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A SINGLE CARRIER SATELLITE LO SYSTEM

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Although there are a great many schemes for round-trip LO stabilization which could be used via a satellite, they would in general use two fairly narrow carriers separated by a large frequency difference, with the LO information encoded on the phase difference between the two carriers. It is aesthetically more pleasing to use the satellite system carrier itself to be the main phase carrier. A scheme for doing so is given here.

It is presumed that the satellite is a simple transceiver - that is, a signal at frequency ω is received by the satellite, mixed with a signal $\omega_s t + \phi_s$, and retransmitted. ω_s is a moderately stable oscillator, of known frequency, such that copies can be reproduced at the master station and outstation. For convenience of notation we take ω_s to be a multiple β of ω_o, i.e. $\omega_s = \beta\omega_o$. The block diagram of the system is given in the figure. Although the diagram is drawn for a partly digital implementation, the system could be made entirely analog by encoding the phases on a low carrier frequency instead of digitizing them. There are considerable advantages to implementing the digital version. Whichever is used does not affect the analysis below. The analysis reproduces only the phase terms, the proper expression is implicitly the exponential of i times that given. Synthesizers are assumed to be perfect; that is, they simply multiply the signal frequency and phase by some factor (α for the offset synthesizer and β for the ω_s synthesizer). This causes all lobe ambiguity problems to be ignored, for the moment. All line lengths are assumed to be zero, except for the distances from the satellite to the Master station (L_o) and outstation (L_1). These two paths are assumed to be pure delays.

In the analysis below, the phase terms are numbered with numbers corresponding to those on the diagram.

Master Oscillator

$$\omega_o t \tag{1}$$

Outstation Oscillator

$$\omega_o t + \phi_1 \tag{2}$$

Master Carrier radiates

$$\omega_o t \tag{3}$$

Outstation radiates

$$(\omega_o t + \phi_1)(1 + \alpha) \equiv \omega_o t + \omega_p t + \phi_1 + \alpha\phi_1 \tag{4}$$

Master transmission received at satellite

$$\omega_o t - L_o \omega_o \tag{5}$$

Outstation transmission received at satellite

$$\omega_o t + \omega_p + \phi_1 + \alpha\phi_1 - \omega_o L_1 - \omega_p L_1 \tag{6}$$

Transceived master signal

$$\omega_o t + \omega_s t - L_o \omega_o + \phi_s \tag{7}$$

Transceived outstation signal

$$\omega_o t + \omega_p t + \omega_s t + \phi_1 + \alpha\phi_1 - \omega_o L_1 - \omega_p L_1 + \phi_s \tag{8}$$

Master signal received at master station

$$\omega_o t + \omega_s t - 2\omega_o L_o - \omega_s L_o + \phi_s \tag{9}$$

Master signal received at outstation

$$\omega_o t + \omega_s t - \omega_o L_o - \omega_o L_1 - \omega_s L_1 + \phi_s \tag{10}$$

Outstation signal received at outstation

$$\omega_o t + \omega_s t + \omega_p t + \phi_1 + \alpha\phi_1 - 2\omega_o L_o - \omega_s L_1 - 2\omega_p L_1 + \phi_s \quad (11)$$

Transmit/Receive mixer output, master station

$$\omega_s t - 2\omega_o L_o - \omega_s L_o + \phi_s \quad (12)$$

Transmit/Receive mixer output, outstation

$$\omega_s t - 2\omega_1 L_1 - \omega_s L_1 - 2\omega_p L_1 + \phi_s \quad (13)$$

ω_s synthesizer, master station

$$\beta\ \omega_o t = \omega_s t \quad (14)$$

ω_s synthesizer, outstation

$$\beta\ (\omega_o t + \phi_1) = \omega_s t + \beta\phi_1 \quad (15)$$

Phase detector output, master station

$$2\omega_o L_o + \omega_s L_o = \phi_s \quad (16)$$

Phase detector, outstation

$$2\omega_o L_1 + \omega_s L_1 + 2\omega_p L_1 - \phi_s + \beta\phi_1 \quad (17)$$

The delay is inserted so that the items presented to the subtractor represent samples of the same ϕ_s. This removes dependence on stability of the tranceiver oscillator.

Phase subtractor output, outstation

$$(2\omega_o + \omega_s)(L_o - L_1) - 2\omega_p L_1 - \beta\phi_1 \quad (18)$$

Master/Local mixer, outstation

$$\omega_p t + \phi_1 + \alpha\phi_1 + \omega_o(L_o - L_1) - 2\omega_p L_1 \quad (19)$$

Main phase detector, outstation

$$\phi_1 + \omega_o\ (L_o - L_1) - 2\omega_p L_1 \quad (20)$$

Phase multiplier, outstation

$$\omega_o\ (L_o - L_1) - \frac{1}{2+\beta}\ (2\omega_p L_1 - \beta\phi_1) \quad (21)$$

Phase difference - Servo input, outstation

$$\phi_1 \frac{2}{2+\beta} + 2\omega_p L_1 \frac{1+\beta}{2+\beta} \quad (22)$$

The order of magnitude component stabilities necessary to achieve an oscillator locked to 3 ps (operation at 50 GHz) are given below.

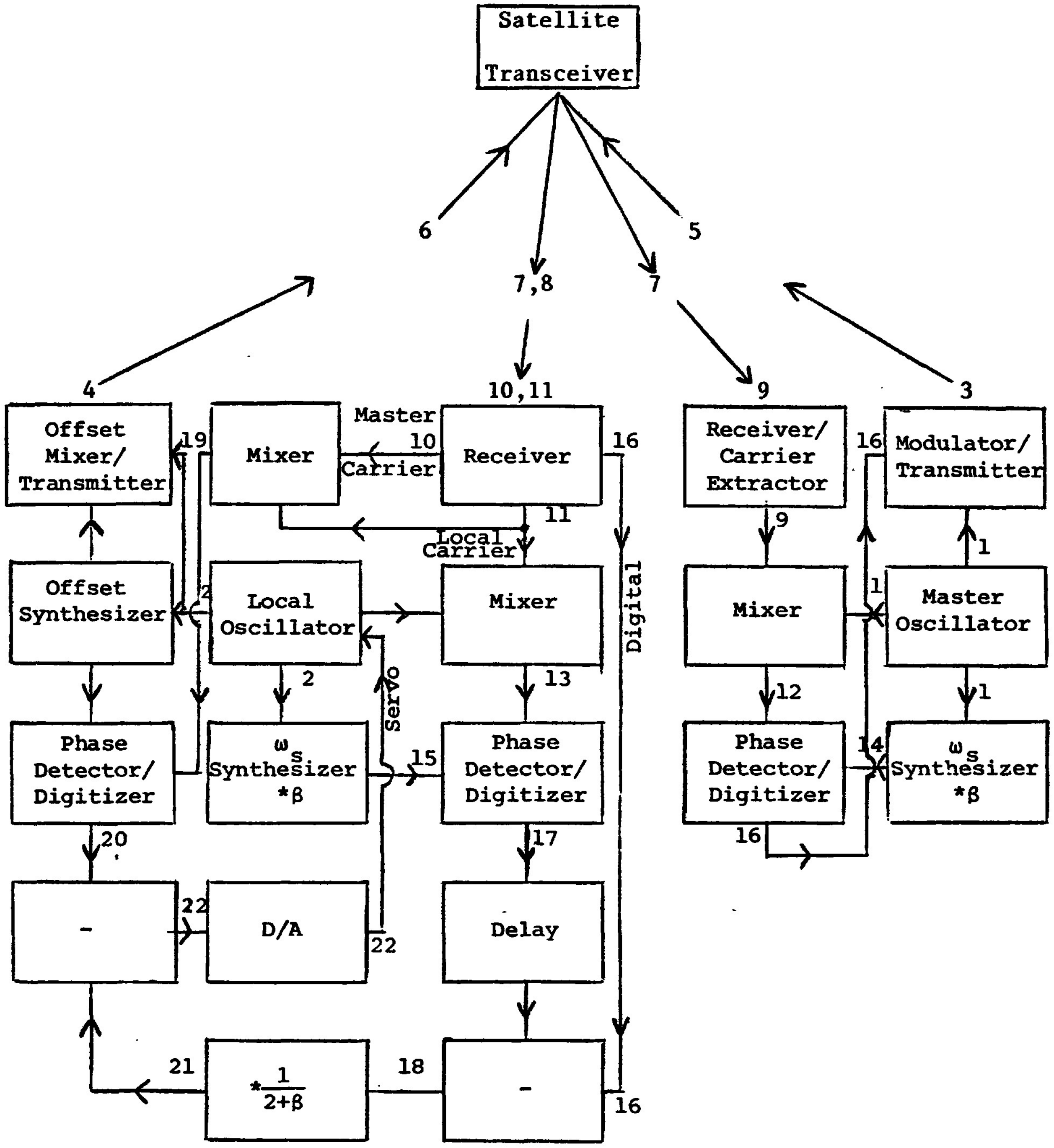
To simplify the design of the system, it would appear advantageous to have fixed frequency channels in the receiver; that is, ω_p should be large enough that the residual doppler of the satellite would not permit confusion of the signals at ω_o and $\omega_o + \omega_p$. This suggests $\alpha > 10^{-6}$. For a ten station array, spacing the ω_p (different for each station) by $10^{-6}\omega_p$ means the maximum ω_p is $10^{-5}\omega_o$. To hold the second, unwanted, term in the servo input (expression (22)) to 3 ps, requires an a priori knowledge of L_1 to 300 ns, about the state of the art in satellite orbit determination. However, the term degrades gracefully, introducing a diurnal phase term looking much like a position error, and accurate satellite astrometry need not be done except for astrometric experiments. The satellite tranceiver oscillator must be stable over the time of operation of the phase detector - a few times greater than the offset signal period - $\sim 10^{-7}$. Any old crystal oscillator should do this.

The stability of the servo loop is only assumed if it has a bandwidth several times smaller than the reciprocal of the round trip path to the satellite, say 1 Hz. The outstation oscillator must therefore have an intrinsic stability of $\sim 3 \times 10^{-12}$ on a 1 second timescale. This sounds a bit too good for a simple crystal, and a rubidium or superconducting cavity controlled oscillator would be needed. The latter is especially attractive if affordable, and the removal of any requirement for stability over periods longer than one second may make it so. The servo could even be implemented as a part of the temperature controller, simplifying the design of that component.

This system has a greater dependence on remote site oscillator stability than the conventional, two-rail, system which removes the tranceiver oscillator phase by presuming it to be the same on both rails, rather than, as in this system, by feeding both the remote and local oscillator signals through it. However, an oscillator of this stability range is desireable at the remote station anyway as a back-up for the satellite link. The narrow loop bandwidths will also likely make this system "fussy" to deal with. This must be weighed against the operational advantage of needing only a single band through the satellite.

Lobe ambiguities have been steadfastly ignored throughout this document. This is fine so long as the system is in continuous operation and so long as the satellite velocity is a priori known to an accuracy of a few inches per second or so. Given this, phases may nicely be carried past one turn, and processing proceeds undisturbed. Any little glitch however - especially loss of power to the micro-processor which does the digital operations or a glitch in the satellite position predictor - will cause the system to drop one or more loops of the primary reference frequency (the satellite carrier, presumably at L or S band). The SCCO would be capable of remembering the phase of the carrier for a few seconds, but I anticipate a major effort to meet a reasonable goal of, say, having the system run for a week without a phase jump.

It is interesting to note that the total bandwidth requirements of this system (~20 KHz) are only slightly greater than one telephone channel.


Satellite Transceiver
6
7,8
7
5
4
10,11
9
3
Offset Mixer/ Transmitter
19
Mixer
Master Carrier
10
Receiver
16
Receiver/ Carrier Extractor
16
Modulator/ Transmitter
11
Local Carrier
9
1
Offset Synthesizer
2
Local Oscillator
Mixer
Digital
Mixer
1
Master Oscillator
2
Servo
13
12
1
Phase Detector/ Digitizer
ωs Synthesizer *β
15
Phase Detector/ Digitizer
Phase Detector/ Digitizer
14
ωs Synthesizer *β
20
17
16
-
22
D/A
22
Delay
21
*1/(2+β)
18
-
16