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Mobile Terminal Equipment Design Utilising Split-loop Phase-lock Techniques

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Abstract

The design and resultant performance of the terminal equipment in a mobile satellite system is vitally important in respect of the overall cost/performance compromise of the whole system. Improvements in system performance which also result in a reduction of the equipment cost are rare. However, this paper details a significant advance in terminal design, utilising a novel form of 'Split-loop' phase-locked receiver/downconverter system to enable an accurate, stable and wide coverage terminal to be realised at a reduced cost. The system has the capability of automatically locking onto any carrier within a complete transponder, and can cope with severe amplitude modulation and fading effects.

1 Introduction

The split-loop phase-lock configuration has replaced the conventional long-loop as the state of the art in PLL receiver technology. It has been shown to possess superior qualities in both acquisition and in the tracking of difficult signals and has recently been applied to the field of mobile satellite receiver design in conjunction with the Electronic Beam-Squint tracking system [1], [2]. The superior stability of the design can be exploited to permit phase-locked control of the complete receive/downconversion chain, thus giving far greater versatility to a mobile terminal.

The split-loop phase-locked loop (PLL) receiver configuration was originally conceived as a method of eliminating the problem of false-lock inherent in the long-loop PLL configuration [3]. The problem of false-lock manifests itself by the cessation of the natural pull-in effect of the long-loop on a frequency which bears no obvious relationship to the wanted signal or its modulation (if present). The effect is caused by the delay present in the receiver's IF stages, and particularly the crystal filter. The split-loop is able to eliminate this effect as it effectively removes the IF delay from the time critical parts of the phase control loop. It is this elimination of the effects of the IF delay which also leads to a number of other advantages of the technique, and these will be discussed below.

One of the candidate schemes for mobile terminal tracking is the Electronic Beam-Squint (EBS) tracking system. The EBS system is a new form of satellite tracking system combining an accuracy approaching that of monopulse with a cost of the same order as that of a step-track system. The tracking information in this system is derived by switching the main lobe direction of the antenna into four positions around boresight using PIN diodes. This results in a very rapid method of determining the tracking error and leads to the possibility of performing averaging on the received tracking information in order to remove noise and scintilation effects. The result of this is that the antenna need only move to actually follow the satellite, and not also to determine the tracking information. This leads to a further advantage in the reduced wear of the antenna positioning mechanics.

The rapid switching operations described above lead to a switched amplitude modulation on the received beacon signal as seen by the tracking receiver. The tracking receiver must be able to accurately detect and reproduce this modulation in order for the tracking controller to make correct decisions. The current long-loop design of receiver is unable to perform this task satisfactorily due to the presence of the IF delay within the loop.

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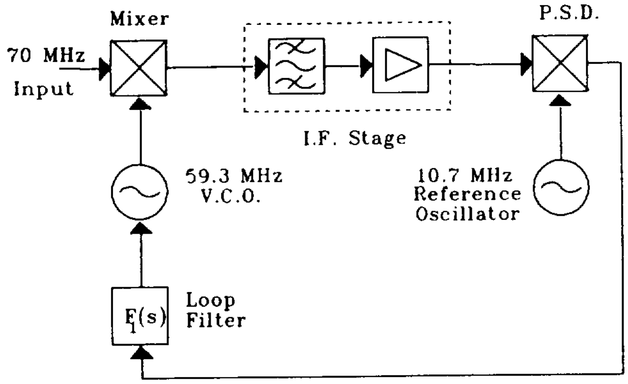

Figure 1: Configuration of the long-loop receiver

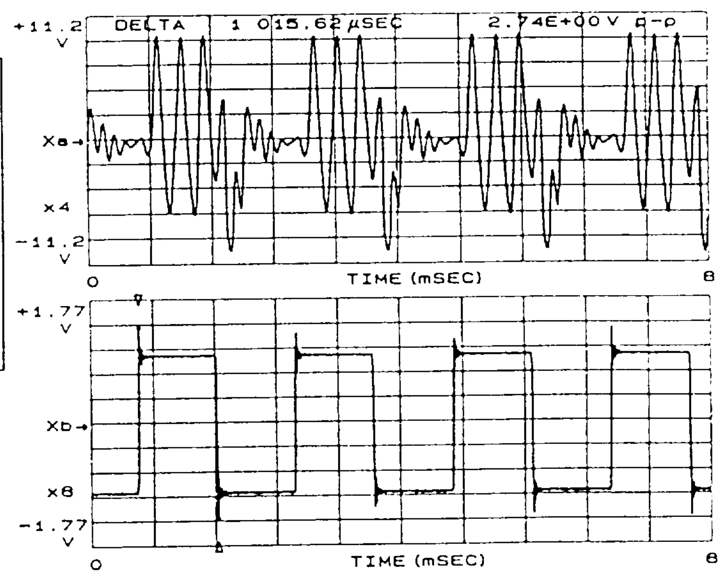

Figure 2: Upper trace: Experimental results showing the coherently detected output of a long-loop receiver, when receiving a squarewave AM signal with a modulation index of 0.95 and using an IF filter bandwidth of 15 kHz.
Lower trace: Squarewave modulating signal.

2 The Long-Loop Receiver

In general, current tracking receivers are based around the 'Long-Loop' phase-lock technique. The basic configuration is shown in block diagram form in Figure 1 [4]. This is intended to be a simplified diagram, and does not include any of the automatic gain control or coherent detection elements which are assumed.

Enhancements of the conventional long-loop receiver have been developed for use in satellite systems. One example is described in [5], utilising two phase-locked loops to detect both co-polar and cross-polar beacon polarization states. Level detection in this case is provided coherently as mentioned above.

There are a number of disadvantages inherent in this type of receiver. Biswas *et al* [6] noted the problem of false-locking, and has suggested a method for its elimination. However, this method is less than straightforward to implement, and its inclusion greatly complicates the loop analysis under certain circumstances.

A second disadvantage is inherent in the loop filter utilised in the long-loop configuration. This filter requires a proportional term as part of its characteristic (to obtain a non-zero damping factor [4]), and as a result, any noise on the beat-note will phase modulate the down-converting local oscillator. Modulation components, such as those described below, which appear at the output of the IF filter, will be mixed with the reference oscillator in Figure 1. The resulting sum and difference outputs of the phase sensitive detector give rise to sidebands at the first local oscillator.

Further to these inherent problems, E.B.S. causes the beacon signal to be corrupted by severe, discontinuous amplitude modulation, and this creates a number of problems of its own. This is not true of, say, step-track or conical scan systems, as they produce a continuous amplitude modulation which is generally of quite a low level. It is essential to construct a receiver which has the ability to supply a valid output to the tracking controller and one which is as stable as possible when faced with this type of signal.

If we now examine, in detail, two of the problems which EBS causes to a long-loop tracking receiver, it will become apparent why the long-loop is inappropriate for this system. Figure 2 (top trace) shows the coherently detected output of a long-loop receiver, when receiving a carrier which is amplitude modulated by the squarewave shown in the lower trace. It is evident from this figure that the long-loop is slipping cycles when faced with the severe amplitude modulation representative of the signals produced by the EBS system. This effect is caused by the inclusion of the IF stage delay within the control loop of the long-loop receiver. Thus a long-loop receiver is unable to correctly interpret the EBS tracking information present on the beacon signal.

Figure 3 shows the first local oscillator spectrum of a long-loop receiver when receiving the signals mentioned above. It can be seen that this oscillator is being

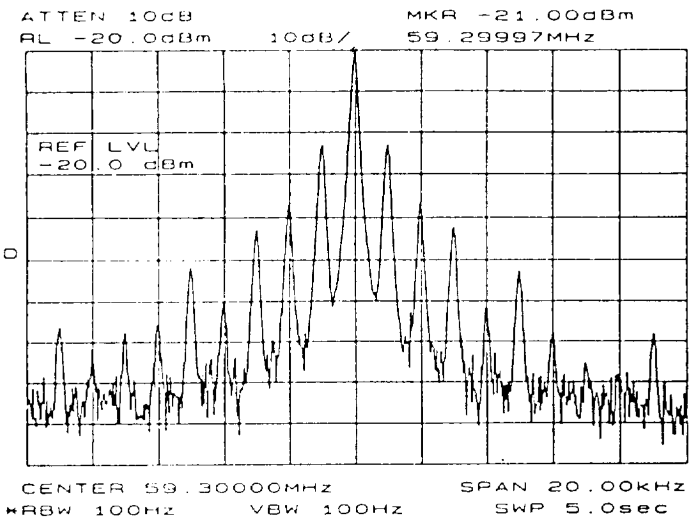

Figure 3: Experimental result showing the first local oscillator spectrum of a long-loop receiver, when receiving a squarewave AM signal with a modulation index of 0.95 and using an IF filter bandwidth of 15 kHz.

phase-modulated by spurious signals present on the receiver's beat-note, resulting in undesirable sidebands. These sidebands can downconvert adjacent channels, which will in turn cause interference to the wanted channel and degrade the performance of the receiver. This problem, known as *reciprocal mixing*, has previously been reported in the literature [7].

3 The Split-Loop Receiver

The split-loop derives its name from the technique of 'splitting' the loop filter into proportional and integral components, with each feeding its own local oscillator. The first local oscillator of Figure 4 is fed by an integrator, with the second being fed by a directly-coupled (DC) broadband amplifier.

Thus, it can be seen that the integrator and first local oscillator are responsible for tracking long-term drift of the carrier, with the proportional stage and second local oscillator passing the beat-note signal and tracking rapid frequency changes, such as doppler shifts. Since the loop formed around the PSD, the proportional stage and the second local oscillator is effectively first-order, the beat frequency bypasses the IF stage, and all other primary sources of delay, and

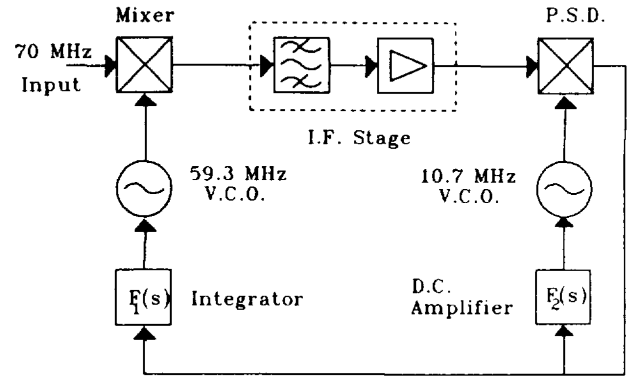

Figure 4: Configuration of the split-loop receiver

as a result the possibility of false-lock is eliminated [8].

Furthermore, since the action of correcting for rapid changes is independent of the IF delay, the split-loop is better able to correct for the rapid changes in loop bandwidth caused by the tracking information present on the beacon signal in the Electronic Beam-Squint tracking system. This is demonstrated by Figure 5 which shows the split-loop response under the same conditions as those of the long-loop above (Figure 2).

Finally, if we again examine the spectrum of the first local oscillator (Figure 6), a notable improvement in the level of the unwanted sidebands can be observed. This is due both to the improvement in overall stability of the loop, and also to the fact that the first local oscillator is fed by an integrator, which greatly attenuates any residual modulation on the beat-note. This modulation is thus effectively isolated from the oscillator input, resulting in its improved spectral purity.

4 Incorporation of the Downconverter in the Split-loop Mobile Terminal

The superior performance of the split-loop configuration makes it ideal for use in a mobile terminal, particularly if the downconversion stages are included within the loop. Figure 7 outlines a new form of satellite receiver which permits locked frequency control to extend to include the front-end downconversion system. Again, only the main loop components are shown, with coherent detection elements being assumed.

This new technique enables the whole of the down-

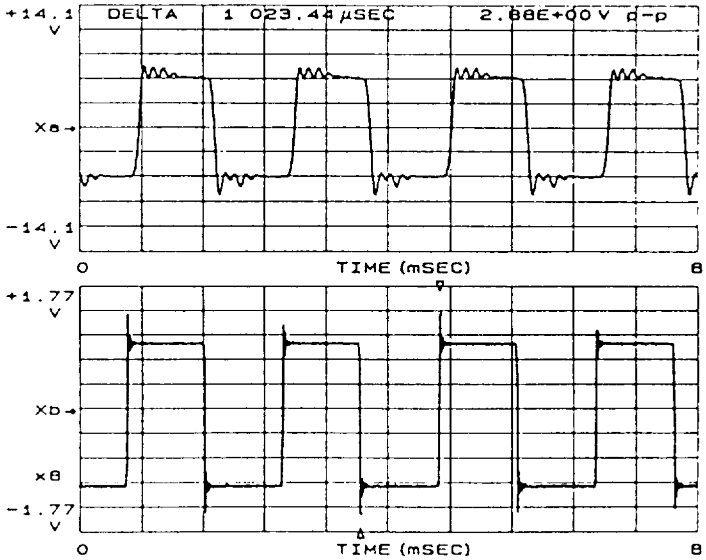

Figure 5: Upper trace: Experimental results showing the coherently detected output of a split-loop receiver, when receiving a squarewave AM signal with a modulation index of 0.95 and using an IF filter bandwidth of 15 kHz.
Lower trace: Squarewave modulating signal.

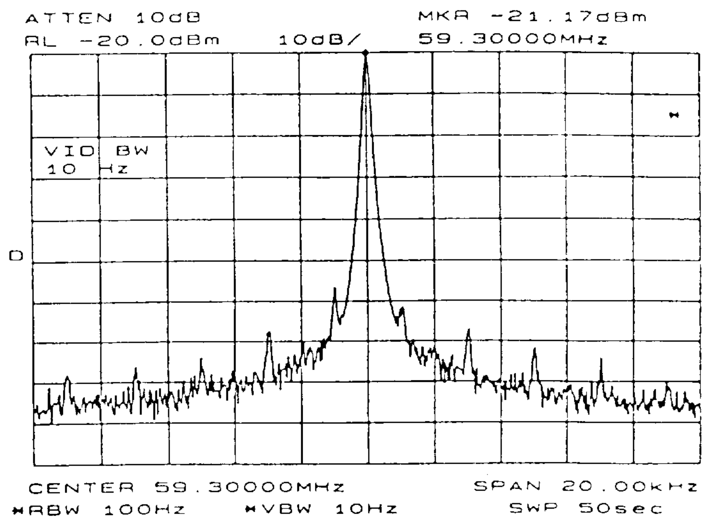

Figure 6: Experimental result showing the first local oscillator of a split-loop receiver, when receiving a squarewave AM signal with a modulation index of 0.95 and using an IF filter bandwidth of 15 kHz.

conversion, tracking and reception chain to be phase-locked using a single loop. This in turn results in the frequency coverage of the system being limited only by the downconverter system employed, thus permitting the whole of a transponder or even a whole satellite allocation to be accessed automatically. Thus, a system can be conceived in which the operator requires only to aid in the initial satellite positional acquisition, with all further operation in both tracking (utilising the 'Electronic Beam-Squint' tracking system [1], [2]) and frequency acquisition being automatic.

A principle advantage of this configuration is the ability for automatic acquisition and tracking over a wide frequency bandwidth. This is extremely advantageous in a military scenario, as it provides almost total immunity from jamming of the beacon signal, since automatic tracking and wide-bandwidth locking would permit operation anywhere within the band, and not only on the beacon signal.

In a civil context, terminal equipment designed using this technique would be both cheaper and easier to operate. The specification of the intermediate local oscillators is relaxed, resulting in a more cost-effective system, and this is combined with the capability of fully automatic operation.

5 Conclusions

This paper has outlined the advantages of the split-loop receiver configuration, particularly with reference to its remarkable ability to cope with severe forms of modulation and fading. The system as described has the ability to automatically control the operation of the downconverter to enable tracking to be performed on any carrier within a transponder. This removes the need for manual tuning of the downconverter or an expensive microwave synthesizer.

The use of the split-loop in a new form of mobile satellite receiver results in considerable improvements in many areas, together with a reduction in cost due to a relaxation of the specification of some of the system components. Although this receiver configuration was originally envisaged for use with the Electronic Beam-Squint tracking system, its numerous advantages make it ideal for use in most phase-locked mobile satellite receiver applications.

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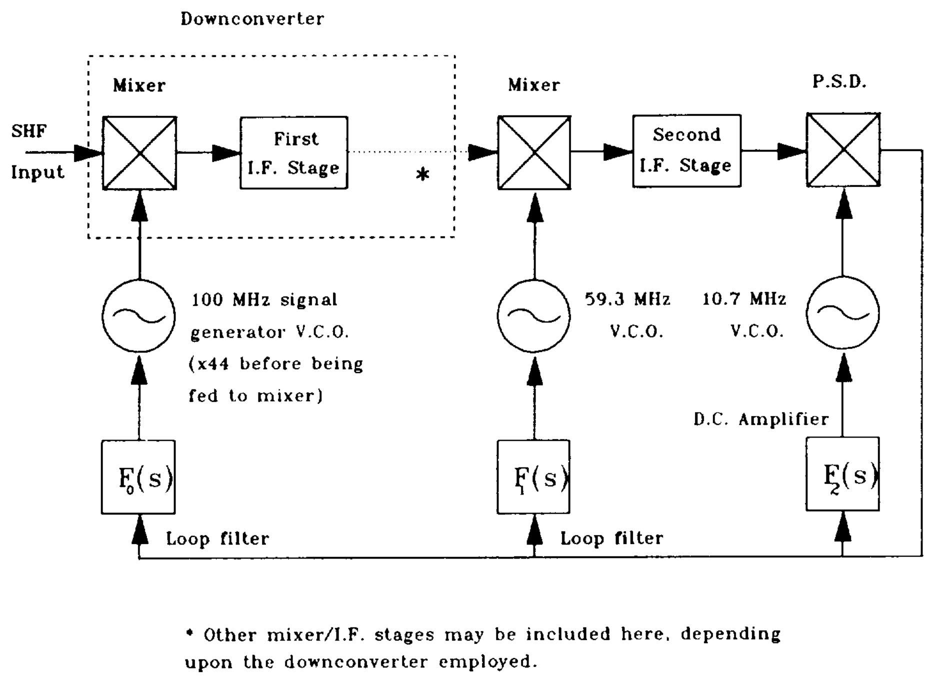

Figure 7: Configuration of the split-loop receiver/downconverter mobile terminal

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