EXP 1

In [10]:
```
# Complex pytorch
import torch
import torch.nn as nn
import torch.nn.functional as F
from torch.utils.data import DataLoader
from torchvision import datasets, transforms
from complexPyTorch.complexLayers import *
from complexPyTorch.complexFunctions import *

# Plot
import matplotlib.pyplot as plt
import seaborn as sns
import time

# Load Data
import numpy as np
import json
import os
import math
import librosa
import pathlib
from scipy.spatial.distance import cdist
from torch.utils.data import Dataset

# MFCCS
from scipy.io import wavfile
import scipy.fftpack as fft
from scipy.signal import get_window
```

In [11]:
```
def train(model, device, train_loader, test_loader, optimizer, epoch, met
    model.train()
    total_loss = 0
    correct = 0
    total_samples = len(train_loader.dataset)
    start_time = time.time()

    for batch_idx, (data, target) in enumerate(train_loader):
        data, target = data.to(device), target.to(device)
        if complexify: data = data.type(torch.complex64)
        if data_fn != None: data = data_fn(data)
        optimizer.zero_grad()
        output = model(data)
        loss = F.nll_loss(output, target)
        loss.backward()
        optimizer.step()
        total_loss += loss.item()
        pred = output.argmax(dim=1, keepdim=True)
        correct += pred.eq(target.view_as(pred)).sum().item()

        if batch_idx % 100 == 0:
            batch_accuracy = 100. * correct / ((batch_idx + 1) * len(data
            print('Train Epoch: {:3} [{:6}/{:6} ({:3.0f}%)]\tLoss: {:.6f}
                epoch,
                batch_idx * len(data),
```

```
                total_samples,
                100. * batch_idx / len(train_loader),
                loss.item(),
                batch_accuracy)
            )

    end_time = time.time()
    epoch_times = metrics_dict['epoch_times']
    epoch_times.append(end_time - start_time)
    epoch_loss = total_loss / len(train_loader)
    epoch_accuracy = 100. * correct / total_samples
    train_losses = metrics_dict['train_losses']
    train_accuracies = metrics_dict['train_accuracies']
    train_losses.append(epoch_loss)
    train_accuracies.append(epoch_accuracy)
    print('Epoch {} - Time: {:.2f}s - Train Loss: {:.6f} - Train Accuracy

    # Evaluate on test data
    model.eval()
    test_loss = 0
    correct = 0
    with torch.no_grad():
        for data, target in test_loader:
            data, target = data.to(device), target.to(device)
            if complexify:
                data = data.type(torch.complex64)
            output = model(data)
            test_loss += F.nll_loss(output, target, reduction='sum').item
            pred = output.argmax(dim=1, keepdim=True)
            correct += pred.eq(target.view_as(pred)).sum().item()

    test_loss /= len(test_loader.dataset)
    test_accuracy = 100. * correct / len(test_loader.dataset)
    test_losses = metrics_dict['test_losses']
    test_accuracies = metrics_dict['test_accuracies']
    test_losses.append(test_loss)
    test_accuracies.append(test_accuracy)
    print('Test Loss: {:.6f} - Test Accuracy: {:.2f}%\n'.format(test_loss
```

FMNIST

In [12]:
```
NUM_EPOCHS = 10
batch_size = 64
trans = transforms.Compose([transforms.ToTensor(), transforms.Normalize((

train_set = datasets.FashionMNIST('../data', train=True, transform=trans,
test_set = datasets.FashionMNIST('../data', train=False, transform=trans,

train_loader = torch.utils.data.DataLoader(train_set, batch_size= batch_s
test_loader = torch.utils.data.DataLoader(test_set, batch_size= batch_siz
```

1. Real Net

In [13]:
```
class RealNet(nn.Module):

    def __init__(self):
```

```
        super(RealNet, self).__init__()
        self.conv1 = nn.Conv2d(1, 32, 5, 1)
        self.bn  = nn.BatchNorm2d(32)
        self.conv2 = nn.Conv2d(32, 64, 5, 1)
        self.fc1 = nn.Linear(4*4*64, 500)
        self.fc2 = nn.Linear(500, 10)

    def forward(self,x):
        x = self.conv1(x)
        x = F.relu(x)
        x = F.max_pool2d(x, 2, 2)
        x = self.bn(x)
        x = self.conv2(x)
        x = F.relu(x)
        x = F.max_pool2d(x, 2, 2)
        x = x.view(-1,4*4*64)
        x = self.fc1(x)
        x = F.relu(x)
        x = self.fc2(x)
        x = x.abs()
        x =  F.log_softmax(x, dim=1)
        return x

device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
model = RealNet().to(device)
optimizer = torch.optim.SGD(model.parameters(), lr=0.01, momentum=0.9)

metrics_dict_e1 = {
    'epoch_times': [],
    'train_losses': [],
    'train_accuracies': [],
    'test_losses': [],
    'test_accuracies': []
}

for epoch in range(NUM_EPOCHS):
    train(model,
          device,
          train_loader,
          test_loader,
          optimizer,
          epoch,
          metrics_dict_e1,
          complexify = False)

print("-"*100)
print("-"*100)
print("FINAL RESULTS:")
print("-"*100)
for key, value in metrics_dict_e1.items():
    print(f'{key}: {value}')
```

```
Train Epoch:   0 [     0/ 60000 (  0%)] Loss: 2.315676  Accuracy: 6.25%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.409841  Accuracy: 67.56%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.346875  Accuracy: 74.31%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.396097  Accuracy: 77.75%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.371347  Accuracy: 79.56%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.318651  Accuracy: 80.86%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.323610  Accuracy: 81.82%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.451838  Accuracy: 82.55%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.514816  Accuracy: 83.15%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.168160  Accuracy: 83.69%
Epoch 0 - Time: 30.00s - Train Loss: 0.444738 - Train Accuracy: 83.86%
Test Loss: 0.327203 - Test Accuracy: 88.00%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.286846  Accuracy: 90.62%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.317968  Accuracy: 89.23%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.158048  Accuracy: 89.89%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.402442  Accuracy: 89.79%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.284155  Accuracy: 89.74%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.115175  Accuracy: 89.82%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.149641  Accuracy: 89.68%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.315912  Accuracy: 89.69%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.334580  Accuracy: 89.74%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.102470  Accuracy: 89.76%
Epoch 1 - Time: 28.28s - Train Loss: 0.278525 - Train Accuracy: 89.78%
Test Loss: 0.315291 - Test Accuracy: 88.39%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.130112  Accuracy: 96.88%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.188076  Accuracy: 91.52%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.161182  Accuracy: 91.32%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.111061  Accuracy: 91.42%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.157193  Accuracy: 91.39%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.252118  Accuracy: 91.26%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.377096  Accuracy: 91.35%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.151818  Accuracy: 91.31%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.189430  Accuracy: 91.27%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.379258  Accuracy: 91.30%
Epoch 2 - Time: 24.28s - Train Loss: 0.237062 - Train Accuracy: 91.30%
Test Loss: 0.307424 - Test Accuracy: 88.86%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.230534  Accuracy: 90.62%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.145297  Accuracy: 92.45%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.094162  Accuracy: 92.89%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.117132  Accuracy: 92.96%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.142862  Accuracy: 92.81%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.204783  Accuracy: 92.74%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.369322  Accuracy: 92.64%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.234956  Accuracy: 92.60%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.229509  Accuracy: 92.55%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.145785  Accuracy: 92.56%
Epoch 3 - Time: 23.78s - Train Loss: 0.203410 - Train Accuracy: 92.55%
Test Loss: 0.257693 - Test Accuracy: 90.92%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.214308  Accuracy: 92.19%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.224392  Accuracy: 93.73%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.270269  Accuracy: 93.90%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.207187  Accuracy: 93.73%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.072001  Accuracy: 93.61%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.189297  Accuracy: 93.58%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.139014  Accuracy: 93.46%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.325308  Accuracy: 93.44%
```

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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.141790  Accuracy: 93.45%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.244016  Accuracy: 93.40%
Epoch 4 - Time: 23.47s - Train Loss: 0.178924 - Train Accuracy: 93.34%
Test Loss: 0.256589 - Test Accuracy: 90.75%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.075818  Accuracy: 96.88%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.135667  Accuracy: 94.31%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.076029  Accuracy: 94.25%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.206006  Accuracy: 94.39%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.128900  Accuracy: 94.33%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.142515  Accuracy: 94.23%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.130265  Accuracy: 94.16%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.139709  Accuracy: 94.20%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.154686  Accuracy: 94.22%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.327506  Accuracy: 94.19%
Epoch 5 - Time: 23.54s - Train Loss: 0.156530 - Train Accuracy: 94.19%
Test Loss: 0.262994 - Test Accuracy: 91.13%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.058499  Accuracy: 98.44%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.076676  Accuracy: 95.92%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.200752  Accuracy: 95.23%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.107956  Accuracy: 95.10%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.179231  Accuracy: 94.97%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.144495  Accuracy: 94.91%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.219555  Accuracy: 94.96%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.154494  Accuracy: 94.92%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.101774  Accuracy: 94.89%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.139406  Accuracy: 94.92%
Epoch 6 - Time: 23.45s - Train Loss: 0.135409 - Train Accuracy: 94.94%
Test Loss: 0.286969 - Test Accuracy: 90.53%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.097917  Accuracy: 96.88%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.204961  Accuracy: 95.92%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.064484  Accuracy: 95.84%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.074877  Accuracy: 95.85%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.070930  Accuracy: 95.85%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.055788  Accuracy: 95.65%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.020323  Accuracy: 95.63%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.133942  Accuracy: 95.62%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.104698  Accuracy: 95.57%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.084805  Accuracy: 95.52%
Epoch 7 - Time: 23.43s - Train Loss: 0.118414 - Train Accuracy: 95.52%
Test Loss: 0.279694 - Test Accuracy: 91.55%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.058727  Accuracy: 98.44%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.170708  Accuracy: 96.55%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.087986  Accuracy: 96.47%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.072921  Accuracy: 96.46%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.087852  Accuracy: 96.35%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.082728  Accuracy: 96.24%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.128710  Accuracy: 96.25%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.091293  Accuracy: 96.16%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.129144  Accuracy: 96.15%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.036152  Accuracy: 96.08%
Epoch 8 - Time: 23.54s - Train Loss: 0.104453 - Train Accuracy: 96.11%
Test Loss: 0.308633 - Test Accuracy: 91.02%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.081624  Accuracy: 98.44%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.017054  Accuracy: 96.52%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.015555  Accuracy: 96.82%
```

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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.050732  Accuracy: 96.76%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.130537  Accuracy: 96.70%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.102304  Accuracy: 96.66%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.031097  Accuracy: 96.66%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.176796  Accuracy: 96.66%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.053709  Accuracy: 96.53%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.145290  Accuracy: 96.52%
Epoch 9 - Time: 23.35s - Train Loss: 0.091282 - Train Accuracy: 96.53%
Test Loss: 0.295521 - Test Accuracy: 91.30%

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FINAL RESULTS:
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epoch_times: [30.000770092010498, 28.2760169506073, 24.27866506576538, 23.
77922797203064, 23.47247004508972, 23.537068843841553, 23.449074745178223,
23.432597875595093, 23.53719687461853, 23.348009824752808]
train_losses: [0.4447379891139104, 0.2785253383314559, 0.2370622137875191,
0.20341022475473663, 0.17892430245236896, 0.1565301854993457, 0.1354088897
3263535, 0.11841420300984021, 0.10445319112342621, 0.09128239292647443]
train_accuracies: [83.85666666666667, 89.785, 91.30333333333333, 92.55, 9
3.34, 94.18666666666667, 94.94, 95.52333333333333, 96.115, 96.526666666666
67]
test_losses: [0.3272031702518463, 0.3152910099506378, 0.307423547744751,
0.25769291825294494, 0.2565886893749237, 0.26299426438808443, 0.2869687207
698822, 0.27969385023117066, 0.3086325029730797, 0.29552067153453826]
test_accuracies: [88.0, 88.39, 88.86, 90.92, 90.75, 91.13, 90.53, 91.55, 9
1.02, 91.3]
```

2. Complex Net

In [15]:

```
class ComplexNet(nn.Module):

    def __init__(self):
        super(ComplexNet, self).__init__()
        self.conv1 = ComplexConv2d(1, 32, 5, 1)
        self.bn  = ComplexBatchNorm2d(32)
        self.conv2 = ComplexConv2d(32, 64, 5, 1)
        self.fc1 = ComplexLinear(4*4*64, 500)
        self.fc2 = ComplexLinear(500, 10)

    def forward(self,x):
        x = self.conv1(x)
        x = complex_relu(x)
        x = complex_max_pool2d(x, 2, 2)
        x = self.bn(x)
        x = self.conv2(x)
        x = complex_relu(x)
        x = complex_max_pool2d(x, 2, 2)
        x = x.view(-1,4*4*64)
        x = self.fc1(x)
        x = complex_relu(x)
        x = self.fc2(x)
        x = x.abs()
        x =  F.log_softmax(x, dim=1)
        return x
```

```
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
model = ComplexNet().to(device)
optimizer = torch.optim.SGD(model.parameters(), lr=0.01, momentum=0.9)

metrics_dict_e2 = {
    'epoch_times': [],
    'train_losses': [],
    'train_accuracies': [],
    'test_losses': [],
    'test_accuracies': []
}

for epoch in range(NUM_EPOCHS):
    train(model,
          device,
          train_loader,
          test_loader,
          optimizer,
          epoch,
          metrics_dict_e2)

print("-"*100)
print("-"*100)
print("FINAL RESULTS:")
print("-"*100)
for key, value in metrics_dict_e2.items():
    print(f'{key}: {value}')
```

```
Train Epoch:   0 [     0/ 60000 (  0%)] Loss: 2.366736  Accuracy: 10.94%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.593536  Accuracy: 73.42%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.455262  Accuracy: 78.03%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.297775  Accuracy: 80.40%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.579144  Accuracy: 81.84%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.191195  Accuracy: 82.87%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.317243  Accuracy: 83.73%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.363055  Accuracy: 84.31%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.283739  Accuracy: 84.85%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.296508  Accuracy: 85.21%
Epoch 0 - Time: 143.58s - Train Loss: 0.409262 - Train Accuracy: 85.28%
Test Loss: 0.354548 - Test Accuracy: 86.77%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.386739  Accuracy: 87.50%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.213967  Accuracy: 89.73%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.253813  Accuracy: 89.57%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.194220  Accuracy: 89.38%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.357974  Accuracy: 89.53%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.386522  Accuracy: 89.71%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.210178  Accuracy: 89.88%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.272176  Accuracy: 89.97%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.169558  Accuracy: 90.04%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.242087  Accuracy: 90.01%
Epoch 1 - Time: 154.01s - Train Loss: 0.270937 - Train Accuracy: 90.00%
Test Loss: 0.303149 - Test Accuracy: 89.33%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.196990  Accuracy: 89.06%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.256082  Accuracy: 92.26%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.103455  Accuracy: 92.16%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.107491  Accuracy: 92.26%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.250412  Accuracy: 92.16%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.214511  Accuracy: 92.08%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.163439  Accuracy: 91.93%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.379869  Accuracy: 91.84%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.198713  Accuracy: 91.87%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.227796  Accuracy: 91.78%
Epoch 2 - Time: 152.94s - Train Loss: 0.224858 - Train Accuracy: 91.80%
Test Loss: 0.277237 - Test Accuracy: 90.14%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.253995  Accuracy: 92.19%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.160087  Accuracy: 93.67%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.182691  Accuracy: 93.54%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.059996  Accuracy: 93.35%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.128626  Accuracy: 93.21%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.243489  Accuracy: 93.10%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.186772  Accuracy: 93.03%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.256917  Accuracy: 93.00%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.116986  Accuracy: 93.02%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.244468  Accuracy: 93.03%
Epoch 3 - Time: 153.71s - Train Loss: 0.189086 - Train Accuracy: 93.05%
Test Loss: 0.284554 - Test Accuracy: 90.28%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.151767  Accuracy: 93.75%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.208808  Accuracy: 94.38%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.108951  Accuracy: 94.46%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.173201  Accuracy: 94.32%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.136274  Accuracy: 94.22%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.224998  Accuracy: 94.21%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.186675  Accuracy: 94.15%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.205426  Accuracy: 94.11%
```

```
Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.215227  Accuracy: 94.09%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.123406  Accuracy: 94.02%
Epoch 4 - Time: 154.76s - Train Loss: 0.159523 - Train Accuracy: 94.07%
Test Loss: 0.273106 - Test Accuracy: 91.08%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.124026  Accuracy: 95.31%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.158429  Accuracy: 95.67%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.139809  Accuracy: 95.61%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.147876  Accuracy: 95.42%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.171237  Accuracy: 95.40%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.106195  Accuracy: 95.34%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.184949  Accuracy: 95.34%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.147065  Accuracy: 95.19%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.083868  Accuracy: 95.16%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.100962  Accuracy: 95.10%
Epoch 5 - Time: 154.13s - Train Loss: 0.130625 - Train Accuracy: 95.11%
Test Loss: 0.268581 - Test Accuracy: 91.43%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.048213  Accuracy: 98.44%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.225368  Accuracy: 96.58%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.109850  Accuracy: 96.29%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.129999  Accuracy: 96.13%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.043306  Accuracy: 96.05%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.053671  Accuracy: 96.04%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.028164  Accuracy: 95.96%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.072753  Accuracy: 95.95%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.053589  Accuracy: 95.86%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.098598  Accuracy: 95.79%
Epoch 6 - Time: 152.86s - Train Loss: 0.110449 - Train Accuracy: 95.79%
Test Loss: 0.300286 - Test Accuracy: 91.23%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.023783  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.168462  Accuracy: 96.33%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.060488  Accuracy: 96.55%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.202096  Accuracy: 96.66%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.035226  Accuracy: 96.63%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.045404  Accuracy: 96.62%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.087687  Accuracy: 96.59%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.133139  Accuracy: 96.55%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.032404  Accuracy: 96.52%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.049909  Accuracy: 96.48%
Epoch 7 - Time: 154.09s - Train Loss: 0.093692 - Train Accuracy: 96.44%
Test Loss: 0.305205 - Test Accuracy: 90.98%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.074146  Accuracy: 96.88%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.059767  Accuracy: 97.43%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.108348  Accuracy: 97.60%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.103453  Accuracy: 97.35%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.011272  Accuracy: 97.30%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.030128  Accuracy: 97.23%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.112301  Accuracy: 97.04%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.043544  Accuracy: 96.96%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.152963  Accuracy: 96.89%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.033672  Accuracy: 96.91%
Epoch 8 - Time: 153.05s - Train Loss: 0.082373 - Train Accuracy: 96.90%
Test Loss: 0.331076 - Test Accuracy: 90.90%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.027256  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.028739  Accuracy: 97.74%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.034596  Accuracy: 97.86%
```

```
Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.072939  Accuracy: 97.76%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.149534  Accuracy: 97.63%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.094451  Accuracy: 97.61%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.145551  Accuracy: 97.57%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.040354  Accuracy: 97.50%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.055273  Accuracy: 97.47%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.094636  Accuracy: 97.50%
Epoch 9 - Time: 153.28s - Train Loss: 0.067603 - Train Accuracy: 97.48%
Test Loss: 0.355986 - Test Accuracy: 90.58%

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FINAL RESULTS:
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epoch_times: [143.5808389186859, 154.01246881484985, 152.94485807418823, 1
53.70599603652954, 154.76405477523804, 154.1295449733734, 152.856467962265
01, 154.09471702575684, 153.05442190170288, 153.2801730632782]
train_losses: [0.40926206819633687, 0.2709371703607378, 0.2248578871935923
7, 0.18908613583029332, 0.1595229963237829, 0.13062455742034132, 0.1104492
0947768096, 0.09369162203612993, 0.08237296570467749, 0.06760316746962715]
train_accuracies: [85.285, 90.00333333333333, 91.795, 93.04666666666667, 9
4.07, 95.11166666666666, 95.78666666666666, 96.435, 96.90166666666667, 97.
48333333333333]
test_losses: [0.3545477780342102, 0.3031487021327019, 0.2772373955011368,
0.2845541577398777, 0.27310587332248687, 0.26858091340065005, 0.3002856332
540512, 0.30520517792701723, 0.3310755251348019, 0.35598566434383394]
test_accuracies: [86.77, 89.33, 90.14, 90.28, 91.08, 91.43, 91.23, 90.98,
90.9, 90.58]
```

3. Functional changes!

In [16]:
```python
def add_random_small_complex_number(data, small_value=1e-5):
    # Generates a random complex number with small magnitudes
    real_part = torch.randn_like(data.real) * small_value
    imag_part = torch.randn_like(data.imag) * small_value
    small_complex = torch.complex(real_part, imag_part)
    return data + small_complex

def add_fixed_phase(data, phase_value=0.5):
    # Adds a fixed phase to each complex number
    phase_value = torch.tensor(phase_value)
    phase_complex = torch.complex(torch.cos(phase_value), torch.sin(phase
    return data * phase_complex

def add_fixed_imaginary_component(data, imaginary_value=0.1):
    # Adds a fixed imaginary component to each complex number
    real_part = data.real
    imag_part = torch.ones_like(data.imag) * imaginary_value
    return torch.complex(real_part, imag_part)
```

In [17]:
```python
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
model = ComplexNet().to(device)
optimizer = torch.optim.SGD(model.parameters(), lr=0.01, momentum=0.9)

metrics_dict_e3 = {
    'epoch_times': [],
```

```
    'train_losses': [],
    'train_accuracies': [],
    'test_losses': [],
    'test_accuracies': []
}

for epoch in range(NUM_EPOCHS):
    train(model,
          device,
          train_loader,
          test_loader,
          optimizer,
          epoch,
          metrics_dict_e3,
          data_fn = add_random_small_complex_number)

print("-"*100)
print("-"*100)
print("FINAL RESULTS:")
print("-"*100)
for key, value in metrics_dict_e3.items():
    print(f'{key}: {value}')
```

```
Train Epoch:   0 [     0/ 60000 (  0%)] Loss: 2.267548  Accuracy: 18.75%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.493518  Accuracy: 74.04%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.428392  Accuracy: 79.08%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.517525  Accuracy: 80.93%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.427470  Accuracy: 82.26%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.269348  Accuracy: 83.11%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.117582  Accuracy: 83.76%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.366793  Accuracy: 84.30%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.417431  Accuracy: 84.75%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.203596  Accuracy: 85.22%
Epoch 0 - Time: 155.01s - Train Loss: 0.406308 - Train Accuracy: 85.34%
Test Loss: 0.306169 - Test Accuracy: 88.88%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.174027  Accuracy: 93.75%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.303287  Accuracy: 90.16%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.202293  Accuracy: 90.21%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.314936  Accuracy: 90.16%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.119811  Accuracy: 90.40%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.503697  Accuracy: 90.36%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.166824  Accuracy: 90.35%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.210098  Accuracy: 90.35%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.342508  Accuracy: 90.23%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.227942  Accuracy: 90.17%
Epoch 1 - Time: 123.39s - Train Loss: 0.267375 - Train Accuracy: 90.21%
Test Loss: 0.282528 - Test Accuracy: 89.70%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.152135  Accuracy: 96.88%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.197516  Accuracy: 92.22%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.423585  Accuracy: 92.28%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.106981  Accuracy: 92.19%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.245743  Accuracy: 92.17%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.270468  Accuracy: 91.97%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.241965  Accuracy: 92.02%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.084855  Accuracy: 91.98%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.126624  Accuracy: 91.88%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.163835  Accuracy: 91.91%
Epoch 2 - Time: 123.42s - Train Loss: 0.219970 - Train Accuracy: 91.92%
Test Loss: 0.281140 - Test Accuracy: 89.67%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.114456  Accuracy: 95.31%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.359989  Accuracy: 93.61%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.239066  Accuracy: 93.07%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.144771  Accuracy: 93.19%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.253212  Accuracy: 93.15%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.244296  Accuracy: 93.11%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.162868  Accuracy: 93.13%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.183134  Accuracy: 93.11%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.120323  Accuracy: 93.17%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.116076  Accuracy: 93.07%
Epoch 3 - Time: 123.31s - Train Loss: 0.184741 - Train Accuracy: 93.09%
Test Loss: 0.279209 - Test Accuracy: 90.34%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.086554  Accuracy: 96.88%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.139259  Accuracy: 94.52%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.046676  Accuracy: 94.27%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.151515  Accuracy: 94.31%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.180290  Accuracy: 94.33%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.106869  Accuracy: 94.27%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.147669  Accuracy: 94.33%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.110742  Accuracy: 94.22%
```

```
Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.182568  Accuracy: 94.20%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.110031  Accuracy: 94.20%
Epoch 4 - Time: 123.59s - Train Loss: 0.153532 - Train Accuracy: 94.18%
Test Loss: 0.267725 - Test Accuracy: 90.97%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.131503  Accuracy: 92.19%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.118395  Accuracy: 96.12%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.071713  Accuracy: 95.84%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.208242  Accuracy: 95.64%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.135326  Accuracy: 95.46%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.160826  Accuracy: 95.40%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.113022  Accuracy: 95.35%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.091297  Accuracy: 95.31%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.051082  Accuracy: 95.30%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.066328  Accuracy: 95.31%
Epoch 5 - Time: 123.78s - Train Loss: 0.128000 - Train Accuracy: 95.27%
Test Loss: 0.288224 - Test Accuracy: 90.54%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.056733  Accuracy: 98.44%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.077830  Accuracy: 96.40%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.072403  Accuracy: 96.37%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.092674  Accuracy: 96.31%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.050813  Accuracy: 96.31%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.065588  Accuracy: 96.19%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.087885  Accuracy: 96.14%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.200516  Accuracy: 96.09%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.031812  Accuracy: 96.07%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.181292  Accuracy: 96.05%
Epoch 6 - Time: 123.93s - Train Loss: 0.105461 - Train Accuracy: 96.05%
Test Loss: 0.290544 - Test Accuracy: 91.19%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.089795  Accuracy: 98.44%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.058839  Accuracy: 97.14%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.057335  Accuracy: 97.24%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.049508  Accuracy: 97.23%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.158319  Accuracy: 97.08%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.103904  Accuracy: 97.08%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.066755  Accuracy: 96.98%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.115614  Accuracy: 96.93%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.138426  Accuracy: 96.81%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.078396  Accuracy: 96.66%
Epoch 7 - Time: 123.51s - Train Loss: 0.088815 - Train Accuracy: 96.64%
Test Loss: 0.306645 - Test Accuracy: 90.94%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.023935  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.060169  Accuracy: 97.94%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.026333  Accuracy: 98.03%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.093060  Accuracy: 97.91%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.070305  Accuracy: 97.63%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.064213  Accuracy: 97.44%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.071707  Accuracy: 97.40%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.073250  Accuracy: 97.34%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.055017  Accuracy: 97.34%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.115776  Accuracy: 97.29%
Epoch 8 - Time: 123.61s - Train Loss: 0.074257 - Train Accuracy: 97.29%
Test Loss: 0.349132 - Test Accuracy: 91.03%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.078221  Accuracy: 96.88%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.014182  Accuracy: 98.34%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.065292  Accuracy: 98.14%
```

```
Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.032332  Accuracy: 98.10%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.022154  Accuracy: 97.97%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.078138  Accuracy: 97.92%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.007022  Accuracy: 97.84%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.022633  Accuracy: 97.72%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.096457  Accuracy: 97.70%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.019549  Accuracy: 97.65%
Epoch 9 - Time: 193.80s - Train Loss: 0.062057 - Train Accuracy: 97.66%
Test Loss: 0.356072 - Test Accuracy: 91.41%

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FINAL RESULTS:
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epoch_times: [155.0069441795349, 123.39364099502563, 123.42352986335754, 1
23.3135461807251, 123.59244108200073, 123.78225111961365, 123.933153867721
56, 123.5058867931366, 123.61309599876404, 193.8048062324524]
train_losses: [0.40630790159932334, 0.26737450661340245, 0.219970063919991
83, 0.1847413487668866, 0.1535322213374666, 0.12800018675228172, 0.1054607
3751814013, 0.08881496450504356, 0.07425731428956459, 0.06205681729878086]
train_accuracies: [85.345, 90.20666666666666, 91.92166666666667, 93.088333
33333334, 94.17833333333333, 95.27333333333333, 96.05333333333333, 96.6383
3333333334, 97.28833333333333, 97.65833333333333]
test_losses: [0.30616937565803526, 0.28252782888412475, 0.281139652252197
3, 0.2792087951660156, 0.26772472477555276, 0.2882242383003235, 0.29054448
52590561, 0.30664465823173526, 0.3491319559335709, 0.3560717505455017]
test_accuracies: [88.88, 89.7, 89.67, 90.34, 90.97, 90.54, 91.19, 90.94, 9
1.03, 91.41]
```

In [18]:

```
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
model = ComplexNet().to(device)
optimizer = torch.optim.SGD(model.parameters(), lr=0.01, momentum=0.9)

metrics_dict_e4 = {
    'epoch_times': [],
    'train_losses': [],
    'train_accuracies': [],
    'test_losses': [],
    'test_accuracies': []
}

for epoch in range(NUM_EPOCHS):
    train(model,
          device,
          train_loader,
          test_loader,
          optimizer,
          epoch,
          metrics_dict_e4,
          data_fn = add_fixed_imaginary_component)

print("-"*100)
print("-"*100)
print("FINAL RESULTS:")
print("-"*100)
for key, value in metrics_dict_e4.items():
    print(f'{key}: {value}')
```

```
Train Epoch:   0 [     0/ 60000 (  0%)] Loss: 2.281212  Accuracy: 4.69%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.561859  Accuracy: 75.00%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.471281  Accuracy: 79.28%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.317071  Accuracy: 81.38%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.357579  Accuracy: 82.58%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.289863  Accuracy: 83.31%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.145885  Accuracy: 84.01%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.250581  Accuracy: 84.52%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.368730  Accuracy: 84.97%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.254343  Accuracy: 85.27%
Epoch 0 - Time: 122.92s - Train Loss: 0.399164 - Train Accuracy: 85.33%
Test Loss: 0.465300 - Test Accuracy: 84.39%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.263987  Accuracy: 92.19%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.448529  Accuracy: 90.70%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.156225  Accuracy: 90.54%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.221878  Accuracy: 90.39%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.287891  Accuracy: 90.39%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.317484  Accuracy: 90.40%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.211111  Accuracy: 90.37%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.242587  Accuracy: 90.29%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.265320  Accuracy: 90.33%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.412185  Accuracy: 90.30%
Epoch 1 - Time: 156.47s - Train Loss: 0.265892 - Train Accuracy: 90.31%
Test Loss: 0.442176 - Test Accuracy: 85.34%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.155601  Accuracy: 95.31%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.107565  Accuracy: 92.26%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.193288  Accuracy: 91.92%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.213435  Accuracy: 91.88%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.348861  Accuracy: 91.87%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.158087  Accuracy: 91.87%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.088486  Accuracy: 91.90%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.290410  Accuracy: 91.90%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.492278  Accuracy: 91.89%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.250099  Accuracy: 91.84%
Epoch 2 - Time: 123.63s - Train Loss: 0.220992 - Train Accuracy: 91.82%
Test Loss: 0.532274 - Test Accuracy: 81.25%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.112578  Accuracy: 96.88%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.102113  Accuracy: 92.99%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.247591  Accuracy: 92.84%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.278429  Accuracy: 93.02%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.101040  Accuracy: 93.03%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.333024  Accuracy: 92.93%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.495630  Accuracy: 93.03%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.201081  Accuracy: 93.06%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.195190  Accuracy: 93.06%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.478219  Accuracy: 93.03%
Epoch 3 - Time: 242.18s - Train Loss: 0.183705 - Train Accuracy: 93.07%
Test Loss: 0.401983 - Test Accuracy: 87.16%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.193049  Accuracy: 96.88%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.205673  Accuracy: 94.28%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.096494  Accuracy: 94.39%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.095212  Accuracy: 94.33%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.175564  Accuracy: 94.30%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.329352  Accuracy: 94.27%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.128674  Accuracy: 94.29%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.186193  Accuracy: 94.34%
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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.218003  Accuracy: 94.26%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.316179  Accuracy: 94.26%
Epoch 4 - Time: 124.28s - Train Loss: 0.154559 - Train Accuracy: 94.23%
Test Loss: 0.443886 - Test Accuracy: 85.97%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.060100  Accuracy: 98.44%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.129019  Accuracy: 96.01%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.106848  Accuracy: 95.89%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.101842  Accuracy: 95.74%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.128173  Accuracy: 95.53%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.130214  Accuracy: 95.37%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.303305  Accuracy: 95.23%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.107114  Accuracy: 95.16%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.227459  Accuracy: 95.11%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.077774  Accuracy: 95.11%
Epoch 5 - Time: 124.32s - Train Loss: 0.131770 - Train Accuracy: 95.09%
Test Loss: 0.495739 - Test Accuracy: 85.90%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.088138  Accuracy: 96.88%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.142576  Accuracy: 96.61%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.029904  Accuracy: 96.52%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.200596  Accuracy: 96.44%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.089968  Accuracy: 96.42%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.138760  Accuracy: 96.37%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.048609  Accuracy: 96.21%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.213168  Accuracy: 96.05%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.277458  Accuracy: 95.98%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.137293  Accuracy: 95.94%
Epoch 6 - Time: 125.42s - Train Loss: 0.110049 - Train Accuracy: 95.92%
Test Loss: 0.584112 - Test Accuracy: 84.49%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.095980  Accuracy: 96.88%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.068880  Accuracy: 97.11%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.104086  Accuracy: 97.29%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.051302  Accuracy: 97.16%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.052997  Accuracy: 96.98%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.162645  Accuracy: 96.91%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.137825  Accuracy: 96.84%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.030486  Accuracy: 96.75%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.047082  Accuracy: 96.66%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.075918  Accuracy: 96.65%
Epoch 7 - Time: 126.74s - Train Loss: 0.090150 - Train Accuracy: 96.65%
Test Loss: 0.745320 - Test Accuracy: 82.38%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.143829  Accuracy: 96.88%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.066783  Accuracy: 97.00%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.075248  Accuracy: 97.15%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.135047  Accuracy: 97.05%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.061488  Accuracy: 97.13%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.042286  Accuracy: 97.14%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.115032  Accuracy: 97.12%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.061866  Accuracy: 97.05%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.109971  Accuracy: 97.03%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.067666  Accuracy: 96.99%
Epoch 8 - Time: 241.80s - Train Loss: 0.080055 - Train Accuracy: 96.98%
Test Loss: 0.809725 - Test Accuracy: 83.49%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.025116  Accuracy: 98.44%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.020932  Accuracy: 98.22%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.013123  Accuracy: 98.16%
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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.043180  Accuracy: 98.03%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.071158  Accuracy: 97.89%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.139440  Accuracy: 97.79%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.112468  Accuracy: 97.67%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.080286  Accuracy: 97.57%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.018900  Accuracy: 97.53%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.126165  Accuracy: 97.47%
Epoch 9 - Time: 144.04s - Train Loss: 0.070157 - Train Accuracy: 97.43%
Test Loss: 0.953061 - Test Accuracy: 81.52%

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FINAL RESULTS:
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epoch_times: [122.92476105690002, 156.4689118862152, 123.63417100906372, 2
42.17900395393372, 124.28268218040466, 124.31797909736633, 125.41707897186
28, 126.73632717132568, 241.7970471382141, 144.041424036026]
train_losses: [0.39916432145307823, 0.2658923736243233, 0.220991845244664
9, 0.18370505852072733, 0.15455944031111593, 0.13176991757370835, 0.110048
94912274661, 0.09015022547863948, 0.08005547139601016, 0.0701574071241951
7]
train_accuracies: [85.335, 90.31, 91.82166666666667, 93.07, 94.235, 95.09
5, 95.92333333333333, 96.64666666666666, 96.97833333333334, 97.43]
test_losses: [0.46530043115615843, 0.4421762631893158, 0.5322737041473389,
0.40198310327529907, 0.44388615269660947, 0.4957394739151001, 0.5841120913
982392, 0.7453199653744698, 0.8097254085540772, 0.953061169052124]
test_accuracies: [84.39, 85.34, 81.25, 87.16, 85.97, 85.9, 84.49, 82.38, 8
3.49, 81.52]
```

In [19]:

```python
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
model = ComplexNet().to(device)
optimizer = torch.optim.SGD(model.parameters(), lr=0.01, momentum=0.9)

metrics_dict_e5 = {
    'epoch_times': [],
    'train_losses': [],
    'train_accuracies': [],
    'test_losses': [],
    'test_accuracies': []
}

for epoch in range(NUM_EPOCHS):
    train(model,
          device,
          train_loader,
          test_loader,
          optimizer,
          epoch,
          metrics_dict_e5,
          data_fn = add_fixed_phase)

print("-"*100)
print("-"*100)
print("FINAL RESULTS:")
print("-"*100)
for key, value in metrics_dict_e5.items():
    print(f'{key}: {value}')
```

```
Train Epoch:   0 [     0/ 60000 (  0%)] Loss: 2.439648  Accuracy: 9.38%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.375745  Accuracy: 72.83%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.472308  Accuracy: 78.61%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.442351  Accuracy: 80.69%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.545118  Accuracy: 82.04%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.335789  Accuracy: 82.98%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.477791  Accuracy: 83.81%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.419692  Accuracy: 84.30%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.432741  Accuracy: 84.70%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.421974  Accuracy: 85.20%
Epoch 0 - Time: 150.85s - Train Loss: 0.408624 - Train Accuracy: 85.27%
Test Loss: 0.566016 - Test Accuracy: 79.18%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.236218  Accuracy: 92.19%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.244225  Accuracy: 89.82%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.165282  Accuracy: 89.73%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.199633  Accuracy: 89.97%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.142578  Accuracy: 90.05%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.334225  Accuracy: 90.09%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.267117  Accuracy: 90.15%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.277749  Accuracy: 90.17%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.412241  Accuracy: 90.14%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.295771  Accuracy: 90.14%
Epoch 1 - Time: 161.93s - Train Loss: 0.269735 - Train Accuracy: 90.17%
Test Loss: 0.449481 - Test Accuracy: 84.20%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.190146  Accuracy: 92.19%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.219025  Accuracy: 92.54%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.287568  Accuracy: 92.43%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.240999  Accuracy: 92.24%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.243537  Accuracy: 92.06%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.102380  Accuracy: 91.98%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.275399  Accuracy: 91.95%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.171788  Accuracy: 91.91%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.224290  Accuracy: 91.88%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.241883  Accuracy: 91.90%
Epoch 2 - Time: 162.31s - Train Loss: 0.220595 - Train Accuracy: 91.92%
Test Loss: 0.738705 - Test Accuracy: 74.26%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.285712  Accuracy: 90.62%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.196342  Accuracy: 93.02%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.208875  Accuracy: 93.24%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.112060  Accuracy: 93.32%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.117812  Accuracy: 93.24%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.120033  Accuracy: 93.22%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.198263  Accuracy: 93.24%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.156565  Accuracy: 93.22%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.166598  Accuracy: 93.20%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.157222  Accuracy: 93.12%
Epoch 3 - Time: 127.43s - Train Loss: 0.182930 - Train Accuracy: 93.11%
Test Loss: 0.607045 - Test Accuracy: 79.41%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.104988  Accuracy: 95.31%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.153572  Accuracy: 94.55%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.071831  Accuracy: 94.83%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.226381  Accuracy: 94.63%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.171223  Accuracy: 94.40%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.265504  Accuracy: 94.35%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.050209  Accuracy: 94.35%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.193829  Accuracy: 94.41%
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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.168259  Accuracy: 94.34%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.072911  Accuracy: 94.28%
Epoch 4 - Time: 126.64s - Train Loss: 0.154978 - Train Accuracy: 94.26%
Test Loss: 0.476898 - Test Accuracy: 83.19%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.087436  Accuracy: 96.88%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.174677  Accuracy: 95.82%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.136154  Accuracy: 95.71%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.106022  Accuracy: 95.55%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.077038  Accuracy: 95.55%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.161420  Accuracy: 95.52%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.100422  Accuracy: 95.37%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.101695  Accuracy: 95.28%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.066391  Accuracy: 95.25%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.135731  Accuracy: 95.21%
Epoch 5 - Time: 126.37s - Train Loss: 0.129056 - Train Accuracy: 95.22%
Test Loss: 0.575785 - Test Accuracy: 81.10%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.229018  Accuracy: 90.62%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.032648  Accuracy: 96.13%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.093016  Accuracy: 96.21%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.066618  Accuracy: 96.21%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.174314  Accuracy: 96.08%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.187148  Accuracy: 96.00%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.039346  Accuracy: 95.94%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.096124  Accuracy: 95.89%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.100896  Accuracy: 95.77%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.142553  Accuracy: 95.73%
Epoch 6 - Time: 127.16s - Train Loss: 0.114519 - Train Accuracy: 95.70%
Test Loss: 0.541980 - Test Accuracy: 82.24%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.152689  Accuracy: 95.31%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.085903  Accuracy: 96.78%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.054159  Accuracy: 96.90%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.074465  Accuracy: 96.76%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.073769  Accuracy: 96.63%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.054670  Accuracy: 96.58%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.089991  Accuracy: 96.56%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.088969  Accuracy: 96.54%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.037310  Accuracy: 96.55%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.149789  Accuracy: 96.51%
Epoch 7 - Time: 126.67s - Train Loss: 0.095211 - Train Accuracy: 96.50%
Test Loss: 0.598916 - Test Accuracy: 81.70%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.074934  Accuracy: 96.88%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.083981  Accuracy: 97.15%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.083114  Accuracy: 97.52%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.096580  Accuracy: 97.41%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.116942  Accuracy: 97.36%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.105212  Accuracy: 97.40%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.159023  Accuracy: 97.37%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.040296  Accuracy: 97.25%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.070378  Accuracy: 97.17%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.035759  Accuracy: 97.14%
Epoch 8 - Time: 125.95s - Train Loss: 0.076946 - Train Accuracy: 97.09%
Test Loss: 0.605865 - Test Accuracy: 82.05%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.077572  Accuracy: 98.44%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.013453  Accuracy: 97.71%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.184746  Accuracy: 97.96%
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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.094958  Accuracy: 98.01%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.039384  Accuracy: 97.99%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.053809  Accuracy: 97.89%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.089805  Accuracy: 97.83%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.115195  Accuracy: 97.70%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.062834  Accuracy: 97.65%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.219106  Accuracy: 97.66%
Epoch 9 - Time: 126.29s - Train Loss: 0.063956 - Train Accuracy: 97.66%
Test Loss: 0.740749 - Test Accuracy: 80.54%

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FINAL RESULTS:
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epoch_times: [150.84765005111694, 161.93292689323425, 162.31339406967163,
127.43101406097412, 126.64466094970703, 126.37208795547485, 127.1582348346
7102, 126.66988801956177, 125.95267391204834, 126.29214096069336]
train_losses: [0.4086239220920021, 0.2697347767476334, 0.2205946452216680
2, 0.1829302068065002, 0.15497831526651248, 0.12905555964211252, 0.1145194
5945556992, 0.09521112332134438, 0.0769460244523262, 0.063955979123374]
train_accuracies: [85.27166666666666, 90.16833333333334, 91.925, 93.105, 9
4.25833333333334, 95.21666666666667, 95.70333333333333, 96.505, 97.09, 97.
66333333333333]
test_losses: [0.5660160296440124, 0.44948103823661806, 0.7387051340103149,
0.6070450304985047, 0.476897850227356, 0.5757848576545715, 0.5419797437667
847, 0.5989160963058472, 0.6058654038190842, 0.7407494941711426]
test_accuracies: [79.18, 84.2, 74.26, 79.41, 83.19, 81.1, 82.24, 81.7, 82.
05, 80.54]
```
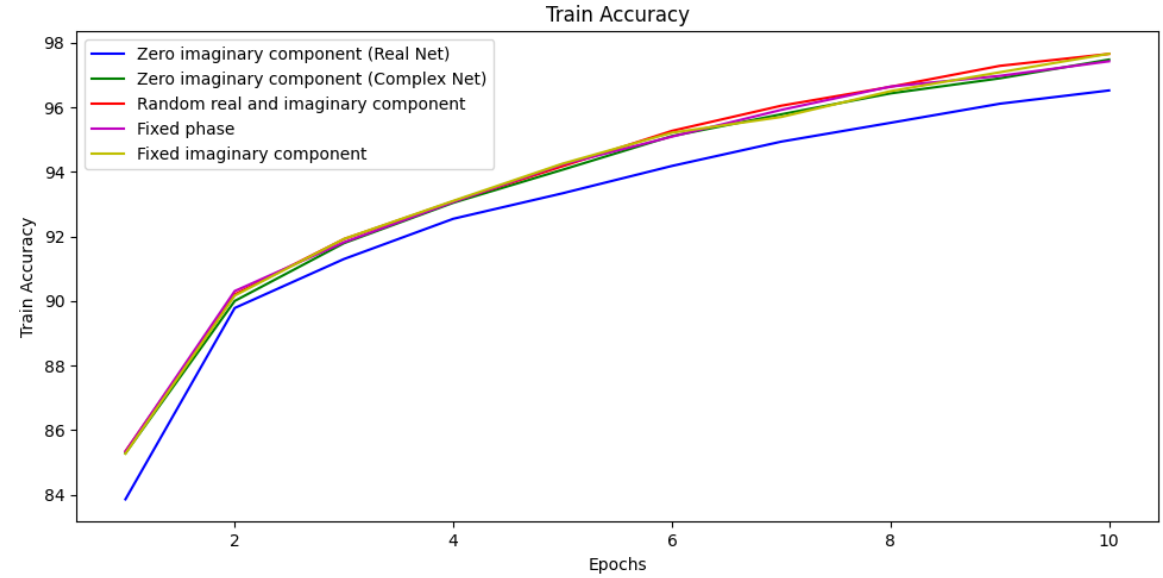
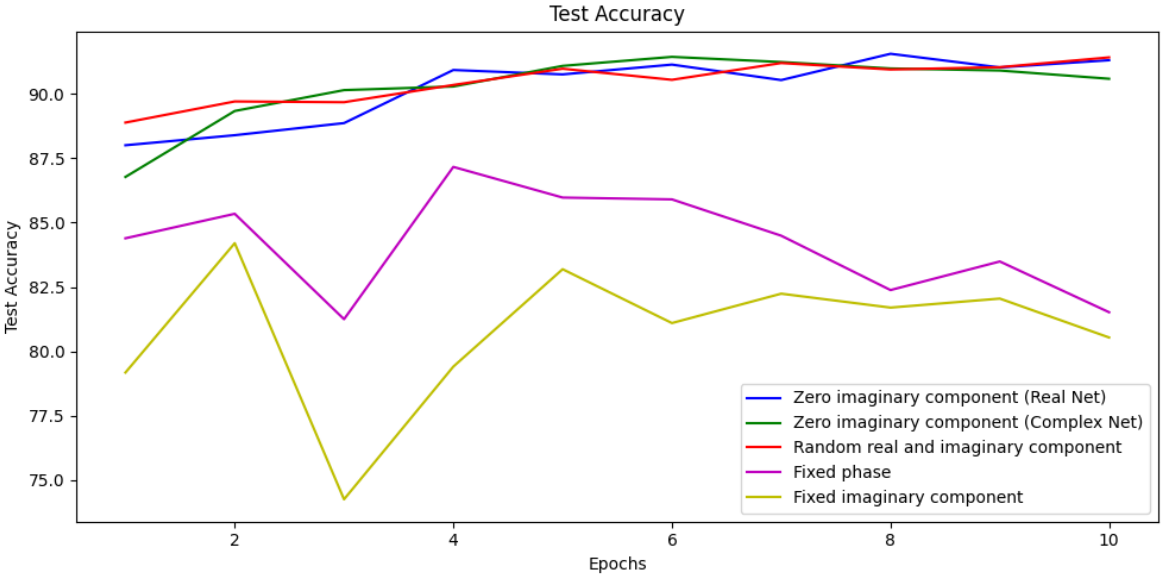
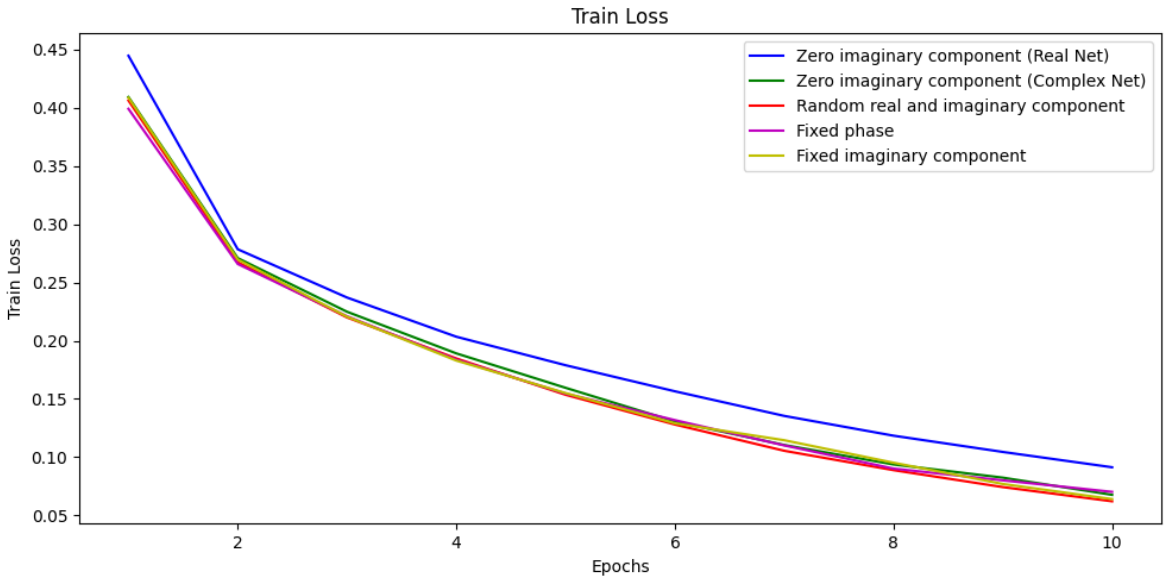

Plots

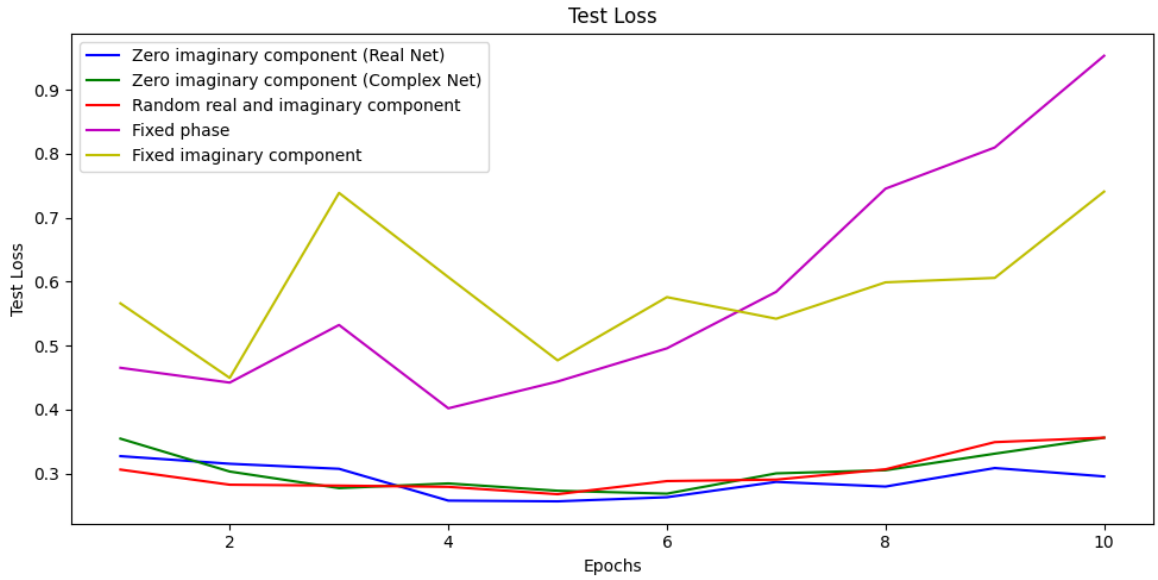
In [20]:
```python
# Data for the four scenarios
data = {
    "Zero imaginary component (Real Net)": metrics_dict_e1,
    "Zero imaginary component (Complex Net)": metrics_dict_e2,
    "Random real and imaginary component": metrics_dict_e3,
    "Fixed phase": metrics_dict_e4,
    "Fixed imaginary component": metrics_dict_e5
}

# Data for plotting
epochs = range(1, 11)
colors = ['b', 'g', 'r', 'm', 'y']
scenarios = list(data.keys())

fig, axes = plt.subplots(2, 1, figsize=(10, 10))

for i, scenario in enumerate(scenarios):
    axes[0].plot(epochs, data[scenario]["train_accuracies"], label=scenar

axes[0].set_title("Train Accuracy")
axes[0].set_xlabel("Epochs")
axes[0].set_ylabel("Train Accuracy")
axes[0].legend()
```

```
for i, scenario in enumerate(scenarios):
    axes[1].plot(epochs, data[scenario]["test_accuracies"], label=scenari

axes[1].set_title("Test Accuracy")
axes[1].set_xlabel("Epochs")
axes[1].set_ylabel("Test Accuracy")
axes[1].legend()

plt.tight_layout()
plt.show()

fig, axes = plt.subplots(2, 1, figsize=(10, 10))

for i, scenario in enumerate(scenarios):
    axes[0].plot(epochs, data[scenario]["train_losses"], label=scenario,

axes[0].set_title("Train Loss")
axes[0].set_xlabel("Epochs")
axes[0].set_ylabel("Train Loss")
axes[0].legend()

for i, scenario in enumerate(scenarios):
    axes[1].plot(epochs, data[scenario]["test_losses"], label=scenario, c

axes[1].set_title("Test Loss")
axes[1].set_xlabel("Epochs")
axes[1].set_ylabel("Test Loss")
axes[1].legend()

plt.tight_layout()
plt.show()

fig, axes = plt.subplots(1, 1, figsize=(10, 5))
for i, scenario in enumerate(scenarios):
    axes.plot(epochs, data[scenario]["epoch_times"], label=scenario, colo
axes.set_title("Time")
axes.set_xlabel("Epochs")
axes.set_ylabel("Time (secs)")
axes.legend()
```

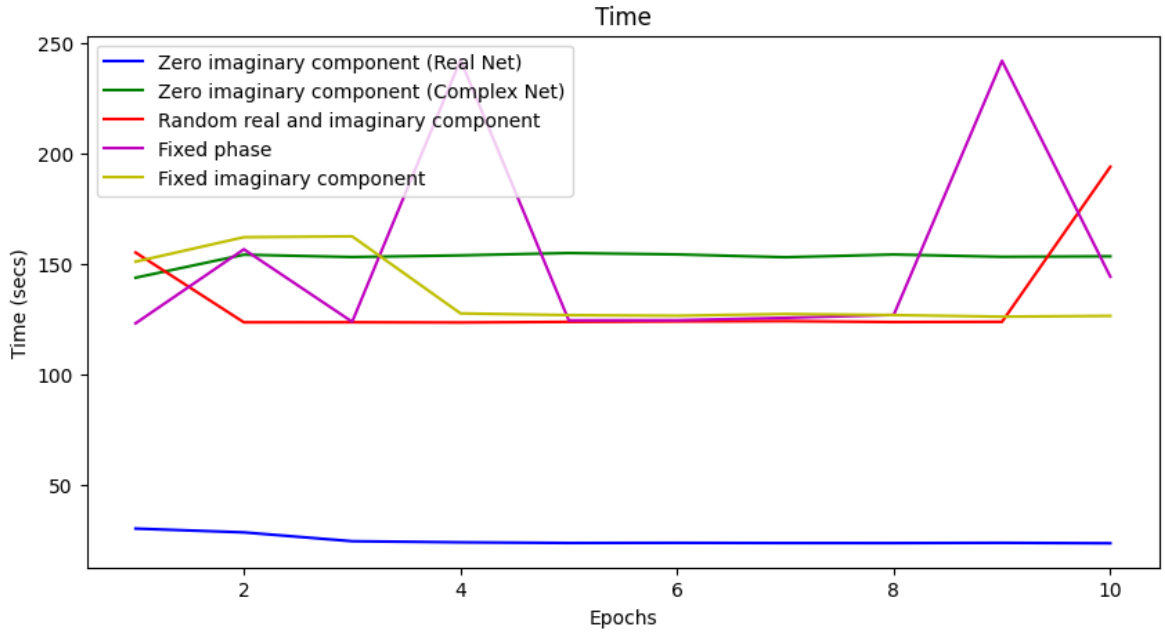

Train Accuracy
Zero imaginary component (Real Net)
Zero imaginary component (Complex Net)
Random real and imaginary component
Fixed phase
Fixed imaginary component
Train Accuracy
Epochs
98
96
94
92
90
88
86
84
2
4
6
8
10


Test Accuracy
Zero imaginary component (Real Net)
Zero imaginary component (Complex Net)
Random real and imaginary component
Fixed phase
Fixed imaginary component
Test Accuracy
Epochs
90.0
87.5
85.0
82.5
80.0
77.5
75.0
2
4
6
8
10





Out[20]: <matplotlib.legend.Legend at 0x2b344ead0>



In [21]:
```
fig, axes = plt.subplots(2, 1, figsize=(10, 10))

for i, scenario in enumerate(scenarios):
```

```
    axes[0].plot(epochs, data[scenario]["train_losses"], label=scenario,

axes[0].set_title("Train Loss (log scale)")
axes[0].set_xlabel("Epochs")
axes[0].set_ylabel("Train Loss")
axes[0].set_yscale('log')
axes[0].legend()

for i, scenario in enumerate(scenarios):
    axes[1].plot(epochs, data[scenario]["test_losses"], label=scenario, c

axes[1].set_title("Test Loss (log scale)")
axes[1].set_xlabel("Epochs")
axes[1].set_ylabel("Test Loss")
axes[1].set_yscale('log')
axes[1].legend()

plt.tight_layout()
plt.show()
```