EXP 1

In [6]:
```
# 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 [7]:
```
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
```

KMNIST

In [8]:
```
NUM_EPOCHS = 10
batch_size = 64
trans = transforms.Compose([transforms.ToTensor(), transforms.Normalize((

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

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 [9]:
```
class RealNet(nn.Module):

    def __init__(self):
```

```
        super(RealNet, self).__init__()
        self.conv1 = nn.Conv2d(1, 10, 5, 1)
        self.bn  = nn.BatchNorm2d(10)
        self.conv2 = nn.Conv2d(10, 20, 5, 1)
        self.fc1 = nn.Linear(4*4*20, 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*20)
        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: 2.299822  Accuracy: 7.81%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.645948  Accuracy: 63.83%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.342383  Accuracy: 75.71%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.228811  Accuracy: 81.28%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.184278  Accuracy: 84.28%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.222639  Accuracy: 86.34%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.110536  Accuracy: 87.83%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.110267  Accuracy: 88.94%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.119024  Accuracy: 89.78%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.081295  Accuracy: 90.51%
Epoch 0 - Time: 14.82s - Train Loss: 0.303351 - Train Accuracy: 90.75%
Test Loss: 0.325120 - Test Accuracy: 90.77%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.023676  Accuracy: 100.00%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.026986  Accuracy: 97.17%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.072912  Accuracy: 97.09%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.023078  Accuracy: 97.17%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.206522  Accuracy: 97.17%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.036550  Accuracy: 97.28%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.112846  Accuracy: 97.30%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.029004  Accuracy: 97.30%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.209676  Accuracy: 97.40%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.052730  Accuracy: 97.45%
Epoch 1 - Time: 14.91s - Train Loss: 0.081906 - Train Accuracy: 97.48%
Test Loss: 0.243643 - Test Accuracy: 93.15%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.048002  Accuracy: 98.44%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.041958  Accuracy: 98.48%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.031844  Accuracy: 98.34%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.088833  Accuracy: 98.45%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.079508  Accuracy: 98.46%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.071731  Accuracy: 98.47%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.043459  Accuracy: 98.49%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.094887  Accuracy: 98.47%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.004167  Accuracy: 98.45%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.029071  Accuracy: 98.43%
Epoch 2 - Time: 14.79s - Train Loss: 0.051451 - Train Accuracy: 98.43%
Test Loss: 0.220487 - Test Accuracy: 93.89%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.103220  Accuracy: 96.88%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.012172  Accuracy: 99.15%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.054952  Accuracy: 99.11%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.012859  Accuracy: 99.04%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.008959  Accuracy: 99.07%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.043366  Accuracy: 99.04%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.037084  Accuracy: 98.98%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.012054  Accuracy: 98.96%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.112474  Accuracy: 98.95%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.029366  Accuracy: 98.91%
Epoch 3 - Time: 15.19s - Train Loss: 0.035495 - Train Accuracy: 98.89%
Test Loss: 0.200834 - Test Accuracy: 94.68%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.011888  Accuracy: 100.00%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.001281  Accuracy: 99.24%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.071764  Accuracy: 99.28%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.003089  Accuracy: 99.23%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.014301  Accuracy: 99.24%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.008151  Accuracy: 99.27%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.032189  Accuracy: 99.27%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.005610  Accuracy: 99.27%
```

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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.022686  Accuracy: 99.24%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.029784  Accuracy: 99.23%
Epoch 4 - Time: 14.84s - Train Loss: 0.024780 - Train Accuracy: 99.23%
Test Loss: 0.206799 - Test Accuracy: 94.82%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.021269  Accuracy: 98.44%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.000508  Accuracy: 99.71%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.007130  Accuracy: 99.66%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.049632  Accuracy: 99.64%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.011401  Accuracy: 99.60%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.000770  Accuracy: 99.57%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.009979  Accuracy: 99.57%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.006596  Accuracy: 99.55%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.073190  Accuracy: 99.52%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.000635  Accuracy: 99.50%
Epoch 5 - Time: 15.00s - Train Loss: 0.016699 - Train Accuracy: 99.50%
Test Loss: 0.216198 - Test Accuracy: 95.19%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.014575  Accuracy: 98.44%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.034370  Accuracy: 99.50%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.004221  Accuracy: 99.51%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.008506  Accuracy: 99.62%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.048218  Accuracy: 99.63%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.001763  Accuracy: 99.64%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.001877  Accuracy: 99.64%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.002447  Accuracy: 99.63%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.001043  Accuracy: 99.63%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.018756  Accuracy: 99.63%
Epoch 6 - Time: 14.84s - Train Loss: 0.012295 - Train Accuracy: 99.62%
Test Loss: 0.249394 - Test Accuracy: 94.64%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.001627  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.004348  Accuracy: 99.85%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.004645  Accuracy: 99.82%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.001372  Accuracy: 99.83%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.000111  Accuracy: 99.84%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000058  Accuracy: 99.83%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.000209  Accuracy: 99.82%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.011108  Accuracy: 99.82%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.005229  Accuracy: 99.83%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.002285  Accuracy: 99.83%
Epoch 7 - Time: 14.84s - Train Loss: 0.006227 - Train Accuracy: 99.83%
Test Loss: 0.225778 - Test Accuracy: 95.27%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.034173  Accuracy: 98.44%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.002115  Accuracy: 99.83%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.003176  Accuracy: 99.84%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.005483  Accuracy: 99.82%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000367  Accuracy: 99.84%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.002771  Accuracy: 99.85%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000081  Accuracy: 99.86%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.004987  Accuracy: 99.86%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.030449  Accuracy: 99.84%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.001408  Accuracy: 99.81%
Epoch 8 - Time: 14.84s - Train Loss: 0.006346 - Train Accuracy: 99.81%
Test Loss: 0.303706 - Test Accuracy: 94.39%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000218  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.001267  Accuracy: 99.86%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000189  Accuracy: 99.91%
```

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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000032  Accuracy: 99.91%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.001684  Accuracy: 99.93%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000420  Accuracy: 99.94%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000091  Accuracy: 99.94%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000051  Accuracy: 99.95%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000426  Accuracy: 99.95%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000656  Accuracy: 99.94%
Epoch 9 - Time: 14.89s - Train Loss: 0.002958 - Train Accuracy: 99.94%
Test Loss: 0.230870 - Test Accuracy: 95.35%

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FINAL RESULTS:
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epoch_times: [14.81559705734253, 14.91343903541565, 14.789677858352661, 1
5.187710046768188, 14.839202165603638, 15.0032799243927, 14.8441531658172
6, 14.840829849243164, 14.837812900543213, 14.88591718673706]
train_losses: [0.303350762247658, 0.08190603258072345, 0.0514510576455627
5, 0.035495182277070284, 0.024779529880459505, 0.016699122956693683, 0.012
295063701000619, 0.006226658859859352, 0.006345728470990161, 0.00295786307
98616713]
train_accuracies: [90.75166666666667, 97.47833333333334, 98.4283333333333
3, 98.89, 99.23333333333333, 99.49666666666667, 99.62166666666667, 99.825,
99.80833333333334, 99.93833333333333]
test_losses: [0.32511974229812624, 0.24364278271198272, 0.2204871367931365
8, 0.200833865070343, 0.206799219340086, 0.21619762632250786, 0.2493938609
3467475, 0.22577770985513926, 0.30370588126704096, 0.23086978563815092]
test_accuracies: [90.77, 93.15, 93.89, 94.68, 94.82, 95.19, 94.64, 95.27,
94.39, 95.35]
```

2. Complex Net

In [10]:

```
class ComplexNet(nn.Module):

    def __init__(self):
        super(ComplexNet, self).__init__()
        self.conv1 = ComplexConv2d(1, 10, 5, 1)
        self.bn  = ComplexBatchNorm2d(10)
        self.conv2 = ComplexConv2d(10, 20, 5, 1)
        self.fc1 = ComplexLinear(4*4*20, 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*20)
        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: 2.363183  Accuracy: 12.50%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.527289  Accuracy: 76.22%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.146513  Accuracy: 83.59%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.239793  Accuracy: 86.85%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.139277  Accuracy: 88.86%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.172021  Accuracy: 90.24%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.132572  Accuracy: 91.10%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.321070  Accuracy: 91.82%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.142820  Accuracy: 92.44%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.149327  Accuracy: 92.97%
Epoch 0 - Time: 68.60s - Train Loss: 0.222081 - Train Accuracy: 93.12%
Test Loss: 0.291691 - Test Accuracy: 91.71%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.110369  Accuracy: 95.31%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.128573  Accuracy: 98.10%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.060001  Accuracy: 98.03%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.054394  Accuracy: 97.99%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.115615  Accuracy: 97.94%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.153815  Accuracy: 97.99%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.026950  Accuracy: 98.02%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.080837  Accuracy: 98.05%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.073736  Accuracy: 98.00%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.049522  Accuracy: 98.04%
Epoch 1 - Time: 76.71s - Train Loss: 0.063500 - Train Accuracy: 98.04%
Test Loss: 0.209250 - Test Accuracy: 94.26%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.052468  Accuracy: 96.88%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.008847  Accuracy: 99.13%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.052093  Accuracy: 99.17%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.012123  Accuracy: 99.14%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.008831  Accuracy: 99.04%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.023426  Accuracy: 99.02%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.074864  Accuracy: 98.99%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.005184  Accuracy: 98.98%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.035586  Accuracy: 98.95%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.015149  Accuracy: 98.94%
Epoch 2 - Time: 68.23s - Train Loss: 0.033979 - Train Accuracy: 98.92%
Test Loss: 0.216710 - Test Accuracy: 94.55%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.002368  Accuracy: 100.00%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.061268  Accuracy: 99.24%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.015764  Accuracy: 99.42%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.008026  Accuracy: 99.42%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.002176  Accuracy: 99.41%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.001280  Accuracy: 99.43%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.002030  Accuracy: 99.44%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.006321  Accuracy: 99.43%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.014002  Accuracy: 99.43%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.019580  Accuracy: 99.41%
Epoch 3 - Time: 76.91s - Train Loss: 0.018692 - Train Accuracy: 99.41%
Test Loss: 0.196581 - Test Accuracy: 95.39%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.010244  Accuracy: 100.00%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.026825  Accuracy: 99.55%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.004312  Accuracy: 99.63%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.002948  Accuracy: 99.65%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.020208  Accuracy: 99.64%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.000509  Accuracy: 99.65%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.005565  Accuracy: 99.68%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.013461  Accuracy: 99.66%
```

```
Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.092181  Accuracy: 99.65%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.022234  Accuracy: 99.62%
Epoch 4 - Time: 82.98s - Train Loss: 0.012443 - Train Accuracy: 99.61%
Test Loss: 0.220471 - Test Accuracy: 95.33%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.001449  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.000547  Accuracy: 99.83%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.000100  Accuracy: 99.87%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.002943  Accuracy: 99.88%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.003869  Accuracy: 99.83%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.000367  Accuracy: 99.82%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.001547  Accuracy: 99.81%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.002394  Accuracy: 99.82%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.011300  Accuracy: 99.83%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.002364  Accuracy: 99.83%
Epoch 5 - Time: 69.25s - Train Loss: 0.005371 - Train Accuracy: 99.83%
Test Loss: 0.206127 - Test Accuracy: 95.88%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.001389  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.000542  Accuracy: 99.97%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.002162  Accuracy: 99.97%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.004120  Accuracy: 99.94%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000072  Accuracy: 99.95%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.004653  Accuracy: 99.95%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.003221  Accuracy: 99.94%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.024276  Accuracy: 99.94%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.014123  Accuracy: 99.94%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.002065  Accuracy: 99.94%
Epoch 6 - Time: 68.97s - Train Loss: 0.002654 - Train Accuracy: 99.94%
Test Loss: 0.228897 - Test Accuracy: 95.64%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.000084  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.000047  Accuracy: 100.00%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.001081  Accuracy: 100.00%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000064  Accuracy: 100.00%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.000124  Accuracy: 100.00%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000081  Accuracy: 100.00%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.049257  Accuracy: 99.99%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.000212  Accuracy: 99.99%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.000142  Accuracy: 99.99%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000043  Accuracy: 99.99%
Epoch 7 - Time: 68.59s - Train Loss: 0.000821 - Train Accuracy: 99.99%
Test Loss: 0.225511 - Test Accuracy: 95.97%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.000639  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.000112  Accuracy: 100.00%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.000380  Accuracy: 100.00%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.000020  Accuracy: 100.00%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000417  Accuracy: 100.00%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000156  Accuracy: 100.00%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000119  Accuracy: 100.00%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000239  Accuracy: 100.00%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.000062  Accuracy: 100.00%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.001042  Accuracy: 100.00%
Epoch 8 - Time: 68.64s - Train Loss: 0.000333 - Train Accuracy: 100.00%
Test Loss: 0.231806 - Test Accuracy: 96.00%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000047  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.000161  Accuracy: 100.00%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000082  Accuracy: 100.00%
```

```
Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000022  Accuracy: 100.00%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.000118  Accuracy: 100.00%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000124  Accuracy: 100.00%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000005  Accuracy: 100.00%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000032  Accuracy: 100.00%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000214  Accuracy: 100.00%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000155  Accuracy: 100.00%
Epoch 9 - Time: 68.72s - Train Loss: 0.000183 - Train Accuracy: 100.00%
Test Loss: 0.233151 - Test Accuracy: 95.94%

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FINAL RESULTS:
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epoch_times: [68.60474801063538, 76.70726704597473, 68.22652196884155, 76.
91290402412415, 82.98131823539734, 69.25101804733276, 68.96532821655273, 6
8.59089517593384, 68.6424241065979, 68.72200083732605]
train_losses: [0.22208090815176842, 0.06349992614424627, 0.033978900186524
39, 0.018691982934046645, 0.012442694418593064, 0.005371057638483293, 0.00
26536612756905375, 0.0008205138692603198, 0.0003333077572968731, 0.0001832
314425696231]
train_accuracies: [93.125, 98.03833333333333, 98.91833333333334, 99.406666
66666667, 99.61333333333333, 99.83166666666666, 99.945, 99.99, 99.99833333
333333, 100.0]
test_losses: [0.2916912561893463, 0.2092504269003868, 0.21671021950244904,
0.19658066999614238, 0.2204708132505417, 0.20612741721663624, 0.2288967331
0890793, 0.22551070725396274, 0.23180585793331265, 0.23315062468666584]
test_accuracies: [91.71, 94.26, 94.55, 95.39, 95.33, 95.88, 95.64, 95.97,
96.0, 95.94]
```

3. Functional changes!

In [11]:
```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 [13]:
```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: 2.349576  Accuracy: 12.50%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.273765  Accuracy: 73.65%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.154257  Accuracy: 82.44%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.215670  Accuracy: 86.24%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.146116  Accuracy: 88.30%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.082124  Accuracy: 89.73%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.108917  Accuracy: 90.76%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.113696  Accuracy: 91.52%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.122759  Accuracy: 92.19%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.115304  Accuracy: 92.71%
Epoch 0 - Time: 69.52s - Train Loss: 0.229065 - Train Accuracy: 92.92%
Test Loss: 0.267275 - Test Accuracy: 92.26%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.016448  Accuracy: 100.00%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.014928  Accuracy: 97.87%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.022800  Accuracy: 97.98%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.033628  Accuracy: 97.95%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.047172  Accuracy: 98.04%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.130586  Accuracy: 98.11%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.234149  Accuracy: 98.09%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.022359  Accuracy: 98.04%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.141958  Accuracy: 98.06%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.081954  Accuracy: 98.09%
Epoch 1 - Time: 69.41s - Train Loss: 0.063436 - Train Accuracy: 98.09%
Test Loss: 0.215289 - Test Accuracy: 94.08%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.013361  Accuracy: 100.00%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.052005  Accuracy: 99.23%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.005912  Accuracy: 99.11%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.001514  Accuracy: 99.07%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.042286  Accuracy: 99.05%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.048854  Accuracy: 99.03%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.004127  Accuracy: 99.01%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.002013  Accuracy: 99.00%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.005922  Accuracy: 98.95%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.004329  Accuracy: 98.96%
Epoch 2 - Time: 70.26s - Train Loss: 0.033229 - Train Accuracy: 98.95%
Test Loss: 0.194886 - Test Accuracy: 95.25%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.007679  Accuracy: 100.00%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.038982  Accuracy: 99.46%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.009249  Accuracy: 99.56%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.008021  Accuracy: 99.56%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.024831  Accuracy: 99.54%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.004075  Accuracy: 99.54%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.024160  Accuracy: 99.51%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.005749  Accuracy: 99.51%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.001379  Accuracy: 99.52%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.013917  Accuracy: 99.51%
Epoch 3 - Time: 69.59s - Train Loss: 0.016552 - Train Accuracy: 99.51%
Test Loss: 0.174051 - Test Accuracy: 95.79%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.015290  Accuracy: 100.00%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.008767  Accuracy: 99.78%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.011255  Accuracy: 99.83%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.005200  Accuracy: 99.84%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.001814  Accuracy: 99.83%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.035523  Accuracy: 99.79%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.000361  Accuracy: 99.77%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.049747  Accuracy: 99.75%
```

```
Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.002428  Accuracy: 99.74%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.002734  Accuracy: 99.74%
Epoch 4 - Time: 69.37s - Train Loss: 0.008967 - Train Accuracy: 99.74%
Test Loss: 0.242152 - Test Accuracy: 94.80%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.008701  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.006284  Accuracy: 99.86%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.007861  Accuracy: 99.88%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.000854  Accuracy: 99.91%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.000104  Accuracy: 99.91%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.062572  Accuracy: 99.90%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.000600  Accuracy: 99.90%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.001195  Accuracy: 99.91%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.000244  Accuracy: 99.91%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.025483  Accuracy: 99.91%
Epoch 5 - Time: 69.48s - Train Loss: 0.004017 - Train Accuracy: 99.91%
Test Loss: 0.187091 - Test Accuracy: 96.25%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.000495  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.000625  Accuracy: 99.92%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.002101  Accuracy: 99.95%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.001187  Accuracy: 99.96%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.002153  Accuracy: 99.96%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.001867  Accuracy: 99.97%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.000652  Accuracy: 99.97%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.000200  Accuracy: 99.95%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.005698  Accuracy: 99.95%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.000182  Accuracy: 99.95%
Epoch 6 - Time: 70.09s - Train Loss: 0.002095 - Train Accuracy: 99.94%
Test Loss: 0.207130 - Test Accuracy: 95.80%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.002098  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.000120  Accuracy: 100.00%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000030  Accuracy: 100.00%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000599  Accuracy: 100.00%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.000331  Accuracy: 100.00%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000078  Accuracy: 100.00%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.000443  Accuracy: 100.00%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.001666  Accuracy: 100.00%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.000277  Accuracy: 100.00%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000607  Accuracy: 100.00%
Epoch 7 - Time: 70.74s - Train Loss: 0.000695 - Train Accuracy: 100.00%
Test Loss: 0.200955 - Test Accuracy: 96.17%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.000742  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.000193  Accuracy: 100.00%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.000076  Accuracy: 100.00%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.000021  Accuracy: 100.00%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000509  Accuracy: 100.00%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000156  Accuracy: 100.00%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000016  Accuracy: 100.00%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000005  Accuracy: 100.00%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.000357  Accuracy: 100.00%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.000029  Accuracy: 100.00%
Epoch 8 - Time: 70.31s - Train Loss: 0.000306 - Train Accuracy: 100.00%
Test Loss: 0.204748 - Test Accuracy: 96.13%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000079  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.000526  Accuracy: 100.00%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000305  Accuracy: 100.00%
```

```
Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000104  Accuracy: 100.00%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.000149  Accuracy: 100.00%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000083  Accuracy: 100.00%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000004  Accuracy: 100.00%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000746  Accuracy: 100.00%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000011  Accuracy: 100.00%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000034  Accuracy: 100.00%
Epoch 9 - Time: 78.52s - Train Loss: 0.000192 - Train Accuracy: 100.00%
Test Loss: 0.208604 - Test Accuracy: 96.17%

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FINAL RESULTS:
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epoch_times: [69.51631617546082, 69.40604424476624, 70.26281714439392, 69.
59209704399109, 69.3727650642395, 69.4801549911499, 70.08918619155884, 70.
74221420288086, 70.3086211681366, 78.52263188362122]
train_losses: [0.22906453477870078, 0.0634362316141322, 0.0332292017489629
54, 0.016551600300848037, 0.008967427556097795, 0.004017399415011835, 0.00
20946514760148824, 0.0006948257029763771, 0.0003057825911204377, 0.0001915
9463829897903]
train_accuracies: [92.91833333333334, 98.09333333333333, 98.95, 99.51, 99.
74166666666666, 99.91166666666666, 99.945, 99.99666666666667, 100.0, 100.
0]
test_losses: [0.2672746349930763, 0.21528946563601495, 0.1948863845288753
6, 0.17405127096176148, 0.24215227167643608, 0.187091173755005, 0.20713003
463223575, 0.20095540563613176, 0.20474845223538576, 0.20860398041773587]
test_accuracies: [92.26, 94.08, 95.25, 95.79, 94.8, 96.25, 95.8, 96.17, 9
6.13, 96.17]
```

In [14]:

```
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: 2.522722  Accuracy: 6.25%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.198462  Accuracy: 76.75%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.247714  Accuracy: 84.10%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.210251  Accuracy: 87.47%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.230434  Accuracy: 89.32%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.109318  Accuracy: 90.40%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.255196  Accuracy: 91.37%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.043819  Accuracy: 92.05%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.053947  Accuracy: 92.64%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.033348  Accuracy: 93.10%
Epoch 0 - Time: 87.79s - Train Loss: 0.214707 - Train Accuracy: 93.24%
Test Loss: 0.346711 - Test Accuracy: 89.69%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.019724  Accuracy: 100.00%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.085875  Accuracy: 98.05%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.029935  Accuracy: 98.15%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.050394  Accuracy: 98.09%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.029520  Accuracy: 98.04%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.004634  Accuracy: 98.01%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.059957  Accuracy: 98.06%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.011638  Accuracy: 98.10%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.030198  Accuracy: 98.08%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.033367  Accuracy: 98.12%
Epoch 1 - Time: 83.84s - Train Loss: 0.059684 - Train Accuracy: 98.13%
Test Loss: 0.254870 - Test Accuracy: 93.03%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.036592  Accuracy: 96.88%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.031111  Accuracy: 98.59%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.009452  Accuracy: 98.80%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.004892  Accuracy: 98.88%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.035582  Accuracy: 98.89%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.010976  Accuracy: 98.90%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.024120  Accuracy: 98.94%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.015293  Accuracy: 98.95%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.005381  Accuracy: 98.95%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.036867  Accuracy: 98.93%
Epoch 2 - Time: 84.27s - Train Loss: 0.033979 - Train Accuracy: 98.92%
Test Loss: 0.280412 - Test Accuracy: 92.70%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.008743  Accuracy: 100.00%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.025755  Accuracy: 99.33%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.005757  Accuracy: 99.43%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.006664  Accuracy: 99.43%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.024061  Accuracy: 99.40%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.000971  Accuracy: 99.44%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.003080  Accuracy: 99.42%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.013693  Accuracy: 99.39%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.031059  Accuracy: 99.40%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.021841  Accuracy: 99.40%
Epoch 3 - Time: 83.80s - Train Loss: 0.018302 - Train Accuracy: 99.40%
Test Loss: 0.229331 - Test Accuracy: 94.37%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.020348  Accuracy: 98.44%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.014723  Accuracy: 99.74%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.012821  Accuracy: 99.74%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.000344  Accuracy: 99.75%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.000123  Accuracy: 99.73%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.047013  Accuracy: 99.73%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.001345  Accuracy: 99.75%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.001976  Accuracy: 99.75%
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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.000182  Accuracy: 99.75%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.000223  Accuracy: 99.72%
Epoch 4 - Time: 83.67s - Train Loss: 0.009120 - Train Accuracy: 99.71%
Test Loss: 0.241816 - Test Accuracy: 94.47%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.002606  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.014800  Accuracy: 99.69%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.005746  Accuracy: 99.74%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.014636  Accuracy: 99.77%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.003381  Accuracy: 99.77%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.032281  Accuracy: 99.78%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.019079  Accuracy: 99.75%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.000641  Accuracy: 99.74%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.001546  Accuracy: 99.75%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.015154  Accuracy: 99.76%
Epoch 5 - Time: 83.11s - Train Loss: 0.008269 - Train Accuracy: 99.75%
Test Loss: 0.213409 - Test Accuracy: 94.96%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.002213  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.000321  Accuracy: 99.91%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.000692  Accuracy: 99.94%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.000304  Accuracy: 99.92%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000904  Accuracy: 99.92%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.000908  Accuracy: 99.94%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.000020  Accuracy: 99.93%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.000237  Accuracy: 99.93%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.001141  Accuracy: 99.93%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.000182  Accuracy: 99.92%
Epoch 6 - Time: 83.31s - Train Loss: 0.003312 - Train Accuracy: 99.92%
Test Loss: 0.223763 - Test Accuracy: 95.29%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.000488  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.000616  Accuracy: 99.98%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000124  Accuracy: 99.97%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000633  Accuracy: 99.95%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.011472  Accuracy: 99.96%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000373  Accuracy: 99.96%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.000064  Accuracy: 99.96%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.000529  Accuracy: 99.96%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.000077  Accuracy: 99.96%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.001855  Accuracy: 99.96%
Epoch 7 - Time: 83.44s - Train Loss: 0.001908 - Train Accuracy: 99.95%
Test Loss: 0.221036 - Test Accuracy: 95.19%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.001637  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.000110  Accuracy: 100.00%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.000319  Accuracy: 99.98%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.000688  Accuracy: 99.98%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000112  Accuracy: 99.99%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000013  Accuracy: 99.99%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000202  Accuracy: 99.99%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000493  Accuracy: 99.99%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.000202  Accuracy: 99.99%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.000762  Accuracy: 99.99%
Epoch 8 - Time: 82.80s - Train Loss: 0.000703 - Train Accuracy: 99.99%
Test Loss: 0.222018 - Test Accuracy: 95.68%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000055  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.000012  Accuracy: 100.00%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000030  Accuracy: 100.00%
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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000369  Accuracy: 100.00%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.000026  Accuracy: 100.00%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000531  Accuracy: 100.00%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000020  Accuracy: 100.00%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000161  Accuracy: 100.00%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000116  Accuracy: 100.00%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000785  Accuracy: 100.00%
Epoch 9 - Time: 83.44s - Train Loss: 0.000232 - Train Accuracy: 100.00%
Test Loss: 0.226375 - Test Accuracy: 95.67%

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FINAL RESULTS:
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epoch_times: [87.79366397857666, 83.84330987930298, 84.2671811580658, 83.7
9835510253906, 83.67167472839355, 83.10805606842041, 83.30624508857727, 8
3.43597388267517, 82.80321502685547, 83.43610095977783]
train_losses: [0.2147066465356568, 0.05968409894021359, 0.0339786135554954
04, 0.01830244066378872, 0.009120027898985148, 0.00826933527314938, 0.0033
117794126588233, 0.0019078685497861405, 0.000702777788786376, 0.0002323198
3376858915]
train_accuracies: [93.24333333333334, 98.13166666666666, 98.915, 99.4, 99.
71, 99.75333333333333, 99.91666666666667, 99.95333333333333, 99.9933333333
3334, 100.0]
test_losses: [0.34671128873825074, 0.2548696404695511, 0.2804124435186386,
0.22933072055578232, 0.2418155792593956, 0.21340897348243743, 0.2237634674
0424632, 0.22103586821574717, 0.22201751565039157, 0.22637486218214034]
test_accuracies: [89.69, 93.03, 92.7, 94.37, 94.47, 94.96, 95.29, 95.19, 9
5.68, 95.67]
```

In [15]:

```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: 2.340392  Accuracy: 14.06%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.450846  Accuracy: 75.48%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.295894  Accuracy: 83.55%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.093837  Accuracy: 86.84%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.160595  Accuracy: 89.01%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.143323  Accuracy: 90.27%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.049638  Accuracy: 91.26%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.057915  Accuracy: 92.02%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.061352  Accuracy: 92.63%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.046846  Accuracy: 93.13%
Epoch 0 - Time: 84.07s - Train Loss: 0.213753 - Train Accuracy: 93.29%
Test Loss: 1.059317 - Test Accuracy: 68.01%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.019404  Accuracy: 100.00%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.053578  Accuracy: 98.44%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.143534  Accuracy: 98.31%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.031630  Accuracy: 98.15%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.070845  Accuracy: 98.13%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.111622  Accuracy: 98.13%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.011683  Accuracy: 98.13%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.025103  Accuracy: 98.10%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.118508  Accuracy: 98.12%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.023868  Accuracy: 98.11%
Epoch 1 - Time: 84.00s - Train Loss: 0.060912 - Train Accuracy: 98.12%
Test Loss: 1.494321 - Test Accuracy: 63.64%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.063572  Accuracy: 98.44%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.017151  Accuracy: 99.15%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.125865  Accuracy: 99.19%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.035762  Accuracy: 99.12%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.003402  Accuracy: 99.04%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.033689  Accuracy: 99.00%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.003609  Accuracy: 99.02%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.002873  Accuracy: 99.02%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.020664  Accuracy: 98.98%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.017888  Accuracy: 98.97%
Epoch 2 - Time: 83.65s - Train Loss: 0.032938 - Train Accuracy: 98.95%
Test Loss: 1.085148 - Test Accuracy: 70.63%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.028094  Accuracy: 98.44%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.045521  Accuracy: 99.57%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.002493  Accuracy: 99.56%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.018296  Accuracy: 99.55%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.002470  Accuracy: 99.57%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.070018  Accuracy: 99.54%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.000410  Accuracy: 99.52%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.021471  Accuracy: 99.49%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.038034  Accuracy: 99.45%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.027195  Accuracy: 99.44%
Epoch 3 - Time: 84.63s - Train Loss: 0.018727 - Train Accuracy: 99.44%
Test Loss: 1.204364 - Test Accuracy: 72.14%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.017461  Accuracy: 98.44%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.001650  Accuracy: 99.71%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.021581  Accuracy: 99.78%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.028974  Accuracy: 99.75%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.002473  Accuracy: 99.76%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.004818  Accuracy: 99.76%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.017358  Accuracy: 99.75%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.036678  Accuracy: 99.73%
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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.002829  Accuracy: 99.73%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.000761  Accuracy: 99.73%
Epoch 4 - Time: 83.61s - Train Loss: 0.010226 - Train Accuracy: 99.71%
Test Loss: 1.062858 - Test Accuracy: 74.79%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.003240  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.001642  Accuracy: 99.80%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.012560  Accuracy: 99.85%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.000590  Accuracy: 99.89%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.000860  Accuracy: 99.86%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.001330  Accuracy: 99.84%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.003762  Accuracy: 99.84%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.004698  Accuracy: 99.85%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.000705  Accuracy: 99.85%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.006842  Accuracy: 99.85%
Epoch 5 - Time: 83.43s - Train Loss: 0.005067 - Train Accuracy: 99.85%
Test Loss: 1.875211 - Test Accuracy: 65.43%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.004458  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.001896  Accuracy: 99.92%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.012617  Accuracy: 99.93%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.000321  Accuracy: 99.93%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000006  Accuracy: 99.91%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.001485  Accuracy: 99.90%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.000119  Accuracy: 99.92%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.003429  Accuracy: 99.91%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.000351  Accuracy: 99.91%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.000506  Accuracy: 99.92%
Epoch 6 - Time: 83.37s - Train Loss: 0.003045 - Train Accuracy: 99.92%
Test Loss: 1.446708 - Test Accuracy: 71.49%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.000031  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.004512  Accuracy: 99.97%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000116  Accuracy: 99.97%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000179  Accuracy: 99.95%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.008939  Accuracy: 99.95%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000725  Accuracy: 99.96%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.002606  Accuracy: 99.96%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.000249  Accuracy: 99.96%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.000506  Accuracy: 99.96%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000094  Accuracy: 99.96%
Epoch 7 - Time: 83.51s - Train Loss: 0.001636 - Train Accuracy: 99.96%
Test Loss: 1.335356 - Test Accuracy: 73.04%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.000161  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.002470  Accuracy: 100.00%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.001418  Accuracy: 100.00%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.000016  Accuracy: 100.00%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000029  Accuracy: 100.00%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000317  Accuracy: 100.00%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000082  Accuracy: 100.00%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000090  Accuracy: 100.00%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.000180  Accuracy: 100.00%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.000084  Accuracy: 100.00%
Epoch 8 - Time: 83.61s - Train Loss: 0.000434 - Train Accuracy: 100.00%
Test Loss: 1.550061 - Test Accuracy: 71.13%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000129  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.000031  Accuracy: 100.00%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000180  Accuracy: 100.00%
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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000048  Accuracy: 100.00%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.000046  Accuracy: 100.00%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000077  Accuracy: 100.00%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000667  Accuracy: 100.00%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000857  Accuracy: 100.00%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000012  Accuracy: 100.00%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000034  Accuracy: 100.00%
Epoch 9 - Time: 83.76s - Train Loss: 0.000212 - Train Accuracy: 100.00%
Test Loss: 1.637291 - Test Accuracy: 70.79%

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FINAL RESULTS:
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epoch_times: [84.06951212882996, 83.99921989440918, 83.6530020236969, 84.6
3208723068237, 83.60700798034668, 83.42590284347534, 83.36806607246399, 8
3.5056881904602, 83.60557913780212, 83.76016211509705]
train_losses: [0.21375267487515742, 0.06091224604774254, 0.032938237395274
07, 0.018727370180752573, 0.010225935511777988, 0.005067333571013709, 0.00
30447242696285304, 0.0016360411367590682, 0.00043394808669646156, 0.000211
53687791776416]
train_accuracies: [93.29333333333334, 98.11666666666666, 98.9533333333333
3, 99.435, 99.70833333333333, 99.85, 99.915, 99.96166666666667, 100.0, 10
0.0]
test_losses: [1.0593174184799194, 1.494320530128479, 1.0851484392166137,
1.204363575744629, 1.0628582971572875, 1.8752112689971925, 1.4467078410148
622, 1.3353558588027954, 1.5500606636047363, 1.6372907283782958]
test_accuracies: [68.01, 63.64, 70.63, 72.14, 74.79, 65.43, 71.49, 73.04,
71.13, 70.79]
```
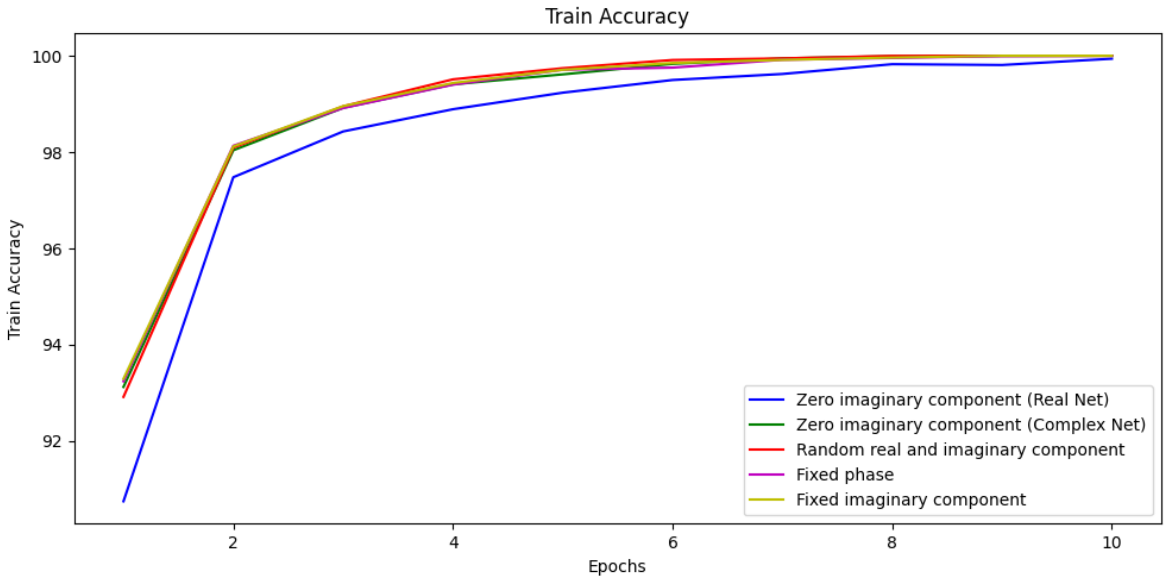
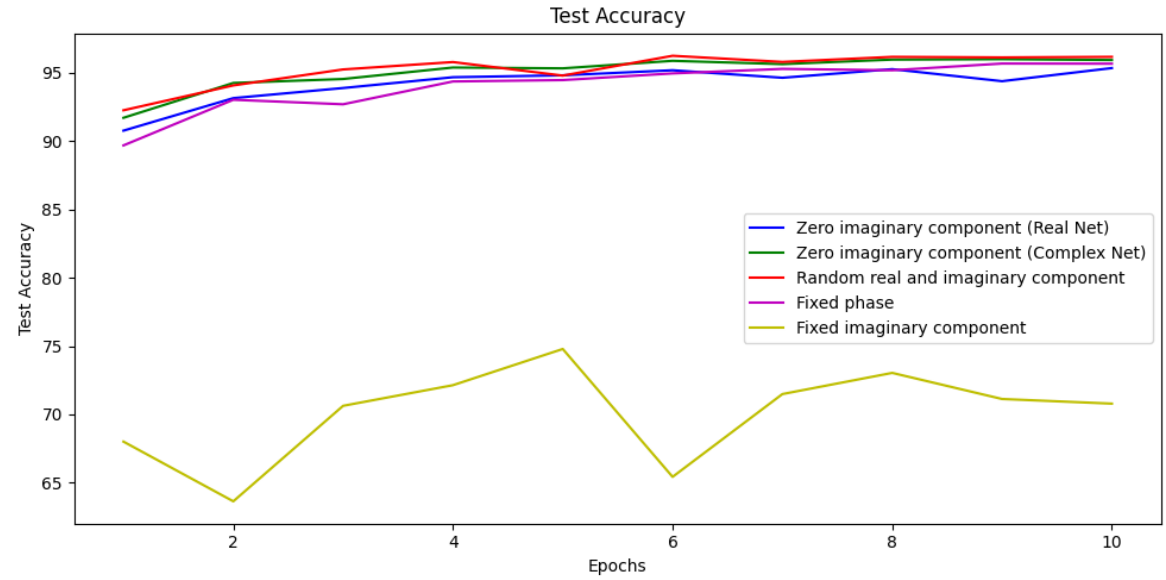
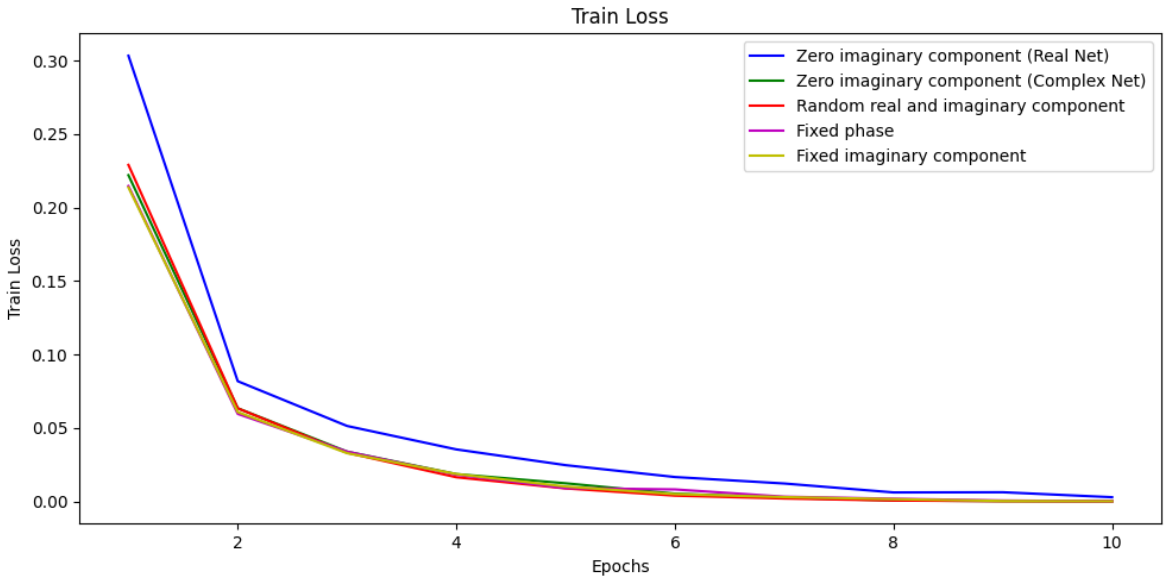

Plots

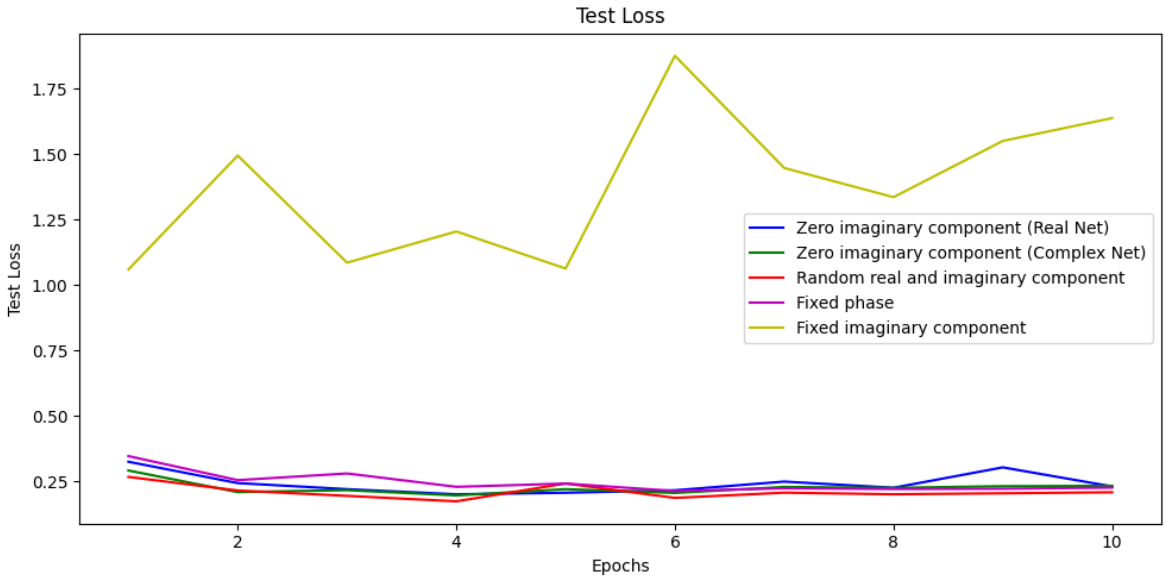
In [16]:
```
# Data for the four scenarios
data = {
    "Zero imaginary component (Real Net)": metrics_dict_e1,
    "Zero imaginary component (Complex Net)": metrics_dict_e2,
    "Random real and imaginary component": metrics_dict_e3,
    "Fixed phase": metrics_dict_e4,
    "Fixed imaginary component": 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()
```

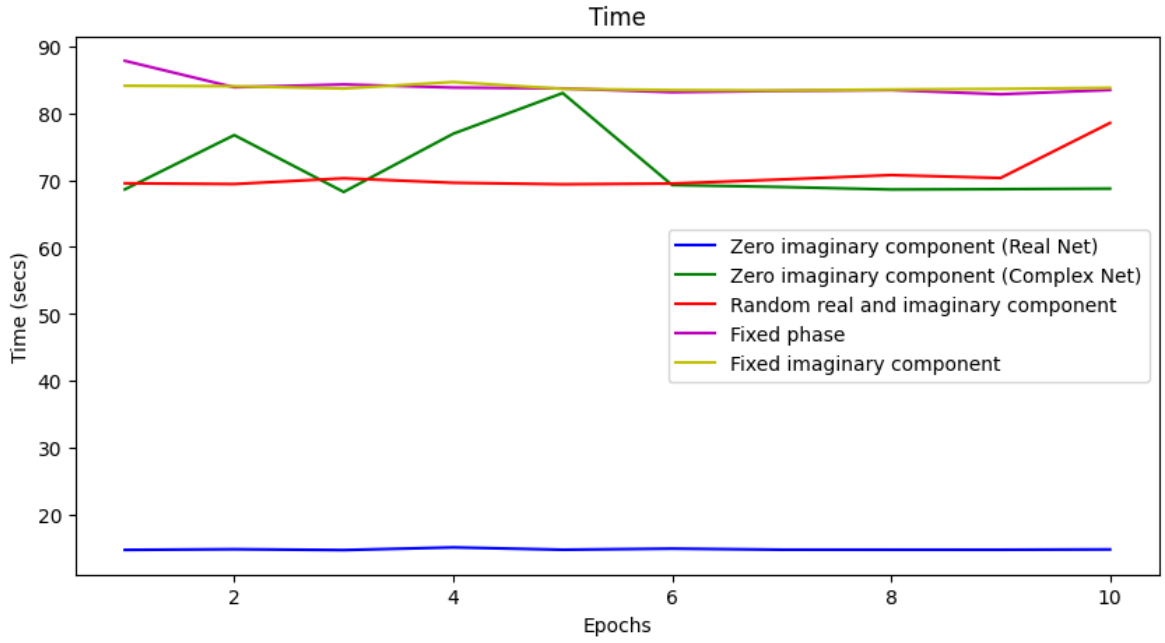

Train Accuracy
Train Accuracy
Epochs
Zero imaginary component (Real Net)
Zero imaginary component (Complex Net)
Random real and imaginary component
Fixed phase
Fixed imaginary component


Test Accuracy
Test Accuracy
Epochs
Zero imaginary component (Real Net)
Zero imaginary component (Complex Net)
Random real and imaginary component
Fixed phase
Fixed imaginary component





Out[16]: `<matplotlib.legend.Legend at 0x29bc73110>`



In [17]:
```
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()
```