**Title:** Reconstructing Near Fields of Antennas via Dipole Approximation  
**Subtitle:** A Heuristic Approach Using Far-Field Data and Antenna Geometry  
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**1. Motivation**

* **Why Near Fields?**
  + Safety considerations for electromagnetic field exposure assessments.
  + Near field data is often unavailable in datasheets, which typically focus on far-field.
* **How?**
  + Develop a program to approximate near fields using only datasheet information.
* **Key Question:**
  + Can near fields be accurately reconstructed from the data typically provided in datasheets?

**2. Typical Datasheet Example**

* **Problem:** Antenna datasheets generally provide far-field data, not near-field data.
* **Solution:** Develop algorithms and tools to approximate the near field using the available far-field and antenna geometry information.

*(Include a visual of the datasheet example here)*

**3. Background**

* **Antenna Basics:**
  + **Far Fields:** Radiated pattern at a large distance.
  + **Near Fields:** Affected by the antenna’s geometry and are more complex to compute.
* **Dipole Approximation:**
  + Model the antenna as a grid of elementary dipoles, each with:
    - Position
    - Orientation
    - Complex amplitude
* **Heuristic Optimization:**

### Use optimization algorithms to minimize the difference between the simulated and true far-field data:Isotropic radiator.

An isotropic radiator is a hypothetical lossless antenna that radiates its energy equally in all directions. This imaginary antenna would have a spherical radiation pattern and the

principal plane cuts would both be circles (indeed, any plane cut would be a circle).

### Gain

The gain of an antenna (in any given direction) is defined as the ratio of the power gain in

a given direction to the power gain of a reference antenna in the same direction. It is standard

practice to use an isotropic radiator as the reference antenna in this definition. Note that an

isotropic radiator would be lossless and that it would radiate its energy equally in all directions.

That means that the gain of an isotropic radiator is G = 1 (or 0 dB). It is customary to use the

unit dBi (decibels relative to an isotropic radiator) for gain with respect to an isotropic radiator.

Occasionally, a theoretical dipole is used as the reference, so the unit dBd (decibels relative to a dipole) will be used to describe the gain with respect to a dipole. This unit tends to be used when referring to the gain of omnidirectional antennas of higher gain. In the case of these higher gain omnidirectional antennas, their gain in dBd would be an expression of their gain above 2.2 dBi. So if an antenna has a gain of 3 dBd it also has a gain of 5.2 dBi.

Note that when a single number is stated for the gain of an antenna, it is assumed that this is the maximum gain (the gain in the direction of the maximum radiation).

It is important to state that an antenna with gain doesn’t create radiated power. The antenn simply directs the way the radiated power is distributed relative to radiating the power equally in all directions and the gain is just a characterization of the way the power is radiated.

### 3-dB beamwidth.

The 3-dB beamwidth (or half-power beamwidth) of an antenna is typically

defined for each of the principal planes. The 3-dB beamwidth in each plane is defined as the angle

between the points in the main lobe that are down from the maximum gain by 3 dB. This is

illustrated in Figure 3. The 3-dB beamwidth in the plot in this figure is shown as the angle between

the two blue lines in the polar plot. In this example, the 3-dB beamwidth in this plane is about 37

degrees. Antennas with wide beamwidths typically have low gain and antennas with narrow

beamwidths tend to have higher gain. Remember that gain is a measure of how much of the power

is radiated in a given direction. So an antenna that directs most of its energy into a narrow beam

(at least in one plane) will have a higher gain.

Front-to-back ratio. The front-to-back ratio (F/B) is used as a figure of merit that attempts to

describe the level of radiation from the back of a directional antenna. Basically, the front-to-back

ratio is the ratio of the peak gain in the forward direction to the gain 180-degrees behind the peak.

Of course on a dB scale, the front-to-back ratio is just the difference between the peak gain in the

forward direction and the gain 180-degrees behind the peak.

Polarization. The polarization or polarization state of an antenna is a somewhat difficult and

involved concept. An antenna will generate an electromagnetic wave that varies in time as it

travels through space. If a wave traveling “outward” varies “up and down” in time with the electric

field always in one plane, that wave (or antenna) is said to be linearly polarized (vertically polarized

since the variation is up and down rather than side to side). If that wave rotates or “spins” in time

as it travels through space, the wave (or antenna) is said to be elliptically polarized. As a special

case, if that wave spins out in a circular path, the wave (or antenna) is circularly polarized. This

implies that certain antennas are sensitive to particular types of electromagnetic waves. The

practical implication of this concept is that antennas with the same polarization provide the best

transmission/reception path.

Consider antennas that generate and are sensitive to linearly polarized waves. If a linearly

polarized antenna launches a linearly polarized electromagnetic wave traveling “up and down” or

vertically, the best possible receiver of that electromagnetic wave will be another antenna that is

similarly linearly polarized (vertically polarized). Linear polarization also includes the possibility of

the electromagnetic waves traveling “right to left” (horizontally) as well. Often antennas can simply

be physically rotated to make them horizontally or vertically polarized, although this may not

always be the best choice.

White Paper

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Circularly polarized antennas can radiate electromagnetic waves that spin clockwise or counter-

clockwise depending on the structure. So a similarly polarized antenna should be used to receive

these signals. This spin direction is typically characterized by left circular polarization (LCP) or right

circular polarization (RCP).

Note that the polarization of an antenna doesn’t always imply anything about the size or shape of

the antenna. A dipole is usually called vertically polarized because of the way a dipole is typically

used, that is, because it is mounted vertically, but the antenna is linearly polarized. Likewise,

antennas that are circular in their construction do not have to be circularly polarized. Many circular

patches are linearly polarized and many rectangular patches are circularly polarized. These

examples are simple demonstrations of the fact that the polarization state of an antenna is not

related to its shape.

VSWR. The voltage standing wave ratio (VSWR) is defined as the ratio of the maximum voltage to

the minimum voltage in a standing wave pattern. A standing wave is developed when power is

reflected from a load. So the VSWR is a measure of how much power is delivered to a device as

opposed to the amount of power that is reflected from the device. If the source and load

impedance are the same, the VSWR is 1:1; there is no reflected power. So the VSWR is also a

measure of how closely the source and load impedance are matched. For most antennas in

WLAN, it is a measure of how close the antenna is to a perfect 50 Ohms.

VSWR bandwidth. The VSWR bandwidth is defined as the frequency range over which an

antenna has a specified VSWR. Often, the 2:1 VSWR bandwidth is specified, but 1.5:1 is also

common

The separation of the electric and magnetic fields into components is mathematical, rather than clearly physical, and is based on the relative rates at which the amplitude of different terms of the electric and magnetic field equations diminish as distance from the radiating element increases. The amplitudes of the far-field components fall off as 1 / r , the *radiative* near-field amplitudes fall off as 1 / r 2 , and the *reactive* near-field amplitudes fall off as 1 / r 3

High human exposure always happens in the vicinity of the antenna / near field. The far-field exposure is small and not relevant. On the contrary, communication happens in the far field; therefore, all catalog data are only far-field data.

It is quite important that these data typically do not contain phase only amplitude.

1. **Particle Swarm Optimization (PSO) for Amplitude Optimization**
   * Since you already have the grid of dipoles (positions and orientations), PSO is a great choice for optimizing the **amplitudes** of these dipoles.
   * **PSO** will help find the optimal amplitude values that minimize the objective function, which compares the simulated and true far-field data.
   * **Why PSO**:
     + PSO works well for continuous optimization problems like this, where you need to tune the amplitudes across the grid.
     + The algorithm is flexible and can be used in combination with the dipole positions and orientations to optimize the amplitudes iteratively.
2. **Differential Evolution (DE) for Fine-Tuning and Global Refinement**
   * **DE** can further enhance the optimization by refining the amplitude values found by PSO. It is particularly effective in minimizing the difference between the simulated and actual far fields, especially when the objective function is highly non-linear.
   * **Why DE**:
     + DE can explore the solution space with less parameter tuning and works well for continuous variables like the dipole amplitudes.
     + The mutation and crossover operations in DE will allow for better exploration and exploitation of the amplitude space.

**Workflow:**

1. **Initial Guess (PSO)**:
   * Start with **PSO** to optimize the amplitudes based on the far-field data (using your dipole positions and orientations as fixed).
2. **Refinement (DE)**:
   * After an initial solution is found using PSO, you can use **DE** to refine the amplitudes and minimize any remaining errors in the objective function.

This hybrid approach, combining **PSO** and **DE**, should be effective in determining the unknown dipole amplitudes and improving the overall reconstruction of the antenna's near field.

Let me know if you'd like more help with the setup or implementation!

**Why Combine GA and Newton's Method?**

1. **Genetic Algorithm (GA)**:
   * **Global Search**: GA excels in exploring large, complex, and multi-modal search spaces. It doesn't require the objective function to be continuous or differentiable, which is particularly useful when you have highly non-linear optimization problems.
   * **Exploration**: It uses populations of candidate solutions and can explore the space broadly through mechanisms like **mutation** and **crossover**, avoiding premature convergence to local minima.
   * **Adaptability**: GA can work with both **continuous and discrete variables**, making it flexible for optimization tasks like determining the dipole amplitudes.
2. **Newton's Method**:
   * **Local Search**: Newton's Method is a **local optimization technique**. It works well when you are near the **local optimum** because it uses gradient information to find a minimum more efficiently.
   * **Precision**: Once a good solution is found (through GA or other methods), **Newton's Method** can **fine-tune** the solution more precisely, especially if the objective function is smooth and differentiable.
   * **Speed**: Newton's Method converges very quickly when close to the minimum, making it highly efficient when starting with a good initial guess.

**Combining GA and Newton's Method**

**Step-by-Step Process:**

1. **Step 1: Use GA for Global Search**
   * Start by using **GA** to explore the solution space. GA will generate a population of dipole amplitudes and iteratively evolve them to minimize the objective function.
   * This will give you a **global view** of the solution space and help you avoid getting stuck in local minima.
   * You can treat the amplitudes of the dipoles as continuous variables and use GA to optimize them based on the far-field data.
2. **Step 2: Fine-Tune with Newton's Method**
   * Once GA finds a **near-optimal solution**, switch to **Newton's Method** to **refine the solution**.
   * **Newton's Method** will take the solution found by GA and iteratively adjust the amplitudes by following the gradient of the objective function.
   * This method will rapidly converge to a precise solution as long as the starting point (the solution found by GA) is close enough to the minimum.
   * Newton's Method can be used iteratively to fine-tune the dipole amplitudes for minimal error between the simulated and true far-field data.

**Why This Combination Works:**

* **GA** is ideal for exploring a large search space and avoiding local minima, but it may take longer to converge because it does not leverage local information (gradients) about the objective function.
* **Newton's Method** takes advantage of gradient information to converge quickly to a precise solution, but it requires a good starting point (which GA can provide).
* By combining **GA and Newton's Method**, you can achieve both **efficient global exploration** (with GA) and **quick, precise local refinement** (with Newton's Method).

**Practical Workflow Example:**

1. **Initialize** the population of dipole amplitudes using GA.
2. **Evaluate** the objective function (comparison between simulated and actual far-field).
3. **Evolve** the population based on the fitness function, iterating through mutation and crossover.
4. Once a solution is found, apply **Newton's Method** to **refine** the amplitudes by using gradient information.
5. Iterate between GA and Newton's Method if necessary, progressively improving the solution.

**When is This Approach Useful?**

* If your objective function is **non-linear** and **multi-modal**, GA can help avoid getting stuck in local minima.
* If you already have a **good initial guess** for the solution, Newton’s Method can help **quickly refine** the solution.
* This approach is particularly useful if the objective function becomes **smooth and differentiable** after GA has already found a near-optimal solution.

**Summary**

* **GA** is excellent for **global exploration** of the solution space, especially when dealing with non-linear, non-differentiable objective functions.
* **Newton's Method** excels at **local refinement**, converging very quickly when a good starting point is provided.
* Combining the two gives you the best of both worlds: **GA for broad exploration** and **Newton’s Method for precise, fast optimization**.