APPLICATIONS FOR COORDINATED MOTION IN RADOME TESTING

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ABSTRACT

Traditional data collection strategy for antenna measurement is to perform a step and scan operation. This method moves a particular axis while holding all other source and AUT axes in a fixed location. Modern radome measurements require the coordinated motion of two or more axes due to the desired measurements, the radome testing geometries or a combination of both. An example would be transmission efficiency testing of a radome associated with a tracking antenna. In this measurement scenario, the antenna azimuth and elevation axes must maintain an orientation along the range axis while the radome is moved in front of the antenna. The axis coordination could be linear or non-linear in nature.

This paper describes the concept of coordinated motion and the needs for coordinated motion in radome measurements that have been identified. Additional potential applications for coordinated motion in radome measurements are described. Two methods of coordinated motion that have been implemented in instrumentation are described. They are geared motion, which is a linear master/slave relationship between two axes and generalized coordinated motion where the relationship of axes motion is described via linear or non-linear equations.

Keywords: Antenna Measurements, Commercial products, Data acquisition, Instrumentation, Measurement systems

1. Definition of Coordinated Motion

Coordinated motion as defined in this paper is the synchronization of one or more positioner axes during an antenna measurement so that a desired relationship among the axes' position is maintained while the axes are in motion. This relationship may be linear or non-linear.

Coordinated motion is a superset of simultaneous motion. Simultaneous motion merely implies that multiple axes are moving at the same time, and may reach their destinations at different times.

Most applications for coordinated motion will involve two or more axes.

Radome measurements generally require a complex relationship among the range RF axis, any radome motion axes, and the axes of a test antenna mounted in or behind the radome. The range antenna may also have axes of motion, such as polarization.

2. Types of Radome Measurements

Several standard measurements exist specifically for radome testing [1, 2, 3].

Transmission efficiency: This measurement determines the amount of energy lost due to transmission through the radome. This measurement is usually collected at various radome aspects relative to the range axis. This measurement requires that the antenna behind or in the radome remain fixed relative to the range RF axis while the radome is moved so that the change in energy is solely due to changes in radome aspect angle.

Boresight shift: In this measurement, the change in tracking angle or main beam location for the test antenna between data collected with no radome and with a radome mounted is determined. This measurement normally requires some form of closed-loop RF tracking system. The antenna used for this tracking system might be the antenna inside or behind the radome or the range antenna. If using the range antenna, it may be useful or necessary to counter-steer the test antenna to keep it aligned with the range axis.

Reflectivity: This measurement determines the change in test antenna reflectivity due to the radome. Ideally, this type of measurement is independent of the pointing direction of the test antenna. However, since no antenna range is completely free of scattering effects, it will usually be beneficial to keep the test antenna pointed in a particular direction. The pointing direction desired for reflectivity measurements will often be different than the one desired for transmission efficiency.

Antenna pattern distortion: This measurement requires that the test antenna rotate with the radome to maintain a particular antenna-to-radome aspect as the antenna pattern is sampled.

3. Radome Testing Geometries

One requirement of a radome testing system is to align the antenna inside the radome, as it would be in the actual system. The antenna axes' order of rotation is also required to match that of the actual system [1, 2]. There are many possible axis configurations for testing radomes. One of the key features of each configuration is the method of aligning the antenna inside the radome. Most configurations fall into one of two groups: suspending the antenna inside the radome so that antenna motion is independent of radome motion, and mounting the antenna on a structure that moves with the radome.

Antenna suspended inside radome: In this geometry, the antenna mount remains stationary as the radome axes are moved. This geometry can greatly simplify transmission efficiency, reflectivity, and boresight shift measurements, though it generally restricts the available radome rotation angles. For pattern distortion measurements in this geometry, the test antenna requires a gimbal to maintain alignment with the radome. Figure 1 shows this type of structure. The large disk contains the mounting fixture for the radome. The independently mounted test antenna is shown protruding through the radome-mounting fixture.

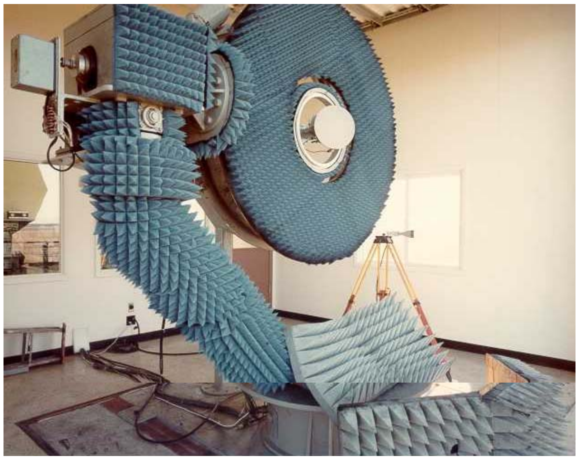

Figure 1 – Sample Axis Geometry with Antenna Suspended inside Radome

Antenna axes mounted above radome axes: A common method to remove the angular restrictions of the suspended antenna is to mount the antenna mast above one or more of the radome axes, specifically the radome azimuth. This geometry typically has a multi-axis antenna positioner at the end of the mast. Figure 2 shows an actual aircraft nose radome with the antenna in its normal mounting fixture. In this geometry, the antenna moves with the radome azimuth and has a two-axis positioner to move the antenna within the radome. If the test antenna must remain fixed relative to the range RF axis (as it must for transmission efficiency measurements), coordinated motion is required among the radome and test antenna axes.

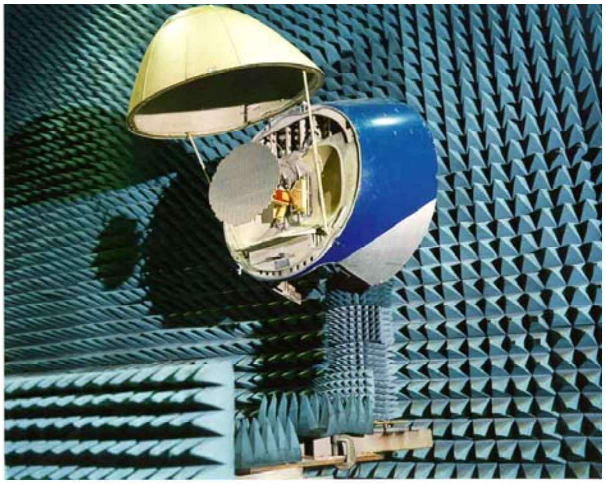

Figure 2 – Sample axis geometry with antenna gimbal above radome axes

4. Counter-Steering

Any multi-purpose radome test facility will greatly benefit from, and perhaps require, some form of coordinated motion. If the antenna is suspended inside the radome, then pattern distortion measurements require that the antenna follow the movement of the radome axes. If the antenna is not suspended inside the radome, then transmission efficiency measurements require that the antenna axes counter the movement of the radome axes.

For a two-axis antenna gimbal mounted on a roll-over-azimuth radome positioner, the gimbal motion required to counter-steer the radome azimuth is non-linear for all roll angles except 0 and 90 degrees of radome roll from normal radome aspect. Figure 3 shows the locus of azimuth-over-elevation gimbal axis positions required to counter-steer radome azimuth rotation of +/-85 degrees at 10-degree roll increments.

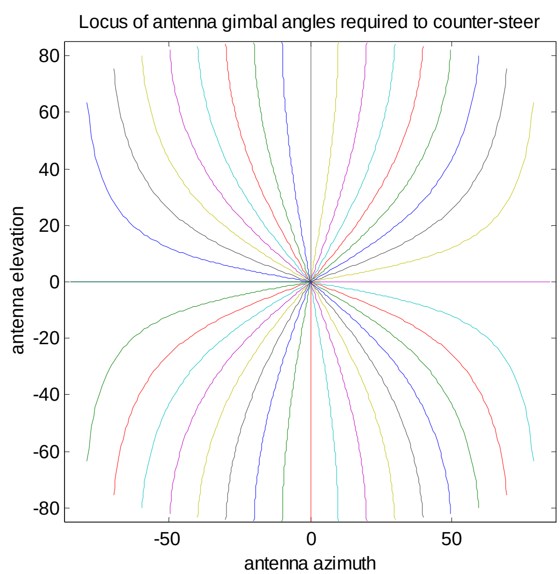

Figure 3 – Locus of Gimbal Angles Required to Counter-Steer Antenna Elevation and Azimuth for various Radome Roll and Azimuth Positions

If the test antenna is suspended inside the radome, there is no need to counter-steer the radome axes. The need for coordinated motion in this geometry is driven by any requirement to measure antenna pattern distortion. In this case, the motion coordination maintains the antenna orientation relative to the radome as the radome is rotated. The nature of the antenna gimbal motion needed to co-rotate the radome axes will be similar to that shown in Figure 3.

5. Existing Coordinated Motion Applications

Maintaining pointing angle of antenna relative to the range axis: Transmission efficiency measurements on a range that has the test antenna axes mounted above the radome axes require coordinated motion. For radome roll angles of 0 and/or 90 degrees, a simple linear relationship between a single test antenna axis and radome azimuth exists. For other radome roll angles, two test antenna axes are required, each with a non-linear relationship to radome azimuth. Figure 3 above shows one example of the nature of that required coordination.

Reflectivity measurements can require some form of coordinated motion to keep the test antenna from pointing at scattering sources in the range. Since the range antenna can be a significant source of reflections, the coordination needed for reflectivity measurements can be different (and more complicated) than the coordination needed for transmission efficiency measurements.

Maintaining polarization: If the radome is mounted on a roll-over-azimuth positioner, it is usually necessary to coordinate the range antenna's polarization with the radome roll. In addition, the antenna often has its own roll axis that may need to be coordinated with the radome roll.

Ordinarily, the coordination required to maintain polarization is a simple linear relationship. If the antenna is tilted inside the radome, however, it is sometimes desirable to coordinate the range antenna's polarization with the test antenna's azimuth angle. In this case the coordination becomes non-linear.

Keeping a rotating radome within a compact-range quiet zone: It is desirable to illuminate the entire radome with the approximated plane wave [3]. For a long, narrow radome, the compact-range quiet zone normally needs to be twice as wide as the radome is long to accomplish this desire. If, however, the radome-antenna-positioning system is mounted on a lateral slide axis, the quiet zone width can be cut in nearly half. Figure 4 shows a radome that would require a quiet zone of 6 units by 4.5 units when the radome azimuth is moved from –90 degrees to +90 degrees. The figure shows the radome extent at the +/- 90, +/-45 and 0 degree azimuth locations. The cross-hairs (+) represent the center of an axis of rotation.

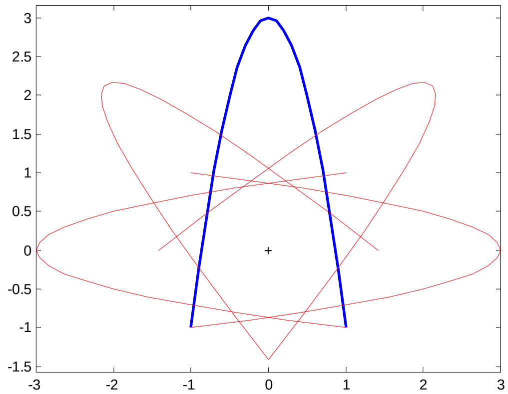

Figure 4 – Quiet Zone Needed for a Static Radome Azimuth Center of Rotation

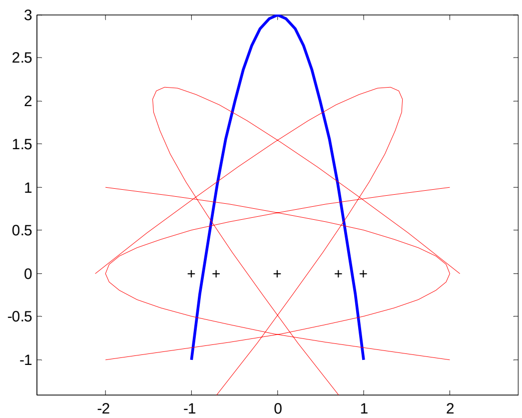

Figure 5 – Quiet Zone Needed for a Radome Azimuth Center of Rotation Coordinated with a Lateral Slide

Figure 5 shows that by coordinating a lateral slide motion of +/-1 unit with the radome azimuth motion; the quiet zone width requirement is reduced to +/- 2 units. This 33% quiet zone size reduction could provide significant facility cost savings.

6. Other Potential Applications in Radome Measurements

Reducing effects of mutual coupling: In a tightly coupled facility such as a compact range, transmission efficiency measurements can have significant artificial ripple induced on each trace due to mutual coupling. This is especially true if the test antenna's azimuth axis (if any) does not coincide with the radome azimuth axis. If there is such misalignment, motion along a longitudinal slide axis could be coordinated with azimuth motion to keep the antenna at a fixed distance along the range axis. Coordinated motion can be used to reduce the artificial ripple in each trace of data.

Maintaining antenna-to-radome aspect: The geometry described in section 3 where the test antenna is suspended inside the radome is well suited for transmission efficiency and reflectivity measurements. Pattern distortion measurements in this geometry require coordination of motion between the radome axes and the test antenna axes. The need for and form of that coordination are discussed in section 4.

Coordinated motion has potential applications outside radome testing in the areas of near-field planarity correction, maintaining polarization in a Ludwig III geometry and variable-rate single-axis scanning.

7. MI Technologies' Mechanisms for Coordinated Motion

The MI-4190 positioner controller is a multi-axis controller that has been designed for control of motion, oriented toward antenna and radome measurements in the near field, far field and compact range environments. The MI-4190 positioner controller has two distinct mechanisms for coordinating the motion of multiple axes: "Geared Motion" for linear axis relationships and a generalized coordinated motion to enable motion through a "Virtual Axis".

Geared Motion: This mechanism is used when linear coordination is required among two or more axes. Recall that the general equation of a line is

$$y = mx + b$$

where m is the slope and b is the y-axis intercept. With geared motion, one axis is identified as the 'master' axis x, and the remainder of the axes to be coordinated are slaved to that master axis. Each slave axis y has its own slope m and intercept b.

Each of the slave axes is initialized to automatically move with a velocity m times the master-axis velocity any time the master axis moves. The slope m can thus also be thought of as a gear ratio. During initialization, the current master-axis position x is read, and each slave axis y is moved, if necessary, to satisfy the linear equation for that slave axis.

The most common usage of the geared mode is for co- or counter-rotation. The gear ratio (slope) m in this case would be either +1 or –1, and the offset b would usually be zero.

In this mode, the slave axes can be configured to follow either the commanded or the actual master-axis positions.

Generalized coordinated motion: This mechanism can be used to perform either linear or non-linear coordinated motion. Whereas the geared motion above always follows the equation of a line, the generalized coordinated motion takes the equation to be followed as user input.

The user first defines a 'Virtual Axis', which might or might not coincide with a positioner axis. No assumptions are made in the MI-4190 about the units or physical meaning, if any, of motion along the virtual axis.

One or more of the positioner axes in the system are mapped to that virtual axis, and will automatically move when motion is commanded on that virtual axis. The virtual axis can be positioned in the same manner as a positioner axis, once it is defined. Additional positioner axes can be identified as 'Variable' axes, whose fixed positions affect the equations of motion.

The user enters Visual Basic functions that each yields a positioner-axis position given a virtual-axis position, one function per positioner axis. The functions can make use of the current positions on the 'Variable' axes. Once the virtual axis has been defined, it can be used in an acquisition just like any other axis known to the system.

When moving a virtual axis, the positioner axes are first moved (uncoordinated if necessary) to the start point on the virtual axis. When a motion along the virtual axis is requested, the MI-4190 creates an array of waypoints, indexed by time, which the collection of axes will pass through. As the MI-4190 commands motion incrementally at its internal update rate, the commanded position on each positioner axis is linearly interpolated between the waypoints.

As a simple example of generalized coordinated motion, let's suppose we have two orthogonal axes (X and Y) that move an RF probe in a plane. An application of coordinated motion would be to make the probe move in a circle with radius 15 cm. The first step is to decide what the virtual axis is. Obvious choices are:

- Angle from horizontal or vertical in degrees or radians
- Distance along the circumference in linear units

For simplicity, let's suppose we want to think of motion along the virtual axis as an angular displacement from the horizontal in radians. If the axes X and Y are scaled to display centimeters, our equations for motion in X and Y are then

```
Function X(V)
      X = 15*Cos(V)
End Function
Function Y(V)
      Y = 15*Sin(V)
End Function
```

Because we have chosen the virtual axis V to have units of radians, then motion along V of 2π units will trace a full circle. Likewise, commanded speed along the virtual axis will be in radians per second due to the equations of motion.

Figure 6 displays another example of coordinated motion highlighting the configuration screen for defining a virtual axis. The example shows coordination of a lateral slide axis with a radome azimuth axis as was discussed in Section 5. The user defines a new axis that is a combination of the Slide axis and the Radome Azimuth. The Equation Entry area is where the user enters a Visual Basic set of equations that govern the motion of the positioner axes that are part of the virtual axis. This example equation moves the slide axis to counter the radome azimuth motion.

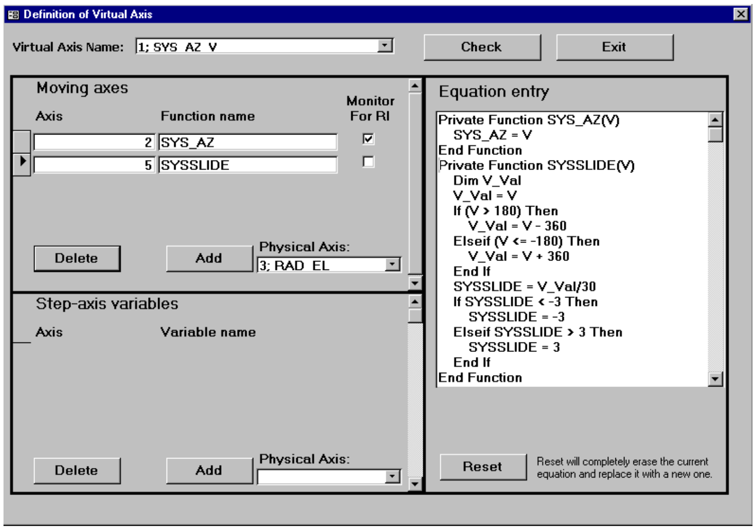

Figure 6 – Virtual Axis Configuration Screen Example

8. Conclusions

Coordinated motion of multiple axes can greatly simplify the management of radome data collection to satisfy standard measurement scenarios. A single range geometry that is used to measure both pattern distortion and transmission efficiency will require coordinated motion for at least one of those measurements. The Geared Motion and Virtual Axis implementations in the MI-4190 provide the flexibility and configurability to make coordinated motion data acquisition for radome measurements a practical and efficient reality.

9. References

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