Dynamically Configurable Selective PRS-based Filter Design

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Agenda

- Introduction
- Problem and Requirements
- Filter Design
- Results
- Conclusion

Problem Statement

- 5G Communication
- Bandwidth 26 GHz
- Communication within fixed number of frequencies at regular intervals
- Minimise interference
- Use only one frequency at a single timeslot
- Dynamically switch from one frequency to another
- Routing/demultiplexer in dense wavelength-division multiplexing networking.
- Low profile requirements

State of the art

- Semiconductors Based
- Ferroelectric Based
- MEMS actuators and lumped elements
  - Recent Advances in Reconfigurable Microwave Filters, SBMO/IEEE MTT-S, Zabdiel Brito-Brito, 2011
- DSP-FPGA based
  - Implementation of a real-time, frequency selective, RF channel simulator using a hybrid DSP-FPGA architecture, IEEE Radio and Wireless Symposium (RWS formerly RAWCON), M.A. Wickert; J. Papenfuss, 2000
- Metasurfaces
  - Dynamic Metasurface Antennas for 6G Extreme Massive MIMO Communications, Nir Shlezinger; George C. Alexandropoulos; Mohammadreza F. Imani; Yonina C. Eldar; David R. Smith, IEEE Wireless Communications, 2001

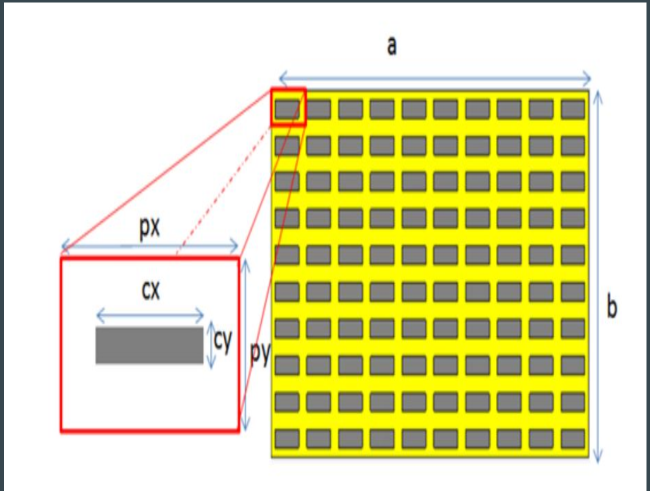
Approach

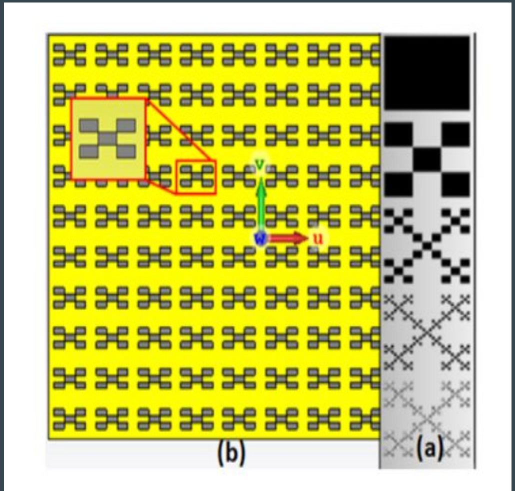
- Metasurfaces
- PRS (Partially Reflective Surfaces)
- Fabry-Perot Cavity (Low profile)
- Adjustable Capacity (varicap)

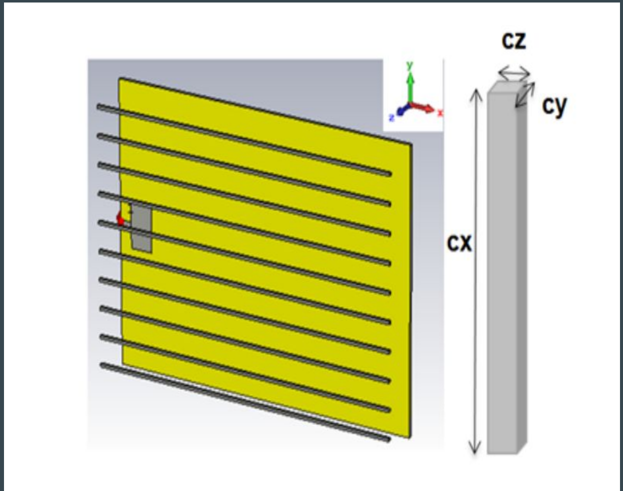
Metasurfaces

- Thin-films composed of individual elements
- Periodic / Aperiodic Patterns
- The principle of operation of metasurfaces is based on the phenomenon of diffraction
- Applications
  - Frequency Selective (FSS)
  - Electromagnetic Band-Gap (EBG)
  - Negative Refractive Index

PRS examples

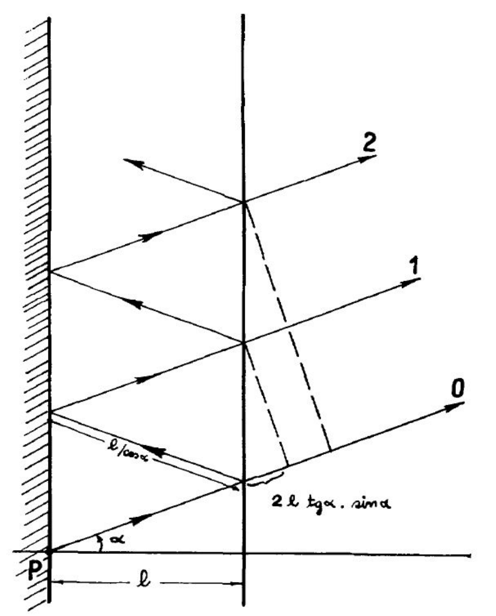






Theory

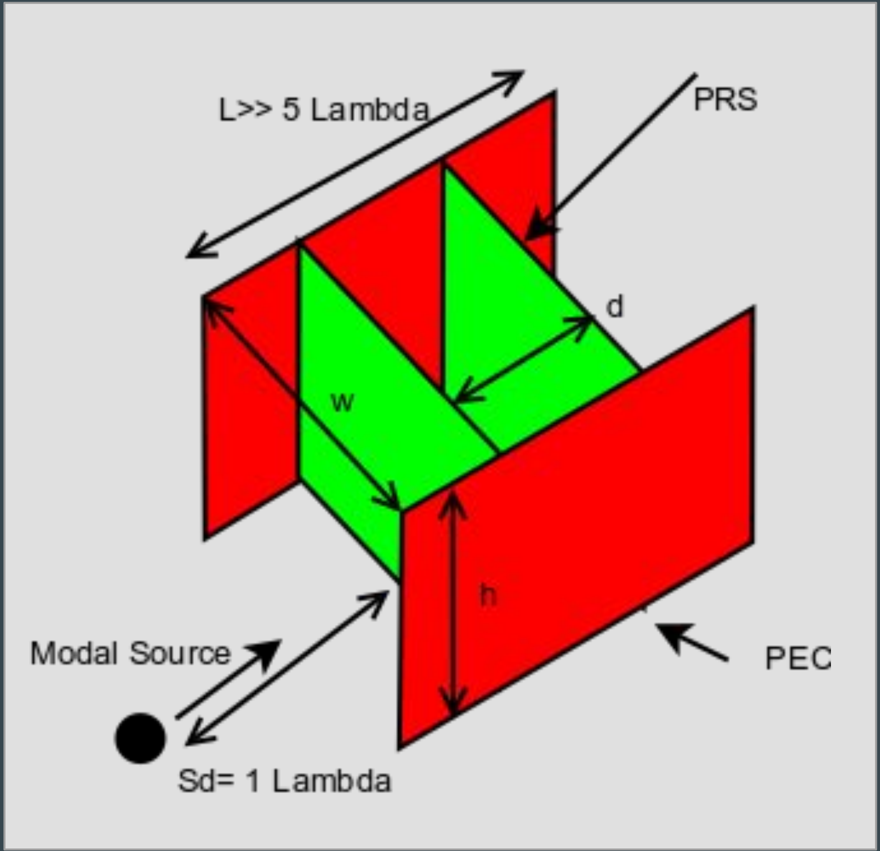
- Partially Reflecting Sheet Arrays, TRENTINI, 1956, IEEE Transactions on Antennas



$$E = \sum_{n}^{\infty} f(\alpha) E_0 \rho^n \sqrt{1-\rho^2} \exp(i\theta_n)$$

$$Poy = f(\alpha)^2 \frac{1-\rho^2}{1+\rho^2 - 2\rho\cos(\psi - \pi - \frac{4\pi}{\lambda} l \cos\alpha)}$$

Filter Design



Theory

- Partially Reflecting Sheet Arrays, TRENTINI, 1956, IEEE Transactions on Antennas

Reflection coefficient

- $\rho = \dfrac{1}{\sqrt{\left(1+\left(\frac{V}{60\pi}\right)^2\right)}}$
- $\psi = \arctan\left(-\frac{V}{60\pi}\right)$

Resonance coefficient

- $Q = \frac{f_0}{\Delta f} = \left(1 + \left(\frac{d}{w}\right)^2\right) .F$
- where $F = \frac{\sqrt{\rho}\pi}{1-\rho}$

Approach

- The problem is now to find out the appropriate PRS (the appropriate CAPA) to match the requirements
- Multiple unknowns
  - V
  - Reflection Coefficient module
  - Reflection Coefficient Phase
  - Ze
  - d

$$
\begin{cases}
\frac{f_0}{\Delta f} = \left(1 + \left(\frac{d}{w}\right)^2\right) .F \\
F = \frac{\sqrt{\rho}\pi}{1-\rho} \\
\psi = \frac{2\pi d}{\lambda} \\
Z_e = \frac{-jV * Z_m}{Z - jV} \\
X_m = \rho e^{j\psi} = \frac{Z_e - Z_m}{Z_e + Z_m}
\end{cases}
$$

Approach

- Numerical Resolution

$$\begin{cases} G1_{freq=f0}\left(V\right) = \left(1 + \left(\frac{\arg(X_m(V))\lambda}{2\pi w}\right)^2\right) \cdot \frac{\Delta f \sqrt{|X_m(V)|\pi}}{f_0(1-|X_m(V)|)} - 1 = 0 \\ G2_{freq!=f0}\left(V\right) = \left(1 + \left(\frac{d}{w}\right)^2\right) \cdot \frac{\Delta f \sqrt{|X_m(V)|\pi}}{f_0(1-|X_m(V)|)} - 1 = 0 \end{cases}$$

Hadra Code

```
import net.thevpc.scholar:hadrumaths;


  val εᵣ = 1
  val f₀ = 26.5 GHZ
  val Δf = 128 MHZ
  val fₛ = f₀:Δf:f₀+9*Δf
  var w = 1.5 * C / (2 * 10 * GHZ)
  var h = w / 2
  var freqIndexForReferenceD = 0;
  Map<double, Data> data();
  plotS_interval_all;
  Maths.Config.frequencyFormatter="HT I2 D3 F";
  Maths.Config.metricFormatter="M-6 M3 I2 D4 F";
  println("");
  println("---------------------------------");
  println("");
  println("w, εᵣ, Δf, w, f, fi, λ, d, ρ, Ψ, V, ird, Cte, Cvar");
  for(x:fₛ){
    var dd = calcData(x);
    printf("%s, %s, %s, %s, %s, %s, %s, %s, %s, %s, %s, %s, %s, %s\n",
      w,εᵣ, Δf, w, dd.ff, dd.fᵣ, dd.λ,dd.d , dd.ρ, dd.Ψ, dd.V,
      dd.find_ird,
      dd.Capa_TE,
      dd.Capa_Vari,
    )
  }
  println("");
  println("---------------------------------");
  println("");

  fun Data calcData(double f){
    if (f : datas) {
      return datas(f);
    } else {
      Data nv(f, f_threshold(f)).find_Vd();
      datas = datas :+ Map(f ⇒ nv);
      return nv;
    }
  }
```

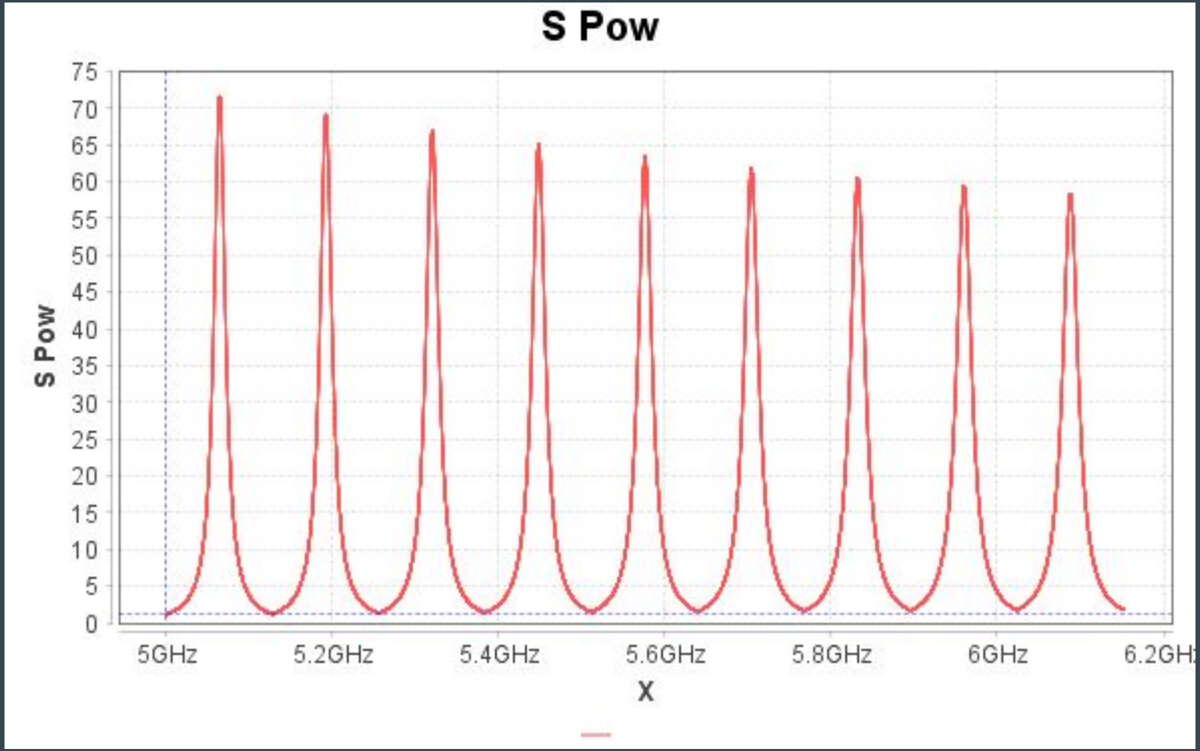
Hadra Code

```
fun double G0(double V){
  val ρ2 = ρ(V)
  val Ψ2 = /*π +*/ Ψ(V)
  val d2 = Ψ2 * λ / (2 * π)
  val gg = (1 + (d2 / w)²) * (√(ρ2) * π / (1 - ρ2)) - f / Δf
  return gg;
}

fun double Gr(double V){
  val d2 = d
  val ρ2 = ρ(V)
  val gg = (1 + (d2 / w)²) * (√(ρ2) * π / (1 - ρ2)) - f / Δf
  return gg;
}

fun double S(double ρ1, double Ψ1){
  (1 - ρ1²) / (1 + ρ1² - 2 * ρ1 * cos(2 * Ψ1 - 4 * π / λ * d));
}

fun Data find_Vd() {
  if (f == fₛ(freqIndexForReferenceD)) {
    V = solve(G0(_), Vmin, Vmax, Vtimes);
    d = d(V);
    ρ = ρ(V);
    F = √(ρ) * π / (1 - ρ);
    Δf2 = f / ((1 + (d / w)²) * F);
    Ψ = 2 * π * d / λ;
    S = S(ρ, Ψ);
    S1 = S;
  } else if (f == fᵣ /*Maths.rerr(f1,f)<1E-5*/ ) {
    V = solve(Gr(_), Vmin, Vmax, Vtimes);
    d = calcData(fₛ[freqIndexForReferenceD]).d;
    ρ = ρ(V);
    F = √(ρ) * π / (1 - ρ);
    Δf2 = f / ((1 + (d / w)²) * F);
    Ψ = 2 * π * d / λ;
    S = S(ρ, Ψ);
    S1 = S;
  } else {
    val dataRef = calcData(fᵣ);
    V = dataRef.V;
    ρ = dataRef.ρ;
    F = dataRef.F;
```

$$Poy = f(\alpha)^2 \frac{1-\rho^2}{1+\rho^2-2\rho\cos(\psi-\pi-\frac{4\pi}{\lambda}l\cos\alpha)}$$

Solve function

Results


S Pow
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
S Pow
5GHz
5.2GHz
5.4GHz
5.6GHz
5.8GHz
6GHz
X

Conclusion

Context	• 5G multiplexing
Problem	• Metasurface based Filter • Realtime adjustable by tuning varicaps
Numerical Resolution	• Used Hadra Language
TODO	• Inverse Problem to identify the PRS geometry from its reflexion coefficient / impedance

Thank you

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http://github.com/thevpc