AM Directional Antennas in a Digital World

2005 NAB Radio Show
Part 1 – Directional Antenna Basics

AM Directional Antennas in a Digital World

• Day 1 (Wednesday)
  – 8:00 AM – 1:00 PM - DA Basics

• Day 2 (Thursday)
  – 8:00 AM – 11:00 AM – DAs & HD Radio
  – 11:00 AM – Transmitter Loading Panel Discussion

Introduction to DA Patterns

2005 NAB Radio Show
Part 1 – Directional Antenna Basics
Purpose of Directional Antennas?

- Daytime: Groundwave Interference
- Nighttime Protection:
  - Groundwave Service of Class B and C Stations
  - Skywave Service of Class A Stations
- Coverage Improvement
Directional Antenna Pattern Features

- Nulls (or, more properly, Minima)
- Major Lobes
- Minor Lobes

Sample Antenna Pattern

DA Operation Times

- DA-D - Daytime
- DA-N - Nighttime
- DA-CH - Critical Hours
- DA-1 - One Pattern at all times
- DA-2 - Two Patterns Daily
- DA-3 - Three Patterns Daily or Weekly

Types of Directional Antenna Pattern

- What is Pattern Size?
  - Definition of RMS
  - Use of Assumptions about Loss
Pattern Types

- Theoretical Pattern
- Standard Pattern (Known as Expanded Pattern Internationally)
- Modified or Augmented Standard Pattern
- Converted Standard Pattern
Directional Antenna Parameters

- Theoretical Parameters - The Mathematical Assumptions and Basis for the Pattern
- Operating Parameters - The Pattern Parameters on the FCC License (or Industry Canada TCOC)

Theoretical Parameters

- Geometry
  - Spacing
  - Orientation
  - Antenna Tower Electrical Height
- Electrical Parameters
  - Field Ratio
  - Field Phase

Operating Parameters

- Antenna Monitor
  - Tower Current Sample Ratio
  - Tower Current Sample Phase
- Base Current
- Common Point Current
Directional Antenna Tests and Measurements

- Proof of Performance (Known as a “Full Proof”)
- Partial Proof of Performance
- Monitor Point Field Strengths
  - “Radial Partial Proof” to change a monitor point location

Overall Block Diagram

- Common Point Matching Network
- Power Divider
- Phase Adjustments
- Transmission Lines
- ATUs
- Radiating Elements
- Ground System
- Antenna Monitoring System
System Block Diagram

**Phasor**
- Input From Transmitter
- Outputs to Towers
- Network Adjustments
  - Ratio
  - Phase
  - Common Point Impedance

**Adjustments are Not as Labeled**
- Tower Currents Effected by Mutual Coupling
- Control Labels Follow Tradition
- Necessity to Adjust Several Controls for a Change

**Antenna Tuning Units**
- Network
  - Impedance Matching
  - Phase Shifting
- Other Functions
  - Static Drain
  - Blocking Capacitor
  - Coupling Tower Light Power
  - Antenna Monitor Sampling
    - Toroid Pickup or Sampling Line Isolation Coil
Radiating Structures

- Towers (or Masts)
  - Guyed
  - Self-Supporting
- Other Elements
  - Supported Wire
  - Pole or Mast

Feed Methods

- Series Fed
  - Base Insulated
  - All Circuits on Tower Isolated
- Shunt-Fed
  - Base Grounded
  - Isolation Not Necessary
  - Subject to Mechanical Instability and Icing
  - Circulating Currents Can Be Problematic

Radial Ground Systems

- 120 buried Copper Wires
- Quarter Wave in Length
- Approximately 6 - 12 Inches Deep
- Shortened to Avoid Overlap Between Towers
- Sometimes Shortened at property Boundary

Ground Screens

- Expanded Copper Mesh
- Near Base Only
- Often over Gravel
- Sometimes Buried
DA System Measurements
• Common Point Impedance
• Base Impedance
• Transmission Line Impedance
• Base Current

Part I – Directional Antenna Basics

Introduction
• What we won’t talk about: Tower Structures, Real Estate, Buildings for Equipment
• What we will talk about: The Antenna Feed System from Transmitter output to the antenna tower(s)
The Antenna Feed System

- The feed system receives the power from the transmitter output
- It divides it into the correct proportions for each tower
- It makes sure the phase angle of the energy fed to each tower is in the correct relationship to the other towers

Parts of the Feed System

- The feed system has two parts
  - Networks of lumped components
  - Transmission Lines

Components

- Capacitors - Categorized by Dielectric
  - Mica
  - Vacuum
  - (Occasionally Air, Ceramic, or Polystyrene)
- Only Vacuum and Air Capacitors are Available in Variable Versions
Coils (Inductors)

- Low Current (up to 20 A) wound with ribbon, edgewise on frames (these are also used for very low current in good quality systems)
- High Current wound with copper tubing
### Unusual Inductors
- Older very low current coils (up to about 8 A) sometimes wound from large diameter wire on ceramic or other insulators - even on PVC sewer pipe!
- High current coils sometimes wound in ‘Bifilar’ method - two side-by-side windings connected in parallel
- Very high current toroids manufactured of heavy gauge sheet stock or bar stock

### Variable Inductors
- Variable inductors have sliding contacts which are a frequent failure point
- Some older inductors have a 1 turn loop (shorted turn) which can be rotated to make a very minor change in inductance
- Some very old equipment uses a variable inductor or transformer called a “variometer”

### Switching Devices
- Antennas that are operated in more than one mode use switches to change modes
  - “contactors” or High Voltage Relays
  - Vacuum Switches
- Manual switches using “J” Plugs
- Temporary Metering and Measurement using “J” plugs

### Current Meters
- Thermocouple Ammeters: A bimetallic thermocouple which produces a DC current proportional to heating caused by the RF current, used to drive a meter movement
- Toroidal Current Transformers, whose output is rectified and used to drive a meter movement
**Tower Lighting**

- Insulated “Base fed” towers require isolation of the AC feed to the tower lights
- Three methods
  - Lighting Chokes
  - “Ring” transformers
  - Quarter-wave isolation sections
- Shunt fed or skirt fed towers do not require isolation
Lighting Flashing Generators

- Electromechanical (Motor Driven)
- Electronic

Flashing Unit Location

- Mounted on the tower
- Located on the “Cold” side of the RF feed system
- Synchronization

Tower-Mounted Antennas

- Isocouplers
- Isolation Coils
- Quarterwave Isolation

(antenna sample loop isolation follows the same principles)
Antenna Sample Devices

- **Sample Loops**
  A sample loop is a current transformer that couples to the current flowing in the antenna tower.
- **Type Approval rules call for**
  - Single Turn, Fixed position
  - Unshielded
  - Tower Potential

Obsolete Sample Devices

- Older Systems sometimes have shielded, rotatable loops -- these are obsolete, and cannot be used in type approved systems.
Sample Line Isolation Coils
- Relatively high impedance inductors, wound from transmission line
  - Anti-resonated: Shunted with a capacitor of the same magnitude of reactance so the combined parallel resonant circuit has very high impedance
  - Not-resonated: Sometimes tapped to adjust resistive component of drive impedance

Toroidal Pickup Units
- Toroidal transformers, with the primary a straight conductor: Output voltage proportional to primary current
- Older Systems sometimes have
  - One turn loops with Faraday shields to reduce capacitive coupling
  - Capacitive Voltage dividers

Shortcomings of Toroids
- Not suitable for use with towers that are over about 120 electrical degrees tall
- Must be installed so that no shunt current changes past the loop can affect the pickup currents
- The tower feed current is not the same as the magnitude and angle of the radiated field

Transmission Lines
- Types of Coaxial Transmission lines
  - Air Dielectric
  - Foam Dielectric
  - Rigid vs. Flexible
  - Solid vs. Braided Outer Conductor
  - Quasi-Coaxial Open Wire
- Direct Feed for Simple non-DA Antennas
- Sample Line Requirements
  - Solid Outer Conductor
  - ½ Degree Environmental Stability
Transmission Line Impedance

- Impedance - Nearly Always 50 ohm
  - BUT: Older Systems may use 65 or 70 ohms
  - Systems using Cable TV Trunk Cable will be 75 ohm - its very high quality cable, and very cheap!
  - Impedance depends on ratio of diameters of inner and outer conductor: the formula is:

\[ Z_0 = \frac{138}{E} \log_{10} \frac{D}{d} \]

Where:
- \( Z_0 \) = characteristic impedance
- \( E \) = dielectric constant (air is 1)
- \( D \) = inside diameter of outer conductor
- \( d \) = outside diameter of outer conductor

Other Transmission Line Characteristics

- Depending upon the Dielectric material, the Velocity Factor of cable may vary from 65% to almost 100%.
- The Power Rating of coaxial cable is dependent on the voltage breakdown or the center conductor temperature rise
- VSWR (Voltage Standing Wave Ratio) has a profound effect on power rating
<table>
<thead>
<tr>
<th>Component Failures</th>
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<tbody>
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<td>Inductors</td>
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<table>
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<tr>
<td>Vacuum (and Air Dielectric) Capacitors are Voltage Limited</td>
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<tr>
<td>Mica (and other solid dielectric) Capacitors are normally Current Limited</td>
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<tr>
<td>Failure modes are nearly always catastrophic BUT Vacuum capacitors slowly become gassy, and should be prepared for use at maximum voltage capability</td>
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</tbody>
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<td>Minor arcs that don’t result in serious damage can often be “cleaned up”</td>
</tr>
<tr>
<td>Variable inductors need maintenance on moveable contacts - esp. older types, and silver-bearing grease is very helpful</td>
</tr>
<tr>
<td>Lightning can cause such large currents that inductors collapse</td>
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<td>Many contactors disassemble themselves over time because of the mechanical vibration of their operation.- maintenance!</td>
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<tr>
<td>Water (including hygroscopic, or capillary moisture) can cause solenoid failure</td>
</tr>
</tbody>
</table>
Contactors, Cont’d

• Malfunction of control systems can cause overcurrent causing solenoid failure
• Microswitches fail or become misaligned
• RF contacts wear with time (or become misaligned) and require replacement

Meters (Thermocouple)

• Any overcurrent event (arc, lightning, AC circuit failure) can cause thermocouples to malfunction
• Meter movements tend to read wrong over time due to decline in permanent magnet strength

Meters, Toroid

• Meter movement malfunctions
• Shorts or overcurrents damage toroid insulation
• Shorts or overcurrents damage or destroy resistive pads or rectifier elements

Sample Loops

• Connector Open Circuits (usually due to mechanical vibration)
• Water in connectors (and lines)
• Failure or damage to insulators (ice)
• Mechanical Movement on Tower
Sample Toroids
• Shorted windings due to overcurrent
• Damage due to arcs to ground
• Reverse Installation (reverses phase angle)

Transmission Lines
• Arc-overs at end connections
• Water in lines
• Split bullets or open bullets
• Installation damage, or damage during other excavation
• Long term corrosion in air dielectric lines that are not pressurized
Network Building Blocks

- T Networks
- L Networks
- Shunt Reactance
- Series Reactance

System Block Diagram

Divider Types

Power Division

\[ Y_x = G_{n} + jB_{n} \]

\[ P_x = G_{n}(E_{Bus})^2 \]

General Power Divider Principle
**Divider Types**

- 10° T NETWORK
- 135° DEGREES
- FIXED L NETWORK
- CAPACITIVE
- QUADRATURE
- FLEXIBLE POWER FLOW

**Examples**

(a) MIXED USE OF POWER DIVIDER TYPES
(b) SIMPLIFICATION BY ELIMINATION OF PARALLEL COMPONENTS

**More Examples**

(c) DIRECT FEED TO HIGHEST POWER TOWER
(d) SPLIT BUSS WITH PATTERN BANDWIDTH IMPROVEMENT

**Two-Tower Phasing System Example**

- Necessary Specifications
  - Parameters
  - Base Impedances
  - Base Currents
  - Power Distribution
  - Transmission Lines and Their Lengths
Traditional Loop Location

- Appropriate Tower Heights
- Subject to Shunt Effects

Toroids

- Appropriate Tower Heights
- Subject to Shunt Effects
Detuning of Structures

- Unused array towers
- Nearby Communications towers
- Power Line Towers
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X 9:00 AM Welcome  Marino
X 9:05 AM Introduction to DA Patterns  Dawson
X 9:25 AM Introduction to DA Systems  Rackley
X 9:55 AM DA Hardware I - Components  Dawson
X 9:55 AM DA Hardware II – Networks  Rackley
X 10:55 AM Break
X 11:10 AM DA Troubleshooting  Rackley
11:50 AM FCC Procedures  Dawson
12:40 PM Questions and Answers  Dawson/Rackley
1:00 PM End

DA Troubleshooting

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Part 1 – Directional Antenna Basics

Problem Types - Immediate

• Internal to Array
  – Radiating System
  – Antenna Monitoring System
• External to Array - Re-radiation

Problem Types - Gradual

• Internal to Array
  – Drifting Component Values
  – Ground System Deterioration
• External to Array
  – Seasonal Variation
  – Permanent Changes
    • Development
    • Water Table Changes
Basic Troubleshooting

• Consider Multiple Factors Simultaneously
  – Antenna Monitor Parameters
  – Monitor Point Field Strengths
  – Common Point Impedance/Transmitter Load
• Always Record Settings and Readings Before Any Action
• Keep Records

Example - Single Tower (Non-Reference) Sampling System Change

• Only Parameters of One Tower Change
• No Common Point Impedance Change
• No Monitor Point Field Strength Change

Example - Single Tower (Reference) Sampling System Change

• All Towers Suffer Parameter Changes of Same Magnitude
• No Common Point Impedance Change
• No Monitor Point Field Strength Change

Example - Single Tower Network Failure

• All Towers Suffer Parameter Changes of Differing Magnitudes
• Common Point Impedance Might Change
• Monitor Point Field Strengths Might Change
• Look For Problem In Circuit of Tower With Largest Change
Example - Single Monitor Point Change Without Parameter Change

- Re-radiation Source Near Monitor Point
- Conductivity Change Over Path to Monitor Point

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Example - Multiple Monitor Point Change W/O Parameter Change

- Re-radiation Source Near the Array
- General Conductivity Change

---

Example - Common Point Impedance Change W/O Parameter Change

- If Sudden and/or Large - Component Failure
- If Gradual and/or small - May be Drift

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Antenna Monitor Sampling System Tests

- Switching Lines on Antenna Monitor to Isolate Problem
- Visual Inspection of Pickup Devices and Lines
- Impedance Measurements into Lines connected to Pickup Devices
- Impedance Measurements of Lines OC & SC
- Dielectric Testing of Lines
Feed System Tests

- Visual Inspection of Components
- Change Patterns (if Possible) to Rule Out Lines, etc.
- Operating Impedance Measurements of Line Terminations
  - Must Be Compared to Baseline Measurements
  - Not Necessarily Matched to Characteristic Impedance
- Impedance Measurements of Network Branches and Components

Component Replacement

- Assure Correct Rating
- Adjust the Affected Network Branch to Restore Parameters

Test Equipment

- Field Strength Meter
- Operating Impedance Bridge
- Generator/Detector
- Network Analyzer System

Wednesday, September 21, 2005

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FCC Procedures

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Part 1 – Directional Antenna Basics

How FCC Technical Procedures Work

• Applications for CP – FCC Form 301
  – Major - City Change, non–adjacent Frequency Change
  – Minor - Most Other
• Current Technical Standards for Allocation from MM Docket 87-267

Technical Procedures

• Applications for License (FCC Form 302)
  – Direct Power Measurement
  – License covering CP for NEW Construction
  – License to Change Parameters, Monitor Point Location, Sample System Changes

FCC Rules - Construction

• Tower Fencing for NIER
• Sample System Construction
• Metering Requirements
FCC Rules - Operation

- Keep MP’s within Limits
- Antenna Monitor Parameters
  - ±3 degrees phase angles, ±5% current ratios
  - +5%, -10% Power

Construction Rule - 73.1615

- (If no Frequency Change)
  - Reduced Power, MP’s in Limits
  - non-DA, 25% of DA Licensed Power
  - DA as Necessary for Field Strength Meas.
  - DA w/ New Pattern “Substantially Adjusted”
  - Up to 30 Days without Prior Authority

STA Rule - 73.1635

- DON’T LIE
- STA Request Due to Damage can be made Electronically (Confirm in Writing)
- Be Specific - What Happened, How Do You Propose to Operate?
- Extended Hours Operation ONLY per Emergency Operation Rule 73.3542

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4. Correspondence with MMB Staff re. Measurement Radials or other CP Errors
5. Tables of Measured Inverse Field Strengths, Parameters
6. Sample System Statement
7. Measured Non-DA Pattern
8. Measured DA-N Pattern
9. Graphs of DA-N and Non-DA Measurements
10. Field Intensity Measurement Data Sheets
11. Map Key
12. Monitor Point Locations: Descriptions, Map, Photographs
13. Ground System Layout Drawing
14. Antenna impedance Measurements
15. Antenna System Diagram
16. Statement of Engineer

The items in RED have normally been required, because of a rule provision, because of a question in the 302 Form, or because the staff informally requires them.
New Requirements for Full Proof-of-Performance

- Maximum 12 Radials – May Assume Symmetry
- Minimum 15 Measurement Points Per Radial
- At Least 7 Measurement Points Within 3 km
- Minimum 6 Radials
- Measurements Unnecessary Beyond 15 km

RADIATION NULLS (VERTICAL ANGLE = 0 DEGREES)

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RADIATION MAXIMAS (VERTICAL ANGLE 0 DEGREES)

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<td>359.4</td>
<td>1066.424</td>
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New Requirements for Partial Proof-of-Performance

- Minimum 4 Radials
- Radials at All Monitor Point Azimuths
- Less Than 4 Monitor Points – Measure Nearest to Monitored Radials
- 8 Measurement Point Per Radial

Partial Proof-of-Performance Analysis Options

- DA/DA Comparison to Last Proof
- DA/ND With New Data – ND Field from Last Proof
- DA/ND With New Data – New ND Analysis Additional Close-In Measurements (< 3 km) and Graphical Analysis Required

New Uses For Partial Proofs-of-Performance

- May Select New Measurements Points Not From Full Proof DA/ND Analysis Required
- May Establish New Monitor Points Not From Full Proof DA/ND Analysis Required
- Monitor Point Limit Can Be Changed With Single-Radial Measurements
- Pattern Augmentation Additional Close-In Measurements (< 3 km) and Graphical Analysis Required
Other Matters

- No Critical Arrays
- No Base Current Meters
- Single Frequency Antenna Impedance Measurements
- Non-Zero Common Point Reactance
- Simplified Monitor Point Descriptions

Monitor Point Change Simplifications:

- If a point from the original proof is used, new measurements on that point
- If a new point is used, “partial proof” measurements on the affected radial
- No monitor point map required

Materials Required to Be kept At Station

- Maps Showing Measurement Locations
- Schematic Showing Impedance Measurement Points
- Impedance Measurement Methodology Details
- Impedance Measurements Results

“Non-Type Approved” Monitor Systems

- If your antenna monitor system uses
  - Shielded or rotatable loops
  - RG-8 or other braided conductor cable

  You need to follow the requirements for logging, MP measurements
Economic Considerations –
It's now less costly to keep your directional array legal!

- Partial Proof-of-Performance
  - About 1/3 the previous cost

- Full Proof-of-Performance
  - About ½ the previous cost

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QUESTIONS ?

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