EXP 1

In [8]:
```
# 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 [12]:
```
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
```

MNIST

In [9]:
```
NUM_EPOCHS = 10
batch_size = 64
trans = transforms.Compose([transforms.ToTensor(), transforms.Normalize((

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

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 [20]:
```
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: 2.262687  Accuracy: 14.06%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.463389  Accuracy: 79.50%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.205152  Accuracy: 87.30%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.152684  Accuracy: 90.42%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.092934  Accuracy: 92.00%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.211287  Accuracy: 92.97%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.107907  Accuracy: 93.69%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.044483  Accuracy: 94.30%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.046212  Accuracy: 94.77%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.036839  Accuracy: 95.15%
Epoch 0 - Time: 14.86s - Train Loss: 0.154970 - Train Accuracy: 95.25%
Test Loss: 0.059407 - Test Accuracy: 98.05%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.093310  Accuracy: 96.88%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.013763  Accuracy: 98.55%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.028580  Accuracy: 98.50%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.015967  Accuracy: 98.52%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.100503  Accuracy: 98.47%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.002658  Accuracy: 98.55%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.048031  Accuracy: 98.53%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.030914  Accuracy: 98.54%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.002889  Accuracy: 98.57%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.027400  Accuracy: 98.56%
Epoch 1 - Time: 14.71s - Train Loss: 0.048723 - Train Accuracy: 98.56%
Test Loss: 0.048223 - Test Accuracy: 98.35%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.052190  Accuracy: 98.44%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.007421  Accuracy: 99.16%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.018550  Accuracy: 99.00%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.020496  Accuracy: 98.96%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.073111  Accuracy: 98.99%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.005395  Accuracy: 99.01%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.036948  Accuracy: 99.01%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.065016  Accuracy: 98.99%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.008750  Accuracy: 98.96%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.061388  Accuracy: 98.97%
Epoch 2 - Time: 14.74s - Train Loss: 0.033304 - Train Accuracy: 98.97%
Test Loss: 0.032136 - Test Accuracy: 98.95%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.018014  Accuracy: 98.44%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.002326  Accuracy: 99.13%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.002422  Accuracy: 99.24%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.039043  Accuracy: 99.23%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.003845  Accuracy: 99.26%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.005673  Accuracy: 99.22%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.004108  Accuracy: 99.22%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.005777  Accuracy: 99.19%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.003549  Accuracy: 99.22%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.031583  Accuracy: 99.22%
Epoch 3 - Time: 14.70s - Train Loss: 0.024227 - Train Accuracy: 99.23%
Test Loss: 0.035127 - Test Accuracy: 98.87%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.002586  Accuracy: 100.00%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.024487  Accuracy: 99.41%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.001295  Accuracy: 99.40%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.005169  Accuracy: 99.42%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.001316  Accuracy: 99.43%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.002367  Accuracy: 99.45%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.000662  Accuracy: 99.48%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.102855  Accuracy: 99.45%
```

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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.003600  Accuracy: 99.42%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.009704  Accuracy: 99.42%
Epoch 4 - Time: 14.78s - Train Loss: 0.018372 - Train Accuracy: 99.42%
Test Loss: 0.028193 - Test Accuracy: 99.16%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.004175  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.000876  Accuracy: 99.47%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.008496  Accuracy: 99.52%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.020368  Accuracy: 99.50%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.000257  Accuracy: 99.52%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.000097  Accuracy: 99.50%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.002391  Accuracy: 99.51%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.001615  Accuracy: 99.51%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.010788  Accuracy: 99.49%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.027811  Accuracy: 99.47%
Epoch 5 - Time: 14.66s - Train Loss: 0.015264 - Train Accuracy: 99.47%
Test Loss: 0.029601 - Test Accuracy: 99.10%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.000658  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.005189  Accuracy: 99.61%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.001752  Accuracy: 99.68%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.007524  Accuracy: 99.70%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000543  Accuracy: 99.66%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.024954  Accuracy: 99.59%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.003854  Accuracy: 99.61%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.000116  Accuracy: 99.61%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.003659  Accuracy: 99.62%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.008980  Accuracy: 99.61%
Epoch 6 - Time: 14.67s - Train Loss: 0.012320 - Train Accuracy: 99.61%
Test Loss: 0.027572 - Test Accuracy: 99.10%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.003599  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.000954  Accuracy: 99.77%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000984  Accuracy: 99.77%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000908  Accuracy: 99.77%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.001214  Accuracy: 99.78%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000068  Accuracy: 99.78%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.021793  Accuracy: 99.76%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.009234  Accuracy: 99.74%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.000039  Accuracy: 99.74%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000378  Accuracy: 99.73%
Epoch 7 - Time: 14.73s - Train Loss: 0.008573 - Train Accuracy: 99.73%
Test Loss: 0.033031 - Test Accuracy: 98.93%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.000695  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.029768  Accuracy: 99.78%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.007411  Accuracy: 99.77%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.002626  Accuracy: 99.78%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000206  Accuracy: 99.77%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000574  Accuracy: 99.76%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000342  Accuracy: 99.74%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.017795  Accuracy: 99.75%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.021130  Accuracy: 99.75%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.010862  Accuracy: 99.74%
Epoch 8 - Time: 14.71s - Train Loss: 0.007986 - Train Accuracy: 99.74%
Test Loss: 0.028056 - Test Accuracy: 99.11%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.003012  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.005233  Accuracy: 99.97%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.005486  Accuracy: 99.93%
```

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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000999  Accuracy: 99.92%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.001251  Accuracy: 99.91%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000213  Accuracy: 99.89%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.015402  Accuracy: 99.87%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000202  Accuracy: 99.87%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.008154  Accuracy: 99.85%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.001221  Accuracy: 99.85%
Epoch 9 - Time: 14.72s - Train Loss: 0.005330 - Train Accuracy: 99.84%
Test Loss: 0.028861 - Test Accuracy: 99.23%

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FINAL RESULTS:
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epoch_times: [14.859425067901611, 14.713163137435913, 14.74114990234375, 1
4.70323920249939, 14.783581972122192, 14.65928602218628, 14.6674487590789
8, 14.727883100509644, 14.712125778198242, 14.715364217758179]
train_losses: [0.15496951191331634, 0.04872267578355174, 0.033303761730719
7, 0.02422716276839498, 0.01837197570765867, 0.015264486825006253, 0.01231
9668897891543, 0.008573238418468196, 0.007985976188644148, 0.0053298718430
51907]
train_accuracies: [95.24666666666667, 98.55666666666667, 98.9683333333333
3, 99.22666666666667, 99.42166666666667, 99.46666666666667, 99.615, 99.726
66666666667, 99.74166666666666, 99.845]
test_losses: [0.05940711457133293, 0.048223168255202474, 0.032135709577519
45, 0.03512672675331123, 0.02819304817682132, 0.029600916524510832, 0.0275
72035235073417, 0.033030651423567904, 0.028056417879034415, 0.028861498356
1798]
test_accuracies: [98.05, 98.35, 98.95, 98.87, 99.16, 99.1, 99.1, 98.93, 9
9.11, 99.23]
```

2. Complex Net

In [21]:

```
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: 2.356533  Accuracy: 14.06%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.138508  Accuracy: 86.37%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.253641  Accuracy: 91.35%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.015434  Accuracy: 93.17%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.008841  Accuracy: 94.31%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.091439  Accuracy: 95.01%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.104785  Accuracy: 95.46%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.016814  Accuracy: 95.79%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.034091  Accuracy: 96.10%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.084565  Accuracy: 96.35%
Epoch 0 - Time: 66.89s - Train Loss: 0.114470 - Train Accuracy: 96.43%
Test Loss: 0.045794 - Test Accuracy: 98.47%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.061229  Accuracy: 98.44%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.005443  Accuracy: 98.78%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.040747  Accuracy: 98.77%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.036018  Accuracy: 98.81%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.017801  Accuracy: 98.75%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.042093  Accuracy: 98.81%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.007323  Accuracy: 98.80%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.023456  Accuracy: 98.81%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.008853  Accuracy: 98.84%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.001166  Accuracy: 98.87%
Epoch 1 - Time: 67.88s - Train Loss: 0.036981 - Train Accuracy: 98.87%
Test Loss: 0.029364 - Test Accuracy: 99.06%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.009778  Accuracy: 100.00%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.003628  Accuracy: 99.20%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.003897  Accuracy: 99.28%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.002003  Accuracy: 99.29%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.037468  Accuracy: 99.27%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.016690  Accuracy: 99.28%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.009586  Accuracy: 99.28%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.021811  Accuracy: 99.28%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.004827  Accuracy: 99.28%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.002287  Accuracy: 99.30%
Epoch 2 - Time: 68.25s - Train Loss: 0.022565 - Train Accuracy: 99.29%
Test Loss: 0.031922 - Test Accuracy: 98.94%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.061141  Accuracy: 98.44%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.002012  Accuracy: 99.54%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.002742  Accuracy: 99.54%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.007194  Accuracy: 99.56%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.086005  Accuracy: 99.50%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.002545  Accuracy: 99.50%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.000510  Accuracy: 99.51%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.009433  Accuracy: 99.52%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.006100  Accuracy: 99.51%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.026886  Accuracy: 99.50%
Epoch 3 - Time: 67.81s - Train Loss: 0.015579 - Train Accuracy: 99.50%
Test Loss: 0.027943 - Test Accuracy: 99.14%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.000514  Accuracy: 100.00%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.003009  Accuracy: 99.66%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.000577  Accuracy: 99.71%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.009478  Accuracy: 99.70%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.000130  Accuracy: 99.72%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.071871  Accuracy: 99.69%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.000591  Accuracy: 99.69%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.000301  Accuracy: 99.67%
```

```
Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.005709  Accuracy: 99.68%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.004903  Accuracy: 99.67%
Epoch 4 - Time: 68.39s - Train Loss: 0.009584 - Train Accuracy: 99.67%
Test Loss: 0.030009 - Test Accuracy: 99.02%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.000536  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.000326  Accuracy: 99.81%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.050702  Accuracy: 99.80%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.000219  Accuracy: 99.82%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.002229  Accuracy: 99.81%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.003607  Accuracy: 99.78%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.002930  Accuracy: 99.78%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.079915  Accuracy: 99.77%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.000348  Accuracy: 99.77%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.054535  Accuracy: 99.77%
Epoch 5 - Time: 68.89s - Train Loss: 0.007321 - Train Accuracy: 99.77%
Test Loss: 0.031254 - Test Accuracy: 99.11%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.000236  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.016890  Accuracy: 99.77%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.000155  Accuracy: 99.81%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.000809  Accuracy: 99.84%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000177  Accuracy: 99.82%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.008819  Accuracy: 99.83%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.008321  Accuracy: 99.83%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.000115  Accuracy: 99.83%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.000271  Accuracy: 99.83%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.000797  Accuracy: 99.82%
Epoch 6 - Time: 69.19s - Train Loss: 0.005004 - Train Accuracy: 99.82%
Test Loss: 0.029534 - Test Accuracy: 99.19%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.000124  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.000068  Accuracy: 99.85%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000426  Accuracy: 99.88%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000320  Accuracy: 99.89%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.000034  Accuracy: 99.89%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.005342  Accuracy: 99.91%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.000028  Accuracy: 99.89%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.002992  Accuracy: 99.89%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.011054  Accuracy: 99.88%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000873  Accuracy: 99.88%
Epoch 7 - Time: 69.36s - Train Loss: 0.003587 - Train Accuracy: 99.88%
Test Loss: 0.026397 - Test Accuracy: 99.21%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.000270  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.000372  Accuracy: 99.91%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.000044  Accuracy: 99.92%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.000225  Accuracy: 99.94%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.002932  Accuracy: 99.95%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000086  Accuracy: 99.94%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000623  Accuracy: 99.94%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000379  Accuracy: 99.94%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.002885  Accuracy: 99.94%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.000132  Accuracy: 99.94%
Epoch 8 - Time: 69.14s - Train Loss: 0.002080 - Train Accuracy: 99.94%
Test Loss: 0.027270 - Test Accuracy: 99.27%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000340  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.000661  Accuracy: 99.95%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000010  Accuracy: 99.93%
```

```
Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000011  Accuracy: 99.95%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.000886  Accuracy: 99.95%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000093  Accuracy: 99.95%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000009  Accuracy: 99.95%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000017  Accuracy: 99.96%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000257  Accuracy: 99.96%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000051  Accuracy: 99.97%
Epoch 9 - Time: 68.70s - Train Loss: 0.001188 - Train Accuracy: 99.97%
Test Loss: 0.027860 - Test Accuracy: 99.24%

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FINAL RESULTS:
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epoch_times: [66.8922438621521, 67.88446807861328, 68.25180101394653, 67.8
0947470664978, 68.38691282272339, 68.89367699623108, 69.18817186355591, 6
9.36455297470093, 69.13587403297424, 68.69659805297852]
train_losses: [0.11447048753024394, 0.03698148076781625, 0.022565020809201
947, 0.01557939026754232, 0.00958381272406524, 0.007321416598128933, 0.005
0036769081827845, 0.003587127722662803, 0.0020803177588724314, 0.001188001
883276359]
train_accuracies: [96.42666666666666, 98.87333333333333, 99.2933333333333
4, 99.5, 99.67333333333333, 99.76833333333333, 99.81666666666666, 99.88166
666666666, 99.945, 99.965]
test_losses: [0.045794190772622825, 0.029364080341532827, 0.03192167275974
0616, 0.02794349688058137, 0.030008691640291362, 0.03125399534851895, 0.02
9533738952863497, 0.026397155034018214, 0.027270437314498124, 0.0278603762
85571694]
test_accuracies: [98.47, 99.06, 98.94, 99.14, 99.02, 99.11, 99.19, 99.21,
99.27, 99.24]
```

3. Functional changes!

In [22]:
```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 [23]:
```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: 2.418295  Accuracy: 10.94%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.186273  Accuracy: 87.50%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.093702  Accuracy: 91.88%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.102505  Accuracy: 93.61%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.030066  Accuracy: 94.56%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.243507  Accuracy: 95.25%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.082576  Accuracy: 95.67%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.042257  Accuracy: 96.05%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.015111  Accuracy: 96.32%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.052347  Accuracy: 96.56%
Epoch 0 - Time: 68.45s - Train Loss: 0.111799 - Train Accuracy: 96.61%
Test Loss: 0.050851 - Test Accuracy: 98.52%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.016430  Accuracy: 98.44%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.059935  Accuracy: 98.64%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.029189  Accuracy: 98.86%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.013682  Accuracy: 98.92%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.057970  Accuracy: 98.90%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.033823  Accuracy: 98.90%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.123594  Accuracy: 98.86%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.093491  Accuracy: 98.87%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.009226  Accuracy: 98.89%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.002259  Accuracy: 98.88%
Epoch 1 - Time: 69.31s - Train Loss: 0.036532 - Train Accuracy: 98.89%
Test Loss: 0.042845 - Test Accuracy: 98.67%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.035499  Accuracy: 96.88%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.005669  Accuracy: 99.27%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.002017  Accuracy: 99.35%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.001058  Accuracy: 99.38%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.063266  Accuracy: 99.36%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.067882  Accuracy: 99.34%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.051122  Accuracy: 99.29%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.020983  Accuracy: 99.28%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.066662  Accuracy: 99.26%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.000581  Accuracy: 99.26%
Epoch 2 - Time: 69.02s - Train Loss: 0.023256 - Train Accuracy: 99.26%
Test Loss: 0.033547 - Test Accuracy: 98.92%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.002919  Accuracy: 100.00%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.007517  Accuracy: 99.57%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.026407  Accuracy: 99.48%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.037755  Accuracy: 99.52%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.000370  Accuracy: 99.52%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.013405  Accuracy: 99.48%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.008408  Accuracy: 99.45%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.009661  Accuracy: 99.44%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.000402  Accuracy: 99.43%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.008215  Accuracy: 99.42%
Epoch 3 - Time: 68.95s - Train Loss: 0.017666 - Train Accuracy: 99.41%
Test Loss: 0.035267 - Test Accuracy: 98.92%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.003681  Accuracy: 100.00%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.001575  Accuracy: 99.61%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.000090  Accuracy: 99.64%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.001501  Accuracy: 99.64%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.000655  Accuracy: 99.68%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.004844  Accuracy: 99.69%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.001100  Accuracy: 99.69%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.017859  Accuracy: 99.67%
```

```
Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.004603  Accuracy: 99.65%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.031361  Accuracy: 99.64%
Epoch 4 - Time: 68.91s - Train Loss: 0.011567 - Train Accuracy: 99.64%
Test Loss: 0.031996 - Test Accuracy: 99.13%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.004428  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.007303  Accuracy: 99.52%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.001828  Accuracy: 99.67%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.000640  Accuracy: 99.71%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.001250  Accuracy: 99.71%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.000170  Accuracy: 99.74%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.002443  Accuracy: 99.76%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.000509  Accuracy: 99.76%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.000337  Accuracy: 99.77%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.022763  Accuracy: 99.76%
Epoch 5 - Time: 69.17s - Train Loss: 0.007103 - Train Accuracy: 99.76%
Test Loss: 0.028458 - Test Accuracy: 99.19%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.000060  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.003919  Accuracy: 99.89%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.001156  Accuracy: 99.88%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.002617  Accuracy: 99.88%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000388  Accuracy: 99.86%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.022316  Accuracy: 99.85%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.000691  Accuracy: 99.85%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.000560  Accuracy: 99.87%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.005232  Accuracy: 99.86%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.001493  Accuracy: 99.85%
Epoch 6 - Time: 70.33s - Train Loss: 0.004877 - Train Accuracy: 99.85%
Test Loss: 0.028068 - Test Accuracy: 99.27%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.000106  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.004753  Accuracy: 99.98%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000041  Accuracy: 99.95%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.008106  Accuracy: 99.94%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.003580  Accuracy: 99.93%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000728  Accuracy: 99.92%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.002214  Accuracy: 99.91%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.000494  Accuracy: 99.90%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.000476  Accuracy: 99.89%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000105  Accuracy: 99.89%
Epoch 7 - Time: 70.24s - Train Loss: 0.003426 - Train Accuracy: 99.89%
Test Loss: 0.028447 - Test Accuracy: 99.27%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.001497  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.000384  Accuracy: 99.95%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.009935  Accuracy: 99.98%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.000958  Accuracy: 99.97%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000286  Accuracy: 99.95%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000926  Accuracy: 99.95%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000169  Accuracy: 99.94%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000141  Accuracy: 99.93%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.005488  Accuracy: 99.92%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.001822  Accuracy: 99.93%
Epoch 8 - Time: 70.63s - Train Loss: 0.002068 - Train Accuracy: 99.93%
Test Loss: 0.029234 - Test Accuracy: 99.29%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000868  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.001021  Accuracy: 99.98%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000012  Accuracy: 99.99%
```

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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.001008  Accuracy: 99.99%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.002366  Accuracy: 100.00%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000583  Accuracy: 100.00%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000047  Accuracy: 99.99%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000354  Accuracy: 99.98%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000868  Accuracy: 99.97%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000414  Accuracy: 99.97%
Epoch 9 - Time: 69.84s - Train Loss: 0.001459 - Train Accuracy: 99.96%
Test Loss: 0.034688 - Test Accuracy: 99.14%

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FINAL RESULTS:
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epoch_times: [68.45487308502197, 69.31177377700806, 69.02261710166931, 68.
95275783538818, 68.91142201423645, 69.16733574867249, 70.33323907852173, 7
0.24401497840881, 70.63105297088623, 69.83879280090332]
train_losses: [0.11179877731150814, 0.036532314554321516, 0.02325619338018
2318, 0.01766572529130165, 0.011566800552571794, 0.007102716255089392, 0.0
04876669276545785, 0.003426181155755272, 0.002068153598553842, 0.001458961
9049042452]
train_accuracies: [96.61333333333333, 98.89166666666667, 99.2616666666666
7, 99.41, 99.635, 99.76333333333334, 99.85166666666667, 99.89333333333333,
99.93166666666667, 99.96166666666667]
test_losses: [0.05085050071962178, 0.042845471642958, 0.03354671207796782
6, 0.03526682399371639, 0.031995763880596495, 0.028458332717069424, 0.0280
6773073094082, 0.02844713626423618, 0.029233853820920922, 0.03468782204197
487]
test_accuracies: [98.52, 98.67, 98.92, 98.92, 99.13, 99.19, 99.27, 99.27,
99.29, 99.14]
```

In [24]:

```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_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: 2.333017  Accuracy: 9.38%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.189741  Accuracy: 87.22%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.054558  Accuracy: 91.60%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.046118  Accuracy: 93.28%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.016258  Accuracy: 94.31%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.039318  Accuracy: 94.91%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.016534  Accuracy: 95.44%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.057901  Accuracy: 95.82%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.046685  Accuracy: 96.05%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.033294  Accuracy: 96.29%
Epoch 0 - Time: 69.46s - Train Loss: 0.116505 - Train Accuracy: 96.36%
Test Loss: 0.040268 - Test Accuracy: 98.61%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.039001  Accuracy: 98.44%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.008181  Accuracy: 98.67%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.034565  Accuracy: 98.73%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.054144  Accuracy: 98.75%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.041237  Accuracy: 98.78%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.024355  Accuracy: 98.81%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.056113  Accuracy: 98.82%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.007743  Accuracy: 98.81%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.027506  Accuracy: 98.81%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.015680  Accuracy: 98.83%
Epoch 1 - Time: 69.09s - Train Loss: 0.038315 - Train Accuracy: 98.84%
Test Loss: 0.055703 - Test Accuracy: 98.18%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.036357  Accuracy: 98.44%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.018464  Accuracy: 99.18%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.000864  Accuracy: 99.18%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.032720  Accuracy: 99.21%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.002700  Accuracy: 99.21%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.002542  Accuracy: 99.18%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.017389  Accuracy: 99.17%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.004287  Accuracy: 99.17%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.080088  Accuracy: 99.20%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.052068  Accuracy: 99.22%
Epoch 2 - Time: 69.05s - Train Loss: 0.023620 - Train Accuracy: 99.23%
Test Loss: 0.033082 - Test Accuracy: 99.04%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.011697  Accuracy: 100.00%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.000114  Accuracy: 99.64%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.000263  Accuracy: 99.59%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.037128  Accuracy: 99.56%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.048475  Accuracy: 99.56%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.002344  Accuracy: 99.49%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.006882  Accuracy: 99.45%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.001724  Accuracy: 99.45%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.001268  Accuracy: 99.45%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.035999  Accuracy: 99.44%
Epoch 3 - Time: 69.13s - Train Loss: 0.016678 - Train Accuracy: 99.43%
Test Loss: 0.036320 - Test Accuracy: 98.75%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.002169  Accuracy: 100.00%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.008548  Accuracy: 99.69%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.077549  Accuracy: 99.64%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.008413  Accuracy: 99.66%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.002899  Accuracy: 99.67%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.012013  Accuracy: 99.65%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.018441  Accuracy: 99.65%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.003743  Accuracy: 99.63%
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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.004543  Accuracy: 99.61%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.001039  Accuracy: 99.61%
Epoch 4 - Time: 68.80s - Train Loss: 0.011468 - Train Accuracy: 99.61%
Test Loss: 0.037179 - Test Accuracy: 98.76%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.000200  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.005604  Accuracy: 99.88%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.000840  Accuracy: 99.88%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.000315  Accuracy: 99.82%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.009290  Accuracy: 99.83%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.000106  Accuracy: 99.85%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.001428  Accuracy: 99.86%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.000180  Accuracy: 99.86%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.001346  Accuracy: 99.83%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.050709  Accuracy: 99.80%
Epoch 5 - Time: 68.80s - Train Loss: 0.006526 - Train Accuracy: 99.79%
Test Loss: 0.045661 - Test Accuracy: 98.45%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.000266  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.000811  Accuracy: 99.94%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.000262  Accuracy: 99.84%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.001022  Accuracy: 99.83%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000431  Accuracy: 99.84%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.000339  Accuracy: 99.84%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.000147  Accuracy: 99.84%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.000547  Accuracy: 99.85%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.002126  Accuracy: 99.86%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.015690  Accuracy: 99.84%
Epoch 6 - Time: 69.06s - Train Loss: 0.005090 - Train Accuracy: 99.84%
Test Loss: 0.039343 - Test Accuracy: 98.85%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.011430  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.008996  Accuracy: 99.92%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000285  Accuracy: 99.92%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000966  Accuracy: 99.93%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.000009  Accuracy: 99.91%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.000057  Accuracy: 99.92%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.005052  Accuracy: 99.92%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.000087  Accuracy: 99.91%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.000695  Accuracy: 99.92%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000463  Accuracy: 99.92%
Epoch 7 - Time: 68.81s - Train Loss: 0.003026 - Train Accuracy: 99.92%
Test Loss: 0.041893 - Test Accuracy: 98.79%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.000107  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.008202  Accuracy: 99.92%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.000760  Accuracy: 99.95%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.000157  Accuracy: 99.96%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.002409  Accuracy: 99.97%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.001064  Accuracy: 99.97%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000264  Accuracy: 99.96%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000410  Accuracy: 99.97%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.000853  Accuracy: 99.97%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.000409  Accuracy: 99.96%
Epoch 8 - Time: 68.37s - Train Loss: 0.001847 - Train Accuracy: 99.96%
Test Loss: 0.039491 - Test Accuracy: 98.87%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.003391  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.003462  Accuracy: 99.94%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000292  Accuracy: 99.95%
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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000021  Accuracy: 99.96%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.000450  Accuracy: 99.97%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000064  Accuracy: 99.97%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000216  Accuracy: 99.97%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000051  Accuracy: 99.97%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000015  Accuracy: 99.97%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000277  Accuracy: 99.97%
Epoch 9 - Time: 68.31s - Train Loss: 0.001487 - Train Accuracy: 99.96%
Test Loss: 0.039804 - Test Accuracy: 98.81%

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FINAL RESULTS:
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epoch_times: [69.46153998374939, 69.08643412590027, 69.04827213287354, 69.
1299078464508, 68.80365586280823, 68.80113220214844, 69.06068587303162, 6
8.814621925354, 68.36748504638672, 68.30529689788818]
train_losses: [0.1165045418600087, 0.0383148765051998, 0.02361968913429125
4, 0.016677591960719964, 0.011468400593935791, 0.006525589841729826, 0.005
090391520813832, 0.003026269047018783, 0.0018470958633829012, 0.0014873364
19191856]
train_accuracies: [96.36333333333333, 98.845, 99.23, 99.42666666666666, 9
9.605, 99.79166666666667, 99.84166666666667, 99.91666666666667, 99.9566666
6666666, 99.96166666666667]
test_losses: [0.0402678507052362, 0.05570287296641618, 0.0330821163208223
9, 0.03632022079601884, 0.03717918113181368, 0.04566071706097573, 0.039343
452182481996, 0.04189313405728899, 0.03949127371949144, 0.0398043800294166
4]
test_accuracies: [98.61, 98.18, 99.04, 98.75, 98.76, 98.45, 98.85, 98.79,
98.87, 98.81]
```

In [25]:

```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: 2.319407  Accuracy: 10.94%
Train Epoch:   0 [  6400/ 60000 ( 11%)] Loss: 0.286392  Accuracy: 86.34%
Train Epoch:   0 [ 12800/ 60000 ( 21%)] Loss: 0.093028  Accuracy: 91.09%
Train Epoch:   0 [ 19200/ 60000 ( 32%)] Loss: 0.126525  Accuracy: 93.13%
Train Epoch:   0 [ 25600/ 60000 ( 43%)] Loss: 0.161198  Accuracy: 94.22%
Train Epoch:   0 [ 32000/ 60000 ( 53%)] Loss: 0.111167  Accuracy: 94.93%
Train Epoch:   0 [ 38400/ 60000 ( 64%)] Loss: 0.028768  Accuracy: 95.44%
Train Epoch:   0 [ 44800/ 60000 ( 75%)] Loss: 0.024672  Accuracy: 95.80%
Train Epoch:   0 [ 51200/ 60000 ( 85%)] Loss: 0.014523  Accuracy: 96.12%
Train Epoch:   0 [ 57600/ 60000 ( 96%)] Loss: 0.034870  Accuracy: 96.35%
Epoch 0 - Time: 68.02s - Train Loss: 0.114271 - Train Accuracy: 96.44%
Test Loss: 1.439397 - Test Accuracy: 58.55%

Train Epoch:   1 [     0/ 60000 (  0%)] Loss: 0.001217  Accuracy: 100.00%
Train Epoch:   1 [  6400/ 60000 ( 11%)] Loss: 0.049699  Accuracy: 98.89%
Train Epoch:   1 [ 12800/ 60000 ( 21%)] Loss: 0.011818  Accuracy: 99.10%
Train Epoch:   1 [ 19200/ 60000 ( 32%)] Loss: 0.071043  Accuracy: 99.03%
Train Epoch:   1 [ 25600/ 60000 ( 43%)] Loss: 0.058499  Accuracy: 98.94%
Train Epoch:   1 [ 32000/ 60000 ( 53%)] Loss: 0.071941  Accuracy: 98.93%
Train Epoch:   1 [ 38400/ 60000 ( 64%)] Loss: 0.030123  Accuracy: 98.93%
Train Epoch:   1 [ 44800/ 60000 ( 75%)] Loss: 0.141005  Accuracy: 98.90%
Train Epoch:   1 [ 51200/ 60000 ( 85%)] Loss: 0.008317  Accuracy: 98.92%
Train Epoch:   1 [ 57600/ 60000 ( 96%)] Loss: 0.077605  Accuracy: 98.92%
Epoch 1 - Time: 68.29s - Train Loss: 0.036054 - Train Accuracy: 98.93%
Test Loss: 0.504420 - Test Accuracy: 82.40%

Train Epoch:   2 [     0/ 60000 (  0%)] Loss: 0.021179  Accuracy: 98.44%
Train Epoch:   2 [  6400/ 60000 ( 11%)] Loss: 0.008526  Accuracy: 99.35%
Train Epoch:   2 [ 12800/ 60000 ( 21%)] Loss: 0.009765  Accuracy: 99.21%
Train Epoch:   2 [ 19200/ 60000 ( 32%)] Loss: 0.012673  Accuracy: 99.26%
Train Epoch:   2 [ 25600/ 60000 ( 43%)] Loss: 0.002242  Accuracy: 99.25%
Train Epoch:   2 [ 32000/ 60000 ( 53%)] Loss: 0.008823  Accuracy: 99.27%
Train Epoch:   2 [ 38400/ 60000 ( 64%)] Loss: 0.008558  Accuracy: 99.28%
Train Epoch:   2 [ 44800/ 60000 ( 75%)] Loss: 0.003051  Accuracy: 99.25%
Train Epoch:   2 [ 51200/ 60000 ( 85%)] Loss: 0.006696  Accuracy: 99.27%
Train Epoch:   2 [ 57600/ 60000 ( 96%)] Loss: 0.036973  Accuracy: 99.27%
Epoch 2 - Time: 68.39s - Train Loss: 0.022766 - Train Accuracy: 99.28%
Test Loss: 0.670568 - Test Accuracy: 78.09%

Train Epoch:   3 [     0/ 60000 (  0%)] Loss: 0.016896  Accuracy: 98.44%
Train Epoch:   3 [  6400/ 60000 ( 11%)] Loss: 0.001295  Accuracy: 99.66%
Train Epoch:   3 [ 12800/ 60000 ( 21%)] Loss: 0.015936  Accuracy: 99.61%
Train Epoch:   3 [ 19200/ 60000 ( 32%)] Loss: 0.004353  Accuracy: 99.66%
Train Epoch:   3 [ 25600/ 60000 ( 43%)] Loss: 0.009259  Accuracy: 99.66%
Train Epoch:   3 [ 32000/ 60000 ( 53%)] Loss: 0.006199  Accuracy: 99.59%
Train Epoch:   3 [ 38400/ 60000 ( 64%)] Loss: 0.003567  Accuracy: 99.57%
Train Epoch:   3 [ 44800/ 60000 ( 75%)] Loss: 0.066978  Accuracy: 99.55%
Train Epoch:   3 [ 51200/ 60000 ( 85%)] Loss: 0.008072  Accuracy: 99.53%
Train Epoch:   3 [ 57600/ 60000 ( 96%)] Loss: 0.004687  Accuracy: 99.52%
Epoch 3 - Time: 68.54s - Train Loss: 0.014626 - Train Accuracy: 99.51%
Test Loss: 0.811405 - Test Accuracy: 73.62%

Train Epoch:   4 [     0/ 60000 (  0%)] Loss: 0.075511  Accuracy: 98.44%
Train Epoch:   4 [  6400/ 60000 ( 11%)] Loss: 0.002061  Accuracy: 99.75%
Train Epoch:   4 [ 12800/ 60000 ( 21%)] Loss: 0.000232  Accuracy: 99.76%
Train Epoch:   4 [ 19200/ 60000 ( 32%)] Loss: 0.006534  Accuracy: 99.74%
Train Epoch:   4 [ 25600/ 60000 ( 43%)] Loss: 0.000715  Accuracy: 99.72%
Train Epoch:   4 [ 32000/ 60000 ( 53%)] Loss: 0.001755  Accuracy: 99.72%
Train Epoch:   4 [ 38400/ 60000 ( 64%)] Loss: 0.079196  Accuracy: 99.71%
Train Epoch:   4 [ 44800/ 60000 ( 75%)] Loss: 0.001286  Accuracy: 99.69%
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Train Epoch:   4 [ 51200/ 60000 ( 85%)] Loss: 0.003327  Accuracy: 99.70%
Train Epoch:   4 [ 57600/ 60000 ( 96%)] Loss: 0.020421  Accuracy: 99.71%
Epoch 4 - Time: 68.68s - Train Loss: 0.009902 - Train Accuracy: 99.70%
Test Loss: 0.804535 - Test Accuracy: 76.11%

Train Epoch:   5 [     0/ 60000 (  0%)] Loss: 0.000495  Accuracy: 100.00%
Train Epoch:   5 [  6400/ 60000 ( 11%)] Loss: 0.000842  Accuracy: 99.88%
Train Epoch:   5 [ 12800/ 60000 ( 21%)] Loss: 0.001565  Accuracy: 99.91%
Train Epoch:   5 [ 19200/ 60000 ( 32%)] Loss: 0.038194  Accuracy: 99.86%
Train Epoch:   5 [ 25600/ 60000 ( 43%)] Loss: 0.000344  Accuracy: 99.83%
Train Epoch:   5 [ 32000/ 60000 ( 53%)] Loss: 0.004818  Accuracy: 99.79%
Train Epoch:   5 [ 38400/ 60000 ( 64%)] Loss: 0.001355  Accuracy: 99.78%
Train Epoch:   5 [ 44800/ 60000 ( 75%)] Loss: 0.000637  Accuracy: 99.76%
Train Epoch:   5 [ 51200/ 60000 ( 85%)] Loss: 0.016351  Accuracy: 99.75%
Train Epoch:   5 [ 57600/ 60000 ( 96%)] Loss: 0.000884  Accuracy: 99.75%
Epoch 5 - Time: 68.93s - Train Loss: 0.007473 - Train Accuracy: 99.75%
Test Loss: 0.488010 - Test Accuracy: 84.90%

Train Epoch:   6 [     0/ 60000 (  0%)] Loss: 0.003943  Accuracy: 100.00%
Train Epoch:   6 [  6400/ 60000 ( 11%)] Loss: 0.010648  Accuracy: 99.85%
Train Epoch:   6 [ 12800/ 60000 ( 21%)] Loss: 0.003078  Accuracy: 99.86%
Train Epoch:   6 [ 19200/ 60000 ( 32%)] Loss: 0.000356  Accuracy: 99.86%
Train Epoch:   6 [ 25600/ 60000 ( 43%)] Loss: 0.000247  Accuracy: 99.84%
Train Epoch:   6 [ 32000/ 60000 ( 53%)] Loss: 0.000148  Accuracy: 99.85%
Train Epoch:   6 [ 38400/ 60000 ( 64%)] Loss: 0.000242  Accuracy: 99.86%
Train Epoch:   6 [ 44800/ 60000 ( 75%)] Loss: 0.007067  Accuracy: 99.86%
Train Epoch:   6 [ 51200/ 60000 ( 85%)] Loss: 0.000386  Accuracy: 99.84%
Train Epoch:   6 [ 57600/ 60000 ( 96%)] Loss: 0.006813  Accuracy: 99.83%
Epoch 6 - Time: 68.15s - Train Loss: 0.005548 - Train Accuracy: 99.83%
Test Loss: 0.885012 - Test Accuracy: 75.15%

Train Epoch:   7 [     0/ 60000 (  0%)] Loss: 0.003658  Accuracy: 100.00%
Train Epoch:   7 [  6400/ 60000 ( 11%)] Loss: 0.012452  Accuracy: 99.91%
Train Epoch:   7 [ 12800/ 60000 ( 21%)] Loss: 0.000674  Accuracy: 99.92%
Train Epoch:   7 [ 19200/ 60000 ( 32%)] Loss: 0.000827  Accuracy: 99.93%
Train Epoch:   7 [ 25600/ 60000 ( 43%)] Loss: 0.000511  Accuracy: 99.93%
Train Epoch:   7 [ 32000/ 60000 ( 53%)] Loss: 0.001008  Accuracy: 99.93%
Train Epoch:   7 [ 38400/ 60000 ( 64%)] Loss: 0.012961  Accuracy: 99.91%
Train Epoch:   7 [ 44800/ 60000 ( 75%)] Loss: 0.001062  Accuracy: 99.92%
Train Epoch:   7 [ 51200/ 60000 ( 85%)] Loss: 0.001723  Accuracy: 99.91%
Train Epoch:   7 [ 57600/ 60000 ( 96%)] Loss: 0.000663  Accuracy: 99.91%
Epoch 7 - Time: 69.23s - Train Loss: 0.003028 - Train Accuracy: 99.91%
Test Loss: 0.854635 - Test Accuracy: 76.82%

Train Epoch:   8 [     0/ 60000 (  0%)] Loss: 0.000140  Accuracy: 100.00%
Train Epoch:   8 [  6400/ 60000 ( 11%)] Loss: 0.001030  Accuracy: 99.98%
Train Epoch:   8 [ 12800/ 60000 ( 21%)] Loss: 0.000283  Accuracy: 99.97%
Train Epoch:   8 [ 19200/ 60000 ( 32%)] Loss: 0.001301  Accuracy: 99.96%
Train Epoch:   8 [ 25600/ 60000 ( 43%)] Loss: 0.000843  Accuracy: 99.96%
Train Epoch:   8 [ 32000/ 60000 ( 53%)] Loss: 0.000131  Accuracy: 99.96%
Train Epoch:   8 [ 38400/ 60000 ( 64%)] Loss: 0.000382  Accuracy: 99.96%
Train Epoch:   8 [ 44800/ 60000 ( 75%)] Loss: 0.000057  Accuracy: 99.96%
Train Epoch:   8 [ 51200/ 60000 ( 85%)] Loss: 0.000330  Accuracy: 99.96%
Train Epoch:   8 [ 57600/ 60000 ( 96%)] Loss: 0.000702  Accuracy: 99.97%
Epoch 8 - Time: 68.72s - Train Loss: 0.001650 - Train Accuracy: 99.96%
Test Loss: 1.218711 - Test Accuracy: 70.65%

Train Epoch:   9 [     0/ 60000 (  0%)] Loss: 0.000853  Accuracy: 100.00%
Train Epoch:   9 [  6400/ 60000 ( 11%)] Loss: 0.000034  Accuracy: 99.97%
Train Epoch:   9 [ 12800/ 60000 ( 21%)] Loss: 0.000067  Accuracy: 99.98%
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Train Epoch:   9 [ 19200/ 60000 ( 32%)] Loss: 0.000596  Accuracy: 99.97%
Train Epoch:   9 [ 25600/ 60000 ( 43%)] Loss: 0.000585  Accuracy: 99.97%
Train Epoch:   9 [ 32000/ 60000 ( 53%)] Loss: 0.000184  Accuracy: 99.98%
Train Epoch:   9 [ 38400/ 60000 ( 64%)] Loss: 0.000114  Accuracy: 99.97%
Train Epoch:   9 [ 44800/ 60000 ( 75%)] Loss: 0.000393  Accuracy: 99.98%
Train Epoch:   9 [ 51200/ 60000 ( 85%)] Loss: 0.000320  Accuracy: 99.98%
Train Epoch:   9 [ 57600/ 60000 ( 96%)] Loss: 0.000983  Accuracy: 99.98%
Epoch 9 - Time: 68.28s - Train Loss: 0.000802 - Train Accuracy: 99.98%
Test Loss: 0.883294 - Test Accuracy: 76.42%

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FINAL RESULTS:
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epoch_times: [68.02429819107056, 68.29214811325073, 68.39058709144592, 68.
53703331947327, 68.68410515785217, 68.9282009601593, 68.1520209312439, 69.
23015975952148, 68.71615290641785, 68.27527284622192]
train_losses: [0.11427061202556593, 0.03605354872275529, 0.022766265975411
804, 0.014626445210869435, 0.00990165050432955, 0.007472796055549855, 0.00
5547961281213237, 0.003027511165123106, 0.001650328743112087, 0.0008017322
982510859]
train_accuracies: [96.43666666666667, 98.93333333333334, 99.2783333333333
4, 99.51333333333334, 99.705, 99.75, 99.825, 99.905, 99.96333333333334, 9
9.98166666666667]
test_losses: [1.4393968572616578, 0.504420235157013, 0.6705678241729737,
0.8114047434806824, 0.8045347493171692, 0.48801029958724973, 0.88501226825
71411, 0.8546347627639771, 1.2187113248825072, 0.8832939685821534]
test_accuracies: [58.55, 82.4, 78.09, 73.62, 76.11, 84.9, 75.15, 76.82, 7
0.65, 76.42]
```
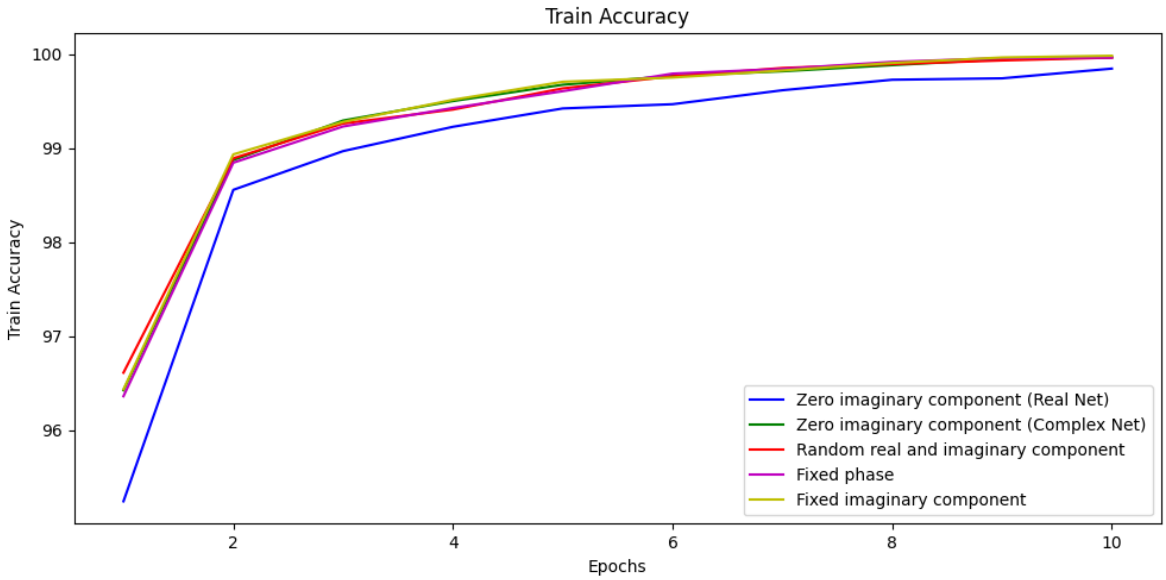
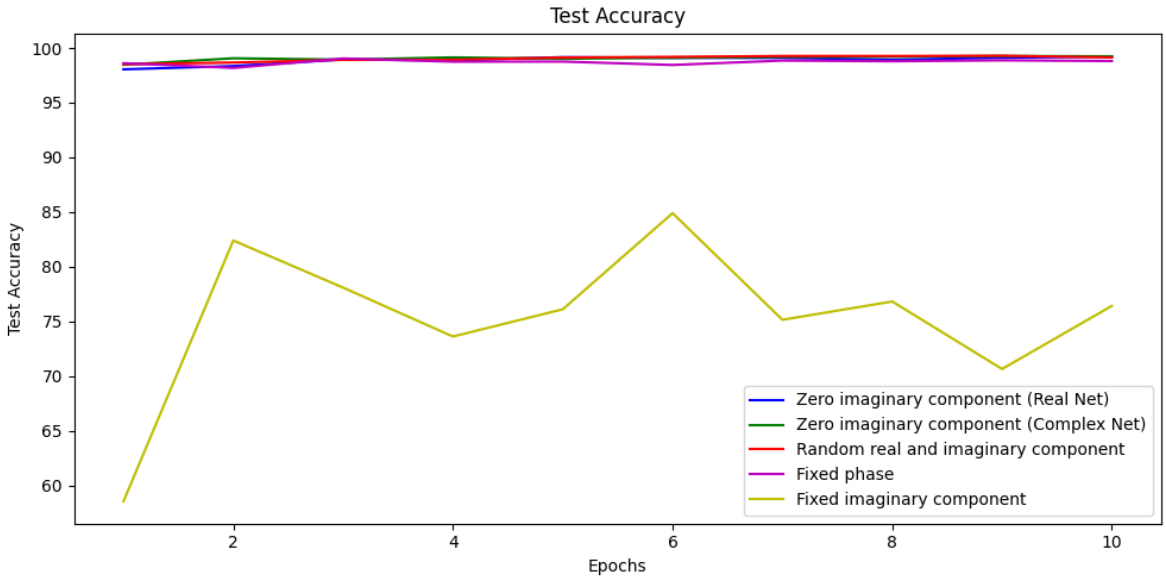

Plots

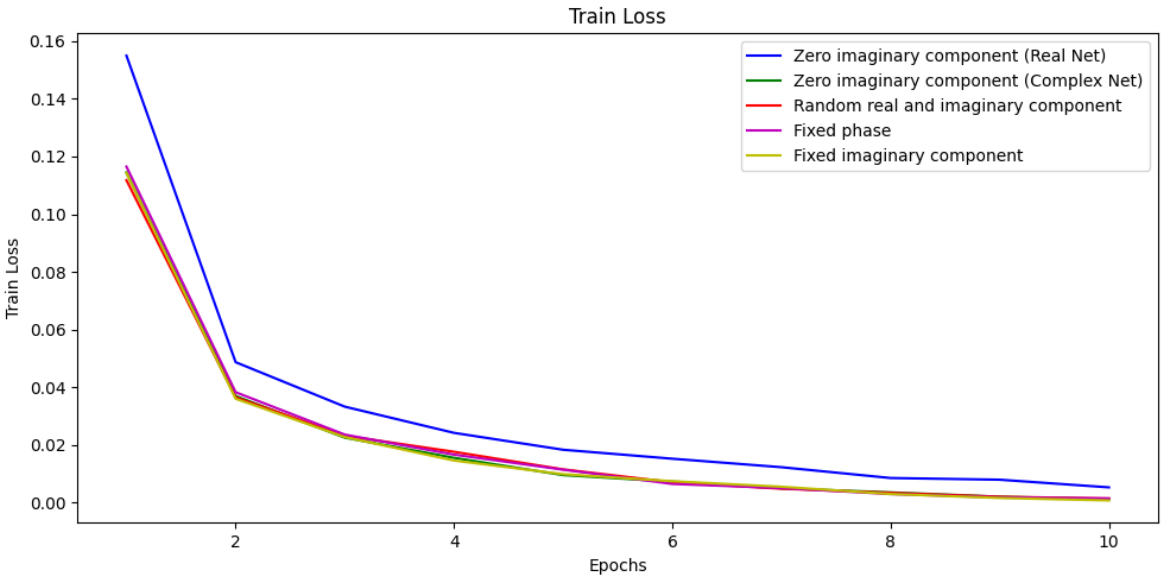
In [28]:

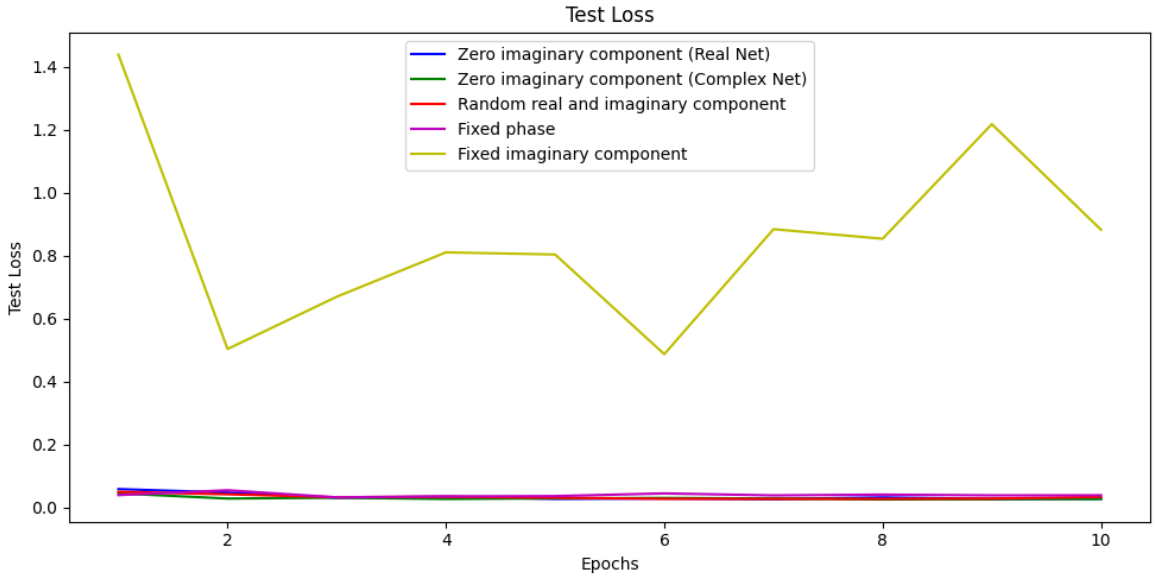
```
# Data for the four scenarios
data = {
    "Zero imaginary component (Real Net)": metrics_dict_e1,
    "Zero imaginary component (Complex Net)": metrics_dict_e2,
    "Random real and imaginary component": metrics_dict_e3,
    "Fixed phase": metrics_dict_e4,
    "Fixed imaginary component": metrics_dict_e5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

# 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()
```

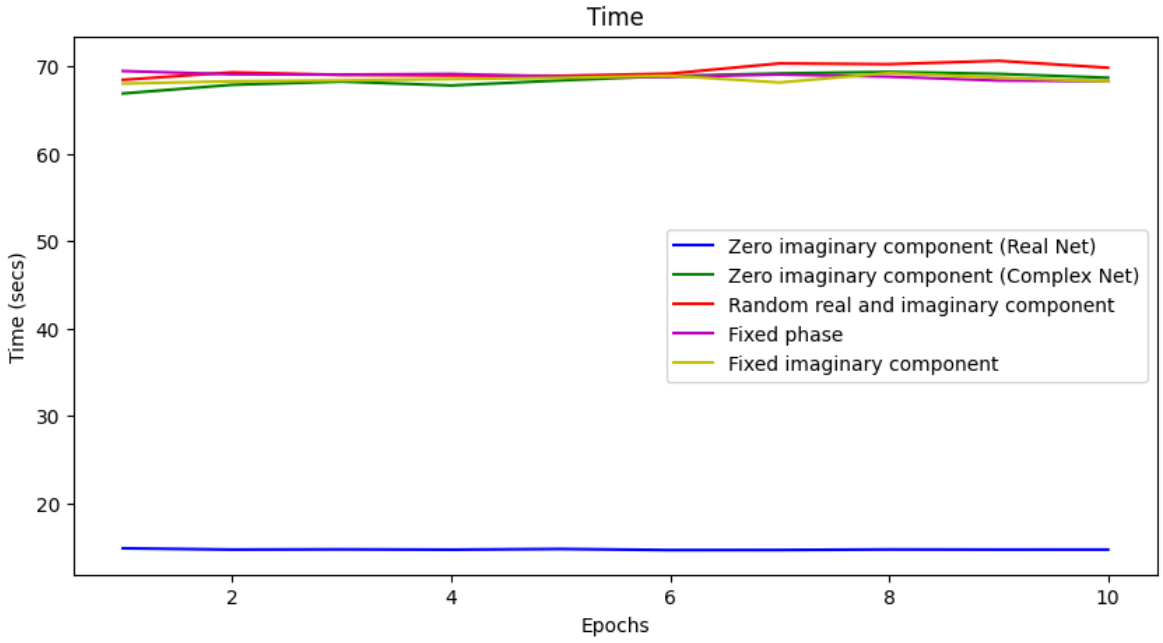

Train Accuracy
Train Accuracy
Epochs
Zero imaginary component (Real Net)
Zero imaginary component (Complex Net)
Random real and imaginary component
Fixed phase
Fixed imaginary component


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[28]: <matplotlib.legend.Legend at 0x2bb7a6490>



In [30]:
```
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()
```