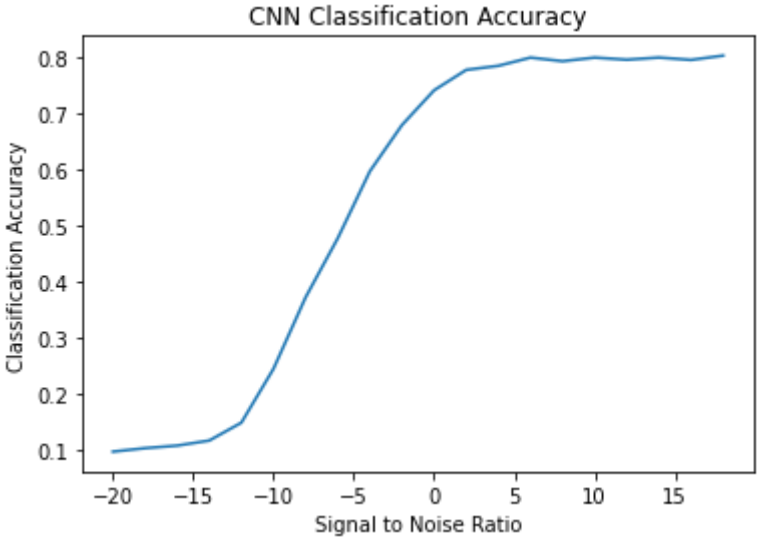
```
Epoch 1/100
 - 29s - loss: 1.7016 - val_loss: 1.4352
Epoch 2/100
 - 28s - loss: 1.4999 - val_loss: 1.3531
Epoch 3/100
 - 28s - loss: 1.4202 - val_loss: 1.2454
Epoch 4/100
 - 28s - loss: 1.3528 - val_loss: 1.2190
Epoch 5/100
 - 28s - loss: 1.3288 - val_loss: 1.1986
Epoch 6/100
 - 28s - loss: 1.3140 - val_loss: 1.1866
Epoch 7/100
 - 28s - loss: 1.3032 - val_loss: 1.1742
Epoch 8/100
 - 28s - loss: 1.2924 - val_loss: 1.1802
Epoch 9/100
 - 28s - loss: 1.2854 - val_loss: 1.1818
Epoch 10/100
 - 28s - loss: 1.2792 - val_loss: 1.1495
Epoch 11/100
 - 28s - loss: 1.2719 - val_loss: 1.1532
Epoch 12/100
 - 28s - loss: 1.2658 - val_loss: 1.1498
Epoch 13/100
 - 28s - loss: 1.2609 - val_loss: 1.1374
Epoch 14/100
 - 28s - loss: 1.2566 - val_loss: 1.1424
Epoch 15/100
 - 28s - loss: 1.2527 - val_loss: 1.1454
Epoch 16/100
 - 28s - loss: 1.2514 - val_loss: 1.1318
Epoch 17/100
 - 28s - loss: 1.2479 - val_loss: 1.1325
Epoch 18/100
 - 28s - loss: 1.2465 - val_loss: 1.1344
Epoch 19/100
 - 28s - loss: 1.2451 - val_loss: 1.1359
Epoch 20/100
 - 28s - loss: 1.2417 - val_loss: 1.1269
Epoch 21/100
 - 28s - loss: 1.2388 - val_loss: 1.1235
Epoch 22/100
 - 28s - loss: 1.2362 - val_loss: 1.1291
Epoch 23/100
 - 28s - loss: 1.2338 - val_loss: 1.1211
Epoch 24/100
Epoch 28/100
 - 28s - loss: 1.2222 - val_loss: 1.1202
Epoch 29/100
 - 28s - loss: 1.2207 - val_loss: 1.1248
Epoch 30/100
 - 28s - loss: 1.2147 - val_loss: 1.1118
Epoch 31/100
 - 28s - loss: 1.2120 - val_loss: 1.1154
Epoch 32/100
 - 28s - loss: 1.2099 - val_loss: 1.1135
Epoch 33/100
 - 28s - loss: 1.2094 - val_loss: 1.1081
Epoch 34/100
 - 28s - loss: 1.2069 - val_loss: 1.1059
Epoch 35/100
 - 28s - loss: 1.2057 - val_loss: 1.0981
Epoch 36/100
 - 28s - loss: 1.2035 - val_loss: 1.1004
Epoch 37/100
 - 28s - loss: 1.2044 - val_loss: 1.1014
Epoch 38/100
 - 28s - loss: 1.2019 - val_loss: 1.0951
Epoch 39/100
 - 28s - loss: 1.2011 - val_loss: 1.1094
Epoch 40/100
 - 28s - loss: 1.1999 - val_loss: 1.0959
Epoch 41/100
 - 28s - loss: 1.1986 - val_loss: 1.0952
Epoch 42/100
 - 28s - loss: 1.1982 - val_loss: 1.0969
Epoch 43/100
 - 28s - loss: 1.1966 - val_loss: 1.0936
Epoch 44/100
 - 28s - loss: 1.1969 - val_loss: 1.0924
Epoch 45/100
 - 28s - loss: 1.1959 - val_loss: 1.0996
Epoch 46/100
 - 28s - loss: 1.1950 - val_loss: 1.0895
Epoch 47/100
 - 28s - loss: 1.1950 - val_loss: 1.0895
Epoch 48/100
 - 28s - loss: 1.1941 - val_loss: 1.1011
Epoch 49/100
 - 28s - loss: 1.1930 - val_loss: 1.0888
Epoch 50/100
 - 28s - loss: 1.1923 - val_loss: 1.0883
Epoch 51/100
```

- 28s - loss: 1.2320 - val_loss: 1.1177 Epoch 25/100 - 28s - loss: 1.2295 - val_loss: 1.1163 Epoch 26/100 - 28s - loss: 1.2262 - val_loss: 1.1177 Epoch 27/100 - 28s - loss: 1.2255 - val_loss: 1.1189	- 28s - loss: 1.1911 - val_loss: 1.0987 Epoch 52/100 - 28s - loss: 1.1903 - val_loss: 1.0967 Epoch 53/100 - 28s - loss: 1.1904 - val_loss: 1.0917 Epoch 54/100 - 28s - loss: 1.1895 - val_loss: 1.0897 Epoch 55/100 - 28s - loss: 1.1900 - val_loss: 1.0995

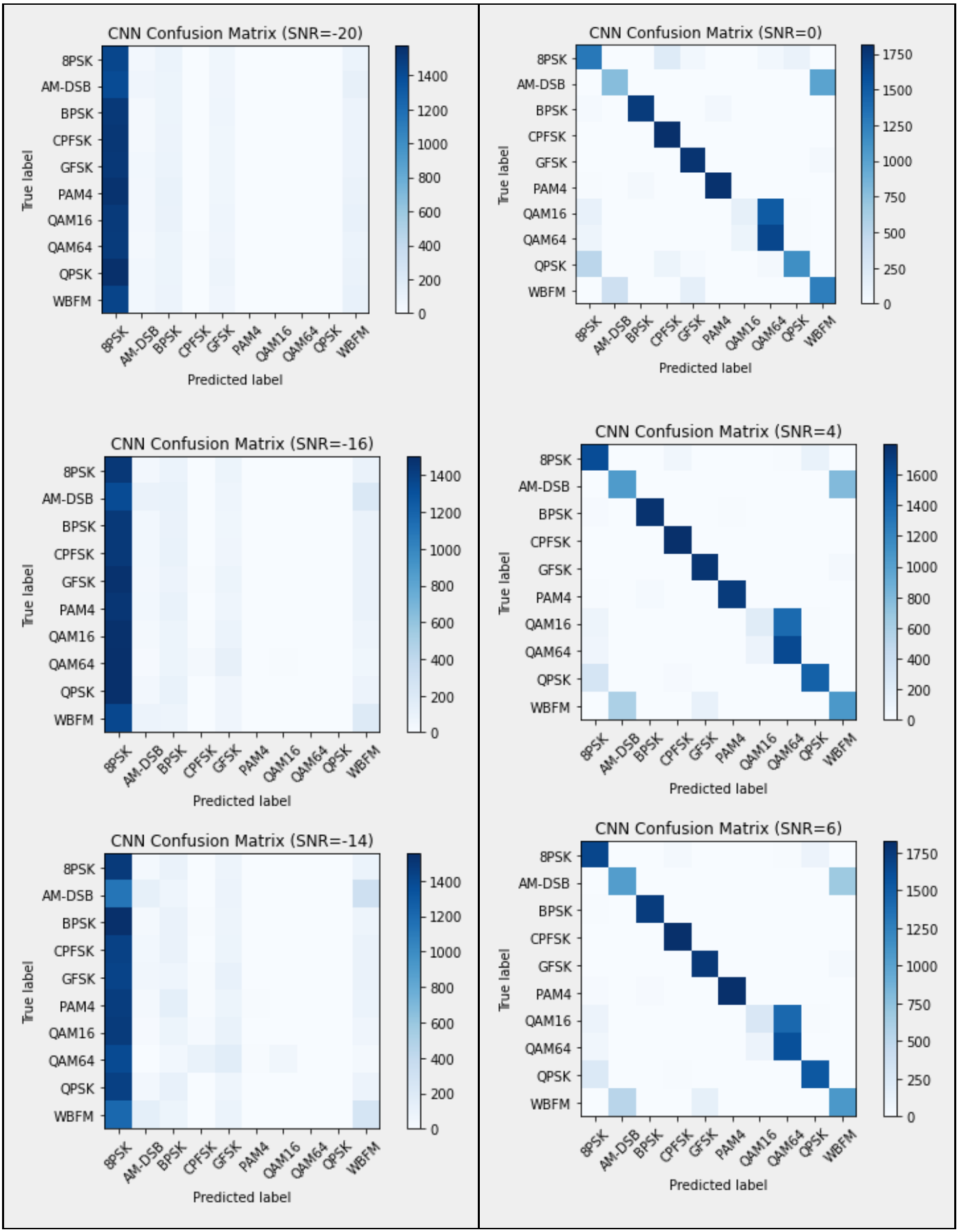
- Accuracies

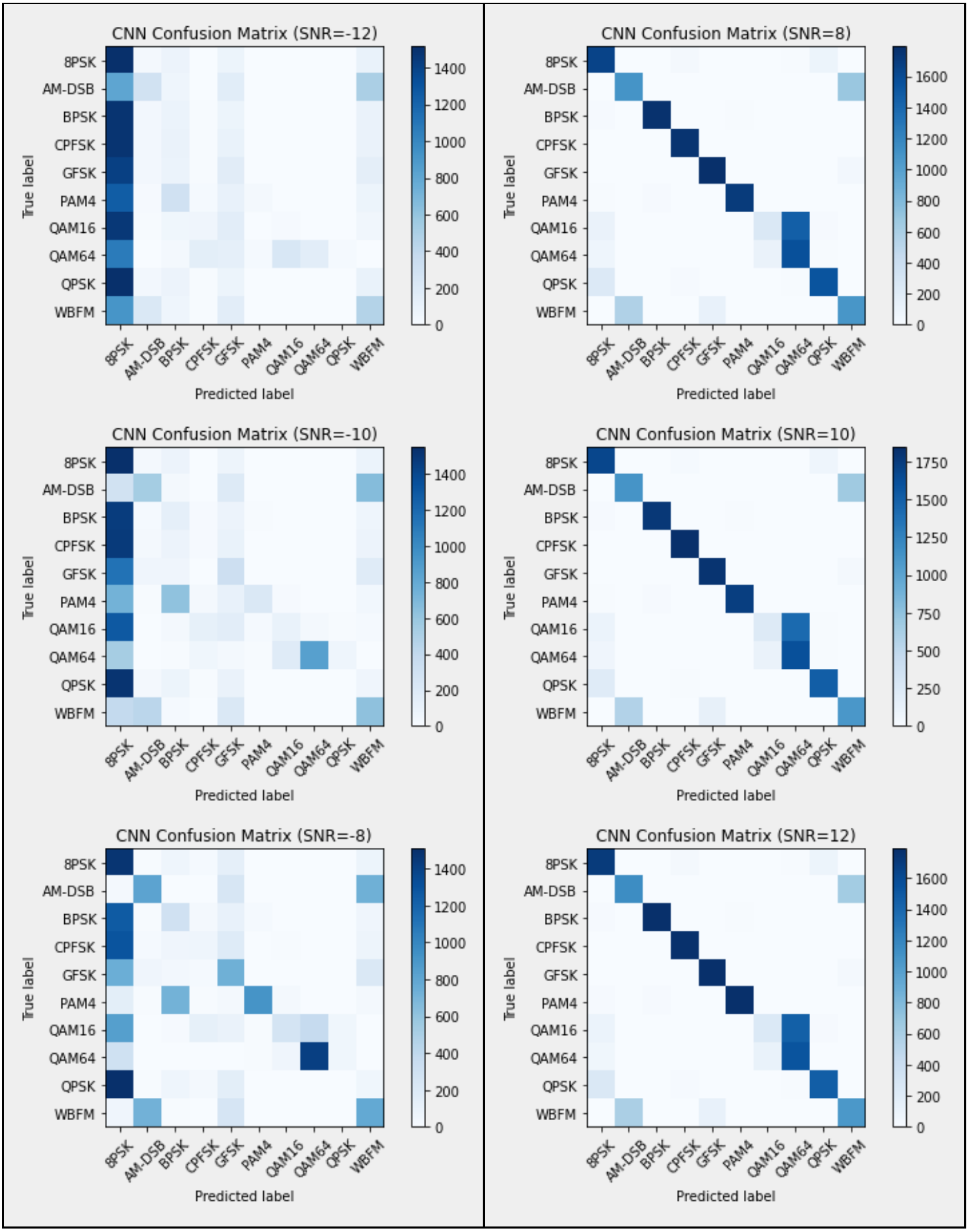
Accuracy = 0.09779232305302862 Accuracy = 0.10397228895469021 Accuracy = 0.10853104492680464 Accuracy = 0.11753575602426401 Accuracy = 0.14936237753817524 Accuracy = 0.2452746027320881 Accuracy = 0.3724520630734575 Accuracy = 0.4775259103253339 Accuracy = 0.5967410043935265 Accuracy = 0.679131683605833	Accuracy = 0.7409635229843827 Accuracy = 0.7772727272727272 Accuracy = 0.7845112192938279 Accuracy = 0.7991314998329807 Accuracy = 0.7927216070335541 Accuracy = 0.7991273610957693 Accuracy = 0.7954053604128517 Accuracy = 0.799221140472879 Accuracy = 0.7950265437272981 Accuracy = 0.8026774665316684

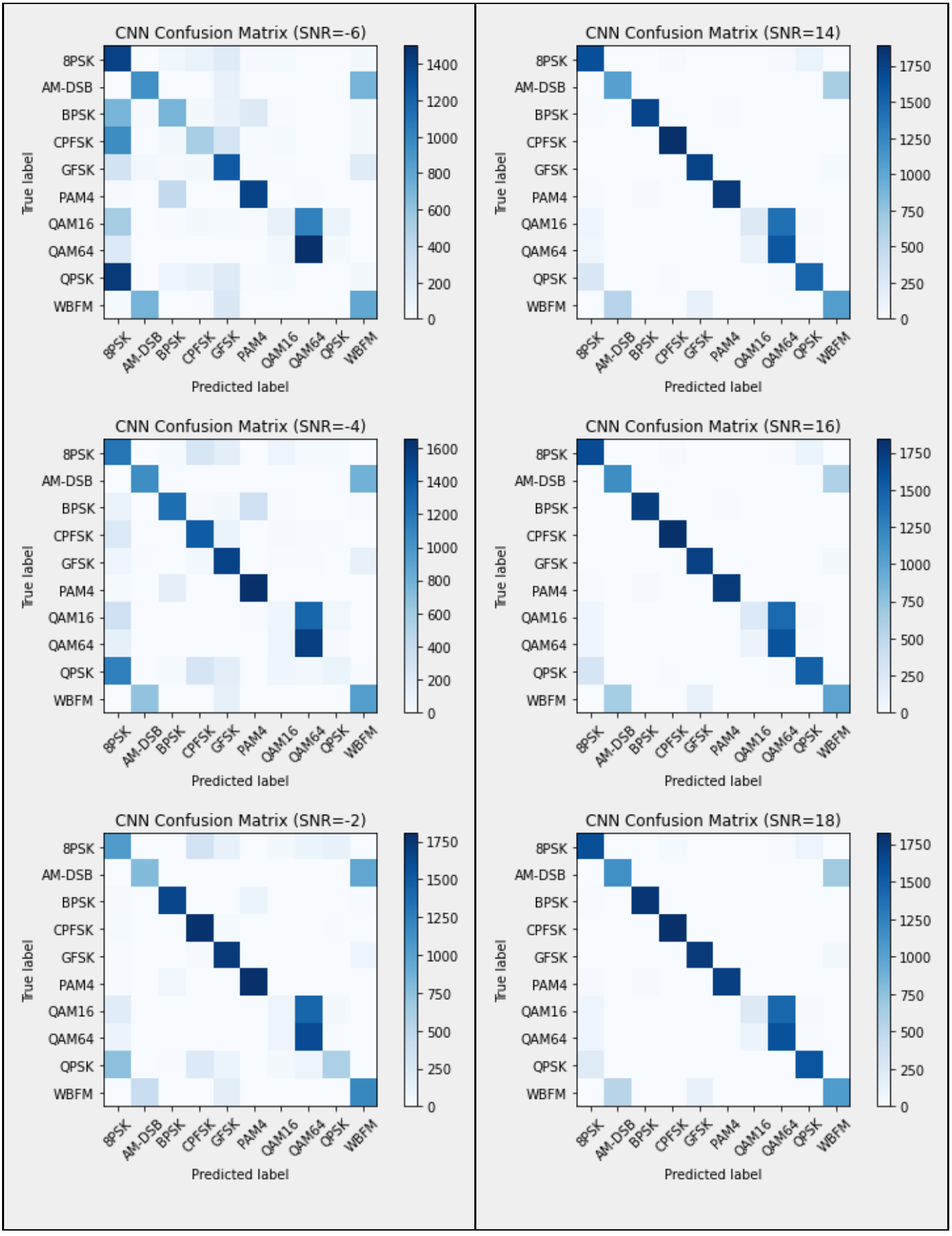
- Accuracy Against SNR



- Confusion Matrices




CNN Confusion Matrix (SNR=-12)
CNN Confusion Matrix (SNR=8)
CNN Confusion Matrix (SNR=-10)
CNN Confusion Matrix (SNR=10)
CNN Confusion Matrix (SNR=-8)
CNN Confusion Matrix (SNR=12)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


CNN Confusion Matrix (SNR=-6)
CNN Confusion Matrix (SNR=14)
CNN Confusion Matrix (SNR=-4)
CNN Confusion Matrix (SNR=16)
CNN Confusion Matrix (SNR=-2)
CNN Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM

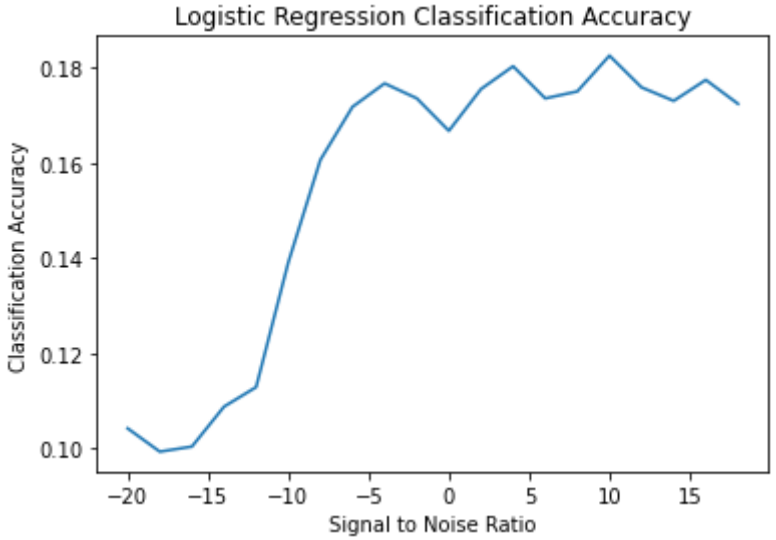
2. First derivative in time

Logistic regression

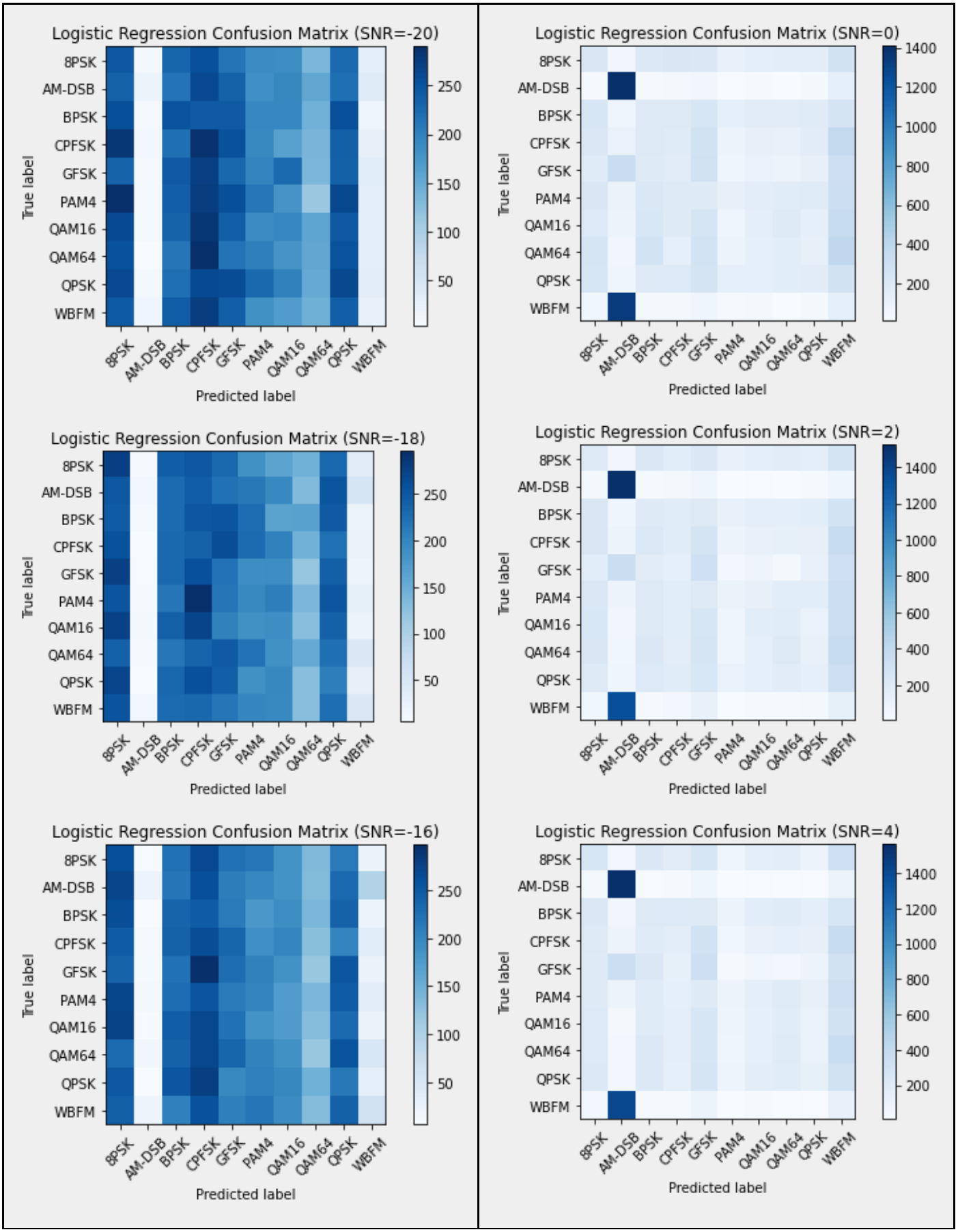
- Accuracies

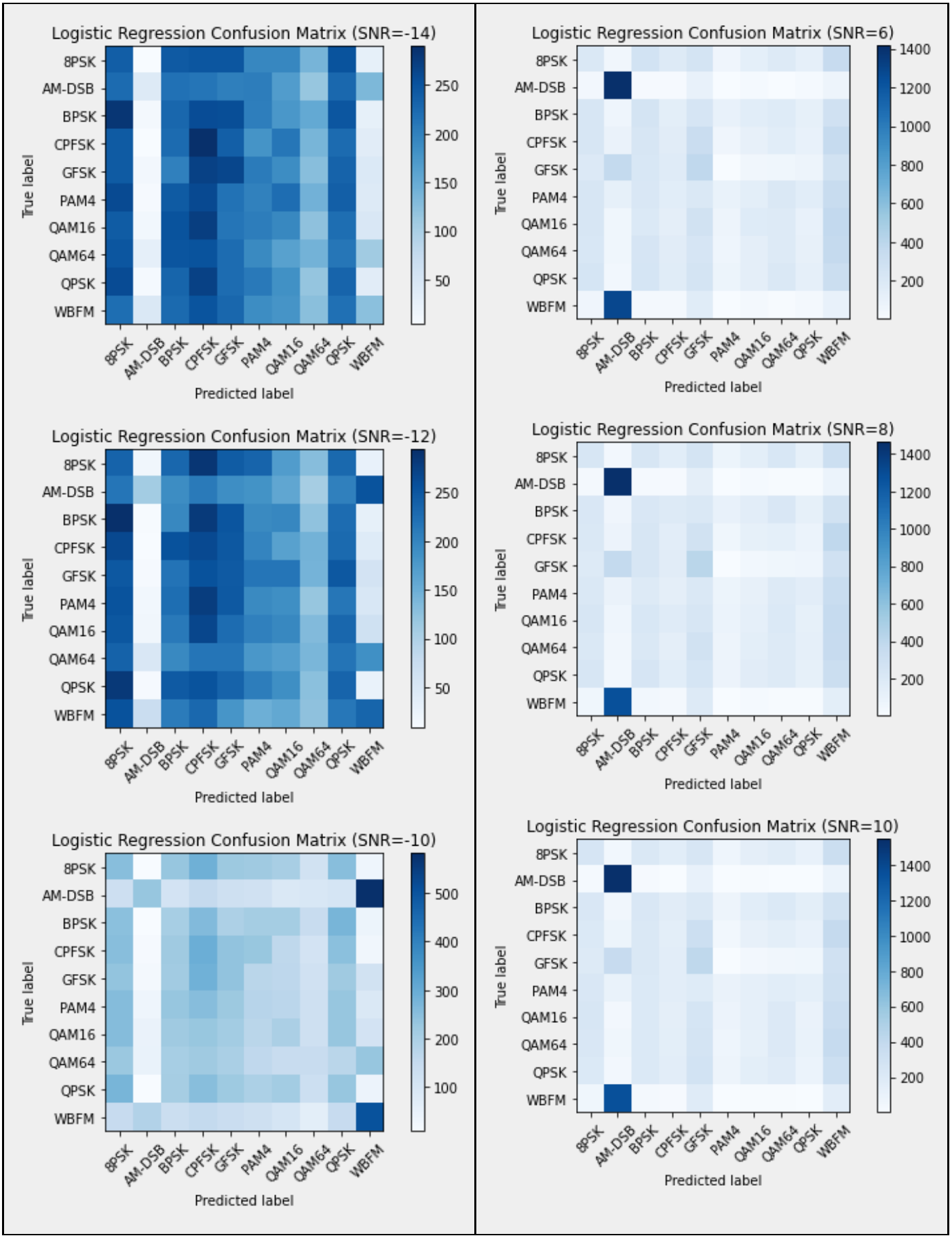
SNR = -20 Accuracy = 0.10417128910583537 SNR = -18 Accuracy = 0.09927928934577351 SNR = -16 Accuracy = 0.10034213921139716 SNR = -14 Accuracy = 0.10874283488229729 SNR = -12 Accuracy = 0.1128564391658913 SNR = -10 Accuracy = 0.13905770839141343 SNR = -8 Accuracy = 0.160650513708038 SNR = -6 Accuracy = 0.1718117829629219 SNR = -4 Accuracy = 0.17674211667871642 SNR = -2 Accuracy = 0.1736080424215643	SNR = 0 Accuracy = 0.16676783841951326 SNR = 2 Accuracy = 0.17555432372505544 SNR = 4 Accuracy = 0.1803480499132673 SNR = 6 Accuracy = 0.1735886872285937 SNR = 8 Accuracy = 0.1750598185966279 SNR = 10 Accuracy = 0.18259140616370265 SNR = 12 Accuracy = 0.17590588757560624 SNR = 14 Accuracy = 0.17307371349095968 SNR = 16 Accuracy = 0.1774797429449567 SNR = 18 Accuracy = 0.17246034424569692

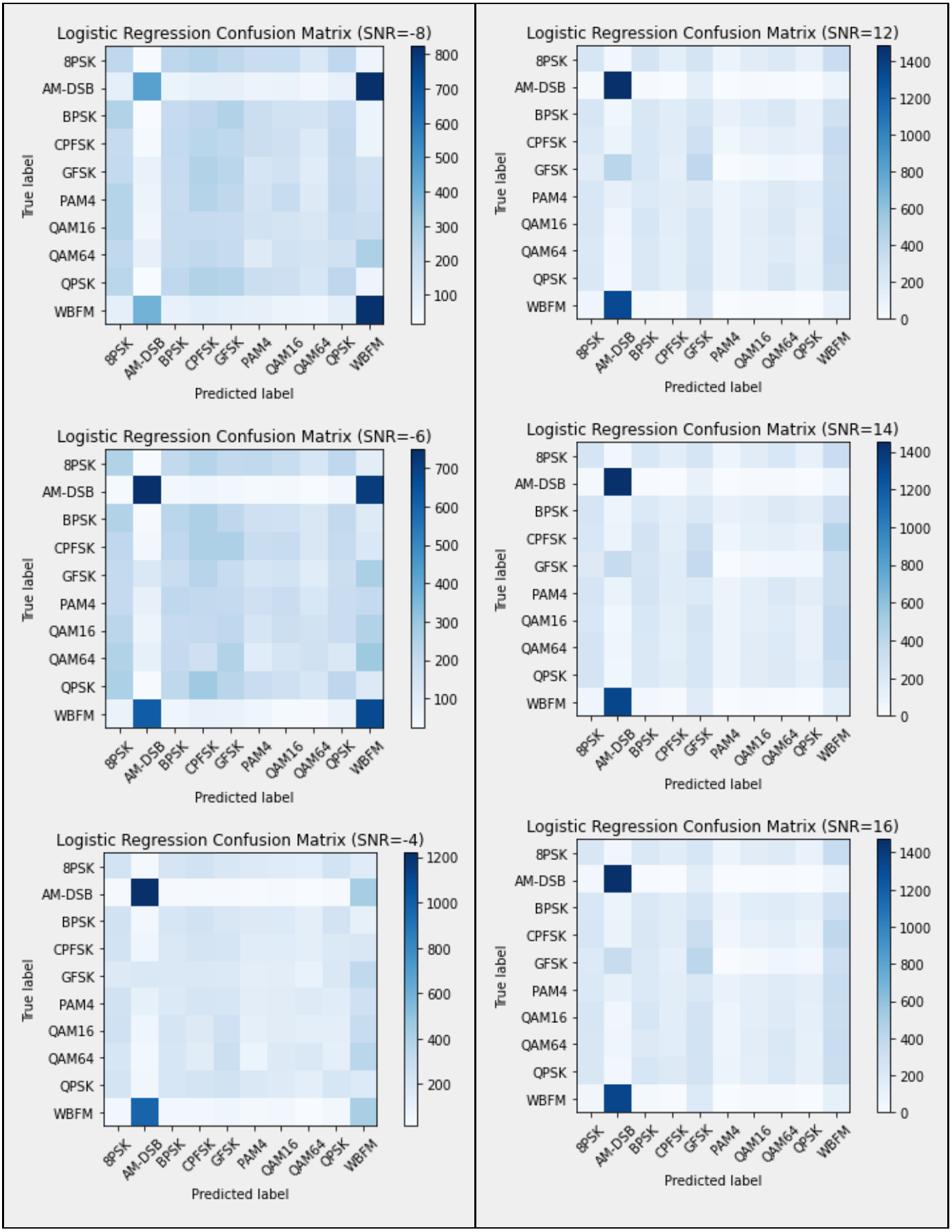
- Accuracy Against SNR

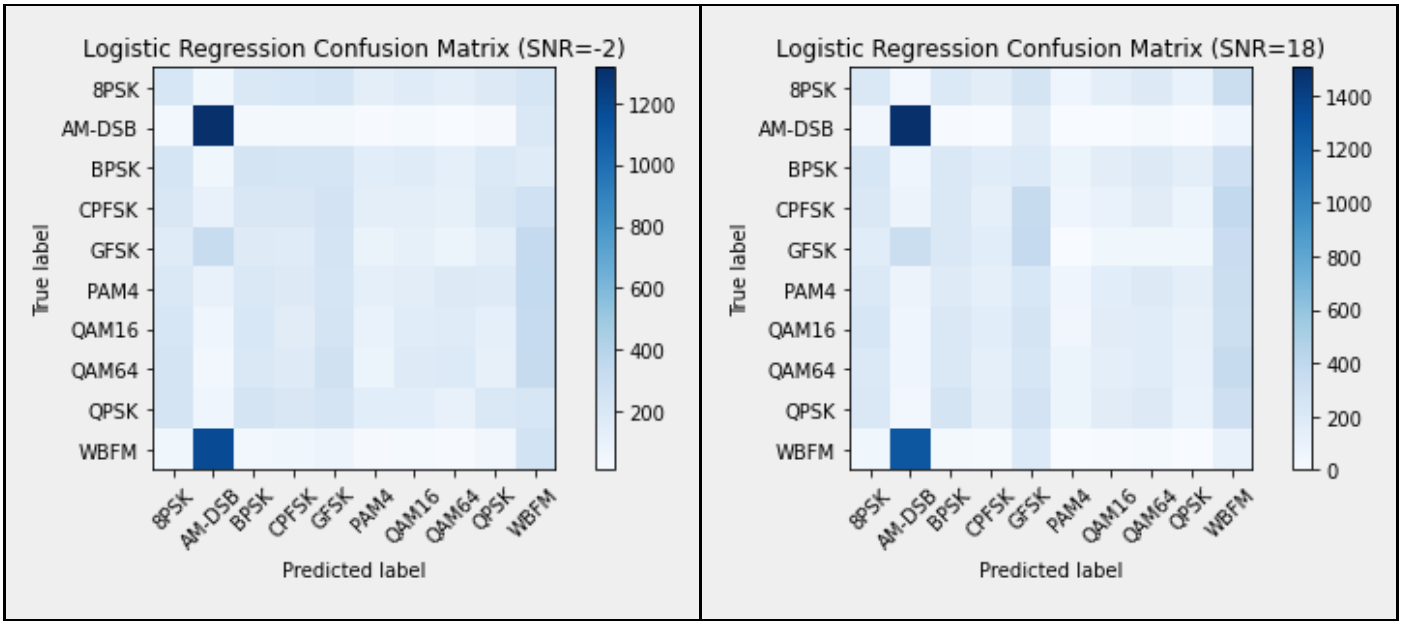


- Confusion Matrices




Logistic Regression Confusion Matrix (SNR=-14)
Logistic Regression Confusion Matrix (SNR=6)
Logistic Regression Confusion Matrix (SNR=-12)
Logistic Regression Confusion Matrix (SNR=8)
Logistic Regression Confusion Matrix (SNR=-10)
Logistic Regression Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


Logistic Regression Confusion Matrix (SNR=-8)
Logistic Regression Confusion Matrix (SNR=12)
Logistic Regression Confusion Matrix (SNR=-6)
Logistic Regression Confusion Matrix (SNR=14)
Logistic Regression Confusion Matrix (SNR=-4)
Logistic Regression Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM

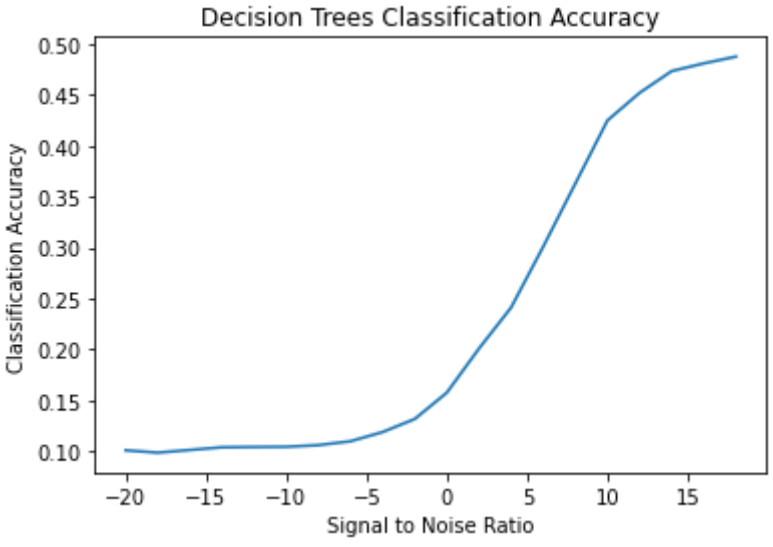

Logistic Regression Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1200
1000
800
600
400
200
Logistic Regression Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1400
1200
1000
800
600
400
200
0

Decision Trees

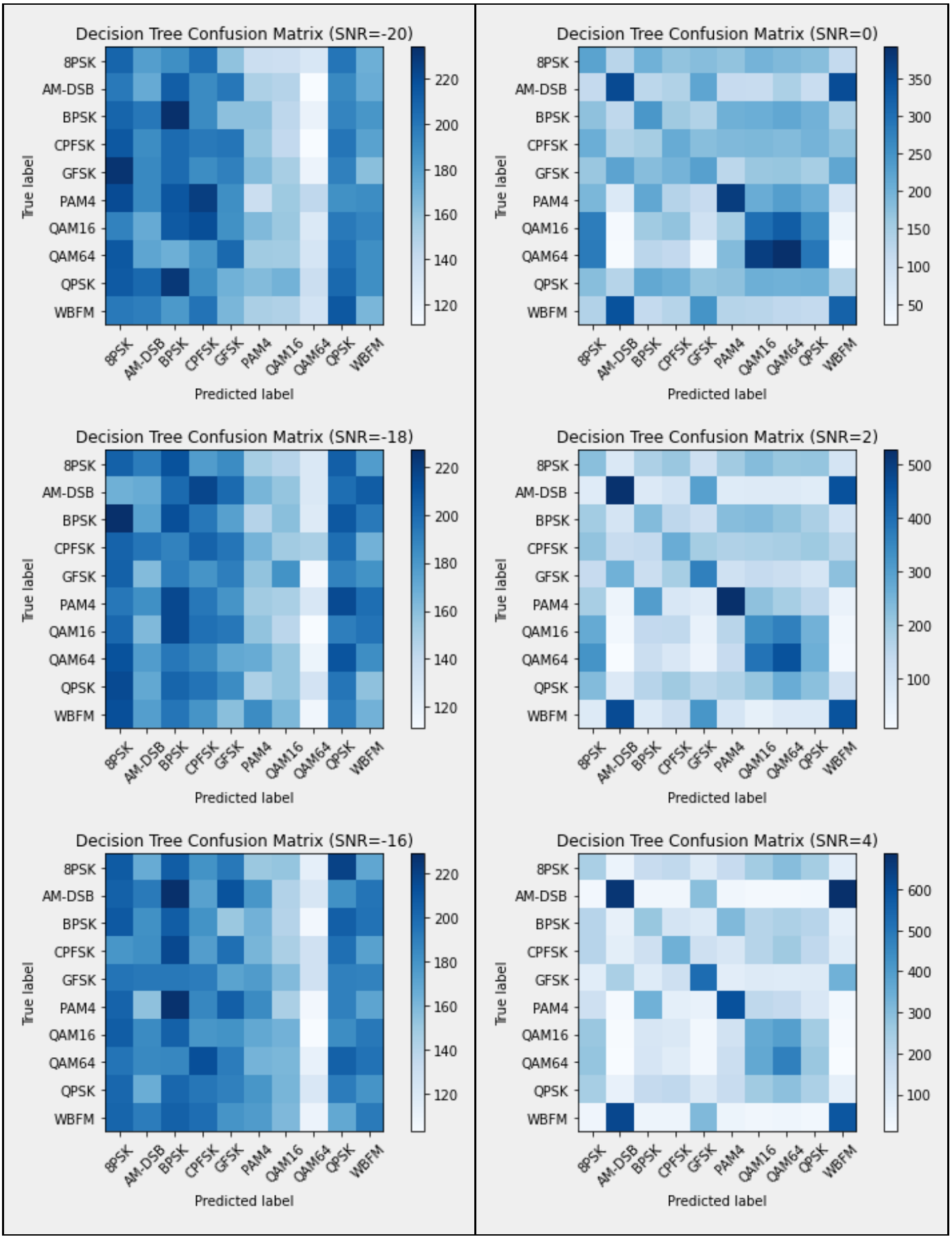
- Accuracies

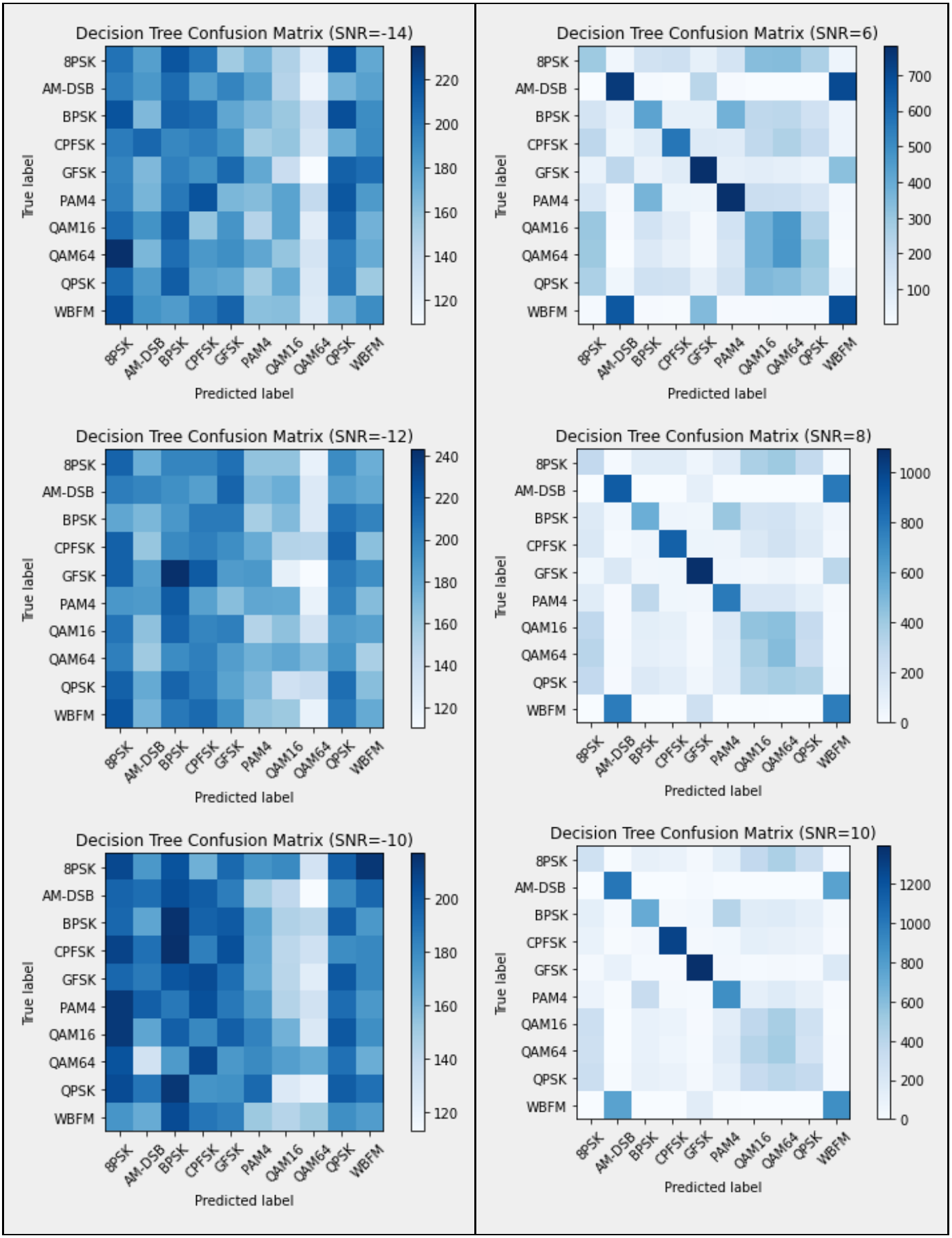
SNR = -20 Accuracy = 0.10067672509429776 SNR = -18 Accuracy = 0.0983853846583608 SNR = -16 Accuracy = 0.10101519995512928 SNR = -14 Accuracy = 0.10367855751572153 SNR = -12 Accuracy = 0.10398992939631109 SNR = -10 Accuracy = 0.10415388904376917 SNR = -8 Accuracy = 0.10576341959233009 SNR = -6 Accuracy = 0.10957157900570859 SNR = -4 Accuracy = 0.11862521550525555 SNR = -2 Accuracy = 0.13146266018559435	SNR = 0 Accuracy = 0.15738645770100987 SNR = 2 Accuracy = 0.20072062084257206 SNR = 4 Accuracy = 0.24106093671311063 SNR = 6 Accuracy = 0.3009130386371228 SNR = 8 Accuracy = 0.36297367981748374 SNR = 10 Accuracy = 0.4249972384844803 SNR = 12 Accuracy = 0.45208368015093503 SNR = 14 Accuracy = 0.4734909596662031 SNR = 16 Accuracy = 0.4810841017043867 SNR = 18 Accuracy = 0.487737653279334

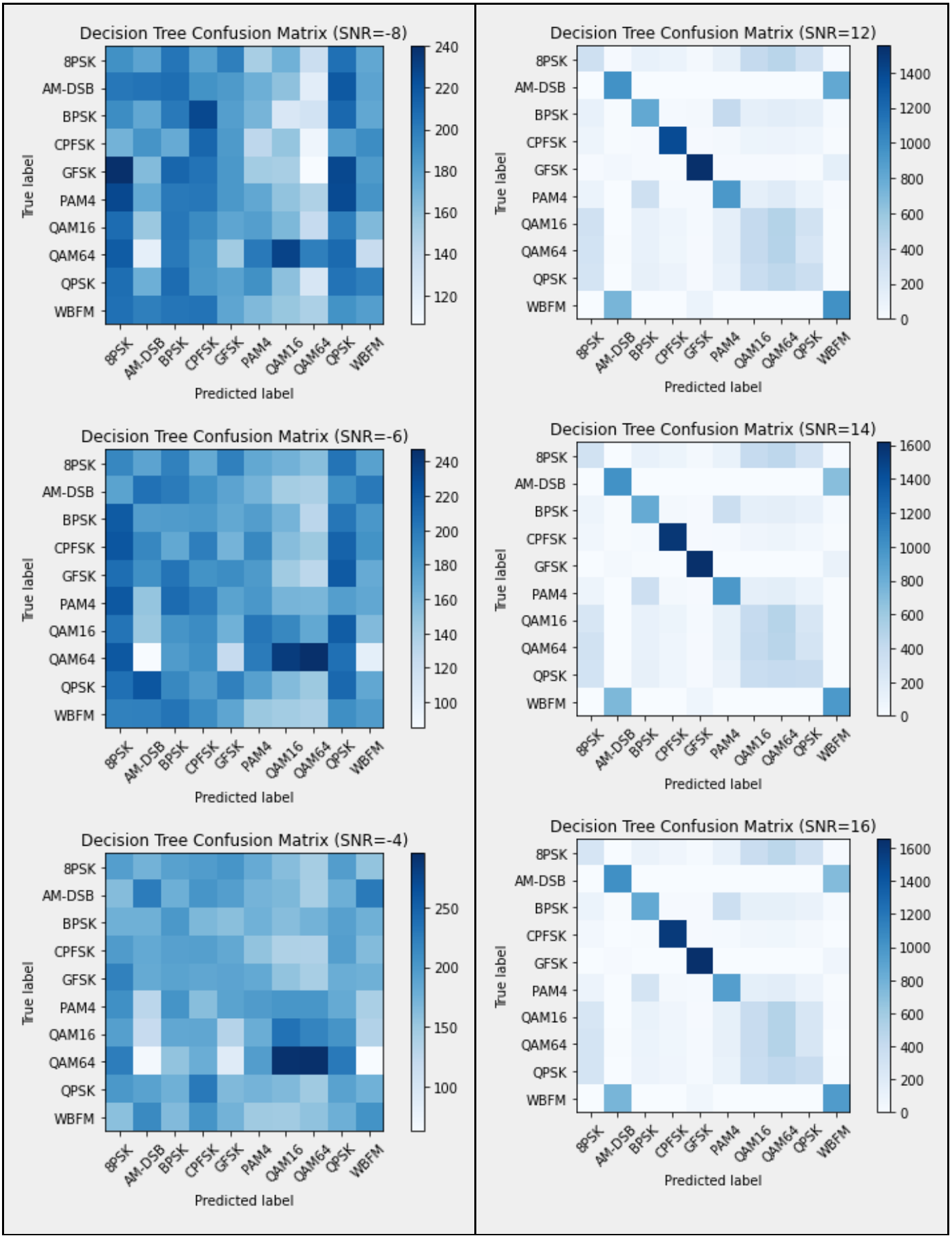
- Accuracy against SNR

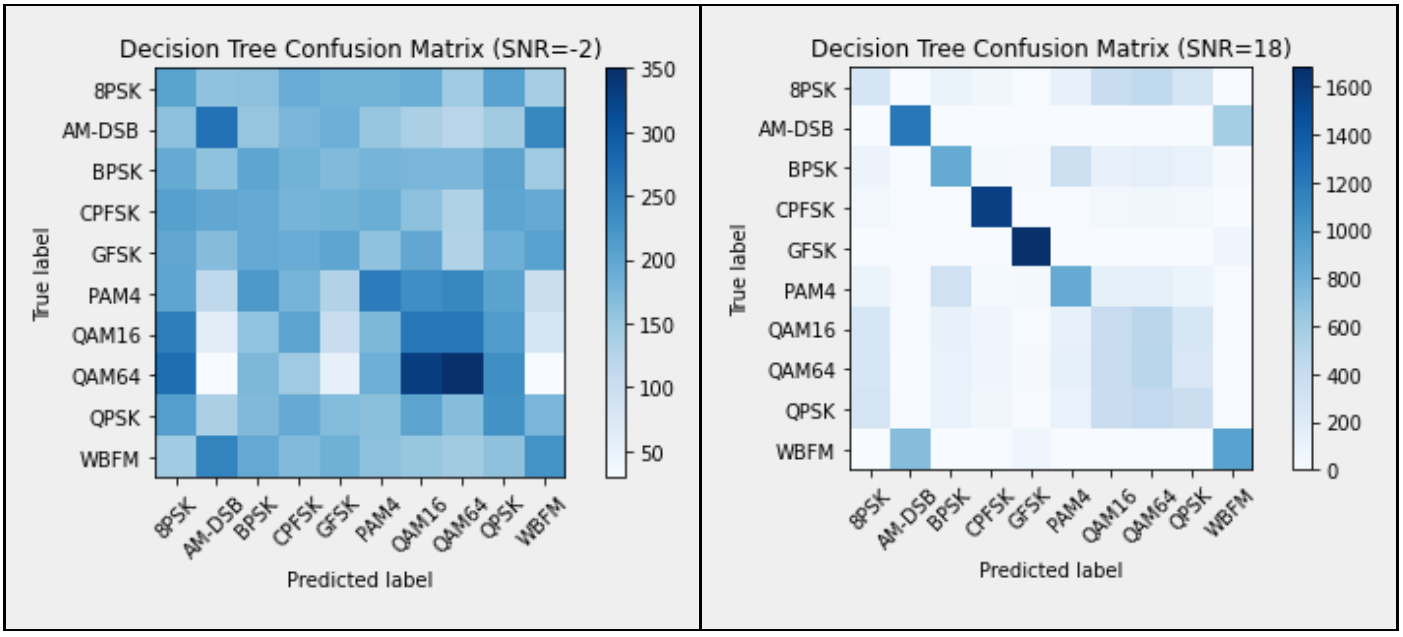


- Confusion matrices




Decision Tree Confusion Matrix (SNR=-14)
Decision Tree Confusion Matrix (SNR=6)
Decision Tree Confusion Matrix (SNR=-12)
Decision Tree Confusion Matrix (SNR=8)
Decision Tree Confusion Matrix (SNR=-10)
Decision Tree Confusion Matrix (SNR=10)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label


Decision Tree Confusion Matrix (SNR=-8)
Decision Tree Confusion Matrix (SNR=12)
Decision Tree Confusion Matrix (SNR=-6)
Decision Tree Confusion Matrix (SNR=14)
Decision Tree Confusion Matrix (SNR=-4)
Decision Tree Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM

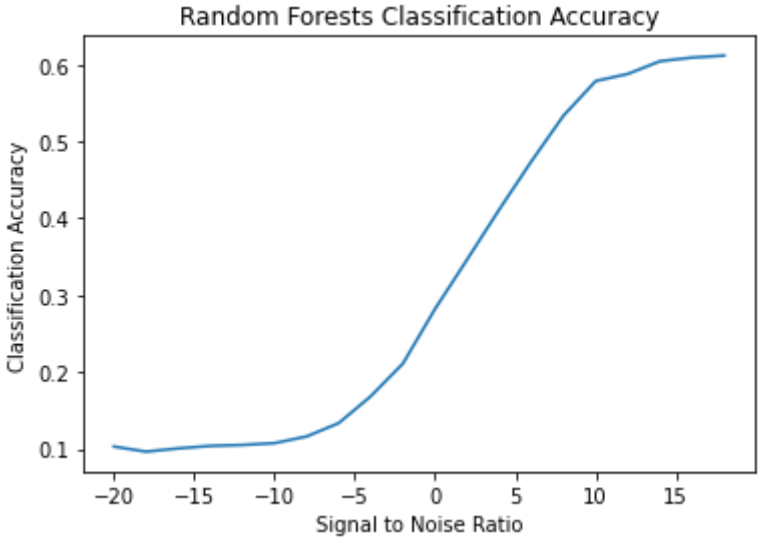

Decision Tree Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
350
300
250
200
150
100
50
Decision Tree Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1600
1400
1200
1000
800
600
400
200
0

Random Forests

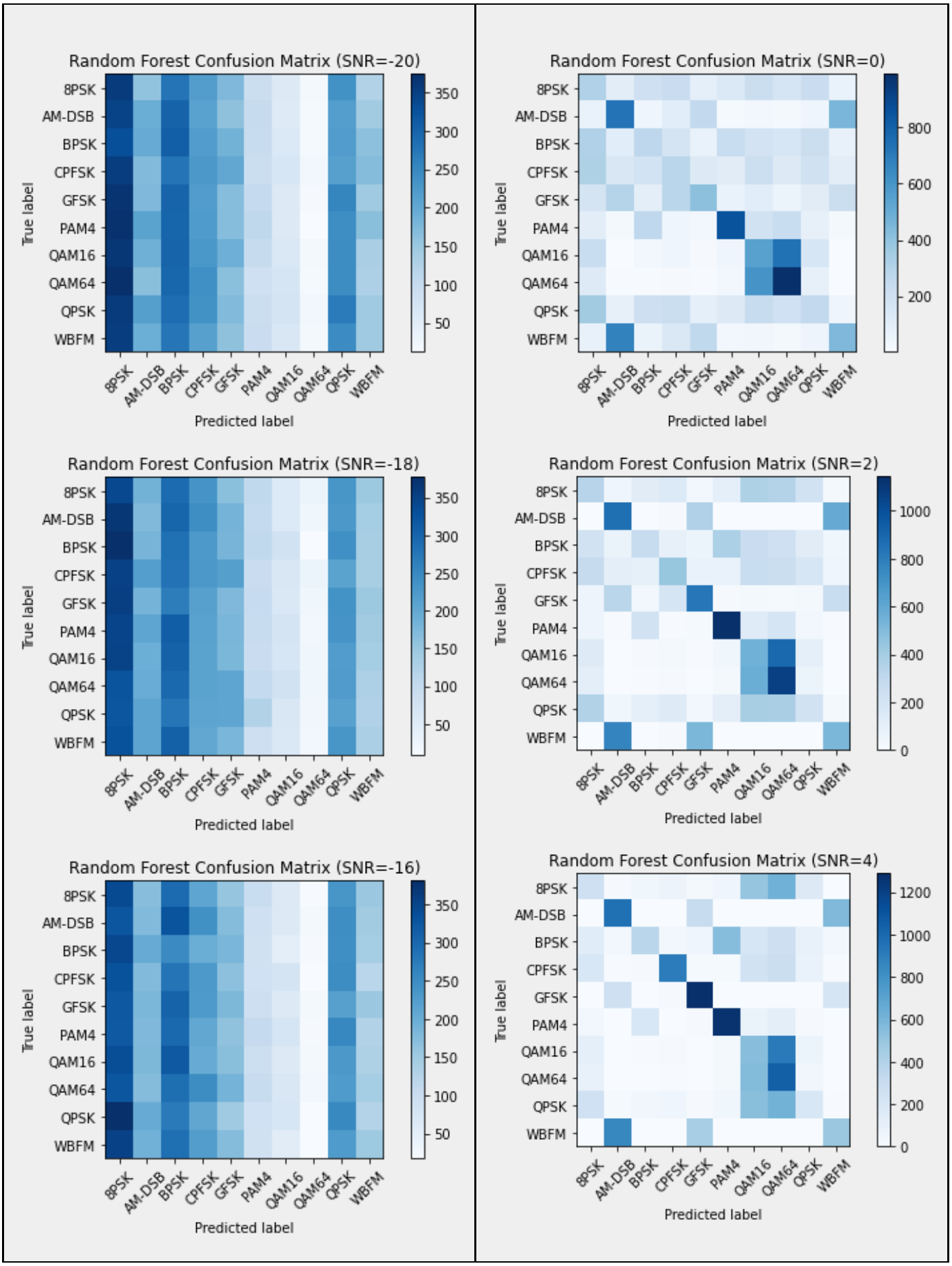
- Accuracies

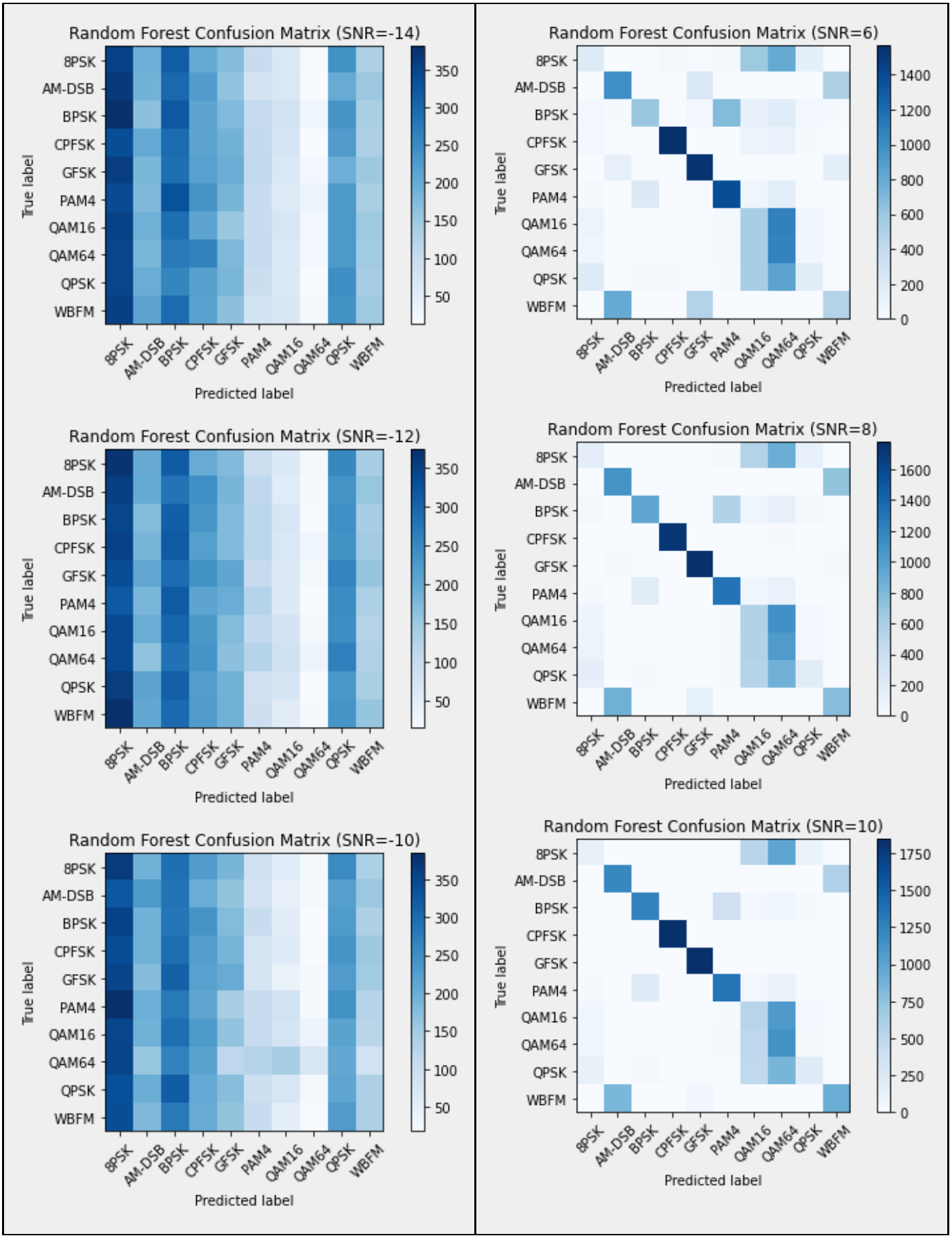
SNR = -20 Accuracy = 0.10328378078544487 SNR = -18 Accuracy = 0.09665344432649868 SNR = -16 Accuracy = 0.10084693476919625 SNR = -14 Accuracy = 0.10412376871278313 SNR = -12 Accuracy = 0.1053582179409994 SNR = -10 Accuracy = 0.1077223306384165 SNR = -8 Accuracy = 0.11636723256963903 SNR = -6 Accuracy = 0.1337914980879011 SNR = -4 Accuracy = 0.16878927757076914 SNR = -2 Accuracy = 0.2113345117101193	SNR = 0 Accuracy = 0.28237955962695216 SNR = 2 Accuracy = 0.3466740576496674 SNR = 4 Accuracy = 0.4117284986850204 SNR = 6 Accuracy = 0.47433470660282817 SNR = 8 Accuracy = 0.533748817539369 SNR = 10 Accuracy = 0.5786479620015464 SNR = 12 Accuracy = 0.5878697075633983 SNR = 14 Accuracy = 0.604394993045897 SNR = 16 Accuracy = 0.6091645711092484 SNR = 18 Accuracy = 0.6117111036112048

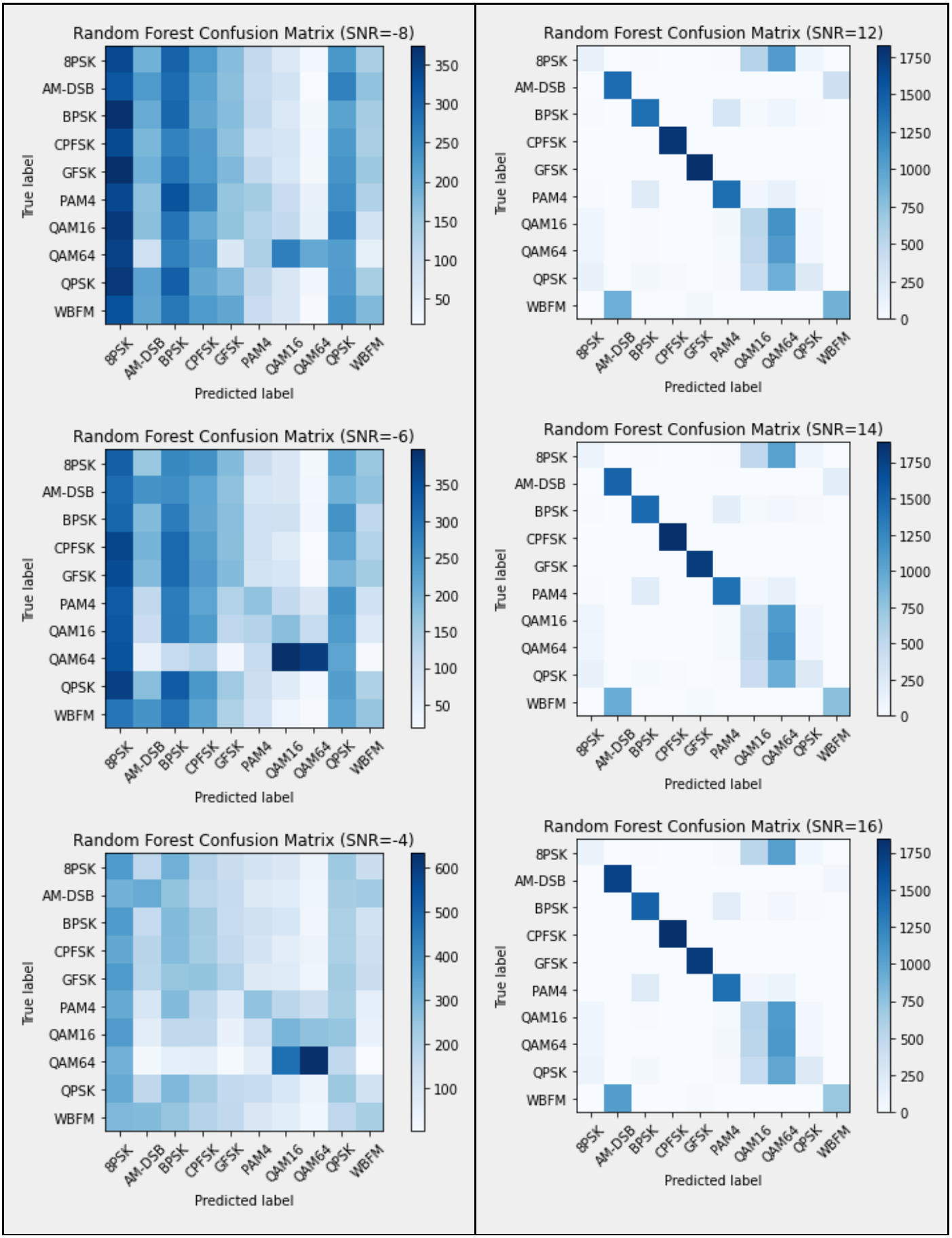
- Accuracy Against SNR

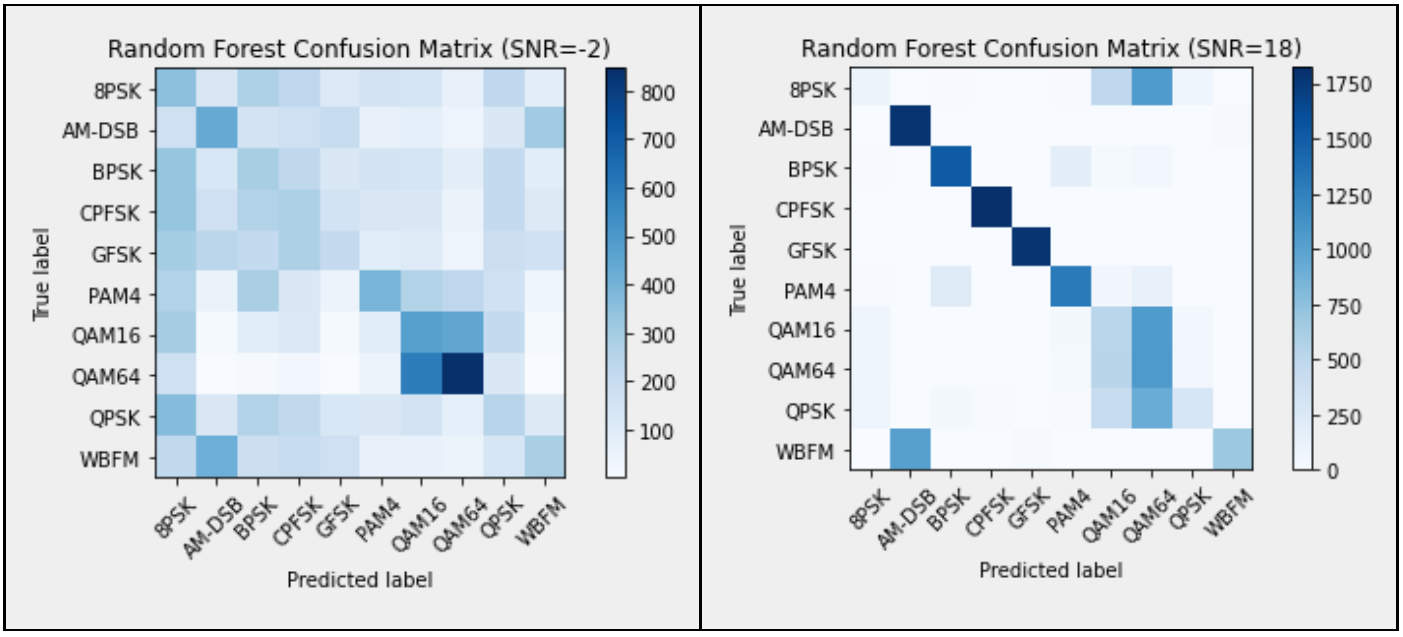


- Confusion Matrices




Random Forest Confusion Matrix (SNR=-14)
Random Forest Confusion Matrix (SNR=6)
Random Forest Confusion Matrix (SNR=-12)
Random Forest Confusion Matrix (SNR=8)
Random Forest Confusion Matrix (SNR=-10)
Random Forest Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


Random Forest Confusion Matrix (SNR=-8)
Random Forest Confusion Matrix (SNR=12)
Random Forest Confusion Matrix (SNR=-6)
Random Forest Confusion Matrix (SNR=14)
Random Forest Confusion Matrix (SNR=-4)
Random Forest Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


Random Forest Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
800
700
600
500
400
300
200
100
Random Forest Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1750
1500
1250
1000
750
500
250
0

Dense layer NN:

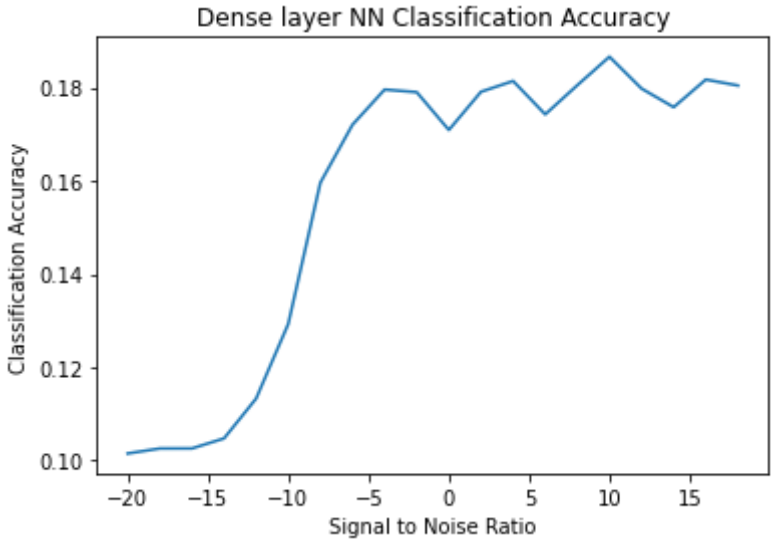
- Epochs

Epoch 1/100 - 4s - loss: 2.3445 - val_loss: 2.2544 Epoch 2/100 - 2s - loss: 2.2449 - val_loss: 2.2378 Epoch 3/100 - 2s - loss: 2.2321 - val_loss: 2.2288 Epoch 4/100 - 2s - loss: 2.2241 - val_loss: 2.2227 Epoch 5/100 - 2s - loss: 2.2187 - val_loss: 2.2170 Epoch 6/100 - 2s - loss: 2.2144 - val_loss: 2.2141 Epoch 7/100 - 2s - loss: 2.2111 - val_loss: 2.2105 Epoch 8/100 - 2s - loss: 2.2083 - val_loss: 2.2079 Epoch 9/100 - 2s - loss: 2.2059 - val_loss: 2.2053 Epoch 10/100 - 2s - loss: 2.2038 - val_loss: 2.2041 Epoch 11/100 - 2s - loss: 2.2020 - val_loss: 2.2026 Epoch 12/100 - 2s - loss: 2.2005 - val_loss: 2.2005 Epoch 13/100 - 2s - loss: 2.1990 - val_loss: 2.1987 Epoch 14/100 - 2s - loss: 2.1977 - val_loss: 2.1977 Epoch 15/100 - 2s - loss: 2.1966 - val_loss: 2.1965 Epoch 16/100 - 2s - loss: 2.1956 - val_loss: 2.1961 Epoch 17/100 - 2s - loss: 2.1948 - val_loss: 2.1958 Epoch 18/100 - 2s - loss: 2.1938 - val_loss: 2.1953 Epoch 19/100 - 2s - loss: 2.1932 - val_loss: 2.1942 Epoch 20/100 - 2s - loss: 2.1925 - val_loss: 2.1933 Epoch 21/100 - 2s - loss: 2.1919 - val_loss: 2.1926 Epoch 22/100 - 2s - loss: 2.1914 - val_loss: 2.1930	Epoch 23/100 - 2s - loss: 2.1908 - val_loss: 2.1911 Epoch 24/100 - 2s - loss: 2.1903 - val_loss: 2.1920 Epoch 25/100 - 2s - loss: 2.1900 - val_loss: 2.1911 Epoch 26/100 - 2s - loss: 2.1896 - val_loss: 2.1900 Epoch 27/100 - 2s - loss: 2.1893 - val_loss: 2.1905 Epoch 28/100 - 2s - loss: 2.1889 - val_loss: 2.1894 Epoch 29/100 - 2s - loss: 2.1887 - val_loss: 2.1893 Epoch 30/100 - 2s - loss: 2.1884 - val_loss: 2.1893 Epoch 31/100 - 2s - loss: 2.1881 - val_loss: 2.1882 Epoch 32/100 - 2s - loss: 2.1880 - val_loss: 2.1877 Epoch 33/100 - 2s - loss: 2.1878 - val_loss: 2.1888 Epoch 34/100 - 2s - loss: 2.1876 - val_loss: 2.1889 Epoch 35/100 - 2s - loss: 2.1874 - val_loss: 2.1883 Epoch 36/100 - 2s - loss: 2.1871 - val_loss: 2.1877 Epoch 37/100 - 2s - loss: 2.1872 - val_loss: 2.1882 Epoch 38/100 - 2s - loss: 2.1870 - val_loss: 2.1876 Epoch 39/100 - 2s - loss: 2.1868 - val_loss: 2.1872 Epoch 40/100 - 2s - loss: 2.1867 - val_loss: 2.1874 Epoch 41/100 - 2s - loss: 2.1866 - val_loss: 2.1882 Epoch 42/100 - 2s - loss: 2.1867 - val_loss: 2.1878 Epoch 43/100 - 2s - loss: 2.1866 - val_loss: 2.1873 Epoch 44/100 - 2s - loss: 2.1865 - val_loss: 2.1881

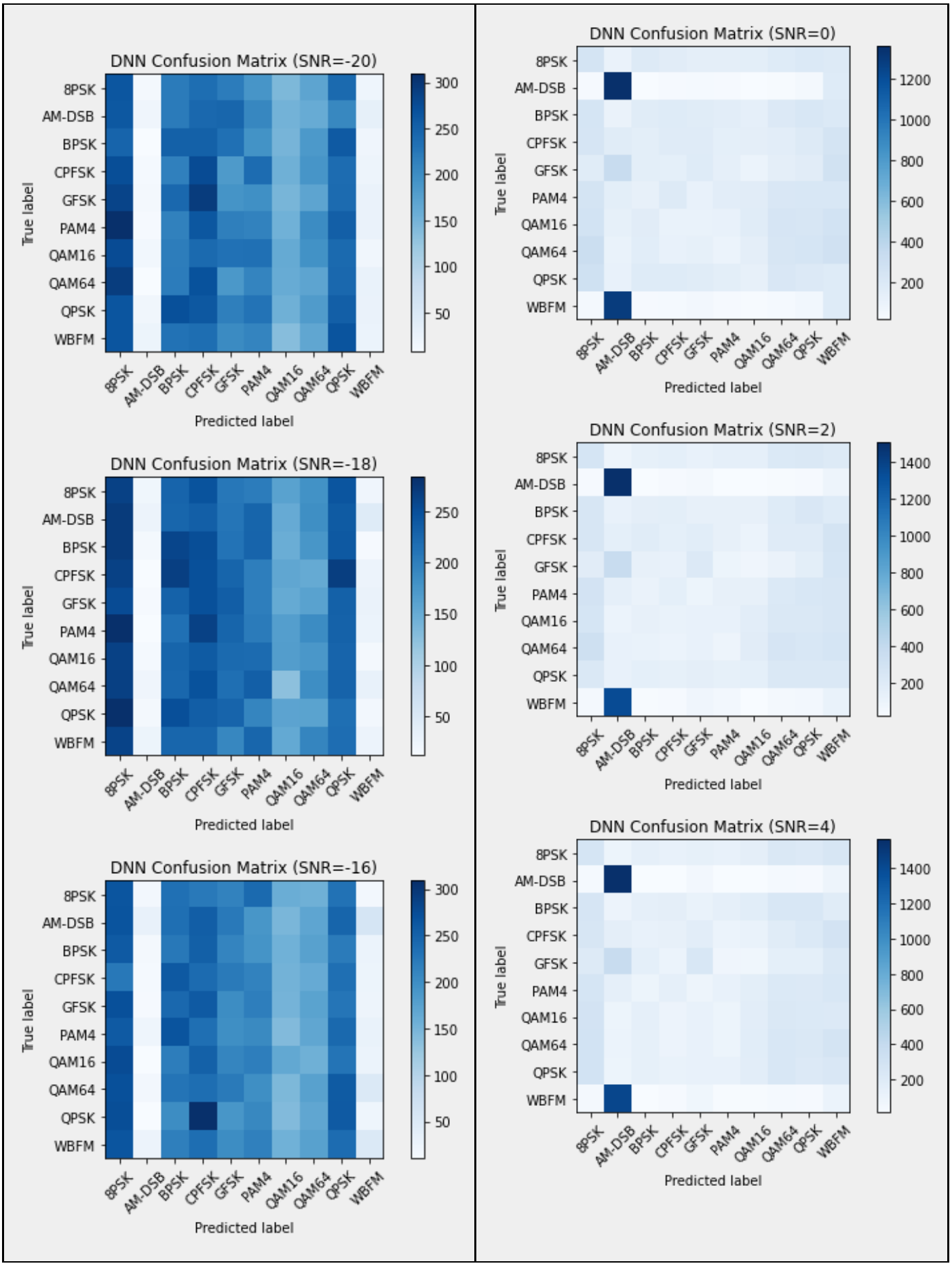
- Accuracies

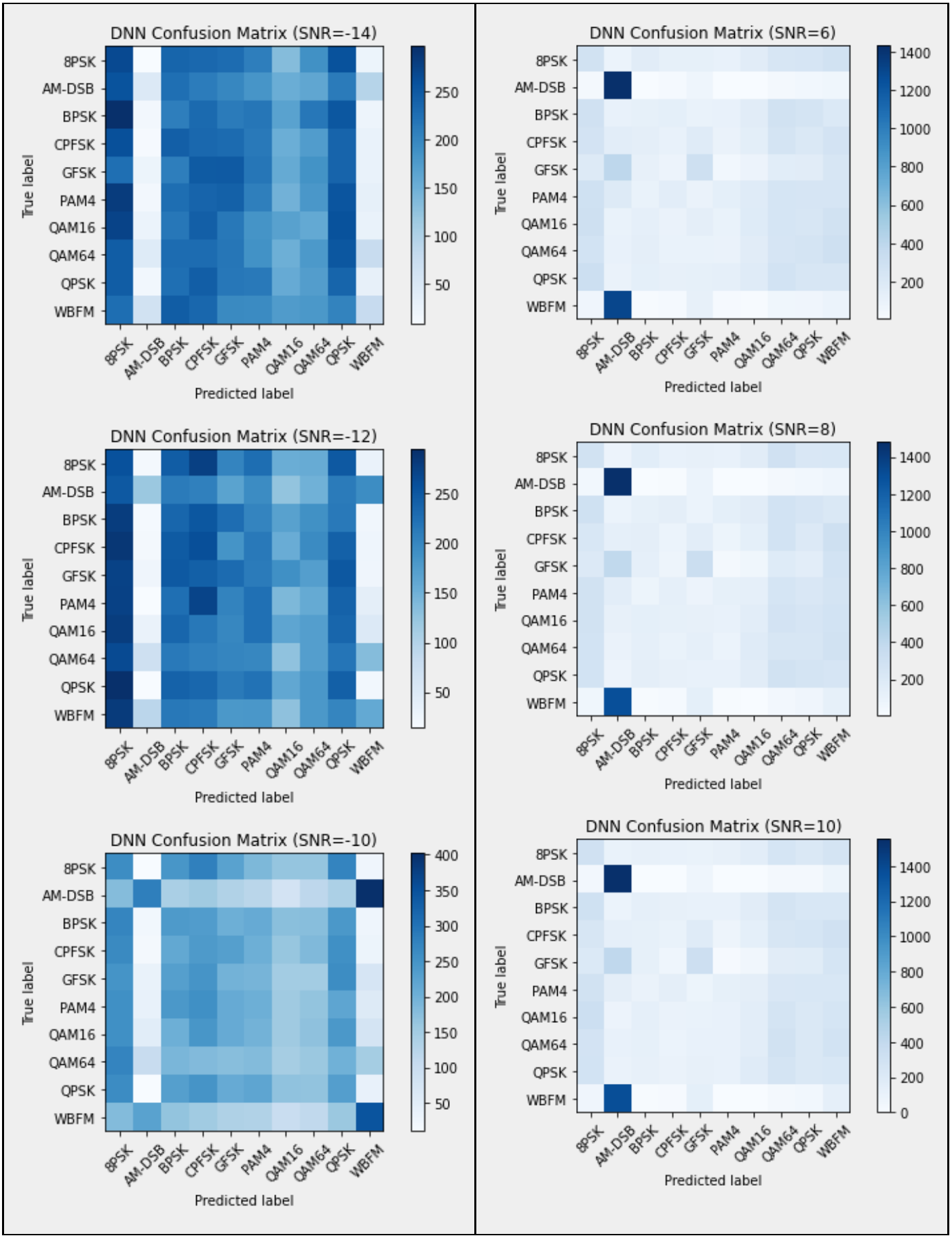
Accuracy = 0.10150876414466385	Accuracy = 0.17090668285414712
Accuracy = 0.10257556288060786	Accuracy = 0.1791019955654102
Accuracy = 0.1025856750238375	Accuracy = 0.18141122488948577
Accuracy = 0.10473593410874284	Accuracy = 0.17425676428014697
Accuracy = 0.11329429150019156	Accuracy = 0.18051304880084582
Accuracy = 0.12930025090604963	Accuracy = 0.18662321882248978
Accuracy = 0.15960661502115267	Accuracy = 0.17979024471449975
Accuracy = 0.17203347558609988	Accuracy = 0.17579972183588316
Accuracy = 0.1795784439130193	Accuracy = 0.18172673931265718
Accuracy = 0.17902121078214758	Accuracy = 0.18044774440319497

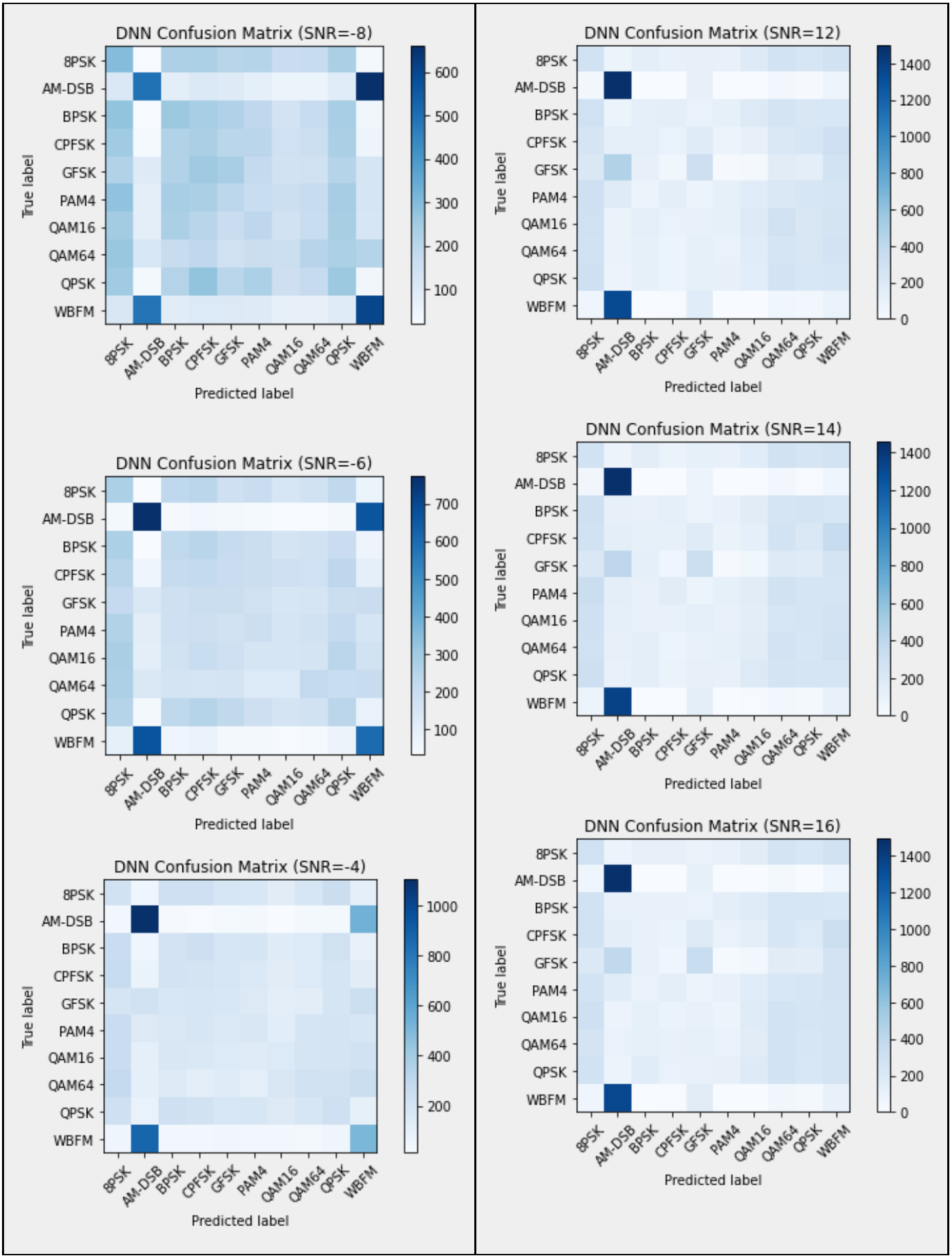
- Accuracies Against SNR

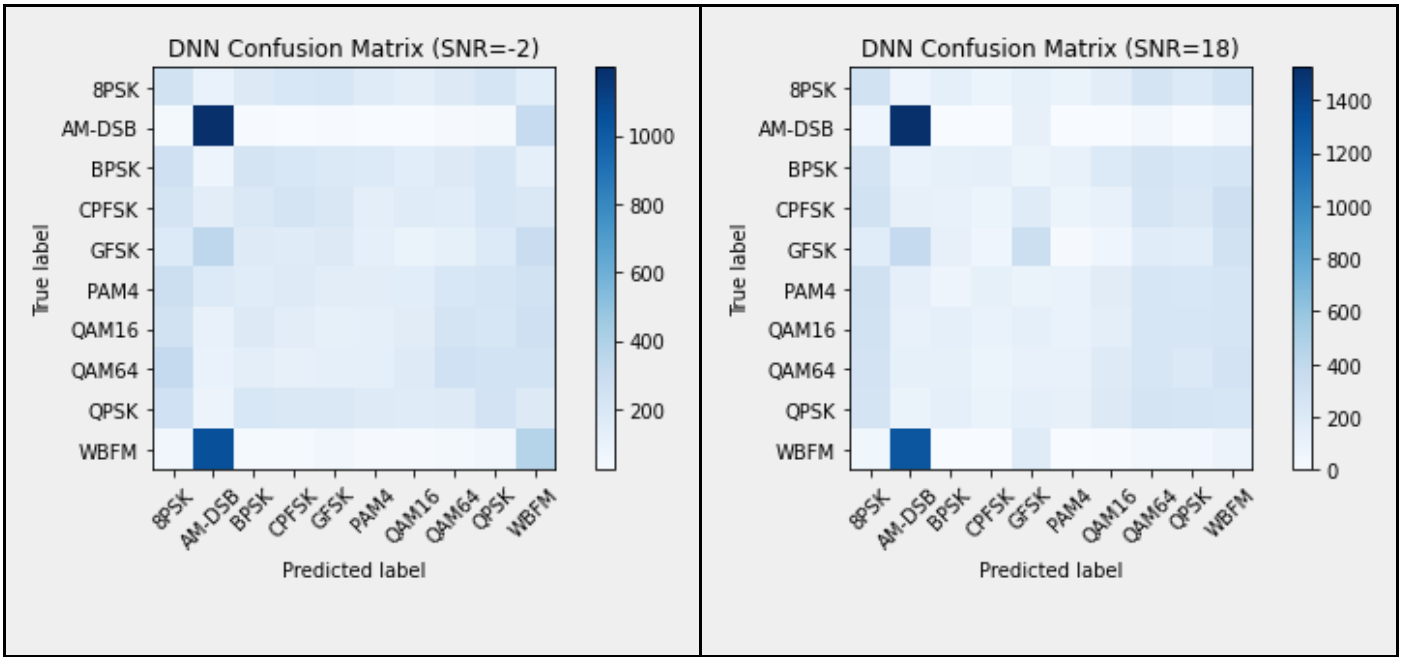


- Confusion Matrices




DNN Confusion Matrix (SNR=-14)
DNN Confusion Matrix (SNR=6)
DNN Confusion Matrix (SNR=-12)
DNN Confusion Matrix (SNR=8)
DNN Confusion Matrix (SNR=-10)
DNN Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


DNN Confusion Matrix (SNR=-8)
DNN Confusion Matrix (SNR=12)
DNN Confusion Matrix (SNR=-6)
DNN Confusion Matrix (SNR=14)
DNN Confusion Matrix (SNR=-4)
DNN Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


DNN Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1000
800
600
400
200
DNN Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1400
1200
1000
800
600
400
200
0

CNN

- Epochs

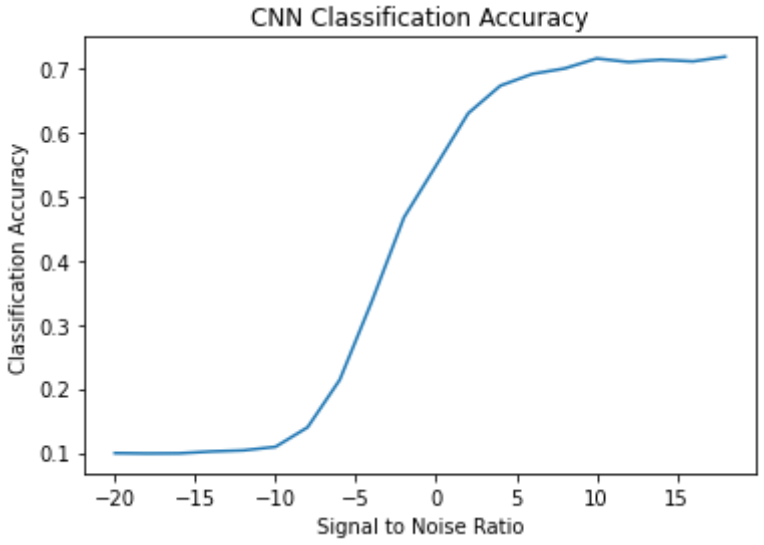
Train on 798000 samples, validate on 42000 samples

```
Epoch 1/100
 - 32s - loss: 1.7009 - val_loss: 1.5093
Epoch 2/100
 - 27s - loss: 1.5420 - val_loss: 1.4674
Epoch 3/100
 - 27s - loss: 1.5221 - val_loss: 1.4937
Epoch 4/100
 - 27s - loss: 1.5107 - val_loss: 1.4419
Epoch 5/100
 - 27s - loss: 1.5031 - val_loss: 1.4319
Epoch 6/100
 - 27s - loss: 1.4977 - val_loss: 1.4248
Epoch 7/100
 - 27s - loss: 1.4927 - val_loss: 1.4213
Epoch 8/100
 - 27s - loss: 1.4879 - val_loss: 1.4199
Epoch 9/100
 - 27s - loss: 1.4850 - val_loss: 1.4168
Epoch 10/100
 - 27s - loss: 1.4806 - val_loss: 1.4172
Epoch 11/100
 - 27s - loss: 1.4781 - val_loss: 1.4102
Epoch 12/100
 - 27s - loss: 1.4750 - val_loss: 1.4040
Epoch 13/100
 - 27s - loss: 1.4713 - val_loss: 1.4136
Epoch 14/100
 - 27s - loss: 1.4667 - val_loss: 1.3912
Epoch 15/100
 - 27s - loss: 1.4640 - val_loss: 1.3925
Epoch 16/100
 - 27s - loss: 1.4621 - val_loss: 1.3959
Epoch 17/100
 - 27s - loss: 1.4606 - val_loss: 1.3815
Epoch 18/100
 - 27s - loss: 1.4573 - val_loss: 1.3768
Epoch 19/100
 - 27s - loss: 1.4555 - val_loss: 1.4032
Epoch 20/100
 - 27s - loss: 1.4527 - val_loss: 1.3807
Epoch 21/100
 - 27s - loss: 1.4486 - val_loss: 1.3680
Epoch 22/100
 - 27s - loss: 1.4482 - val_loss: 1.3696
Epoch 23/100
 - 27s - loss: 1.4469 - val_loss: 1.3709
Epoch 24/100
 - 27s - loss: 1.4439 - val_loss: 1.3662
Epoch 25/100
 - 27s - loss: 1.4437 - val_loss: 1.3697
Epoch 26/100
 - 27s - loss: 1.4422 - val_loss: 1.3674
Epoch 27/100
 - 27s - loss: 1.4406 - val_loss: 1.3636
Epoch 28/100
 - 27s - loss: 1.4410 - val_loss: 1.3627
Epoch 29/100
 - 27s - loss: 1.4390 - val_loss: 1.3830
Epoch 30/100
 - 27s - loss: 1.4384 - val_loss: 1.3635
Epoch 31/100
 - 27s - loss: 1.4366 - val_loss: 1.3639
Epoch 32/100
 - 27s - loss: 1.4363 - val_loss: 1.3690
Epoch 33/100
 - 27s - loss: 1.4354 - val_loss: 1.3733
```

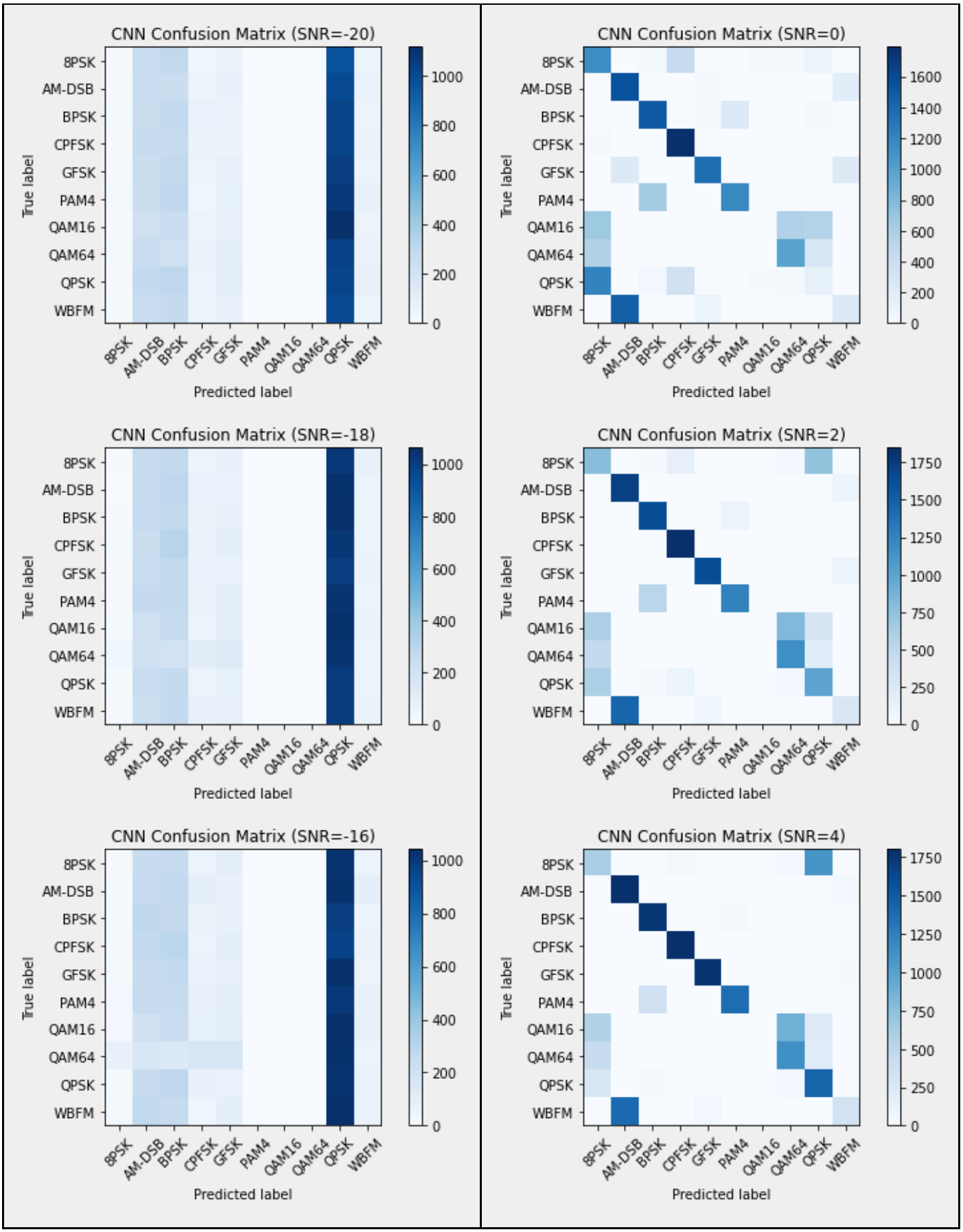
- Accuracies

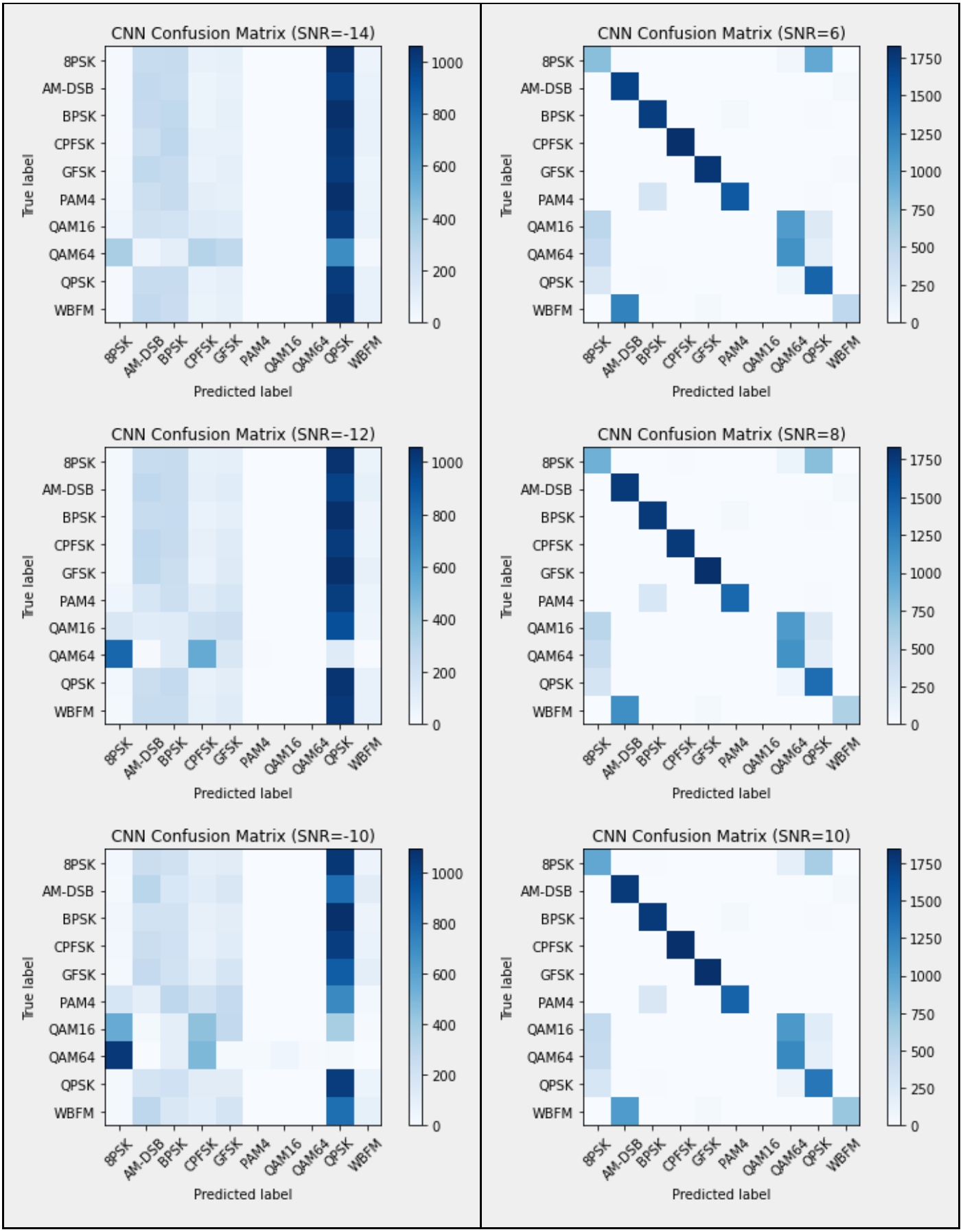
Accuracy = 0.09940093188373642 Accuracy = 0.09883233700206716 Accuracy = 0.09905210611924394 Accuracy = 0.1019533641271078 Accuracy = 0.1036615401455859 Accuracy = 0.10917201003624198 Accuracy = 0.13971759793417943 Accuracy = 0.21371168874355706 Accuracy = 0.3361881986541349 Accuracy = 0.46702386212991603	Accuracy = 0.5480933723304453 Accuracy = 0.6296008869179601 Accuracy = 0.6725980639024117 Accuracy = 0.6910143636566084 Accuracy = 0.6994602415001948 Accuracy = 0.7150668286755771 Accuracy = 0.7095055768270351 Accuracy = 0.7131571627260084 Accuracy = 0.7105336686225202 Accuracy = 0.7177972775340308

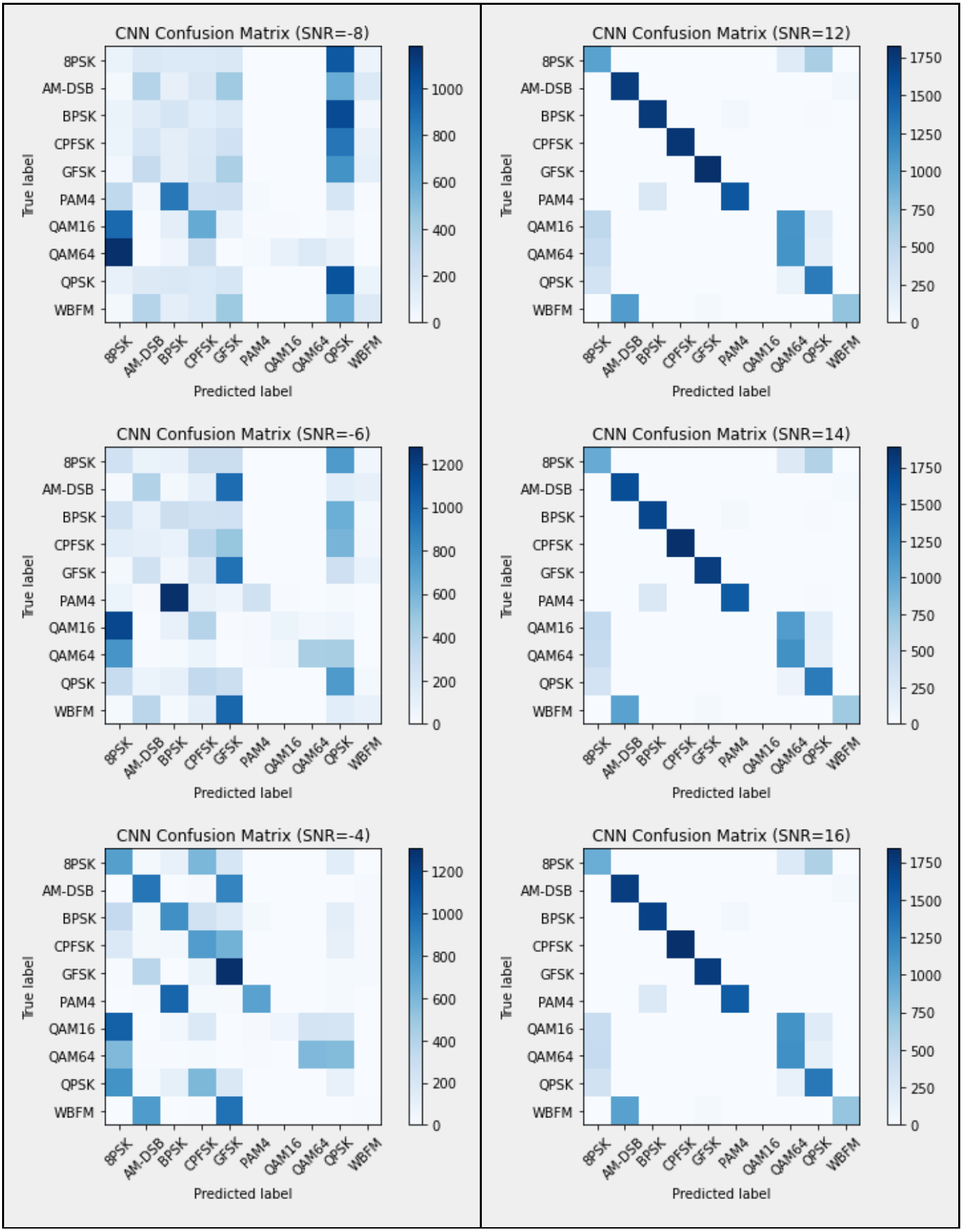
- Accuracy Against SNR

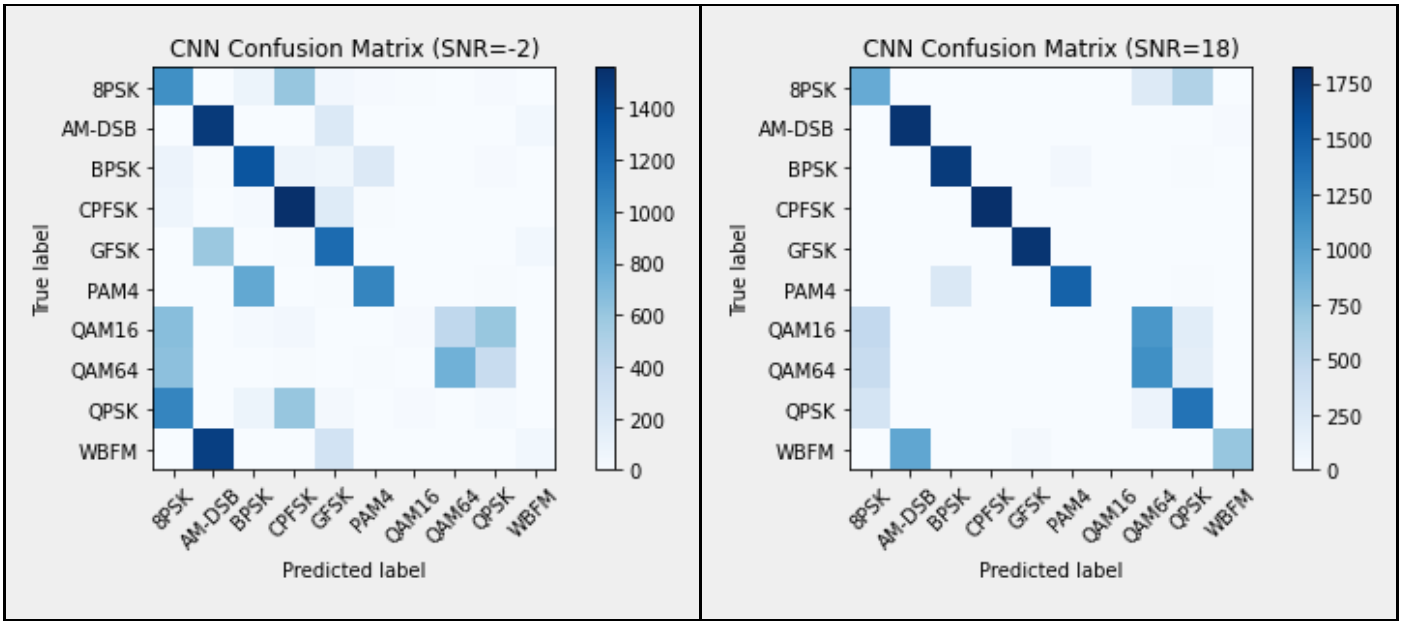


- Confusion Matrices




CNN Confusion Matrix (SNR=-14)
CNN Confusion Matrix (SNR=6)
CNN Confusion Matrix (SNR=-12)
CNN Confusion Matrix (SNR=8)
CNN Confusion Matrix (SNR=-10)
CNN Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
0
200
400
600
800
1000
250
500
750
1000
1250
1500
1750


CNN Confusion Matrix (SNR=-8)
CNN Confusion Matrix (SNR=12)
CNN Confusion Matrix (SNR=-6)
CNN Confusion Matrix (SNR=14)
CNN Confusion Matrix (SNR=-4)
CNN Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


CNN Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1400
1200
1000
800
600
400
200
0
CNN Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1750
1500
1250
1000
750
500
250
0

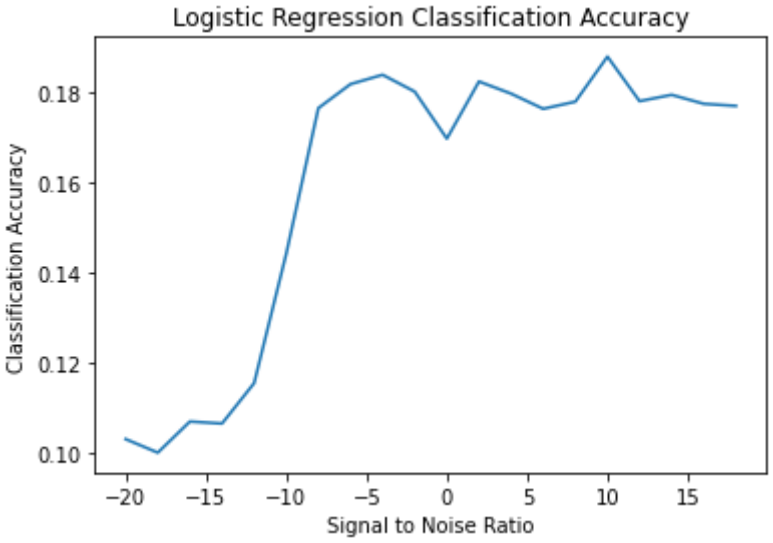
3.Integral in Time

Logistic Regression

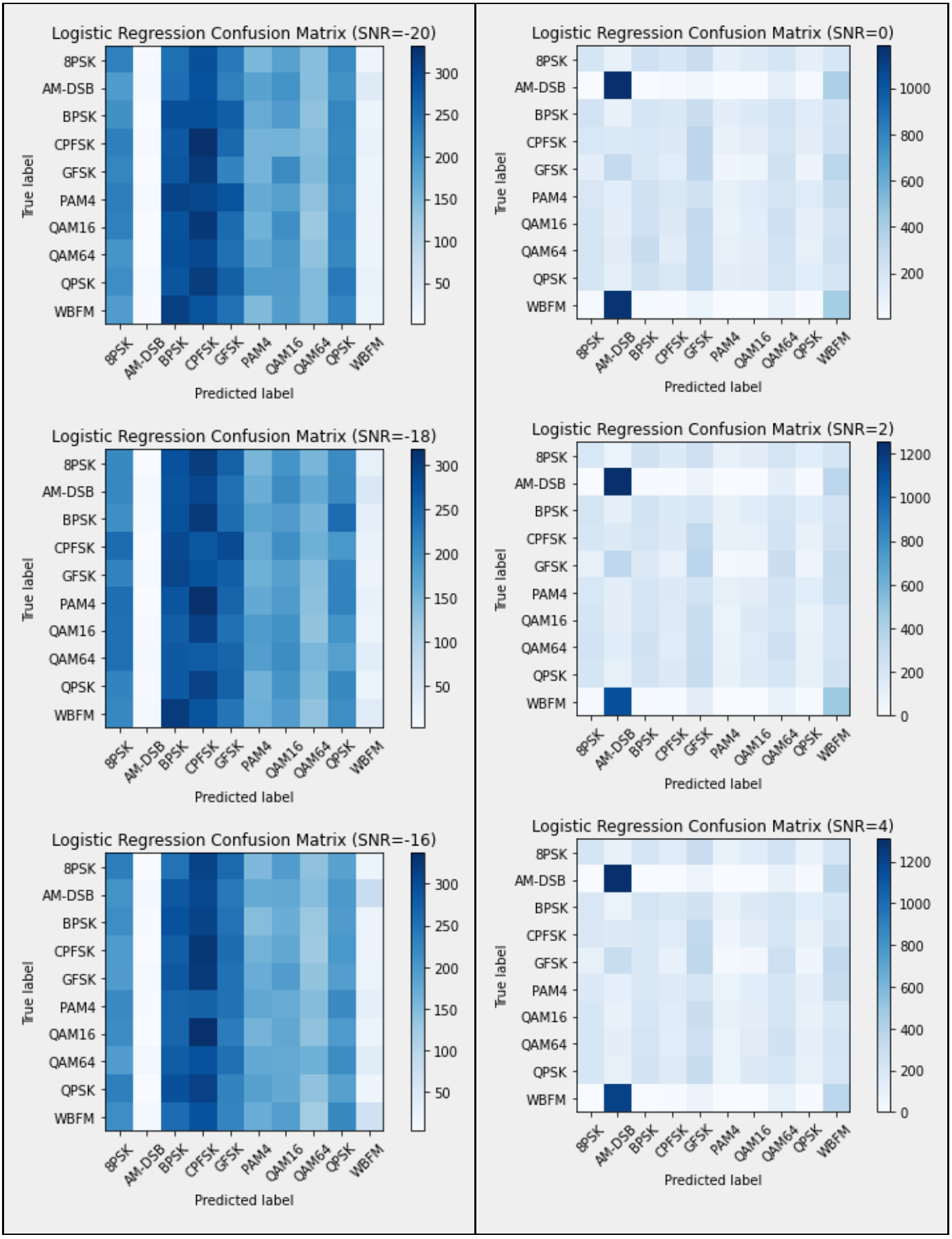
- Accuracies

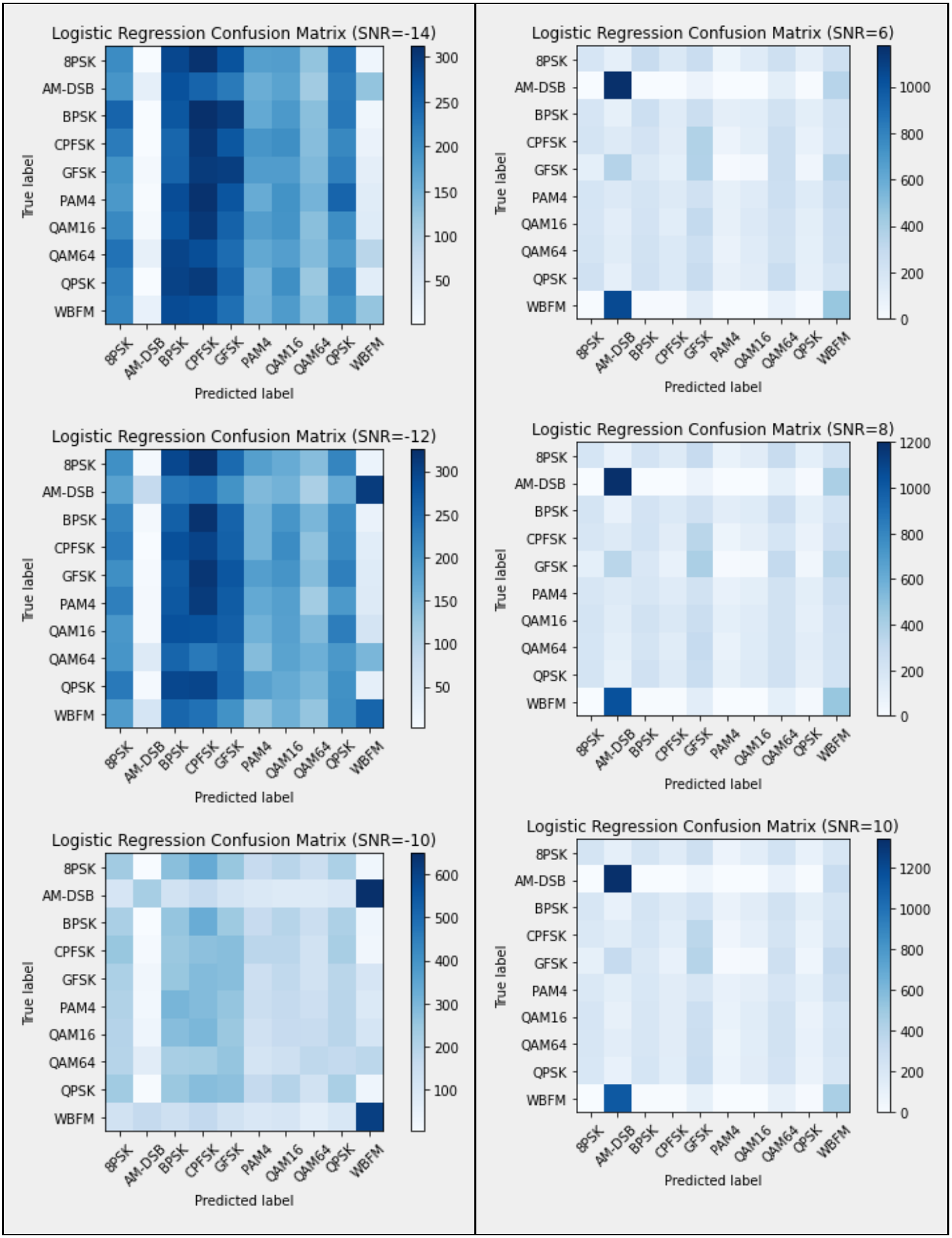
SNR = -20 Accuracy = 0.10311737297537164 SNR = -18 Accuracy = 0.10011732499022291 SNR = -16 Accuracy = 0.10701665825340737 SNR = -14 Accuracy = 0.10657243029662196 SNR = -12 Accuracy = 0.11553828471348038 SNR = -10 Accuracy = 0.14424310008363536 SNR = -8 Accuracy = 0.1765287621559255 SNR = -6 Accuracy = 0.18184337416172477 SNR = -4 Accuracy = 0.18391635615371782 SNR = -2 Accuracy = 0.18018117543084403	SNR = 0 Accuracy = 0.16974780641244963 SNR = 2 Accuracy = 0.1824279379157428 SNR = 4 Accuracy = 0.17973252755861452 SNR = 6 Accuracy = 0.17637234161006568 SNR = 8 Accuracy = 0.17795336931723332 SNR = 10 Accuracy = 0.18794874627195404 SNR = 12 Accuracy = 0.1780700294101326 SNR = 14 Accuracy = 0.17947148817802502 SNR = 16 Accuracy = 0.1774797429449567 SNR = 18 Accuracy = 0.17701653729328384

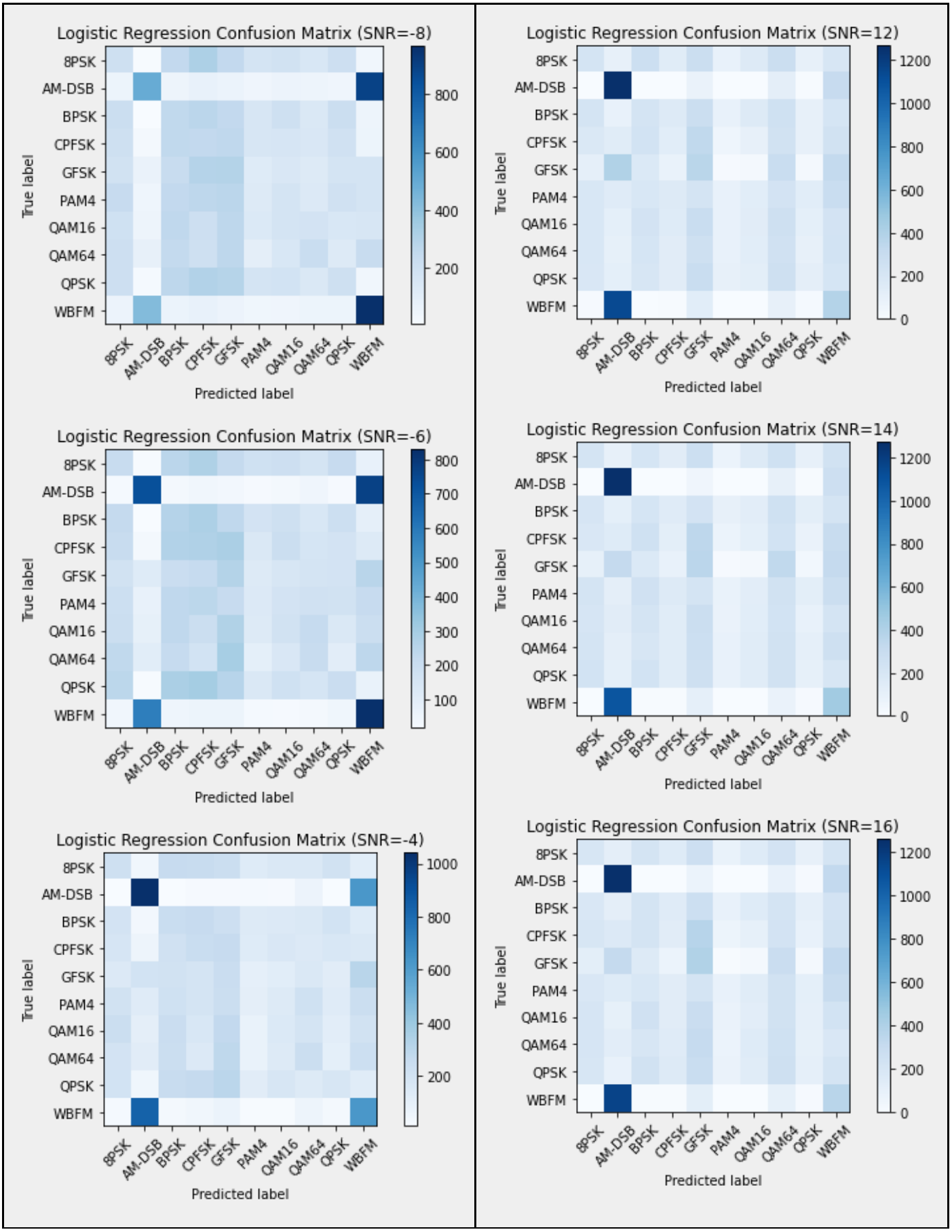
- Accuracies Against SNR

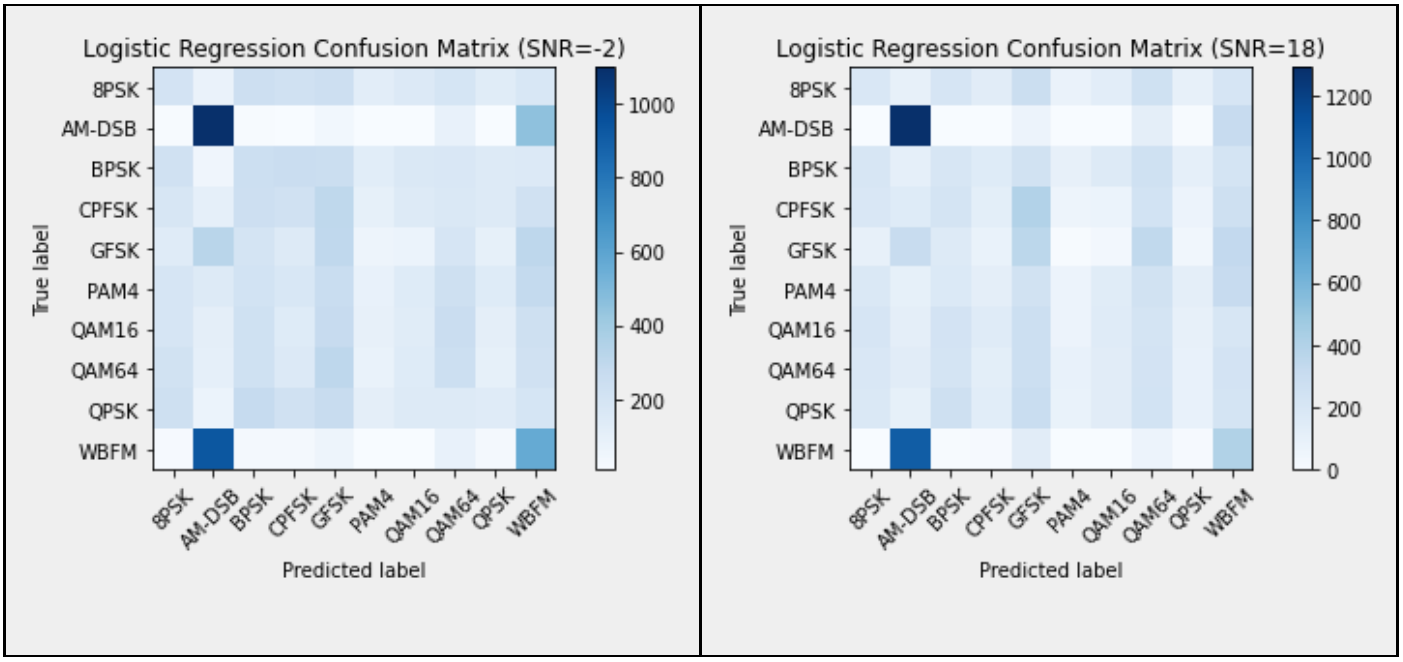


- Confusion Matrices




Logistic Regression Confusion Matrix (SNR=-14)
Logistic Regression Confusion Matrix (SNR=6)
Logistic Regression Confusion Matrix (SNR=-12)
Logistic Regression Confusion Matrix (SNR=8)
Logistic Regression Confusion Matrix (SNR=-10)
Logistic Regression Confusion Matrix (SNR=10)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM


Logistic Regression Confusion Matrix (SNR=-8)
Logistic Regression Confusion Matrix (SNR=12)
Logistic Regression Confusion Matrix (SNR=-6)
Logistic Regression Confusion Matrix (SNR=14)
Logistic Regression Confusion Matrix (SNR=-4)
Logistic Regression Confusion Matrix (SNR=16)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM

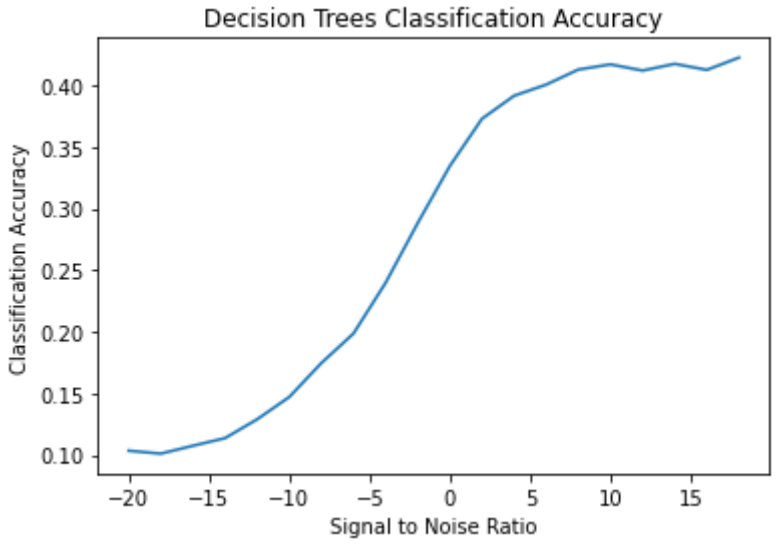

Logistic Regression Confusion Matrix (SNR=-2)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1000
800
600
400
200
Logistic Regression Confusion Matrix (SNR=18)
True label
Predicted label
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
1200
1000
800
600
400
200
0

Decision Trees

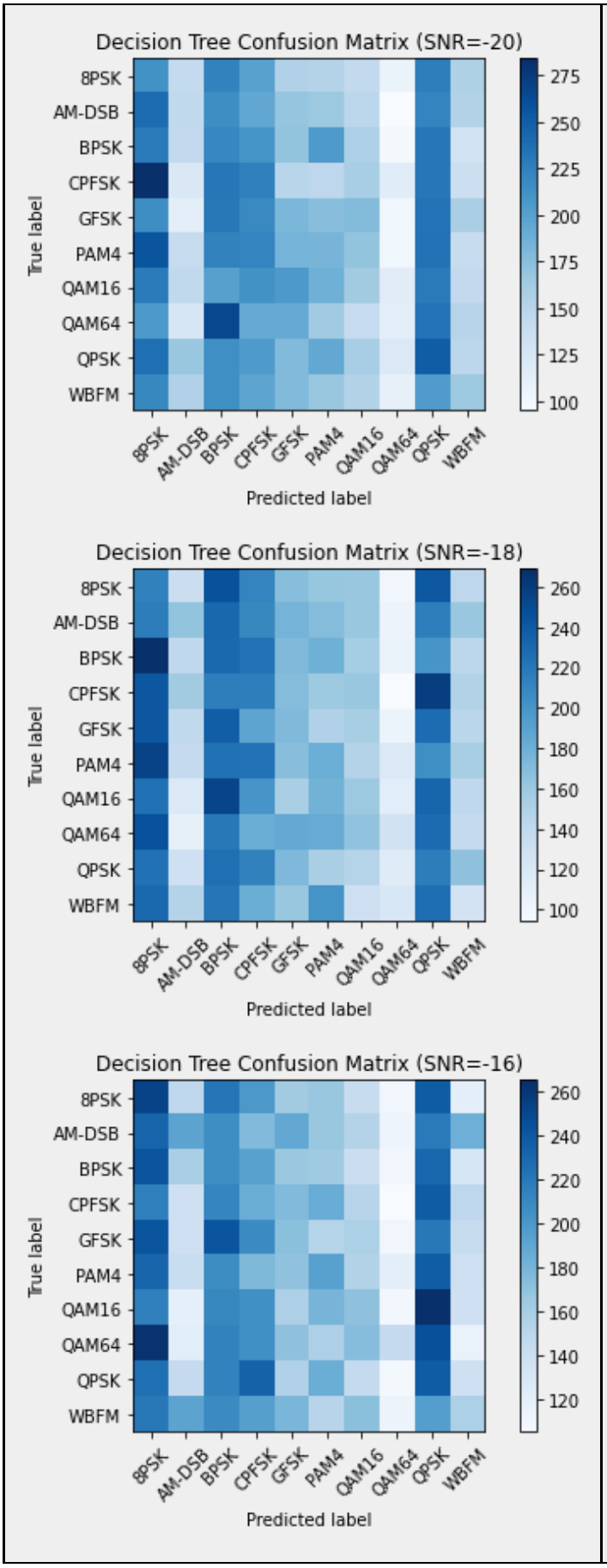
- Accuracies

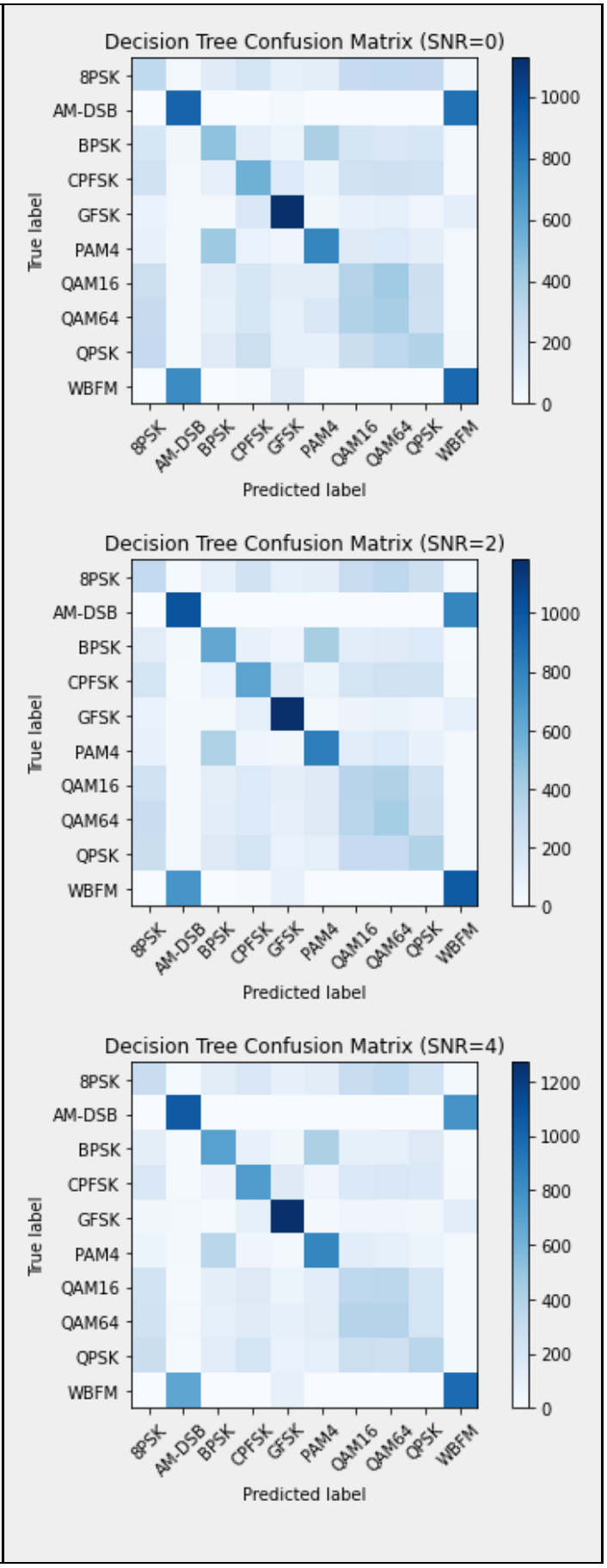
SNR = -20 Accuracy = 0.10339471932549367 SNR = -18 Accuracy = 0.10101122967763562 SNR = -16 Accuracy = 0.10740927702058443 SNR = -14 Accuracy = 0.11358450665034225 SNR = -12 Accuracy = 0.12889278090963824 SNR = -10 Accuracy = 0.14697518817953723 SNR = -8 Accuracy = 0.17455084885445854 SNR = -6 Accuracy = 0.19852574405586654 SNR = -4 Accuracy = 0.23969745842834103 SNR = -2 Accuracy = 0.2882235969951392	SNR = 0 Accuracy = 0.33452899950333864 SNR = 2 Accuracy = 0.37283813747228384 SNR = 4 Accuracy = 0.3915281741368698 SNR = 6 Accuracy = 0.4005678654938203 SNR = 8 Accuracy = 0.41277613933559626 SNR = 10 Accuracy = 0.41698884347730036 SNR = 12 Accuracy = 0.411963819987792 SNR = 14 Accuracy = 0.41741307371349096 SNR = 16 Accuracy = 0.4125174629784856 SNR = 18 Accuracy = 0.4224884688941388

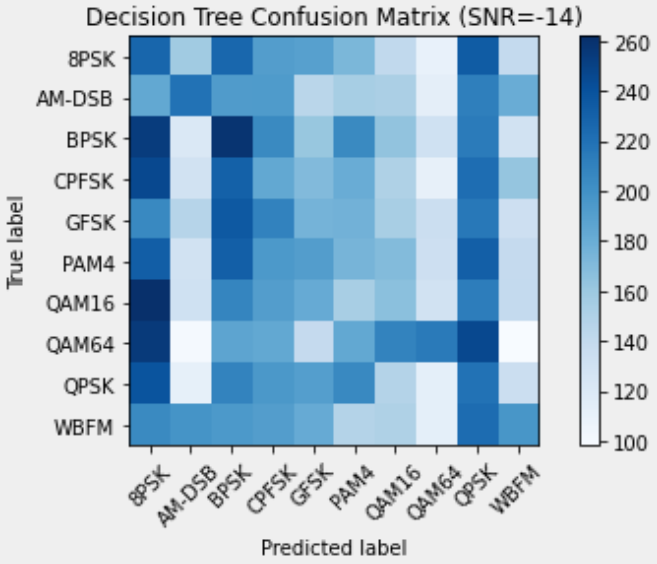
- Accuracies Against SNR

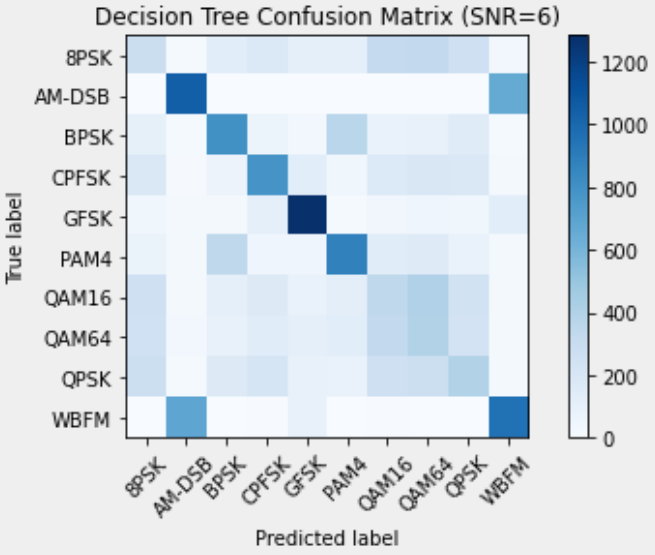


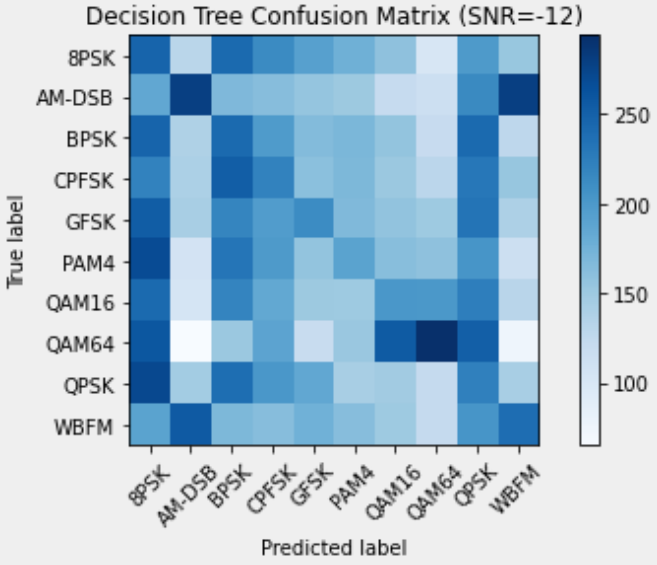
- Confusion Matrices

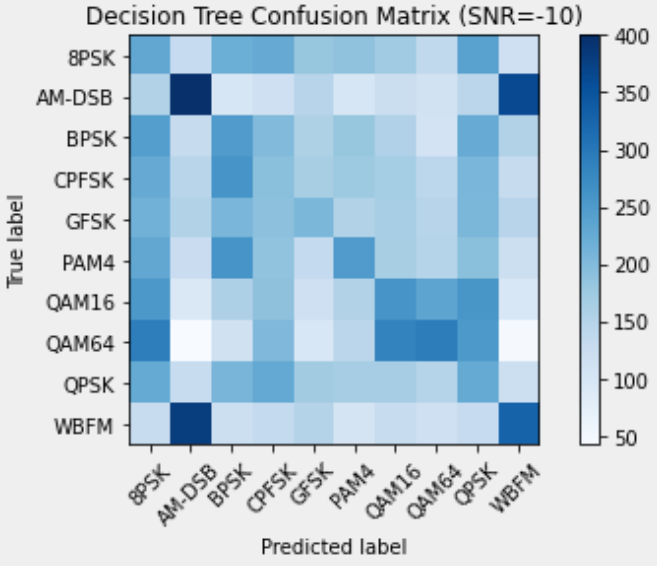





Decision Tree Confusion Matrix (SNR=-14)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
260
240
220
200
180
160
140
120
100


Decision Tree Confusion Matrix (SNR=6)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
1200
1000
800
600
400
200
0


Decision Tree Confusion Matrix (SNR=-12)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
250
200
150
100


Decision Tree Confusion Matrix (SNR=-10)
8PSK
AM-DSB
BPSK
CPFSK
GFSK
PAM4
QAM16
QAM64
QPSK
WBFM
True label
Predicted label
400
350
300
250
200
150
100
50

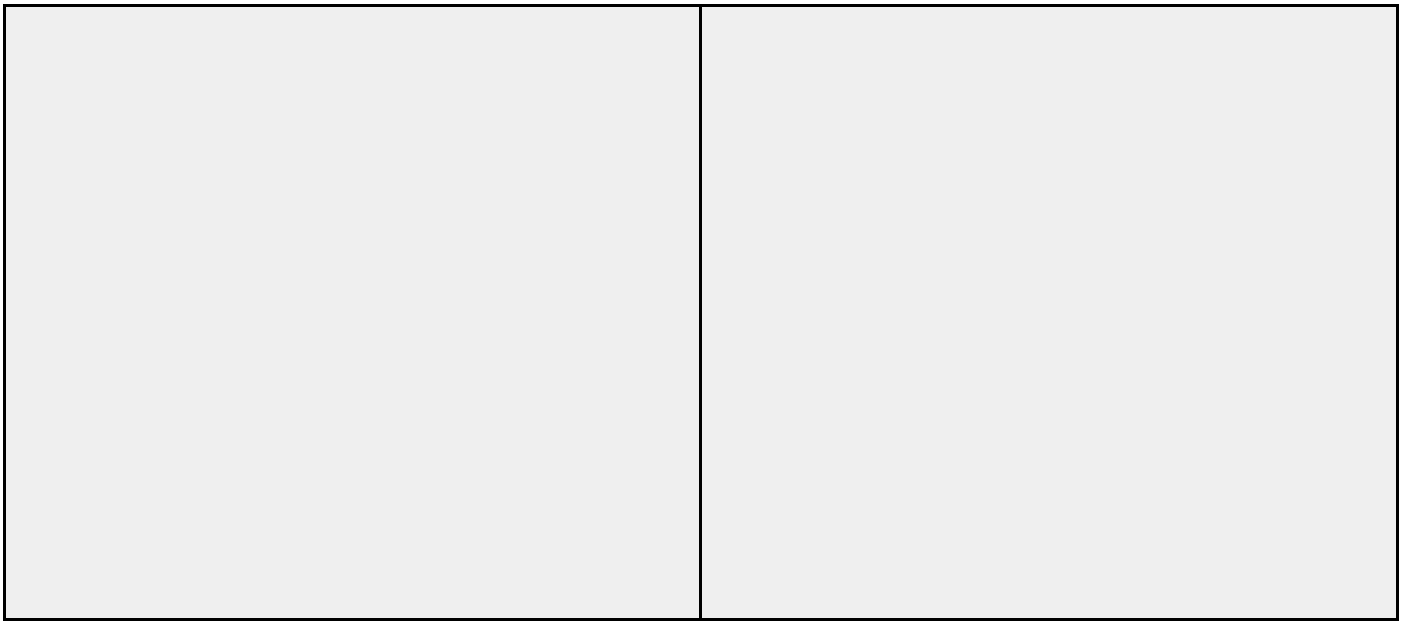
Random Forests

- Accuracies

SNR = -20 Accuracy = 0.09978921677390726 SNR = -18 Accuracy = 0.10196100340801162 SNR = -16 Accuracy = 0.0977620730270907 SNR = -14 Accuracy = 0.1029550893204964 SNR = -12 Accuracy = 0.09933774834437085 SNR = -10 Accuracy = 0.10192361304711459 SNR = -8 Accuracy = 0.10620295588154496 SNR = -6 Accuracy = 0.1400543146926786 SNR = -4 Accuracy = 0.173683332406429 SNR = -2 Accuracy = 0.19327220503756076	SNR = 0 Accuracy = 0.19750565642072734 SNR = 2 Accuracy = 0.20360310421286032 SNR = 4 Accuracy = 0.2037378993900733 SNR = 6 Accuracy = 0.20153657721857254 SNR = 8 Accuracy = 0.20510822992599187 SNR = 10 Accuracy = 0.2091571854633823 SNR = 12 Accuracy = 0.2043171855057988 SNR = 14 Accuracy = 0.20278164116828928 SNR = 16 Accuracy = 0.19485889913383628 SNR = 18 Accuracy = 0.2067724153448082

- Accuracies Against SNR

- Confusion Matrices



Dense layer NN

- Epcohs

```
Train on 798000 samples, validate on 42000 samples
Epoch 1/100
 - 3s - loss: 2.1806 - val_loss: 2.1655
Epoch 2/100
 - 3s - loss: 2.1652 - val_loss: 2.1637
Epoch 3/100
 - 3s - loss: 2.1643 - val_loss: 2.1600
Epoch 4/100
 - 3s - loss: 2.1640 - val_loss: 2.1611
Epoch 5/100
 - 3s - loss: 2.1633 - val_loss: 2.1619
Epoch 6/100
 - 3s - loss: 2.1637 - val_loss: 2.1630
Epoch 7/100
 - 3s - loss: 2.1633 - val_loss: 2.1653
Epoch 8/100
 - 3s - loss: 2.1630 - val_loss: 2.1648
```

- Accuracies

Accuracy = 0.10150876414466385	Accuracy = 0.16974780641244963
Accuracy = 0.10045253924800268	Accuracy = 0.1674611973392461
Accuracy = 0.1005104043973302	Accuracy = 0.17699065525152483
Accuracy = 0.1021203183260059	Accuracy = 0.17169580224919273
Accuracy = 0.11696130479995621	Accuracy = 0.1675477157642869
Accuracy = 0.13688318929467522	Accuracy = 0.17773113884900033
Accuracy = 0.16619965935937586	Accuracy = 0.16841462737916874
Accuracy = 0.16621404422767833	Accuracy = 0.16945757997218358
Accuracy = 0.17423947500139036	Accuracy = 0.17194747136071528
Accuracy = 0.16670349094122847	Accuracy = 0.17172910338620767

- Accuracies Against SNR

- Confusion Matrices

CNN

- Epochs

Train on 798000 samples, validate on 42000 samples

Epoch 1/100 - 35s - loss: 1.9234 - val_loss: 1.7617 Epoch 2/100 - 28s - loss: 1.7436 - val_loss: 1.6288 Epoch 3/100 - 28s - loss: 1.6607 - val_loss: 1.5251 Epoch 4/100 - 28s - loss: 1.5814 - val_loss: 1.3982 Epoch 5/100 - 28s - loss: 1.5247 - val_loss: 1.3473 Epoch 6/100 - 28s - loss: 1.4927 - val_loss: 1.3340 Epoch 7/100 - 28s - loss: 1.4627 - val_loss: 1.3201 Epoch 8/100 - 28s - loss: 1.4456 - val_loss: 1.2839 Epoch 9/100 - 28s - loss: 1.4316 - val_loss: 1.2904 Epoch 10/100 - 28s - loss: 1.4213 - val_loss: 1.2824	Epoch 11/100 - 28s - loss: 1.4122 - val_loss: 1.2509 Epoch 12/100 - 29s - loss: 1.4071 - val_loss: 1.2444 Epoch 13/100 - 28s - loss: 1.3979 - val_loss: 1.2881 Epoch 14/100 - 28s - loss: 1.3943 - val_loss: 1.2184 Epoch 15/100 - 28s - loss: 1.3854 - val_loss: 1.2460 Epoch 16/100 - 28s - loss: 1.3901 - val_loss: 1.2835 Epoch 17/100 - 28s - loss: 1.3817 - val_loss: 1.2219 Epoch 18/100 - 28s - loss: 1.3738 - val_loss: 1.2266 Epoch 19/100 - 28s - loss: 1.3742 - val_loss: 1.2185

- Accuracies

Accuracy = 0.10378300421566453 Accuracy = 0.10799486004804738 Accuracy = 0.11492512199225981 Accuracy = 0.12499304357504591 Accuracy = 0.14810355207706202 Accuracy = 0.22269305826596042 Accuracy = 0.32690511510356574 Accuracy = 0.443551515823311 Accuracy = 0.5880651799121295 Accuracy = 0.6606274856385329	Accuracy = 0.695270680426025 Accuracy = 0.7123614190687362 Accuracy = 0.7203849812545464 Accuracy = 0.7204654270125821 Accuracy = 0.7168771910299928 Accuracy = 0.7222467690268419 Accuracy = 0.710781865601243 Accuracy = 0.721835883171071 Accuracy = 0.7187482537021515 Accuracy = 0.7279221509731129

- Accuracies Against SNR

- Confusion Matrices

4. Combinations of 1,2 and 3

Logistic Regression

- Accuracies

SNR = -20 Accuracy = 0.10417128910583537 SNR = -18 Accuracy = 0.09860886083021397 SNR = -16 Accuracy = 0.10067866958326323 SNR = -14 Accuracy = 0.10835327508486839 SNR = -12 Accuracy = 0.1130206337912539 SNR = -10 Accuracy = 0.14312796208530806 SNR = -8 Accuracy = 0.17158397890225813 SNR = -6 Accuracy = 0.18123371944798536 SNR = -4 Accuracy = 0.18152494299538402 SNR = -2 Accuracy = 0.18338488731771985	SNR = 0 Accuracy = 0.17035483692952927 SNR = 2 Accuracy = 0.1802660753880266 SNR = 4 Accuracy = 0.18040400649096303 SNR = 6 Accuracy = 0.17787551497606058 SNR = 8 Accuracy = 0.17761949808024038 SNR = 10 Accuracy = 0.18783828565116537 SNR = 12 Accuracy = 0.17868042838910161 SNR = 14 Accuracy = 0.18119610570236439 SNR = 16 Accuracy = 0.1767532830399553 SNR = 18 Accuracy = 0.17696028799640004

- Accuracies Against SNR

- Confusion Matrices

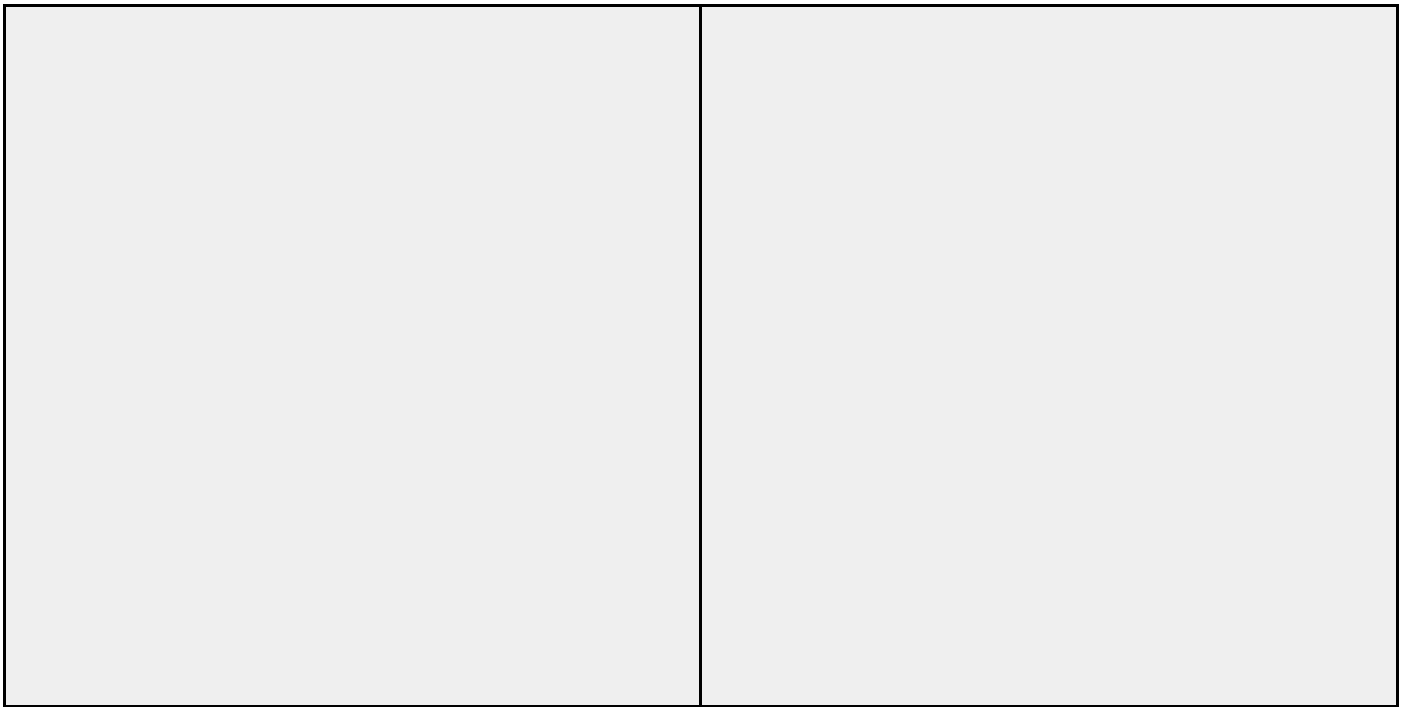
Decision Trees

- Accuracies

SNR = -20 Accuracy = 0.09990015531395607 SNR = -18 Accuracy = 0.10469858651321302 SNR = -16 Accuracy = 0.10752145381120647 SNR = -14 Accuracy = 0.11247147865768824 SNR = -12 Accuracy = 0.1194789557221827 SNR = -10 Accuracy = 0.13208809590186785 SNR = -8 Accuracy = 0.16037580352727873 SNR = -6 Accuracy = 0.18422656986088787 SNR = -4 Accuracy = 0.22690617874423002 SNR = -2 Accuracy = 0.26380910296067167	SNR = 0 Accuracy = 0.31984989790850393 SNR = 2 Accuracy = 0.3564855875831486 SNR = 4 Accuracy = 0.40881875664484363 SNR = 6 Accuracy = 0.4474446052778087 SNR = 8 Accuracy = 0.4798842579711758 SNR = 10 Accuracy = 0.5002761515519717 SNR = 12 Accuracy = 0.5119582709061651 SNR = 14 Accuracy = 0.5171070931849792 SNR = 16 Accuracy = 0.5174070969544565 SNR = 18 Accuracy = 0.5165935425807178

- Accuracies Against SNR

- Confusion Matrices



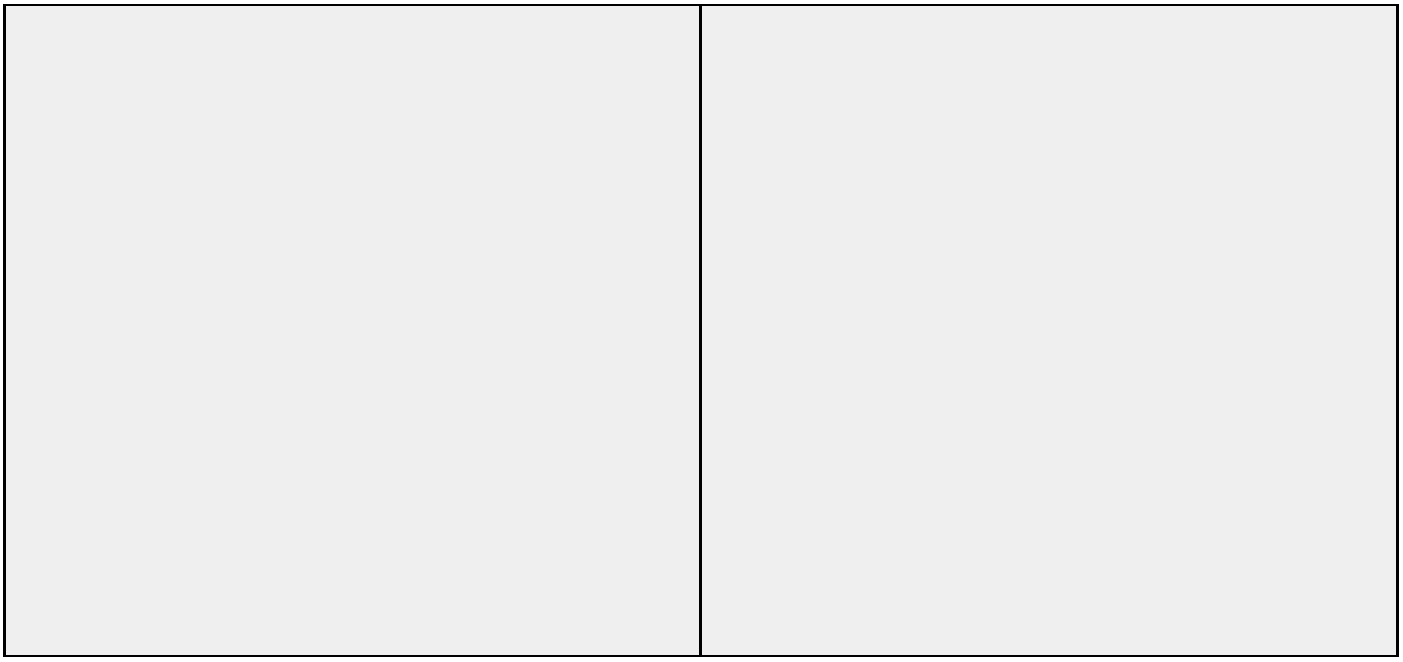
Random Forests

- Accuracies

SNR = -20 Accuracy = 0.10078766363434657 SNR = -18 Accuracy = 0.10900050282138667 SNR = -16 Accuracy = 0.1083066913455606 SNR = -14 Accuracy = 0.1253826033724748 SNR = -12 Accuracy = 0.15177056537682668 SNR = -10 Accuracy = 0.1957624756063563 SNR = -8 Accuracy = 0.24751387286412835 SNR = -6 Accuracy = 0.29557168985202015 SNR = -4 Accuracy = 0.3489238640787498 SNR = -2 Accuracy = 0.3993592576226248	SNR = 0 Accuracy = 0.46057060868605487 SNR = 2 Accuracy = 0.5178492239467849 SNR = 4 Accuracy = 0.5892787197135023 SNR = 6 Accuracy = 0.6229818505734328 SNR = 8 Accuracy = 0.6342440598742418 SNR = 10 Accuracy = 0.647520159063294 SNR = 12 Accuracy = 0.6446923034237834 SNR = 14 Accuracy = 0.6476773296244784 SNR = 16 Accuracy = 0.6501816149762504 SNR = 18 Accuracy = 0.6566542918213523

- Accuracies Against SNR

- Confusion Matrices



Dense layer NN

- Epochs

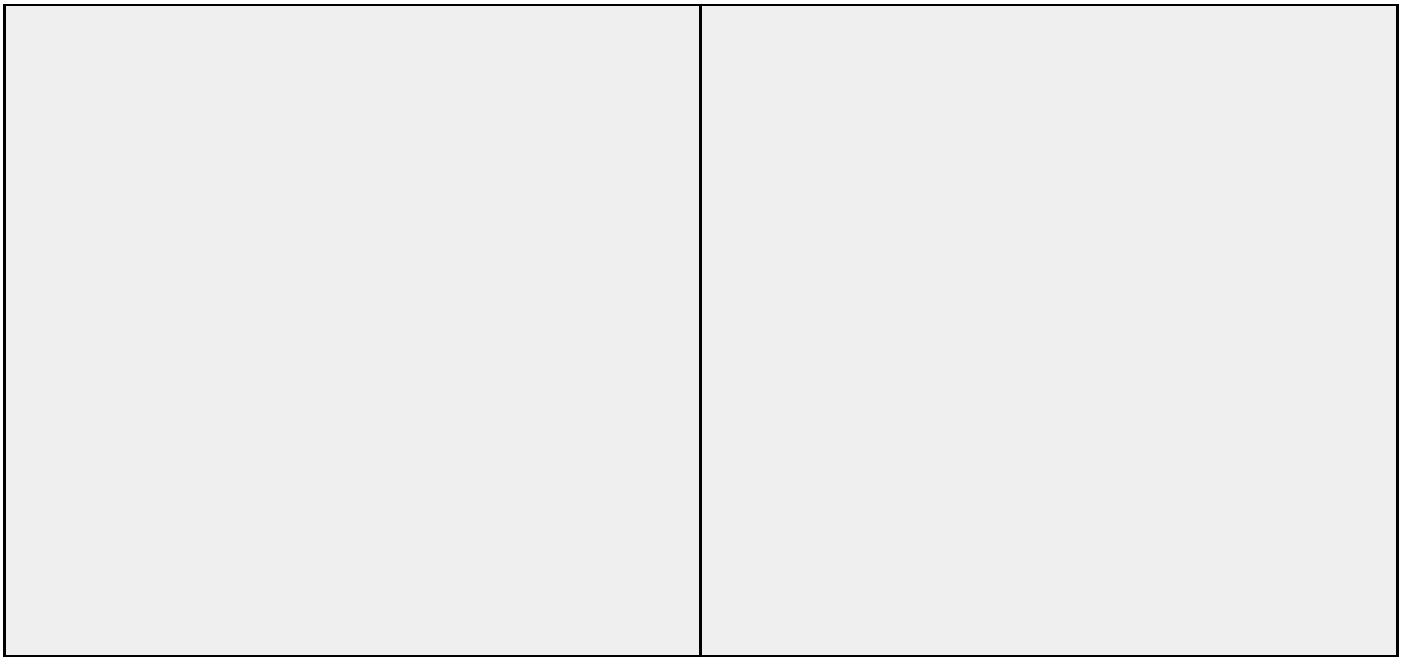
Train on 798000 samples, validate on 42000 samples Epoch 1/100 - 5s - loss: 2.2011 - val_loss: 2.1709 Epoch 2/100 - 4s - loss: 2.1732 - val_loss: 2.1710 Epoch 3/100 - 4s - loss: 2.1735 - val_loss: 2.1720 Epoch 4/100 - 4s - loss: 2.1735 - val_loss: 2.1725 Epoch 5/100 - 4s - loss: 2.1732 - val_loss: 2.1766 Epoch 6/100 - 4s - loss: 2.1736 - val_loss: 2.1689 Epoch 7/100 - 4s - loss: 2.1732 - val_loss: 2.1772 Epoch 8/100 - 4s - loss: 2.1733 - val_loss: 2.1716 Epoch 9/100 - 4s - loss: 2.1731 - val_loss: 2.1728 Epoch 10/100 - 4s - loss: 2.1731 - val_loss: 2.1712 Epoch 11/100 - 4s - loss: 2.1733 - val_loss: 2.1743	

- Accuracies

Accuracy = 0.10073219436432217 Accuracy = 0.10201687245097492 Accuracy = 0.10281002860508161 Accuracy = 0.10696199009405087 Accuracy = 0.11575721088063051 Accuracy = 0.13431837189852244 Accuracy = 0.1644964562386682 Accuracy = 0.177354098542371 Accuracy = 0.18636338357154775 Accuracy = 0.18128590366769776	Accuracy = 0.18420616963743722 Accuracy = 0.18009977827051 Accuracy = 0.18879749314531924 Accuracy = 0.18327580447611624 Accuracy = 0.18819208725168327 Accuracy = 0.18568430354578594 Accuracy = 0.18250929471172522 Accuracy = 0.18147426981919332 Accuracy = 0.18440905280804695 Accuracy = 0.18601642479469008

- Accuracies Against SNR

- Confusion Matrices



CNN

- Epochs

Epoch 1/100 - 48s - loss: 1.6144 - val_loss: 1.3816 Epoch 2/100 - 41s - loss: 1.4560 - val_loss: 1.3065 Epoch 3/100 - 41s - loss: 1.3640 - val_loss: 1.1987 Epoch 4/100 - 40s - loss: 1.3167 - val_loss: 1.1841 Epoch 5/100 - 40s - loss: 1.2979 - val_loss: 1.1700 Epoch 6/100 - 41s - loss: 1.2849 - val_loss: 1.1622 Epoch 7/100 - 40s - loss: 1.2766 - val_loss: 1.1659 Epoch 8/100 - 40s - loss: 1.2685 - val_loss: 1.1568 Epoch 9/100 - 40s - loss: 1.2627 - val_loss: 1.1557 Epoch 10/100 - 40s - loss: 1.2572 - val_loss: 1.1428 Epoch 11/100 - 40s - loss: 1.2541 - val_loss: 1.1443 Epoch 12/100 - 40s - loss: 1.2507 - val_loss: 1.1454 Epoch 13/100 - 40s - loss: 1.2472 - val_loss: 1.1452 Epoch 14/100 - 40s - loss: 1.2458 - val_loss: 1.1393 Epoch 15/100 - 40s - loss: 1.2449 - val_loss: 1.1371 Epoch 16/100 - 40s - loss: 1.2401 - val_loss: 1.1340 Epoch 17/100 - 40s - loss: 1.2353 - val_loss: 1.1333 Epoch 18/100 - 40s - loss: 1.2336 - val_loss: 1.1377 Epoch 19/100 - 40s - loss: 1.2310 - val_loss: 1.1231	Epoch 20/100 - 40s - loss: 1.2298 - val_loss: 1.1307 Epoch 21/100 - 40s - loss: 1.2278 - val_loss: 1.1185 Epoch 22/100 - 40s - loss: 1.2257 - val_loss: 1.1171 Epoch 23/100 - 40s - loss: 1.2238 - val_loss: 1.1209 Epoch 24/100 - 40s - loss: 1.2227 - val_loss: 1.1152 Epoch 25/100 - 40s - loss: 1.2224 - val_loss: 1.1206 Epoch 26/100 - 40s - loss: 1.2200 - val_loss: 1.1134 Epoch 27/100 - 40s - loss: 1.2207 - val_loss: 1.1196 Epoch 28/100 - 40s - loss: 1.2189 - val_loss: 1.1128 Epoch 29/100 - 40s - loss: 1.2167 - val_loss: 1.1227 Epoch 30/100 - 40s - loss: 1.2151 - val_loss: 1.1169 Epoch 31/100 - 40s - loss: 1.2138 - val_loss: 1.1137 Epoch 32/100 - 40s - loss: 1.2130 - val_loss: 1.1147 Epoch 33/100 - 40s - loss: 1.2126 - val_loss: 1.1124 Epoch 34/100 - 40s - loss: 1.2112 - val_loss: 1.1157 Epoch 35/100 - 40s - loss: 1.2109 - val_loss: 1.1170 Epoch 36/100 - 40s - loss: 1.2088 - val_loss: 1.1148 Epoch 37/100 - 40s - loss: 1.2079 - val_loss: 1.1222 Epoch 38/100 - 40s - loss: 1.2068 - val_loss: 1.1221

- Accuracies

Accuracy = 0.09923452407366319 Accuracy = 0.10324599139616739 Accuracy = 0.1099332548095799 Accuracy = 0.12198786799488007 Accuracy = 0.14279459252367138 Accuracy = 0.20814050738778925 Accuracy = 0.32360859293445415 Accuracy = 0.4545807238264147 Accuracy = 0.5808909404371281 Accuracy = 0.6789659743703049	Accuracy = 0.7439434909773192 Accuracy = 0.7706208425720621 Accuracy = 0.7790274746796486 Accuracy = 0.7850462086627324 Accuracy = 0.7867675699738468 Accuracy = 0.7869766928090136 Accuracy = 0.7884690083791133 Accuracy = 0.7920445062586926 Accuracy = 0.7836825929030455 Accuracy = 0.7948588142648217

- Accuracies Against SNR

- Confusion Matrices