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TRACKING PERFORMANCE OF LOW-COST M-SAT MOBILE ANTENNA

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Abstract

In order to achieve a fast and reliable tracking of the satellite, both open-loop and closed-loop tracking algorithms should be incorporated in the overall control strategy of a mobile terminal antenna system. The paper describes the implementation of these algorithms in a mechanically steered antenna system.

1. Introduction

The imminent introduction of Domestic Mobile Satellite (M-Sat) communication services in Australia and in North America has greatly stimulated research in ground-based and air-borne mobile antenna systems.

For a low-cost ground-based system, a mechanically steered antenna system seems to provide a viable solution. This paper discusses one design aspect, namely a method of continually tracking the satellite and locking the antenna beam onto the satellite direction in spite of unpredictable changes in the direction of motion of the vehicle.

Briefly speaking, when the antenna system is activated, it first scans the beam to search for the satellite, i.e. to search for the direction in which the signal is strongest. It then locks the beam to this direction. Subsequently, it will initiate a new search for the satellite whenever the satellite signal drops below a pre-determined threshold. In order to achieve a satisfactory tracking operation irrespective of the manner in which the vehicle behaves, both closed-loop and open-loop tracking should be implemented.

2. Closed-loop tracking algorithm

The fastest method of relocating the satellite by closed-loop tracking is to adopt the well known monopulse technique [1]. However, the cost of implementing it is rather high. For a low-cost mechanically steered antenna system, an alternative to the monopulse tracking is to dither the antenna beam about the broadside direction. This can be accomplished by using simple two-bit digital phase-shifters, which allows the antenna beam to be steered to either side of the broadside direction by a small angle. However, as the phase-shifters require slip rings to provide the biasing voltage for the switching-diodes. the resulting system is vulnerable to strong mechanical vibrations which are to be expected in a land mobile environment, e.g. mining and/or mineral exploration operation.

A more robust scheme, which does not require any slip rings at all, is to program the driving motor to steer the antenna first to one side and then to the other side of its original position. The signals received at these three positions are then compared. If the signal at the original position is still strongest, the system will assume that the satellite has not moved, and that the reduction in the signal strength was caused by dense foliage or obstacles that are semi transparent to microwaves. Otherwise, the antenna will be steadily steered in the direction where the strongest signal was received. As the antenna is being steered, the received signal is continually sampled and compared with that received at the position immediately before it to search for the new location of the satellite, which corresponds to the maximum received signal

The closed-loop algorithm is relatively slow in a mechanically steered antenna system, and is effective only if the vehicle does not change its direction of motion too quickly. In addition, when the vehicle is inside a tunnel, the system noise will cause the motor to steer the antenna beam to the wrong direction. For these reasons, open-loop tracking algorithm must also be used. This will be activated each time the satellite signal drops below a lower threshold.

3. Open-loop tracking principle

As the name implies, open-loop tracking is used to steer the antenna beam back to the direction of the satellite without any feedback information, i.e. without any need for the satellite signal.

3.1 Electronic compass

An electronic compass basically measures two orthogonal components (e.g. x and y components) of the earth magnetic field, and from them determines the magnetic North relative to the compass reference direction [2]. As the satellite position is fixed relative to the magnetic North, an electronic compass mounted on the vehicle can be used to measure the change in the vehicle direction relative to the magnetic North, and hence to the satellite direction. This information is then used to steer the antenna beam back to the satellite. Electronic compasses, however, are highly sensitive to the presence of ferromagnetic bodies and/or extraneous magnetic fields, and are therefore not suitable for use in a land-based M-Sat mobile antenna system.

2.2 Angle rate sensor

Unlike a compass-based system which determines the satellite position by using the magnetic North as a reference, all systems using angle-rate sensors are dead-reckoning systems. As the only reference is the original direction, the error is accumulated with time, and may eventually be quite large, unless a highly accurate angle-rate sensor is used.

For a low-cost mobile terminal, the angle-rate sensor marketed by Etak inc. seems to provide the most appropriate answer. Although no technical details are provided, it appears that the yaw rate is measured by a two-axis gyroscopic turn-rate sensor. Basically, a small motor is used to rotate a thin copper annular disk, which will flex with changes in the yaw rate. The degree of the disk flex, and hence the yaw rate are measured by using four capacitors which are formed by the copper disk itself and four thin copper plates placed in four quadrants opposite the disk. The end effect is that the yaw rate output is represented by a duty-cycle-modulated pulse train. Thus, if the gyro is quiescent, the envelope of the pulse train is a regular square wave with equal positive and negative portions. In this case, the number of pulses in the yaw-rate output is nominally equal to 39,000 per cycle of the modulating envelope. However, if the yaw rate is not zero, the widths of the two portions will differ and the corresponding number of pulses will be larger or smaller than 39,000 depending on the yaw direction. Thus, by counting the number of pulses in the yaw rate output, one can determine the yaw rate and hence the yaw. Although the manufacturer does not recommend a specific time interval over which the number of pulses are to be counted, in order to obtain reliable counts, the measuring interval should be equal to an integral multiple of the period of the modulating envelope, which is nominally equal to 1/600 seconds. In our design, the low-to-high transition of this envelope is used to initiate the pulse counting. The output of the counter is then processed by a Motorola 6809 microprocessor to determine the yaw. The basic open-loop algorithm can be summarised as follows. The system takes no action if the change in the vehicle direction of motion is below a given threshold. Otherwise, it will test for the sign of the change and steer the antenna beam in the opposite direction until a complete cancellation is achieved. When this occurs, the system moves back to its closed-loop tracking operation. The whole algorithm relies on the fact that the total change in the yaw (since the last return to closed-loop operation) is always available each time the open-loop routine is called. In addition, this total change is continuously updated during the open-loop operation. This means that the system controller must continually measure the yaw rate at regular time intervals. In our case, the 6809 microprocessor is interrupted via the PIA control line CA1, which is activated by the low-to-high transition of the modulating envelope of the yaw-rate output signal. Each time an interrupt occurs, the new change in the yaw is measured and added to (or substracted from) the existing yaw to give the new total yaw. During the open-loop tracking operation, the angle through which the antenna is rotated by the motor is substracted from the total yaw. The upshot is that the total yaw is automatically reset to zero at the end of each open-loop operation, i.e. at the beginning of every new closed-loop tracking routine. The same cycle then repeats over and over again.

4. Results and comments

We have built a mechanically steered mobile antenna system incorporating both closed-loop and open-loop tracking algorithms. The array consists of four rectangular microstrip elements designed to operate over the whole transmit and receive bands for mobile satellite communications. The elevation beamwidth is very broad to make allowance for hilly terrain, and changes in the vehicle geographical location, with the beam axis at 50^0 above the horizon. The 3-dB beamwidth in the azimuth plane is approximately 20^0. In order to reduce the antenna profile, the microstrip antenna array is offset mounted, instead of being placed above the motor assembly. As a result of the increase in inertia, the motor tends to slip when the vehicle is turning at high speed. In this respect, a d.c. motor would be a better choice.

Apart from extensive laboratory tests, our mechanically steered antenna system has also been field-tested using the facilities provided by Aussat and the ETS-V satellite provided by the Communications Research Laboratory of Japan. The results are in general very satisfactory.

It should be mentioned, however, that the closed-loop operation is rather sluggish, mainly because of the limited torque available from the small stepper motor used to drive the antenna platform. The upshot is that the closed-loop operation tends to lose track of the satellite whenever the vehicle changes its direction too quickly; and the system must then rely on the open-loop tracking algorithm to restore the satellite signal.

As far as open-loop tracking is concerned, the compass-based system is too unreliable to be of practical use. On the other hand, excellent results have been obtained with the system based on the Etak angle-rate sensor. In this case, the open-loop tracking system has no problem locking the antenna beam to the satellite while the vehicle is travelling in the shadow of buildings or inside a long tunnel. In addition, no significant drift in the angle measurement was recorded during experimental sessions lasting many hours. This means that, the pointing error caused by the drift will be negligible during the entire length of a normal telephone conversation. In fact, our field tests have shown that, the Etak angle rate sensor is accurate enough for the system to completely bypass the closed-loop tracking phase without affecting the pointing accuracy. This approach also significantly speed up the tracking speed since the tracking operation will be initiated as soon as the vehicle changes its direction, even though the satellite signal level has hardly dropped. Again, the only weak link in the system is the stepper motor, which does not have enough torque to handle the inertia of the antenna and its platform when the vehicle is travelling at high speed. As mentioned above, a d.c. motor would solve this problem.

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