AN ALL-DIGITAL ANTENNA CONTROL PROTOCOL

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ABSTRACT

For decades, analog amplitude modulation (AM) imparted by antenna feeds has served as the gold standard by which antenna control units (ACUs) manage tracking. This paper presents a digital alternative, designed to provide AM information, signal quality metrics, and additional real-time status, all over existing analog AM cables. Its benefits include reduced (and known) delay in the tracking loop, smart selection among multiple tracking receivers, and support for advanced features such as tracking through interfering signals and tracking intermittent or time-division-multiplexed transmissions.

INTRODUCTION

Since the middle of the previous century [1,2], telemetry tracking antenna systems have evolved to provide sophisticated target tracking capabilities. New ACU algorithms and feed designs (including conical scan, single-channel monopulse (SCM), and ESCAN) have been developed to improve performance across a broad range of tracking requirements.

At their core, however, these advancements all rely on the same basic information as the earliest tracking systems: AM imparted by the antenna feed on the received signal. Typically, in modern ground stations, AM is conveyed via an analog signal output by a tracking receiver.

This AM signal is usually augmented with additional information: received signal strength from the automatic gain control (AGC) loop in the receiver. AGC is also conveyed via an analog receiver output.

While this technology is fundamentally sound and has stood the test of time, several potential issues remain. This paper describes a digital antenna control protocol that facilitates improved performance and new features impractical or impossible in existing systems.

LEGACY ACU OPERATION

Figure 1 depicts a typical tracking antenna system:

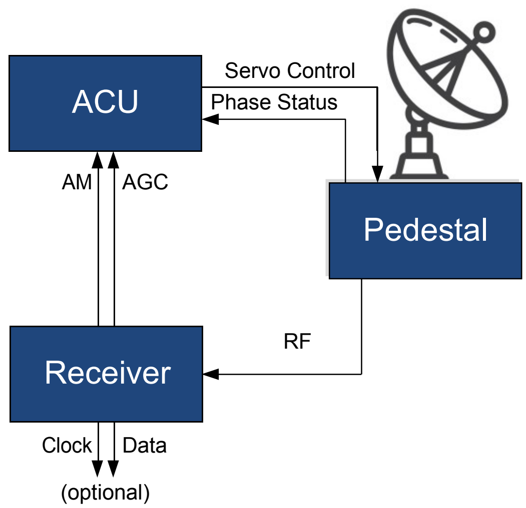


Figure 1 Legacy Tracking Antenna System.

This arrangement forms a closed-loop control system. Radio frequency (RF) signals are received by the antenna and passed to a tracking receiver. The tracking receiver demodulates the signal and outputs its AM envelope and AGC signal strength (and optionally the demodulated data bits). The ACU uses AM information to estimate the pointing error of the antenna and outputs servo control signals to reduce the error.

To understand this process better, consider a conical scan antenna system designed to track azimuth ("left" and "right") and elevation ("up" and "down"). With conical scan, the antenna feed is nutated – that is, the antenna beam is oscillated circularly around the central antenna pointing axis, often referred to as the boresight axis. When the antenna beam is pointed slightly away from the target, the received signal strength is reduced; conversely, when the antenna beam is pointed closer to the target, the received signal strength is increased:

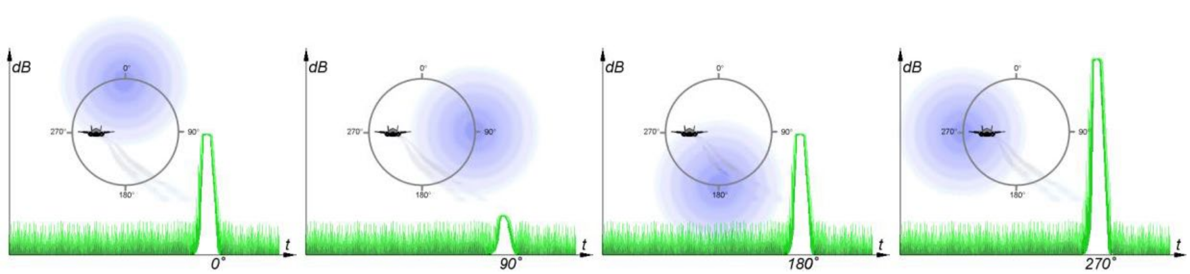


Figure 2 Conical Scanning.[1]

In this system, the phase status signal that is fed back to the ACU from the pedestal in Figure 1 is called top dead center (TDC), which indicates the current scanning phase is precisely 0°. Given

[1] Images by Averse, licensed under CC BY-SA 3.0.

AM and TDC information, it is relatively straightforward to determine the pointing error phase and magnitude, assuming there is no delay in the AM signal path.

Unfortunately, this assumption is untrue. Since the received signal may be weak or corrupted by interference, the AM signal is low-pass filtered by the receiver. This filtering process reduces noise and interference but adds noticeable delay, which is harmful to tracking in two ways. First, any delay within the tracking loop reduces tracking stability. Second, delay shifts the apparent phase of the peak received amplitude, which introduces crosstalk between the azimuth and elevation error estimates and prevents optimal tracking. This phase shift can be calibrated out, but the calibration process is prone to error and must be repeated whenever related system parameters such as AM filter bandwidth change.

Another means to combat weak or corrupted signals is by using multiple tracking receivers. This typically results from having multiple transmit sources on the target, either to provide independent telemetry links or to achieve frequency and/or polarization diversity:

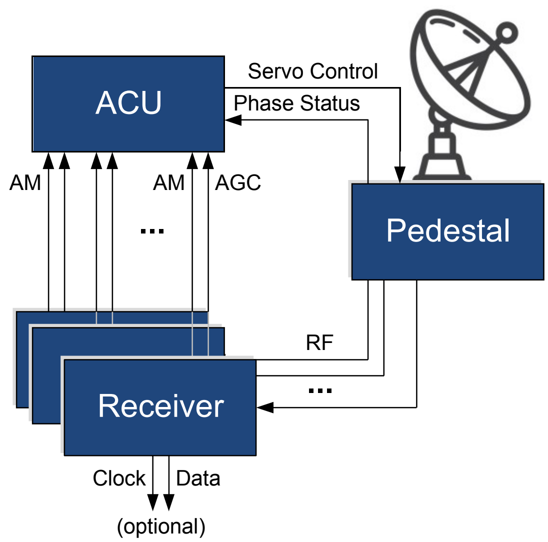


Figure 3 Legacy Tracking Antenna System with Multiple Receivers.

In a multi-receiver system, the AGC signal may be used to select the "best" receiver for tracking, assuming a strong signal is a good one.

Again, however, this assumption is not always true. For example, if a strong interfering signal is present, it may "hijack" the tracking antenna in place of the desired signal. Even if the interference is intermittent, tracking may fail catastrophically if the target moves outside the antenna beam before the interference ends.

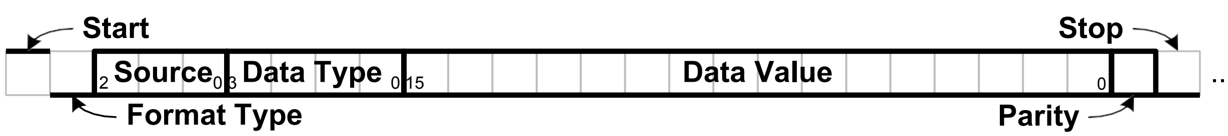
PROPOSED ALL-DIGITAL ACU PROTOCOL

Given some of the potential issues with legacy antenna systems, a new approach is proposed that embodies several improved characteristics:

- All-digital antenna control interface
    - Reduces signal integrity concerns

    - Effectively eliminates control signal latency
    - Allows using existing AM signal wiring over moderate distances (~100 ft.)
    - Allows long distance between receivers and ACU (optical interface if needed)
    - Allows multiplexing multiple interfaces to a single physical connection
- Real-time raw received signal strength indicator (RSSI) information
    - Effectively eliminates AM delay/phase shift (all receivers, all vendors)
    - Encapsulates AM and AGC information in a single value
    - ***Allows optimal tracking algorithms to be implemented at the ACU***
- Real-time data quality metric (DQM) information
    - Accurately describes current received signal usefulness
    - ***Allows optimal selection and/or weighting of receiver information at the ACU***
- Protocol expansion capability
    - Allows future enhancements with minimal impact

These characteristics are achieved using a simple UART-like serial protocol message from the receiver to the ACU:



- **Format Type**
  0: basic format
  1: extended format (future use)
- **Source**
  0 - 7: source channel
- **Data Type**
  0: relative RSSI (dB)
  1: DQM
  2 - 15: other parameter type indexes (future use)
- **Data Value**
  -32768 - +32767: parameter value (fixed point)

Figure 4 Digital Antenna Control Protocol (DACP).

The key data values conveyed by these messages are RSSI and DQM.

RSSI is the instantaneous sampled signal strength relative to AGC zero in dB. It is represented as 16 bits, with 7 fractional bits. Thus, it can represent a level from -256 dB to +256 dB in roughly 0.01 dB increments.

DQM is the Inter-Range Instrumentation Group (IRIG) standard data quality metric [3], sign extended to 16 bits after truncating the least significant bit (i.e., dividing by 2).

For simplicity, the baud rate could be fixed at a single rate. However, as long as the ACU and receivers are set to the same rate, it need only be set high enough to support the required throughput.

The physical layer uses TTL voltage levels driven by 50 Ω line drivers. Baud rates exceeding 20 Mb/s can easily be achieved using existing AM cables over significant distances. This has been demonstrated using fielded receiver hardware and standard coaxial cabling. Optical conversion is available off-the-shelf for longer distances.

These data rates support real-time RSSI updates at about 100,000 samples per second for 8 simultaneous receivers, which substantially oversamples existing and anticipated SCM/ESCAN rates in the 2000-5000 samples per second range.

ALL-DIGITAL ACU OPERATION

Figure 5 depicts a multi-receiver tracking antenna system using the proposed digital antenna control protocol (DACP) interface:

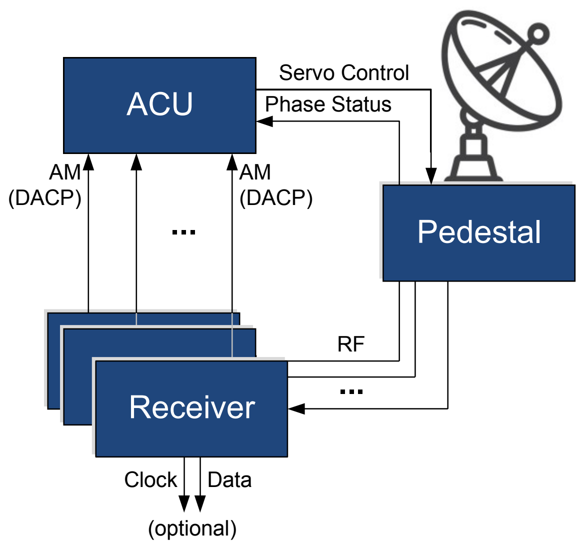


Figure 5 DACP Tracking Antenna System.

Fundamentally, this system appears little different from its legacy counterpart. From a deployment standpoint, this is quite desirable. Beneath the surface, however, lie substantial differences.

One key to improved performance using DACP is effectively zero latency, both in the protocol itself and in the data it conveys to the ACU. It is desirable that the RSSI values update as often as possible, but at any update rate the ACU can determine the sampling delay and factor it into its control algorithms. All other processing latency is self-contained within the ACU, so it also can be accounted for. Thus, *independent of receiver implementation*, the ACU can accurately determine pointing error phase with no need for calibration.

Another key is inclusion of DQM information in the DACP message stream. Assuming the receiver AGCs have been properly zeroed, signal-to-noise ratio (SNR) may be estimated directly from the RSSI. This information, combined with DQM, provides a clear indication of channel conditions, both for the received signal and for the desired signal within it. If a strong interferer is present, SNR may be high, but DQM will be low, signaling to the ACU that this channel is not suitable for tracking. In a one-receiver system, the ACU algorithm may shift to constant velocity to track through the interference. In a multi-receiver system, the ACU algorithm may shift to a truly better receiver. For even better performance, it may use appropriately weighted information from several receivers simultaneously.

These same capabilities facilitate use of tracking antennas in systems that transmit only part of the time. Native tracking in time-division-multiplexed environments opens up many new possibilities for bidirectional and networked telemetry.

A final key element of the DACP is extensibility for future improvements. If additional data items are required to increase performance or add functionality, they may readily be added. The protocol itself may be extended in any desired manner by setting the first message bit to a '1'.

CONCLUSION

The proposed all-digital ACU control protocol eliminates several potential issues with the existing analog AM/AGC interface. It provides the ACU with all needed information for truly optimal tracking, and it does so simply and effectively.

ACKNOWLEDGEMENTS

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[3] Range Commanders Council Telemetry Group, Range Commanders Council, White Sands Missile Range, New Mexico, *IRIG Standard 106-17: Telemetry Standards*, 2017.