

# Automated Probe Changer for Multi-Functional Robotic Antenna Measurement System

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**Abstract**— Automated probe changers allow for the rapid and precise exchange of different probes or probe modules on a machine, such as a Coordinated Measuring Machine (CMM). While automated probe changers are prevalent in the manufacturing industry, very little has been published regarding their application in antenna measurement systems [1]. This type of automated system can greatly improve testing efficiency when characterizing antennas across multiple frequency bands or performing different types of measurements. Industrial robotic arms, which offer excellent repeatability, positioning accuracy, and various tooling mechanisms, are also well suited for this type of task. Probes stored on a fixed docking station can be sequentially exchanged between measurements using a robotic arm without manual intervention. The use of multiple robotic arms within a single antenna measurement system allows for an ever-increasing number of different measurement configurations and other automated tasks. Instead of sequential operation, robots can be instructed to perform different tasks simultaneously. For example, one robot can be commanded to exchange its probe antenna while the other is in the process of off-loading and loading test antennas. However, as the number of robots and possible measurement configurations increases, automation implementation becomes increasingly more complex. Safeguards need to be implemented to ensure seamless and safe operation between all possible configurations. These safeguards include but are not limited to e-stops, door switches, proximity sensors, lidars, and the robots' own internal safety system.

This paper describes an automated probe exchange system that was recently developed for a dual robot antenna measurement system. To maximize efficiency through all test configurations supported by the measurement system, a robot can be tasked to select from several probes stored on the probe docking station. This operation requires careful coordination between robots as well as tracking the location of each selected probe.

**Index Terms:** automated probe changer, robotic antenna measurement, system safety standards,

## I. INTRODUCTION

Six axis robots provide a compelling alternative to antenna measurement systems based on traditional positioners. Though typically used for industrial tasks like pick and place or assembly work, their movement flexibility and high repeatability makes them well-suited to the various types of repetitive motion required during antenna measurement scanning. For example, a single six axis robot can be configured to conduct a Phi over Theta scan, then

immediately swing into a Planar Near-field scan, and then follow those with a Theta over Phi scan arm measurement. All these scans could be performed without needing to change the configuration of the robot, meaning that the only step that must be completed manually is changing the probe between measurement types and frequency bands. However, this step too can be eliminated by including an automated probe changer, thus making the process of switching between measurement configurations completely automated. A second robot can also be included in the system to expand measurement capabilities even further. With this increased capability and flexibility comes increased complexity, and a necessity for additional safeguards to ensure that robotic operations are as safe as they are fast and accurate.

## II. DUAL ROBOTIC MEASUREMENT SYSTEM

An automated probe exchange system was recently developed and delivered with a 14-axis dual robotic antenna measurement system (see Figure 1). This system consists of two 6-axis robotic arms, each mounted atop linear floor rails, and can support numerous near-field/far-field measurement configurations for characterizing a variety of antennas over the operating frequency range of 500 MHz to 75 GHz. Thus, a large number of probes were required to cover all possible measurement scenarios. As the system was to support both production testing and wideband antenna development, there was also the need to be able to automatically and seamlessly switch probes during a measurement campaign. The resulting automated probe exchange system needed to support a selection of up to five probes at any given time.

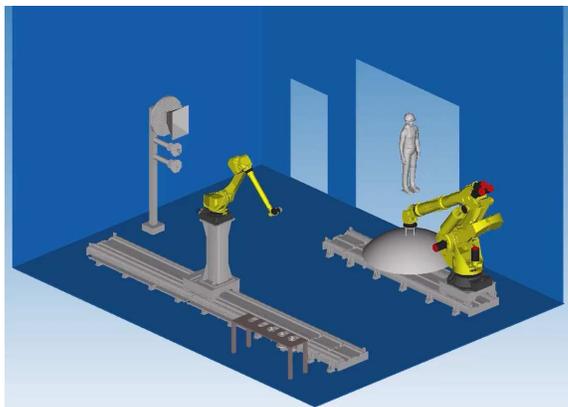


Figure 1: Dual Robotic Antenna Measurement System

### III. PROBE CHANGER

Probe changers can be used to streamline the task of changing a robot probe. Existing industrial robot tool changers have excellent repeatability and alignment provisions and can be adapted for use with RF measurement components. The tool changer has two sides, a “master side” and a tool or “probe side”, as illustrated in . The system also requires a Probe Changer Controller (PCC). The PCC is responsible for responding to user provided inputs, selecting a probe, and controlling the motion of the robot to and from each probe for both pick up and drop off. Once at the correct location, the PCC actuates the master side. The master side is mounted permanently to the face of the robot. All probes are mounted on a probe stand with fixed positions so that the robot can be taught to come to a repeatable “pick-up” position for each probe. The system needs one probe side for each probe on the probe stand. Once the robot is in the pick-up position, pneumatic pressure is used to actuate the master side and pick up the probe side. As a safety feature, the master side will not release the probe if pressure is lost while holding it; releasing a probe requires constant pressure.

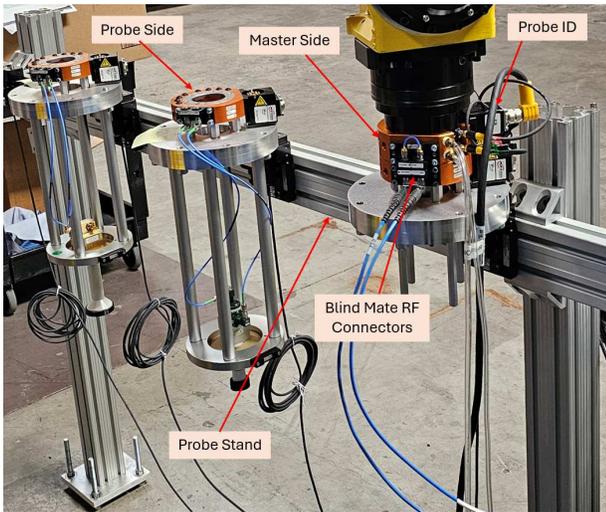


Figure 2: Robot Docked at a Sample Probe Stand

The probe changer comes with Probe ID modules and Lock/Unlock sensors to provide additional safety features and information about the status of the system to the PCC. The PCC can read the sensors and display probe information on the control computer, keeping the user updated on which probe is currently in use. The PCC can also use the Lock/Unlock output in conjunction with the Probe ID to determine if the probe changer is in an abnormal state. Abnormal states include no lock/unlock output or a lock output combined with no valid Probe ID. For passing RF signals, the probe changer is outfitted with two blind-mate RF connectors, which are suitable for operating frequencies up to 40 GHz.

### IV. ROBOT SAFETY MEASURES

Once the robots’ environment has been set, it needs to be protected from collisions. Potential collisions between the robot and a chamber fixture, and potential collisions between the robot and personnel require different prevention strategies [2]; these are discussed in the following sections.

#### A. DCS

For protecting the robot from colliding with the chamber or fixtures within it, the robot’s own internal safety system can be very effective. In particular, Fanuc robots are provided with a DCS (Dual Check Safety) system which includes various parameters for protecting the robot. DCS is designed to meet ISO 13849-1 Category standards [3] and includes provisions to keep the robot from moving too quickly, as well as providing provisions to constrain robot motion called Joint Position Checks and the Cartesian Position Checks. Figure 3 shows the built-in Fanuc DCS menu as it appears on the robotic handheld remote control display.

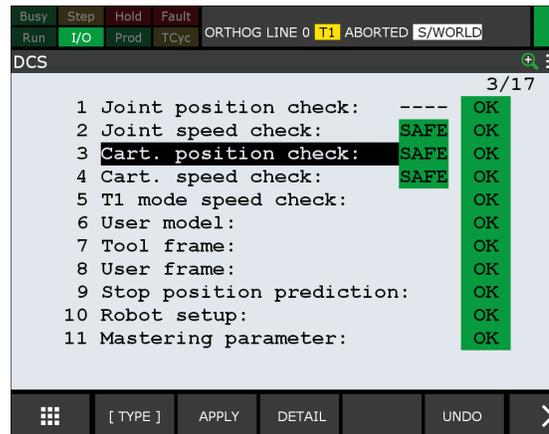


Figure 3: FANUC DCS Menu Overview

Cartesian Position Checks work by defining zones in 3D space. These zones are typically rectangular prisms defined by 2 corner points, though they can be defined as more complex shapes as well. In conjunction with these zones, the robot is constantly aware through its own “Robot Model” of the position of all of its links, as well as the position of any additional links that the operator defines. These additional links are known as “User Models” and they can be defined to be attached to any part of the robot, not just the faceplate. How the robot handles interactions between its own model and these zones depends on how the zones are categorized. Each zone is classified as being either a Working Zone or a Restricted Zone. Working Zones represent the space that the robot is “Working” within, as shown in Figure 4. At no point during a move may any part of the robot model protrude beyond this working zone. If the robot attempts to do so, it will trigger a “DCS Fault” and the robot will stop moving immediately.

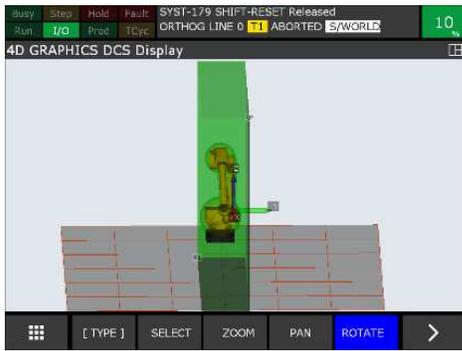


Figure 4: Sample DCS Working Zone. The green box indicates that the robot is obeying the Working Zone and no faults are present

The inverse of the Working Zone is the Restricted Zone. Rather than defining a region the robot cannot leave, it defines a region that the robot cannot enter. An example of a defined Restricted Zone is shown in Figure 5. Generally, a robot will have a single Working Zone which then has multiple Restricted Zones carved out of it to protect things like absorber fixtures, working areas for another robot, antenna mounts, or even the antenna itself.

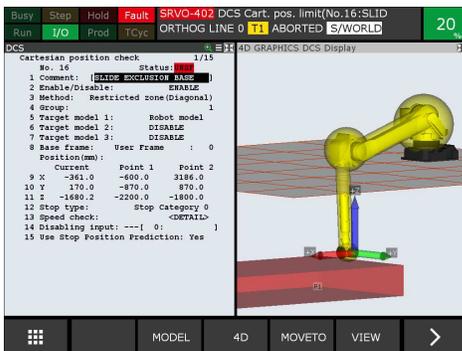


Figure 5: Sample DCS Restricted Zone. The red box indicates that the robot is not obeying the Restricted Zone and there is an active DCS fault

In the case of a robot with a probe changer, DCS can be used to provide protection to the probe changer stand as well. The Probe Changer Controller can toggle individual Restricted Zones on and off when combined with a safety controller (described below). This makes it possible to protect each individual probe on the probe stand with a custom Restricted Zone that keeps the robot from being able to come close to one probe while it is still holding a different probe. Each respective Restricted Zone must be toggled off by the control software in order for the robot to be allowed to pick up any specific probe.

Through the use of DCS, the robot can be given information about where it is and is not allowed to move. What DCS does not do is provide updated information about changes to its environment. For example, DCS does not know if an object is placed where it should not be allowed, if a door

is open, or if there is a person inside the chamber. In order to provide protection against such changes, additional external safety measures must be used.

## B. External Safety Measures

In order to give a robotic system information about its environment and particularly changes to its environment, we can add a safety controller. The safety controller can interface with the PCC over Ethernet to receive commands with regards to which DCS restricted zones should be deactivated to allow probe pick up, and when they should be reactivated. Safety controllers also allow for different types of safety sensors to be added, which can then be defined to have different effects on the system. Some examples of sensors that can be added are as follows:

### 1) Door Switch

Non-contact door switches can work with RFID or with magnetic contacts. ANSI/RIA R15.06-2012 Section 5.6.3.1 [4] states, “Entering the safeguarded space in automatic mode shall lead to a protective stop of all equipment that could present a hazard or hazardous situation.”

By setting the system behavior such that the robotic system stops in automated mode when any door is opened, we ensure compliance with the ANSI/RIA standard. However, to further increase flexibility of the system, we typically configure the Safety Controller to allow usage of the handheld pendant with the personnel door open. This allows for easier teaching of the probe changer operation, as well as providing flexibility to perform other operations on the robot such as mounting probes that are not on the probe changer, verifying scan motion, or performing robot maintenance.

### 2) LIDAR

A LIDAR, which stands for Light Detection and Ranging, system can be combined with the door switches for further compliance with ANSI/RIA R15.06-2012 5.6.3.1 [4]. While door switches prevent new intrusions into the chamber during scanning, they do not provide any information about the status of the interior of the chamber itself. It is possible for personnel to be left inside the chamber while a different person closes the door and begins a scan. A safety rated LIDAR can be used to give the system knowledge about new obstructions (typically a person) in its environment.

LIDAR fields can also be customized for selective conditions. For example, the safety controller can be configured such that it will treat LIDAR obstructions in different areas of the chamber differently. This can be helpful if there are areas where personnel need to be able to stand in order to perform certain operations with the handheld pendant. It would be possible to have a certain area where, during automated moves, an obstruction causes a safety fault and controlled stop, while during pendant moves there would be no fault. If the operator were to leave this area while still in pendant mode and attempt to enter an area which is configured for full protection even during pendant control, the entire system will be stopped until the operator returns to the designated pendant control area.

For systems with a probe changer, the LIDAR fields need to be configured in a way which is compatible with the probe changer. The probes cannot be allowed to violate the LIDAR fields at any point during the probe change operation. In addition, it is good practice to carve out an area near the probe changer where the operator is permitted to stand with the pendant and jog the robot. This makes the process of teaching the probe pick up positions significantly easier.

### 3) Emergency Stop

ANSI/RIA R15.06-2012 5.3.8.1 [4] states, “Every robot system or cell shall have a protective stop function and an independent emergency stop function.”

While DCS provides protective stops, each robot has two native emergency stops with one located on the controller and one located on the pendant. However, these emergency stops are not accessible from outside the chamber and in the case of a multi-robot system, these emergency stops will only stop a single robot when pressed.



Figure 6: FANUC robot controller with both native emergency stops visible.

ANSI/RIA R15.06-2012 5.3.8.1 [4] also states, “Each control station capable of initiating motion or other hazardous functions shall have a manually initiated emergency stop function. The actuation of an emergency stop function shall stop all robot motion and other hazardous functions in the cell, or at the interface between cells and other areas of the workspace.”

To meet these additional requirements for emergency stops, we need to use the safety controller. Additional emergency stops, like the one shown in Figure 7, can be looped into the system and placed in strategic areas, including outside the chamber. In addition to being placed at each control station to satisfy the standard, emergency stops are also commonly placed at chamber and/or personnel doors and near the probe changer.

The safety controller can read the status of each robot controller’s two emergency stops over Ethernet. From there, it can be configured to treat any of those native emergency stops as a safety fault that applies to all robots and stop all other

robots accordingly. This allows all native emergency stops to function the same way and stop the entire system.



Figure 7: Sample emergency stop from SICK with additional reset button.

### 4) Reset Function

After a safety fault has taken place and been cleared, in accordance with ANSI/RIA R15.06-2012 5.6.3.4.2 [4], the system should not automatically return to automated operation.

By using an emergency stop module that includes a reset button and placing it outside the chamber at the control computer, we can satisfy this ANSI/RIA R15.06-2012 criteria. The reset button is configured such that it can only reset the system when there are no active faults, and the system cannot resume automated motion without pressing it. Once the fault has been cleared by pressing the reset button, motion still will not resume until a new move command is sent from the control computer or PCC.

## V. CONCLUSION

When combined with a six-axis robot, automated probe changers can contribute to a highly flexible antenna measurement system that can rapidly change between different measurement configurations without the need for manual human intervention. Using commercial off-the-shelf hardware for the probe changer provides an economically attractive solution while conforming to industrial standards for safety and repeatability of the coupling. Once the system operation has been established, we have shown how different safety measures can be used to prevent collisions between the robot and any fixtures as well as between the robot and personnel. This can all be done in accordance with safety standards through the use of a safety controller as well as various types of standard safety sensors.

Future works include using AI to ensure the selected probe matches the measurement parameters entered by the operator, and automated probe selection based on prior measurement information.

## REFERENCES

- [1] Jeff Fordham, *et al.*, “A Highly Accurate Spherical Near-field Arch Positioning System”, Proceedings of the 33<sup>rd</sup> AMTA Symposium, November 2011
- [2] Chris Smith, Quang Ton, Scott Caslow, Patrick Pelland, “Safety Considerations for Robotic Antenna Measurement Systems”, 2024, 17th

European Conference on Antennas and Propagation Proceedings,  
Glasgow, UK.

- [3] "FANUC Robot Safety Handbook", B-80687EN/15, January 2018, p.5
- [4] "American Standard for Industrial Robots and Robot Systems-Safety Requirements", ANSI/RIA R15.06.2012, March 2013