A New Approach to Spectral Domain Method: Functional Programming

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Abstract. The Spectral Domain Method is powerful technique to analyze planar microwave circuits. But available conventional programming languages used in the literature does not give the enough speed to use the Spectral Domain Method to develop package analysis program. Functional approach to Spectral domain Method gives a high level of programming and a variety of features which help to build elegant yet powerfully and general libraries of functions.

1 Introduction

For the last two decades, open microstrip structures have received special attention from the electromagnetic community because of their potential applications in the design of new devices and components. Meanwhile, high–speed computer has influenced the computation of electromagnetic problem to the point that most practical computations of the fields can be solved numerically on the computer. The reason why, most of the analysis of the devices and components can be achieved numerically but is almost impossible to be solved analytically. A lot of efforts have still been done on improving numerical techniques because complexity of the problems always overstretch the speed of the processors. Moreover the operating frequency raised up for more available bandwidth, full–wave techniques which require more computer power and resources must be used.

A number of numerical full–wave techniques are reported in the literature for the analysis of microstrip antennas [1], resonators [2] and circuits [3]. All techniques reported in the literature have been either written by conventional programming languages such as pascal and C or developed by using commercial analysis tools such as Matlab. In the author knowledge none of the papers can explored the idea of the way of programming such as functional or logic.

This contribution presents a functional programming approach to Spectral Domain Method which is one of the full–wave numerical technique and widely used for the analysis of the microwave and millimeter wave devices and components. With this approach, Spectral Domain Method have gained a high level of

V.N. Alexandrov et al. (Eds.): ICCS 2006, Part IV, LNCS 3994, pp. 638–644, 2006.

programming giving its user a variety of features which help to build elegant yet powerfully and general libraries of functions. Numerical results have also given and compared with publish date to show the accuracy of the re–written Spectral Domain Method by Haskel which is widely used functional programming language instead of conventional language such as pascal used in [3].

2 Functional Approach to SDM

2.1 Introduction

In this paper, five fundamental modules have been rewritten by using functional approach instead of conventional programming language such as pascal to show applicability of the approach. All of the modules are described in the sections below.

2.2 Input Functions

In this module the input parameters are taken and passed to other modules. Operating frequency, substrate layer parameters, k_x, k_z which are Fourier transform variables in x and z directions respectively, n which is number of layers, l_x and l_z which are dimensions of rooftop function are used as input values. The re–written module becomes as follows:

```
type Ind = Double
type D = Double
type M = Double
type E = Double
type Layer = [(Ind,D,M,E)]
type OneLayer = (Ind,D,M,E)
type Kx = Complex Double
type Kz = Complex Double
type Lx = Double
w :: Double
w  = 2*3.1456*saveF
saveLayer :: IO -  Layer
saveKx :: IO -   Kx
saveKz :: IO -  Kz
saveLx :: IO -  Lx
saveN :: IO -  Double
saveF :: IO-  Double
nx = saveKx/sqrt(saveKx*saveKx+saveKz*saveKz)
nz = saveKz/sqrt(saveKx*saveKx+saveKz*saveKz)
```

2.3 Empedans Functions

In this module the Green Function in the spectral domain has been calculated by using functional approach. Mathematical formulation of the Green function can be found in the literature such as [4, Chapter 4].

```
findlayer ::  Ind -> OneLayer
findlayer  indx  = head [(ind,d,m,e) | (ind,d,m,e)
    <- saveLayer , ind==indx ]
layparD :: OneLayer -> D
layparD (ind,d,m,e) = d
layparM ::  OneLayer -> M
layparM (ind,d,m,e) = m
layparE ::  OneLayer -> E
layparE (ind,d,m,e) = e
ztm :: Double -> Complex Double
ztm i  = (gama i)/(w*(layparE(findlayer i)):+0)
gama :: Double -> Complex Double
gama i = sqrt((saveKz*saveKz)+(saveKx*saveKx)-
   ((w*w*(layparM (findlayer i))*(layparE(findlayer i))):+0))
zte :: Double -> Complex Double
zte i  = (w*(layparM(findlayer i)):+0) /gama i
zelist :: Double -> (Complex Double,Double)
zelist n = ((zeN n) ,(n-1) )
zeN :: Double -> Complex Double
zeN n = ztm n / atanh((gama n)*((layparD (findlayer n)):+0))
zhN :: Double -> Complex Double
zhN n = zte n / atanh((gama n)*((layparD (findlayer n)):+0))
zhlist :: Double -> (Complex Double,Double)
zhlist n = ((zhN n) ,(n-1) )
coth :: Double -> Complex Double
coth i = atanh((gama i)*((layparD (findlayer i)):+0))
ze2 :: (Complex Double,Double) -> (Complex Double,Double)
ze2 (n,2)  = (n,2)
ze2 (n,s) =
      ze2
        (
          (
           (ztm s * (n*(coth s ))+ztm s)/
           (ztm s *(coth s)+n)
          )
            ,(s-1)
        )
zh2 :: (Complex Double,Double) -> (Complex Double,Double)
zh2 (n,2)  = (n,2)
zh2 (n,s) =
      zh2
        (
          (
           (zte s * (n*(coth s ))+zte s)/
           (zte s *(coth s)+n)
```

```
          )
            ,(s-1)
        )
ze1 = ztm 1
zh1 = zte 1
ze :: Double -> Complex Double
ze n =
      1/
  (
      ((1:+0)/ze1)
      +
      ((1:+0)/fst((ze2 (zelist n))))
  )
zh :: Double -> Complex Double
zh n =
      1/
  (
      ((1:+0)/zh1)
      +
      ((1:+0)/fst((zh2 (zhlist n))))
  )
gzz n = nz*nz*(ze n) + nx*nx* (zh n)
gzx n = nx*nz*(-(ze n)+(zh n))
gxz n = gzx n
gxx n = nx*nx*(ze n)+nz*nz*(zh n)
```

2.4 Current Functions

In this module current basis functions functions which are roottop functions [4, Chapter3] are calculated by functional approach.

```
jz :: Double ->Complex Double
jz n = (2/saveKx)*sin(saveKx*(saveLx:+0))*
     exp(saveKx*(n*(saveLx):+0))
jx :: Double -> Complex Double
jx n = (2/(saveKx*saveKx))* (1-cos(saveKx*
    (saveLx:+10)))*exp(saveKx*(n*(saveLx):+0))
makeNpar :: Double -> Double -> [Double]
makeNpar 0 n = []
makeNpar n a =(-((n-1)-a)):(makeNpar (n-1) a)
jzn :: Double -> Double -> [Complex Double]
jzn n a = map jz (makeNpar n a)
jxn :: Double -> Double -> [Complex Double]
jxn n a = map jx (makeNpar n a)
mux :: [Complex Double] -> [(Complex Double)]
mux xs = concat (map (fun xs) xs)
```

```
fun :: [Complex Double] ->Complex Double-> [(Complex Double)]
fun as a = [(a*b)| b<-as]
```

2.5 Integral Functions

This model is used to calculate the each element of the impedance matrix

```
makeMat :: Integer -> Integer-> Double ->
[(Complex Double)] -> [(Complex Double)]
makeMat a c k [] = []
makeMat a c k (n:ns)
     | (a>0 && a<=(1*c))  = (n*(gzz k)):(makeMat (a+1) c k ns)
 | (a>(1*c) && a<=(2*c))  = (n*(gzx k)):(makeMat (a+1) c k ns)
 | (a>(2*c) && a<=(3*c))  = (n*(gzz k)):(makeMat (a+1) c k ns)
 | (a>(3*c) && a<=(4*c))  = (n*(gzx k)):(makeMat (a+1) c k ns)
 | (a>(4*c) && a<=(5*c))  = (n*(gxz k)):(makeMat (a+1) c k ns)
 | (a>(5*c) && a<=(6*c))  = (n*(gxx k)):(makeMat (a+1) c k ns)
 | (a>(6*c) && a<=(7*c))  = (n*(gxz k)):(makeMat (a+1) c k ns)
 | (a>(7*c) && a<=(8*c))  = (n*(gxx k)):(makeMat (a+1) c k ns)
```

3 Numerical Results

In these sections below includes several analyzed example microwave structures to show accuracy of the re–written program by using Spectral Domain Method in Haskell which is one of the functional programming language. Total program code have been optimized 55% compared to pascal code. As a result runtime has been reduced 50% compared to pascal code run on the computer. The computer has intel P4 2.4 GHz with 1 GB RD RAM. The operating system is Redhat Linux 8.0.

3.1 Simple Low–Pass Filter

Measurement results are available for the microstrip low–pass filter [5] shown in figure 1. The dimensions and parameters of the dielectric substrate are given in figure 1.

The S–parameter results are plotted in figures 2 where it can be seen that the calculated results and measurements are in very good agreement.

3.2 Edge–Coupled Filter

In order to further prove the accuracy of the re-written program, the analysis of the microstrip edge–coupled filter shown in fig. 6 in [6] is considered. The measurements performed by Shibata *et al* [7] for this filter.

As seen in fig. 3, there is a clear agreement between the newly written program and measured data.

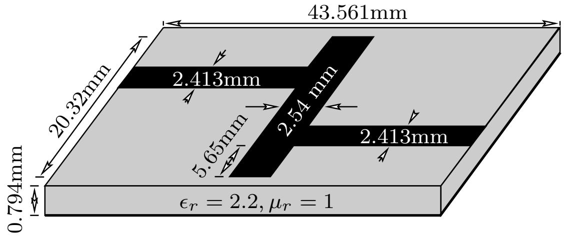

Fig. 1. Low–pass filter detail

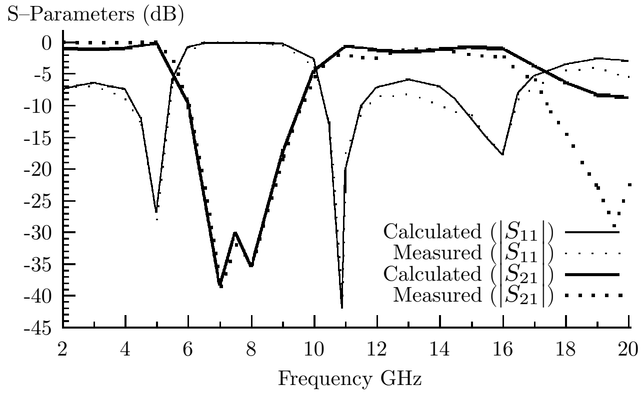

Fig. 2. Plot of S–parameters' magnitude for the low–pass filter

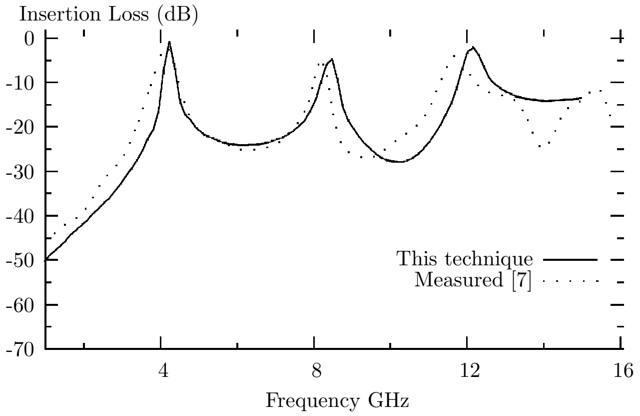

Fig. 3. Magnitude of S–parameters for the edge–coupled filter

4 Conclusion

We have shown that realistically complex microstrip circuits can be rigorously analyzed by re–written program which uses functional approach to Spectral

Domain Method. Accuracy of the program is obvious. The code size and runtime reduction are 55% and 50% respectively on ordinary computers. By this approach a model which retains the accuracy of the full–wave analysis technique as well as the speed of the package programs has been introduced.

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