SATELLITE ACQUISITION USING AN AUTOMATED TECHNIQUE

Dr. Kenneth L. Reinhard
John C. Darlington
Ford Aerospace & Communications Corporation
1260 Crossman Avenue
Sunnyvale, CA 94089-9833

ABSTRACT

Automated acquisition of a satellite's downlink signal by the main beam of a ground station's tracking antenna is complicated by the presence of antenna pattern sidelobes and potential large uncertainties in the spatial and/or frequency location of the signal. Sidelobe acquisition prevents autotracking and telemetry reception, and large uncertainties require time for coordinated antenna and receiver search. Use of an auxiliary antenna assists in resolving the sidelobe intercept problem, and a high speed digital receiver alleviates the problems associated with spatial and frequency uncertainty. The antenna and receiver, under processor control, constitute a fully automated system. The associated processor software controls the antenna motion during the search phase, selects the proper receiver configuration for the expected signal environment, makes the main beam versus sidelobe intercept decision and switches to autotrack mode upon successful signal acquisition.

INTRODUCTION

There is a continuing need to upgrade existing satellite ground stations to support new mission requirements and also to reduce operation and maintenance costs. Future unmanned operations of mobile, survivable ground terminals will require a fully automated signal search and acquisition capability. Automation of the acquisition procedure is also required to support operations with increased uncertainties in satellite orbital parameters, transmitted frequency, Doppler shift, and signal amplitude due to either anomalous conditions or deliberate actions. Recent developments in digital, high-speed search receivers and microprocessor-based antenna control systems have facilitated a fully automated acquisition capability. The approach described herein meets current and anticipated future acquisition requirements for military telemetry, tracking, and command (TT&C) satellite downlinks in the 2.2 - 2.3 GHz band. Application to other frequency bands is also possible since the approach is insensitive to the frequency band of operation.

AUTOMATED ACQUISITION REQUIREMENTS

Automated main beam signal acquisition requires application of automation technology to four distinct phases of downlink signal acquisition:

- The search phase, involving signal search in spatial, frequency, and time domains simultaneously, resulting in signal detection.

- The main beam versus sidelobe intercept discrimination phase, which occurs when excessively large and/or uncertain received signal amplitudes cause acquisition antenna sidelobe intercept detections that require ambiguity resolution.

- The main beam convergence phase, which follows detection and ambiguity resolution and involves refinement of the satellite angle of arrival estimation within the main beam region.

- The autotrack acquisition phase, in which off-boresight estimation errors are reduced to small values by closed-loop monopulse tracking system feedback action.

The selection of a system configuration that can automatically accomplish these functions successfully under a given set of acquisition conditions, or performance requirements, is affected by many considerations, as summarized in Table 1. The degree of success is measured by quantitative values associated with a set of performance criteria, e.g., the probability of signal detection or the mean time to successful acquisition.

Table 2 summarizes typical S-band acquisition performance requirements for future satellite tracking stations. The key requirements for 99.9% probability of spatial intercept and 95% probability of successful acquisition and tracking lead to the following set of conditional probabilities for successful completion of each acquisition phase:

Phase	Probabilitv	Function
1	0.999	Spatial illumination and intercept given signal presence
1	0.99	Signal detection given spatial intercept
2	0.99	Sidelobe dismissal given sidelobe intercept detect
2	0 .99	Mainlobe accept given mainlobe intercept detect
3,4	0.99	Mainlobe overshoot, recovery, convergence, and autotrack given mainlobe accept
5	0.99	Mainlobe autotrack maintenance given mainlobe acquisition
	0.9500	Net probability (of successful acquisition)

Highly reliable acquisition is required for a wide variety of satellites with varying orbits, downlink effective radiated powers (ERPs), signal modulation types and bandwidths. The most demanding acquisition scenario occurs for horizon acquisition of a very low orbiting satellite soon after launch where large uncertainties may exist in the azimuth angle of arrival, the transmitted downlink frequency and ERP, the Doppler frequency shift for the uncertain orbit, and the time of arrival at the tracking station horizon. The uncertainties associated with initial horizon acquisition of satellites injected into transfer orbits from a non-visible point in a low altitude parking orbit must also be accommodated. Finally, acquisition of weak signals from high altitude satellites (which are moving slowly relative to the ground station) is required. The chosen system configuration uses multiple, selectable acquisition receiver modes coupled with selectable antenna spatial scan parameters to accommodate the wide dynamic range of conditions anticipated over all acquisition scenarios.

ACQUISITION SYSTEM CONFIGURATION AND PROCEDURES

The selected configuration for Automated Main Beam Acquisition (AMBA) is illustrated in Figure 1. AMBA includes the major TT&C system elements, i.e., the main TT&C antenna with single-channel monopulse tracking feed and associated antenna controller, the low noise amplifier (LNA), and a telemetry tracking receiver. In addition, AMBA includes the following elements specifically added for automatic acquisition:

- Wideband and narrowband signal acquisition modules under digital control in the tracking receiver,
- A co-boresighted small auxiliary antenna which performs sidelobe intercept discrimination via the classic sidelobe inhibit method of guard antenna amplitude comparison,
- A simple feed for the auxiliary antenna with axial defocusing to broaden the mainlobe region and remove near-sidelobe pattern nulls,
- A low noise amplifier (LNA) in the auxiliary antenna channel,
- An in-line, solid-state switch under digital control, which connects the main antenna to the receiver during the signal search phase and after successful acquisition, and which connects the auxiliary antenna to the receiver after signal detection by the main antenna for amplitude comparison measurement,
- A microprocessor-based “digital excitation generator” in the main antenna controller which accepts and implements antenna scan directives from the AMBA control and

data processor by generating a time sequence of pointing commands to which the antenna servo control pointing system is slaved,

- A microprocessor-based AMBA control and data processor which directs the entire acquisition sequence, including control of antenna, receiver, and switch, by processing algorithms for prepass configuration and control parameter selections, sidelobe intercept discrimination, main beam convergence and failure/contingency responses.

The wideband signal acquisition module in the tracking receiver consists of a noncoherent amplitude detector with selectable predetection and post-detection filter bandwidths under digital control, a digitally controlled receiver local oscillator for step-dwell type frequency scanning, and digitally implemented AFC for wideband signal passband centering and Doppler tracking.

The narrowband signal acquisition module, for signals with a residual carrier component, is implemented with high-speed digital circuitry for improved acquisition performance. Digital step scanning of the local oscillator is also employed for search; in addition, the resulting IF output signal is downconverted to complex (quadrature) baseband signals, low pass filtered, analog-to-digital converted and applied to an N-point Fast Fourier Transform (FFT) processing chip for signal detection processing. The FFT increases the frequency search rate, ideally by a factor of N compared to an envelope detector with bandwidth equal to the FT cell bandwidth, since all N cells are processed simultaneously in the same FFT dwell interval. For detection of a very weak carrier signal the vector of squared magnitudes of all FFT cell outputs are stored from one FFT dwell to the next and (vector) summed to provide post-detection integration gain. The number of dwells summed is selectable by digital control in accordance with prepass-supplied data on expected carrier signal strength.

Figure 2 outlines the overall acquisition procedure. Upon signal detection the frequency search is stopped and main beam incidence is tested by auxiliary antenna amplitude comparison. Antenna scanning in azimuth is continued for sidelobe incidence decisions; upon detecting main beam incidence the antenna is directed to stop. Following antenna directional reversal and elevation angle updating for satellite motion, a return scan is conducted in azimuth about the detection point during which signal amplitude versus azimuth angle data is taken for azimuth centroid processing. The antenna is then directed to the indicated azimuth centroid position with additional elevation position updating. As the central portion of the main beam region is entered, the receiver is directed to AFC lock on wideband signals or AFC/APC lock on narrowband residual carriers. Following receiver lockup, the antenna autotrack mode is activated to complete the acquisition process.

CONCLUSION

The goal of automated acquisition of satellite TT&C downlink signals under a variety of operational conditions is considered achievable using current high-speed digital receiver and antenna controller technology under microprocessor-based system control.

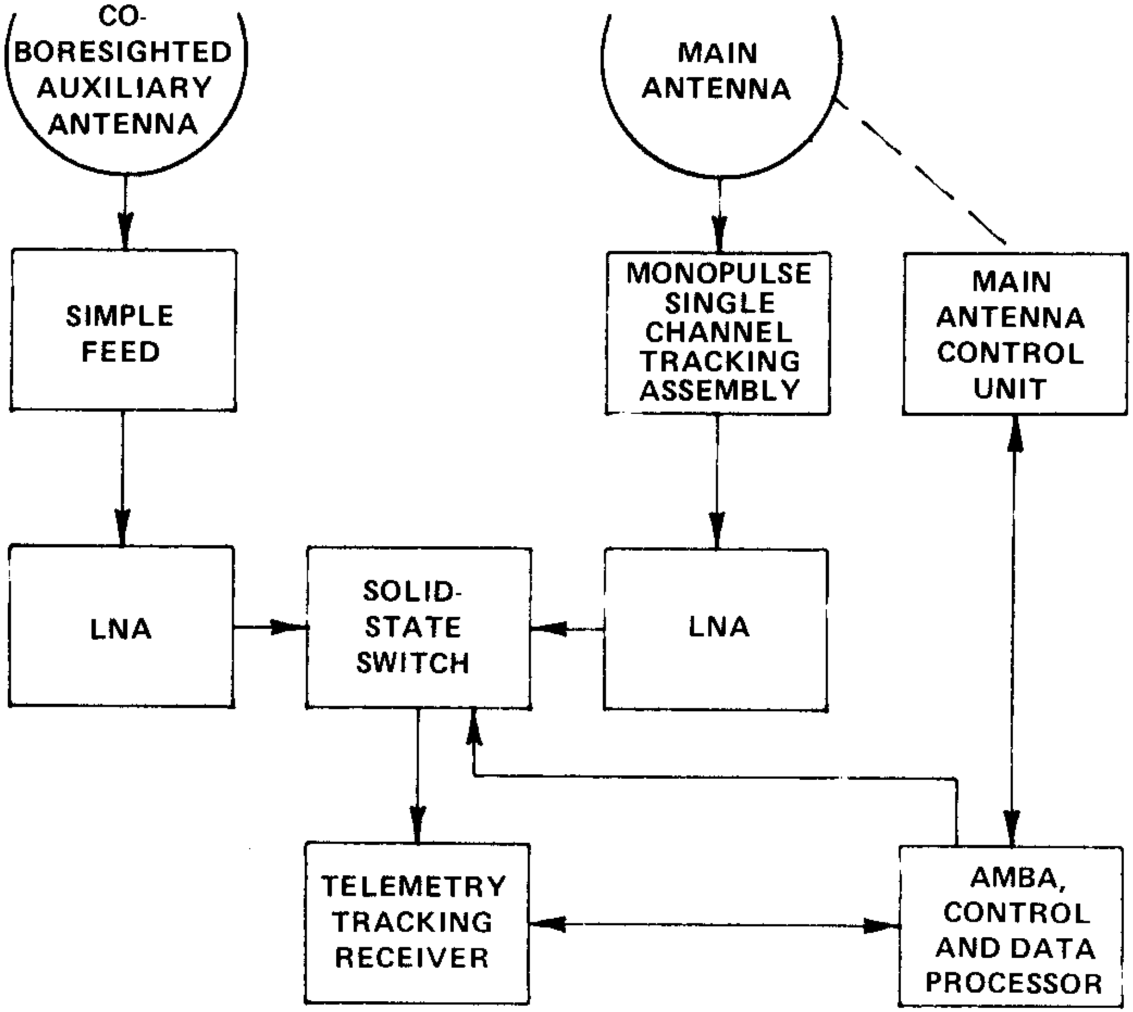

Figure 1. AMBA S-Band Configuration

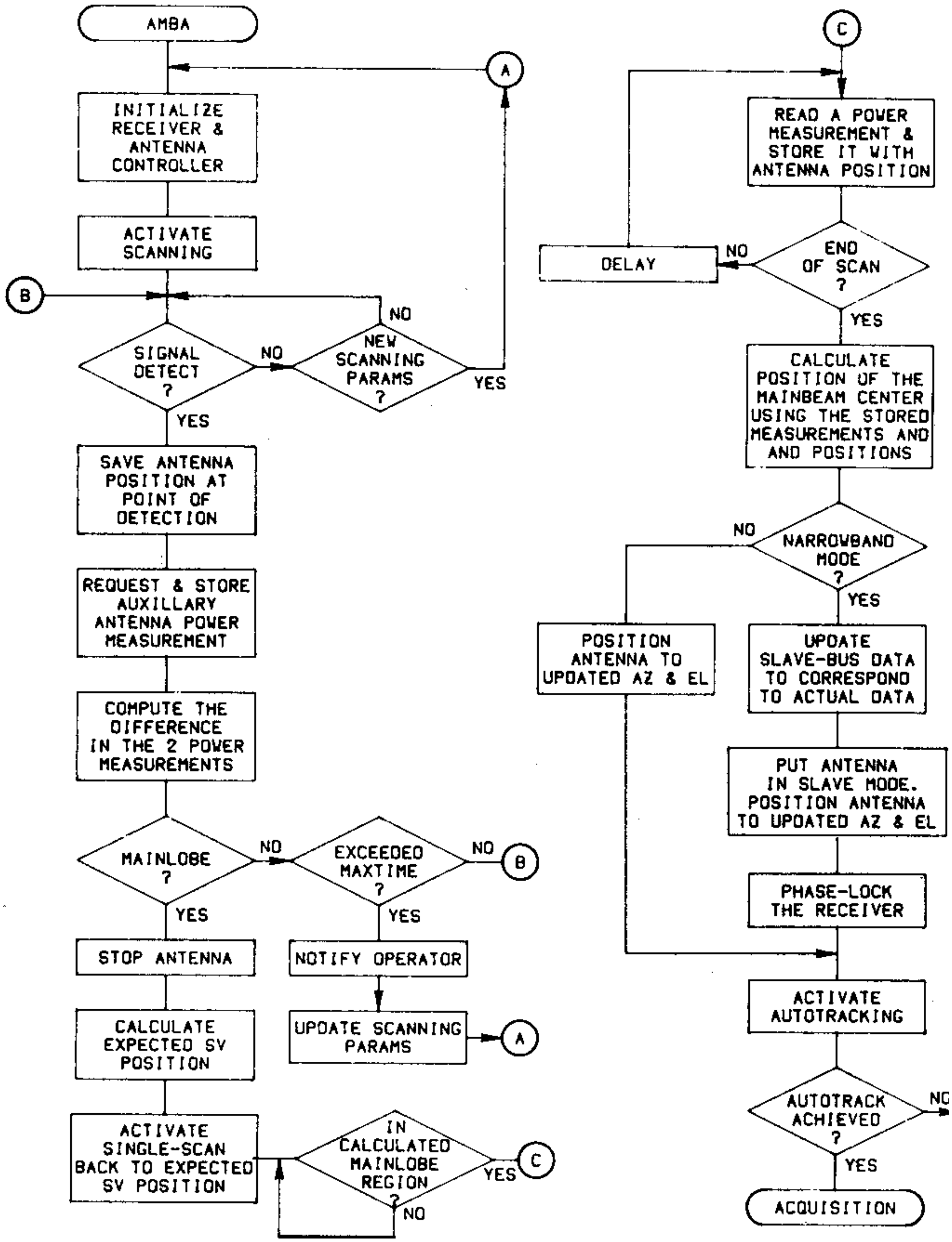

Figure 2. AMBA Acquisition Procedure

Table 1. Acquisition Performance Requirements Analysis Summary

Acquisition Function	Performance Measures	Related System & Performance Parameters
Spatial & Frequency Search & Signal Detection	Probability of Acquisition Antenna Illumination of Satellite (Main Beam Coincidence)	Main & Auxiliary Antenna Beamwidths Main & Auxiliary Antenna Beam Agility – Electronic Steering Range & Rate – Mechanical Steering Range & Rate Satellite Spatial Uncertainty Range – Orbital Parameters – Azimuth Angle Uncertainty – Elevation Angle (or Time of Arrival) Uncertainty
	Mean Time to Signal Detection	Satellite Elevation Velocity and Velocity Uncertainty Satellite Azimuth Velocity & Velocity Uncertainty Received Signal Power Density Range Received Signal Power Density Uncertainty Main Acquisition Antenna G/T
	Probability of Noise False Alarm Successful Dismissal	Auxiliary Antenna G/T Satellite Doppler Frequency Shift – Range – Uncertainty Satellite Transmitter Frequency Instability/ Uncertainty Satellite Signal Modulation – Type (Carrier, Subcarrier, AM,PM, FM) – Carrier Mod. Loss – Bandwidth
	Probability of Signal Detection	Receiver Time-Bandwidth Product – Frequency Search Rate – Predetection Bandwidth – Predetection dwell – Postdetection integration Receiver Detection Method – Coherent Amplitude Detection – Noncoherent (Envelope) Detection
Main Beam versus Sidelobe Intercept Discrimination	Probability of Side Lobe Intercept Detection	Sidelobe Discrimination Method – Sidelobe Amplitudes – Main Antenna Processing – Auxiliary Antenna Processing
	Probability of Successful Sidelobe Intercept Detection Dismissal	
	Probability of Main Beam Intercept Detection	Immunity to Interference – Multipath – Jamming
	Probability of Successful Main Beam Intercept Detection Acceptance	
Main Beam Convergence	Mean Time to Main Beam Convergence	Main Beam Convergence Method – Centroid Software Processing – Monopulse Error Processing
	*Main Beam Convergence Error Distribution (Satellite Angle of Arrival Estimation Error)	
Autotrack Acquisition	Probability of Successful Autotrack Lock-on	
	Mean Acquisition Time (After Main Beam Detection)	

Table 2. Typical Acquisition Performance Requirements

SPATIAL INTERCEPT PROBABILITY:	0.999
MAIN BEAM ACQUISITION & AUTOTRACK MAINTENANCE PROBABILITY:	0.95
AZIMUTH SEARCH RANGE:	±25° MAXIMUM
MINIMUM PM CARRIER POWER:	−146 dBm AT LNA
MINIMUM TOTAL FM POWER:	−110 dBm AT LNA
MINIMUM SV ORBITS:	80 nmi x 80 nmi CIRCULAR 80 nmi x 100 nmi ELLIPTICAL
MAXIMUM (ONE-WAY) DOPPLER SHIFT:	77 kHz
MAXIMUM DOPPLER RATE:	3 kHz/s
SPACECRAFT CARRIER INSTABILITY:	±0.002% MAXIMUM
FREQUENCY SEARCH RANGE:	±10 TO +200 kHz
FREQUENCY SWEEP RATE:	10 kHz/s TO 1.0 MHz/s
FREQUENCY TRACKING RANGE:	±200 kHz AT 3 kHz/s
RECEIVER TRACKING LOOP BANDWIDTH:	OPTIMIZED SELECTION
TIME TO AUTOTRACK (MAINLOBE) AFTER SIGNAL DETECTION RESPONSE TIME:	6 s MAXIMUM; 2 OVERSHOOTS MAXIMUM
SIGNAL DETECTION RESPONSE TIME:	25 ms MAXIMUM
AUTOTRACK SIGNAL AMPLITUDE FLUCTUATION:	UP TO 15 dB AT UP TO 5 Hz RATES
TRACKING ANTENNA G/T:	21 dB/k MINIMUM
MAXIMUM SIGNAL POWER:	−71 dBm
AUTOTRACK DYNAMIC RANGE:	THRESHOLD TO 75 dB ABOVE
TRACKING ANTENNA DYNAMICS:	15° /s MAXIMUM (±10%) 10° /s^2 MAXIMUM (±10%)
HORIZON ACQUISITION ELEVATION ANGLE:	3° ABOVE HORIZON
PM CARRIER MODULATION LOSS:	20 dB MAXIMUM
FM CARRIER MODULATION LOSS:	UP TO TOTAL CARRIER SUPPRESSION
PM SIGNAL BANDWIDTH:	UP TO 10 MHz
FM SIGNAL BANDWIDTH:	UP TO 50 MHz