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AUTONOMOUS ANTENNA TRACKING SYSTEM FOR MOBILE SYMPHONIE
GROUND STATIONS

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16. Abstract The implementation of a satellite tracking and antenna control system is described. Due to the loss of inclina- tion control for the symphonie satellites, it became necessary to equip the parabolic antennas of the mobile Symphonie ground station with tracking facilities. For the relatively low required tracking accuracy of 0.5 dB, a low cost, step track system was selected. The step track system developed for this purpose and tested over a long period of time in 7 ground stations is based on a search step method with subsequent parabola interpolation. As compared with the real search step method, the system has the advantage of a higher pointing angle resolution, and thus a higher tracking accuracy. When the pilot signal has been switched off for a long period of time, as for instance after the eclipse, the antenna is re- pointed towards the satellite by an automatically initiated spiral search scan. The function and design of the tracking system are detailed, while easy handling and tracking result.			
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2. Posing the Problem

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Switching off the inclination stabilization in a geostationary satellite causes initially a time-proportional increase in inclination. This is caused primarily by the modulated gravitation forces of the sun and moon. In the [illeg.] model 2 of the Symphonie satellite, the inclination stabilization was shut off in 1977. Since then, the inclination has increased annually by ca. 0.8 degrees.

The maximum rate of change in line of bearing (LOB) is time-dependent and changes proportionally with the increase in inclination.

Table 1.1 shows the values up to 1982:

Time	Inclination	Max. rate of change of LOB
1978	0.35°	0.087 degrees/h
After 1 year	1.15°	0.29
After 2 years	1.95°	0.49
After 3 years	2.75°	0.69
After 4 years	3.66°	0.80
After 4.5 years	4°	1.0

From the table we see that at the end of 1978, a deviation from stationary alignment of ca. 0.35 degrees had set in. For a 4.5 m antenna, this corresponds to a signal loss of ca. 3.5 dB at 4 GHz downlink. On addition of losses in the Up- and Downlink, the signal loss was max. ca. 10 dB. The antenna must thus track the satellite. /543

Since the earth radio stations were already completed, the tracking system to be developed will require only slight modifications to existing equipment. The interfaces, like motor control, AGC-signal, mains power supply, had to be adapted to the existing equipment.

*Numbers in the margin indicate pagination in the foreign text.

2. Concept Alternatives

In order to track a satellite, there are basically two possible ways:

- a system, time-controlled by stored path data
- a tracking circuit closed over the AGC-signal.

The time-controlled method requires considerable software effort for coordinate transformations in the different axis arrangements of antenna rotation states. The memory size is very large and in addition, the data practically has to be input new, each day.

For reasons of cost and operations, this alternative is rejected.

The second possibility, the AGC-signal tracking system, can be built in two versions:

- Step tracking with fixed search or correction increments (antenna-dependent), or
- Step tracking with fixed measuring increments, but adaptive correction step.

If we proceed from a deviation value ν_0 from the LOB, then the search-correction step method needs $n = \frac{\nu_0}{\Delta\nu} + 1$

steps to reach the maximum in one axis, i.e. the existing asynchronous motors are triggered n-times.

The adaptive method is derived mathematically below:

The antenna characteristic of the used antenna has the following standardized function:

$$\frac{G}{G_0} = \left[\frac{2 J_1\left(\frac{\pi d}{\lambda} \cdot \sin \nu\right)}{\frac{\pi d}{\lambda} \cdot \sin \nu} \right]^2$$

Legend:

$J_1\left(\frac{\pi d}{\lambda} \cdot \sin \nu\right)$ = Bessel function, 1st order

d = antenna diameter
 λ = wavelength
 ψ = deviation angle

The Bessel function $J_1(x)$ can be expanded into the following series:

$$J_1(x) = \frac{x}{2} \left(1 - \frac{x^2}{8} + \frac{x^4}{192} - \dots \right)$$

For small deviation angles, we have:

$$\frac{G}{G_0} \approx \left(1 - \frac{\psi^2}{8} \right)^2 \approx 1 - \frac{\psi^2}{4}$$

This parabola can be uniquely determined by 3 measured points, so that the AGC-maximum, i.e. the optimal alignment, is known.

The equation of a normal parabola has the form:

$$y = ax^2 + bx + c.$$

With the measured AGC values, we obtain the equations

$$y_1 = ax_1^2 + bx_1 + c \quad (1)$$

$$y_2 = ax_2^2 + bx_2 + c \quad (2)$$

$$y_3 = ax_3^2 + bx_3 + c \quad (3)$$

The values y_i are the measured AGC values, the x_i are the attendant angles.

The apex point x_0 of the parabola $y = ax^2 + bx + c$ is defined by the first derivative

$$y' = 2ax_0 + b = 0 \quad (4)$$

from (4)

$$x_0 = -\frac{b}{2a} \quad (5)$$

Solving the equations gives:

$$x_0 = -\frac{1}{2} \begin{vmatrix} x_1^2 & y_1 & 1 \\ x_2^2 & y_2 & 1 \\ x_3^2 & y_3 & 1 \\ \hline y_1 & x_1 & 1 \\ y_2 & x_2 & 1 \\ y_3 & x_3 & 1 \end{vmatrix}$$

For reasons of system complexity, an angle reply is not used. /545

The offset angle $\Delta\psi$, values between 0.1 degrees and 0.2 degrees, were specified via the motor run times of the speed-reduction spindle drives ($\dot{\psi} = 1$ degree/minute).

In order to reduce measuring errors by scintillation effects and transponder switching, during the measurement phase, the AGC value is determined. The response time is 80 sec.

The advantages of the method are summarized:

- only 3 triggerings per axis and track cycle
- knowledge of lobe curvature is unnecessary
- no angle reply of the antenna rotation position.

3. Requirements

The requirements of the tracking unit are defined by the interfaces with the existing ground stations, and by the operating modes of the satellite.

3.1 Functional Requirements

The Symphonie ground stations can be classed in two groups:

- mobile facilities: 3.3 m container antenna
- stationary facilities: 4.5 m and 8.8 m systems.

The tracking system must take into account the following electrical interfaces of existing ground stations:

1. Motor type of the linear adjuster
2. AGC Interface of the various receiver types.

The table below shows the various motor types

Motor Overview

Antenna type	Motor Power Output	Motor type
8.8 CGTI	0.8 KW-1.9 KW	Asynchronous, 3-phase
4.5 m	0.18 KW	Asynchronous, 3-phase, operated as 1-phase motor with operating capacitor

3.3m 0.18 KW Asynchronous, 3-phase, operated as 1-phase motor
with operating capacitor

Table 3.1

The tracking algorithm requires an AGC signal proportional to /546
the antenna characteristic, i.e. the AGC reference voltage must
be a linear function of the receiver damping in the working range.
The function is specified as $V_{AGC} \approx 1 \text{ dB}, U_{AGC_{max}} = 10V$.

Since the receivers of the stations are different, the norming
must be adjustable.

3.2 Operational Requirements

The operational requirements of the tracking unit result from
the operating modes of the Symphonie satellite.

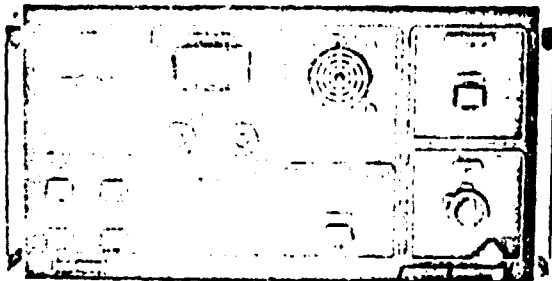


Figure 4.1

The various channel popula-
tions of the transponder and the
shut-off of the transponder due to
earth shadow (eclipse phase) have a
marked influence on the AGC signal.
The shut-down time is 90 minutes.

In order to assure reliable, continuous operation of the /547
tracking system, it is important to cover the "Eclipse" operating
mode by a special program mode.

The software is organized into the following segments:

- initializing
- eclipse wait-phase
- search mode
- tracking mode

As branching criteria for the individual program segments, the
level of the AGC signal is used.

We have:

- $U_{AGC} < 0.3V \Rightarrow$ eclipse waiting-phase
- " $\geq 0.3V \Rightarrow$ search mode
- " $\geq 5V \Rightarrow$ tracking mode.

This specifies the main parts of the software.

4. System Description

In this section, the equipment developed as per the requirements in section 3 and the attendant software are described in detail. Figure 4.1 shows a front view of the control plug-in unit.

4.1 Hardware

4.1.1 Mechanical Design

The control unit is housed in a standard 19 inch plug-in housing with 7 height units. The front side of the unit is also the control panel and the reverse is a plug terminal plate. In the plug-in unit there is a card rack as carrier of the electronic boards and an assembly plate for the circuit elements.

4.1.2 Control Panel

All operating elements needed for normal operation are placed on the control panel.

These are:

- switch for on/off, run/stop, auto/manual
- input switch for waiting time adjustment
- key for manual motor control
- display and potentiometer for the AGC signal smoothing
- alarm tone, alarm indicators and alarm reset switch

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All other input parameters which are programmed only once during installation, are adjusted on a special input circuitboard inside the unit.

4.1.3 Tracking Computer

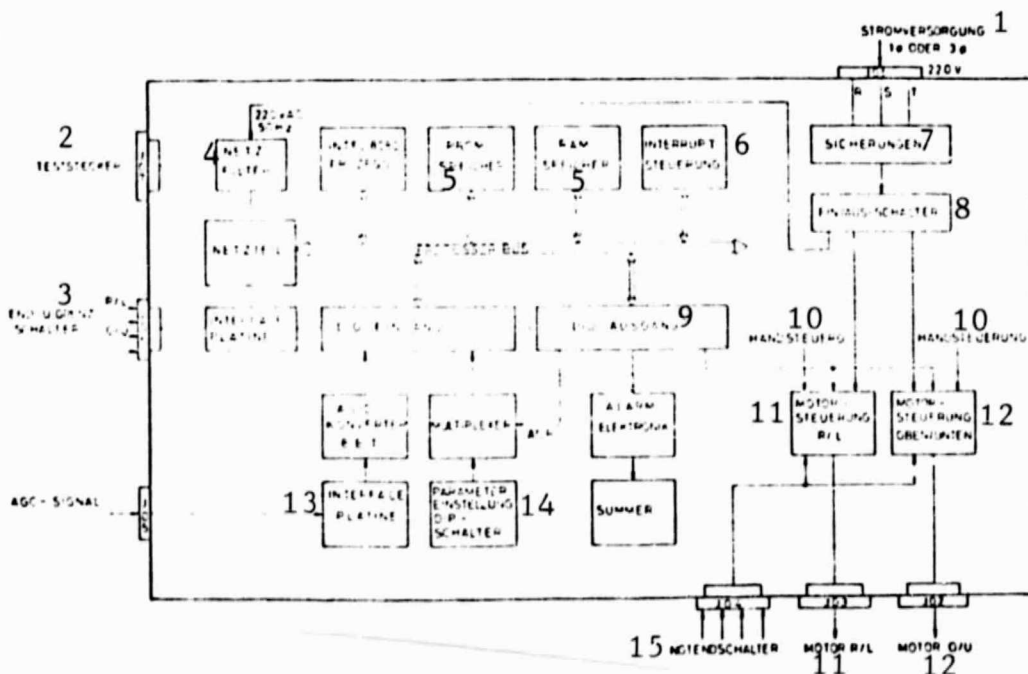
The prescribed tasks of the tracking computer are:

-query measured data and input parameters
-process data according to specific algorithms
-verification of final control elements,
these tasks are performed in the present case, by an 8-bit micro-processor system. The block diagram of the processor system and the attendant periphery are presented in fig. 4.2.

The processor system is of standardized, modular design with modules linked via a normed bus. Besides the actual processor module, a memory module and an interface module are provided.

The memory module has the following components:

- volatile memory for variable data (RAM): 1 K-words (byte)
- nonvolatile memory for program and invariable data (PROM):
4 K-words (byte)



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Fig. 4.2 Block Diagram of Symphonie Antenna Tracking Plug-In Unit
Key: 1-power supply 1 Ø or 3 Ø; 2-test plug; 3-end and limit switch
4-mains filter 5-memory 6-interrupt control 7-fuses 8-on/off
switch 9-output 10-manual control 11-motor control R/L
12-motor control, up/down 13-interface bar 14-param. setting,
OP switch 15-emergency end switch. Others illegible.

The interface module permits query of 40 input signals and /550
output of 32 control signals.

Adaptation of the AGC signal (level) to the interface module
is via an analog electronic circuit and an 8-bit A/D converter.

Due to the limited number of input lines to the interface module,
the digital parameters are fed via a multiplexer. The addressing
needed for this is via the processor over 3 output lines.

The GO/NO GO signal generated by a self-monitoring routine of
the processor, is fed over a booster to the alarm tone and alarm
indicator lamps. Thus, any incorrect operation of the system can
be recognized by the operator at once.

4.1.4 Parameter Input

To adapt the control plug-in unit to the characteristics of
the particular ground station, as mentioned, a special program
card is present. Seven circuits with 8 contacts each are provided.
The programming is by setting these contacts into a binary coded
form. The meaning and weighting of the 7 circuits are given in
the table below:

Circuit Function No. of bits Weighting LSB

S1	$\dot{\theta}$	8	0.000196°/s
S2	$\dot{\phi}$	8	0.000196°/s
S3	Δt	8	0.0007843"
S4	$\Delta \alpha$	8	0.0007843"
S5	$2^{27} \cdot 2^{27}$ Multipl. y-Achse	1	$2^{28} \cdot 2^{27}$ Multipl. y-Achse
S6	t_{H1}	8	100 ms
S7	t_{H2}	8	100 ms

Key: 1-axis

The abbreviations mean:

- $\dot{\theta}$: angular velocity of up/down motions
- $\dot{\phi}$: angular velocity of left/right motions
- Δt : up/down measurement increment trigger time
- $\Delta \alpha$: left/right measurement increment trigger time

t_r : run-up time
 t_b : braking time

The x- and y-multipliers (S5) are used for setting the first spiral steps of the search-Scan increment width. /551

The input of waiting time--which only has to be adapted to the satellite inclination--is via the input switch on the control panel, using decimals in minutes.

4.1.5 Power Interface

The power region of the triggered stepping motors in the various ground stations extends from 0.18 KW to 1.9 KW, either single or 3-phase. In order to cover all possible interfaces, a universal power interface was developed. This interface is based on special semiconductor relays with minimum interference sensitivity by galvanic decoupled triggering. In addition, switching processes occur on voltage or current zero-passage, so that a favorable electromagnetic system compatibility results.

All motors are secured by motor protection switches in the control plug-in unit. In addition, the stepping motors are protected by appropriate end switches which define the permitted range of action.

4.2 Software

The entire software of the control plug-in unit, including the self-monitoring routines, has a size of 4 K words.

4.2.1 Initializing

In this program section, the antenna-specific parameters and the tracking wait-time are read in. The values are checked and prepared for further processing. If the inputs are outside the specified range, an input alarm message is generated.

Branching into the "Search-scan" program section or into "Max-Tracking" is via a comparison of the AGC level with the specified, programmed bounds.

Note here that the named threshold values relate to the normed AGC voltage.

4.2.2 Search Mode

This program section permits finding of satellites after a longer shut-down of the transponder (eclipse etc.).

The subprogram is called up by the branching described above, and controls the stepping motors so that the antenna moves in an opening spiral. If the AGC signal exceeds the 5 V threshold, then the "Max-Tracking" subprogram is called up automatically and the search mode is ended.

For the case where the satellite is not found, the opening spiral is limited by 4 magnetically operated region switches. /552

If all 4 switches have been addressed, the program triggers the motors so that a closing spiral antenna motion occurs. This increases the probability of finding the satellite.

If the antenna makes no contact with the satellite in the closing spiral, then the processor generates a NO-GO alarm.

4.2.3 Maximum Tracking

The program section permits continual contact with the satellite.

The drive of the one axis lasts initially 1 second in order to determine the direction of an ascending AGC signal. The trigger time of the following 2 measuring increments is programmed antenna-specific. We thus obtain 3 AGC measured values as a function of the 3 step angles.

With the tracking algorithm, the program computes the value of the parabola inflection point and triggers the motor as per the position difference = "vertex - last measured point". The trigger time is determined from this difference and the programmed, antenna-

specific adjusting speed.

Incorrect measurements which can occur through noise or jump changes in the field strength during a tracking cycle, are determined by comparison of measured values and suppressed.

The tracking cycle runs as follows:
Elevation to maximum, azimuth to maximum, waiting time, azimuth to maximum, elevation to maximum, waiting time, etc.

The waiting time depends on the size of the inclination.

In order not to increase motor wear unnecessarily, this value is adjusted at longer time intervals of ca. 1 year.