PHASE REFERENCING FOR MA DEMULTIPLEXING IN THE TDRSS

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ABSTRACT

The TDRSS performance is based, to a large extent, on the ability to maintain phase coherency between user, satellite, and ground segment. This is especially true for the MA return subsystem, which uses coherent referencing for multiplexing and demultiplexing between the TDRS and ground processor. Phase noise appearing on these referencing waveforms destroy the phase coherency, and will degrade the overall MA return operation. In this paper the manner in which this phase referencing is achieved is described. In addition, the results of a preliminary study to distinguish the key MA return phase noise sources, and the manner in which each will ultimately influence performance, is presented. The results show that the return phase noise effects can be separated into "coherent" and "noncoherent" contributions, and each must be separately evaluated. The effect of the various tracking loop bandwidths throughout the link is shown, and the manner in which the specific phase noise spectra are eventually filtered is developed.

INTRODUCTION

The communication subsystem of the TDRS is a complex system of interconnected tracking loops in which mutual phase coherence between remote oscillators is to be maintained. This means that phase noise and jitter on any oscillator or carrier waveform is propagated throughout the entire system, and the effect of any phase noise source appears in many system locations. This is especially true of the MA return subsystem, where phase coherency between the TDRS and ground segment is required in order to decode and track the MA user carrier waveforms. This is due to the fact that the MA return from the TDRS multiplexes the user carrier into parallel links, which are phase controlled for beam forming at the ground segment prior to demultiplexing and subsequent data processing. The phase coherency is achieved by returning a reference pilot tone used to multiplex to the ground segment for demultiplexing. This reference is obtained by coherently turning around the TDRS pilot as a carrier for the return telemetry, in addition to providing the

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necessary demultiplexing referencing. Phase noise on these referencing waveforms degrade the multiplexing-demultiplexing operation.

In this paper phase noise sources are identified, and the manner in which they generate telemetry return carrier phase noise and eventually effect the MA demultiplexing is described. It is shown that the coherent and noncoherent phase noise sources associated with the forward links differ from the coherent and noncoherent sources of the MA return. In addition it is found that measurements of the phase noise on the telemetry return carrier at the TDRS do not directly reflect the eventual MA link phase noise at the ground receiver.

The MA return subsystem requires multiplexing at the TDRS of an S-band MA user carrier into 30 separate return links. At the ground segment there links are demultiplexed into a single reconstructed user carrier at 160 MHZ, from which data decoding and doppler tracking ensues. The multiplexing at the TDRS is performed from a mixing generator using frequencies from a spacecraft master frequency generator (MFG) driven by a pilot tone reference. The demultiplexing on the ground is performed by a ground MFG that must be phase referenced to the TDRS. (This is due to the fact that the 30 links must be accurately phase adjusted prior to recombination.) This phase referencing is achieved by driving the demultiplexer with a telemetry return carrier from the TDRS that is theoretically phase coherent with the TDRS pilot tone. This telemetry carrier is generated at the TDRS by coherently truning around the forward pilot, after mixing with the command and TT&C forward carrier. Any phase noise or extraneous phase shifts that destroy the phase coherency between the forward pilot tone and the return telemetry carrier will deteriorate the reconstruction of the 160 MHZ MA carrier.

To analyze the phase noise problem we consider the simplified system diagram in Figure 1. The ground station DTFS is driven by the 5 MHZ Cesium reference and provides the forward pilot (15150 MHZ) and command carrier (14786 MHZ), along with all the user forward carriers (not shown). The pilot sent to the TDRS is separated in the forward processor, phase tracked and recovered, and used to drive the onboard master frequency generator (MFG). The MFG generates the local oscillator frequencies for all TDRS frequency mixing. In addition the MFG generates a 30 MHZ reference that drives the multiple access frequency generator (MAFG) used for the multiplexing of the MA return carrier. The latter is multiplexed into the 30 beam forming channels for the TDRS MA return link. An MFG frequency is also used to mix the forward command carrier to S-band to derive the TT&C input carrier. In the TT&C subsystem this carrier is coherently extracted and used for the telemetry return frequency (13731 MHZ). This telemetry carrier is returned to the ground segment for demodulation, and in addition is used to provide a phase coherent frequency reference for the MA demultiplexing. This is accomplished at the ground segment by phase tracking the return telemetry carrier, and using the recovered reference to drive a ground segment MA element separator. The latter provides the mixing frequencies for demultiplexing the 30 MA links, which are eventually recombined into the MA carrier at 160 MHZ. Since the 30 links must be accurately phase controlled prior to recombining, phase noise introduced during multiplexing and demultiplexing degrades the reconstructed MA carrier. In the analysis here we are primarily concerned with the phase noise introduced by the DTFS and TDRS payload. In Figure 1, Q_{1i},Q_{2i} , i = 1, 2,...,30, represent the frequency and phase multipliers providing the proper mixing frequencies for separating and recombining the 30 MA links.

The equivalent phase noise diagram of the system in Figure 1 is shown in Figure 2. Significant phase noise sources are depicted as noise inputs, and the manner in which an input phase variation affects a carrier waveform at a particular point in the system is obtained from the transfer function along the path from source input to that point. Phase noise sources along a common line have been lumped into a single source. The primary phase noise sources shown in Figure 2 are:

(1) ϕ_r, the cesium standard phase noise. This is often referred to as the coherent forward phase noise component, since it appears simultaneously on all carriers generated from the DTFS.

(2) ϕ_p, the pilot reference frequency (20 MHZ) phase noise, excluding the contribution from the coherent cesium standard. This is referred to as the pilot noncoherent phase noise, since it is independent of all other carriers. This includes any DTFS noncoherent noise, any thermal phase noise of the pilot link, and any phase noise inserted by the pilot tracking loop itself.

(3) ϕ_c, the command forward phase noise at the TDRS, excluding that due to the cesium standard. This represents the noncoherent component of the command carrier, and is primarily due to the noncoherent contribution from the DTFS and any TDRS thermal noise.

(4) ϕ_m , the phase noise inserted by the MFG on the telemetry carrier at the TDRS. This represents the additional phase noise inserted during the frequency multiplications (K_1 and K_2) of the 20 MHZ pilot reference within the MFG.

(5) ϕ_T, the TT&C phase noise. This accounts for the phase noise added to the telemetry carrier by the TT&C subsystem at its output to that which would exist due to its input (2036 MHZ) carrier alone.

(6) ϕ_Q, the MAFG phase noise added to the 30 MA links during multiplexing (Q_{1i}). A similar ground segment contribution should be inserted at the demultiplexer (Q_{2i}) but is excluded in the present model.

Each of the above phase noise sources is describeable by its one sided phase noise spectrum S(f), where f is the frequency measured from the carrier frequency. The particular phase effects of interests here are (1) the total phase noise that will be inserted on the downlink telemetry by the TDRS, (2) the resulting phase noise that the ground referencing system will superimpose on any of the MA return links due to this telemetry noise, (3) the resulting difference in phase between any two MA links. This differential phase noise determines the ability to reconstruct the MA carrier at 160 MH Z.

In analyzing the effect of each of these sources it is evident from Figure 2 that:

(a) The cesium reference (forward coherent) and the pilot link forward noncoherent phase noise produce return MA phase noise that is common to both the TDRS multiplexing operation and the ground station demultiplexing operation. This common phase noise propagates along two separate paths (return MA links and return telemetry carrier) and combines on the resultant reconstructed MA carrier. Hence the cesium reference and the pilot forward noncoherent phase noise produce phase noise that is "coherent" in the return link. Since coherent phase noise is common to two separate paths, it has the theoretical capability of possibly being reduced or cancelled after MA reconstruction. Note however that each of these return coherent sources follow distinctly different paths during their propagation, and must therefore be examined separately.

(b) The forward noncoherent phase noise of the command link the TDRS MFG phase noise, and the TT&C phase are uncommon to the multiplexing and demultiplexing operation, appearing only on the telemetry carrier. Hence these sources produces the return "noncoherent noise" of the telemetry carrier.

(c) The forward pilot-command phase noncoherency does not automatically generate the return noncoherency. The pilot link noncoherent noise is part of the return coherent component, while the forward command noncoherent phase noise contributes directly to the return noncoherency. Hence the degree of noncoherency of the forward pilot and command carriers is secondary, as far as return phase noise is concerned. Of more importance, is the relative amounts of noncoherency produced individually by the pilot and command links.

Other sources of return noncoherent phase noise are generated within the MFG multiplexer telemetry carrier recovery subsystem in the ground. Margin must be provided for their contribution.

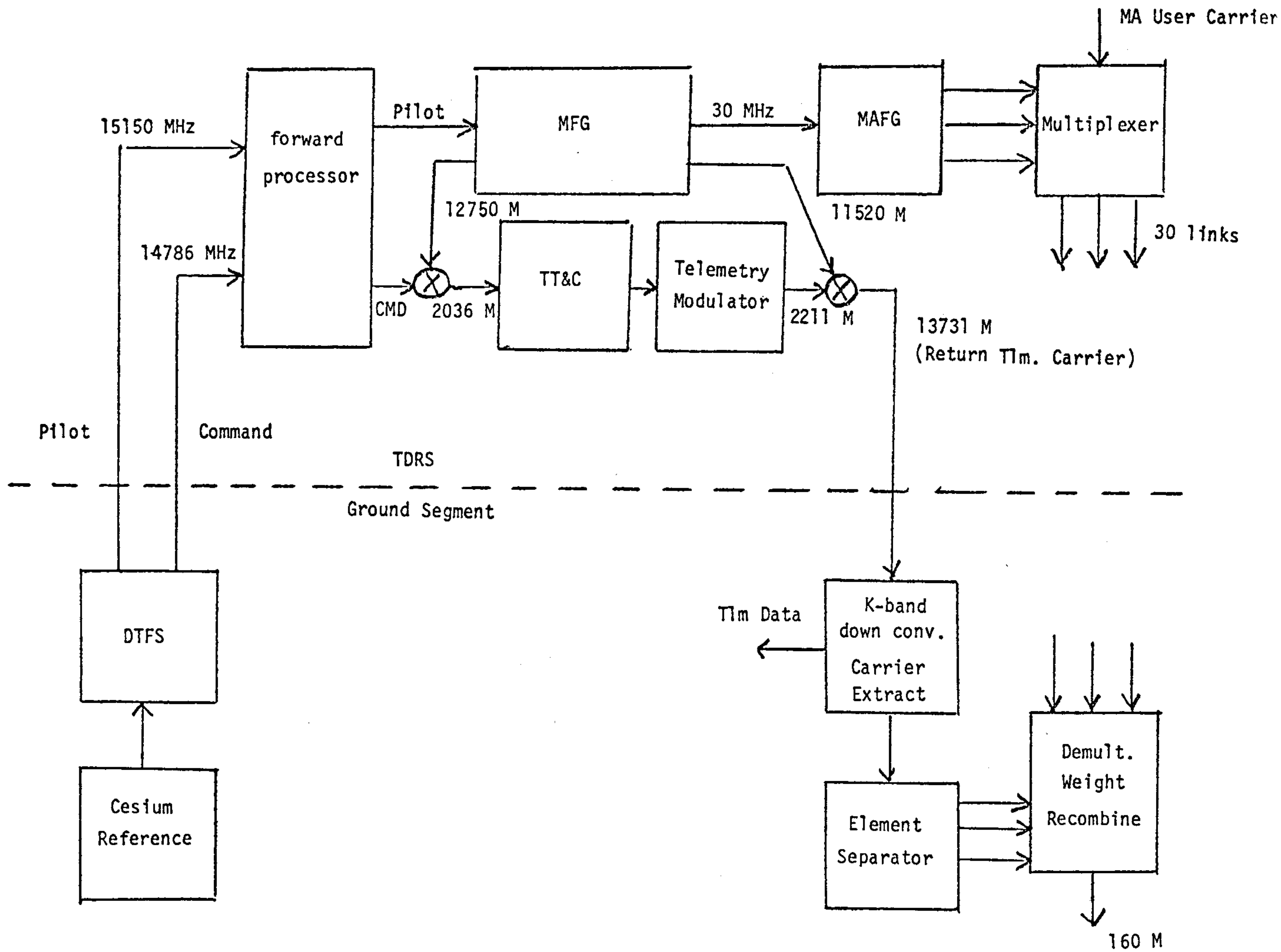

Figure 1. MA Phase Referencing System

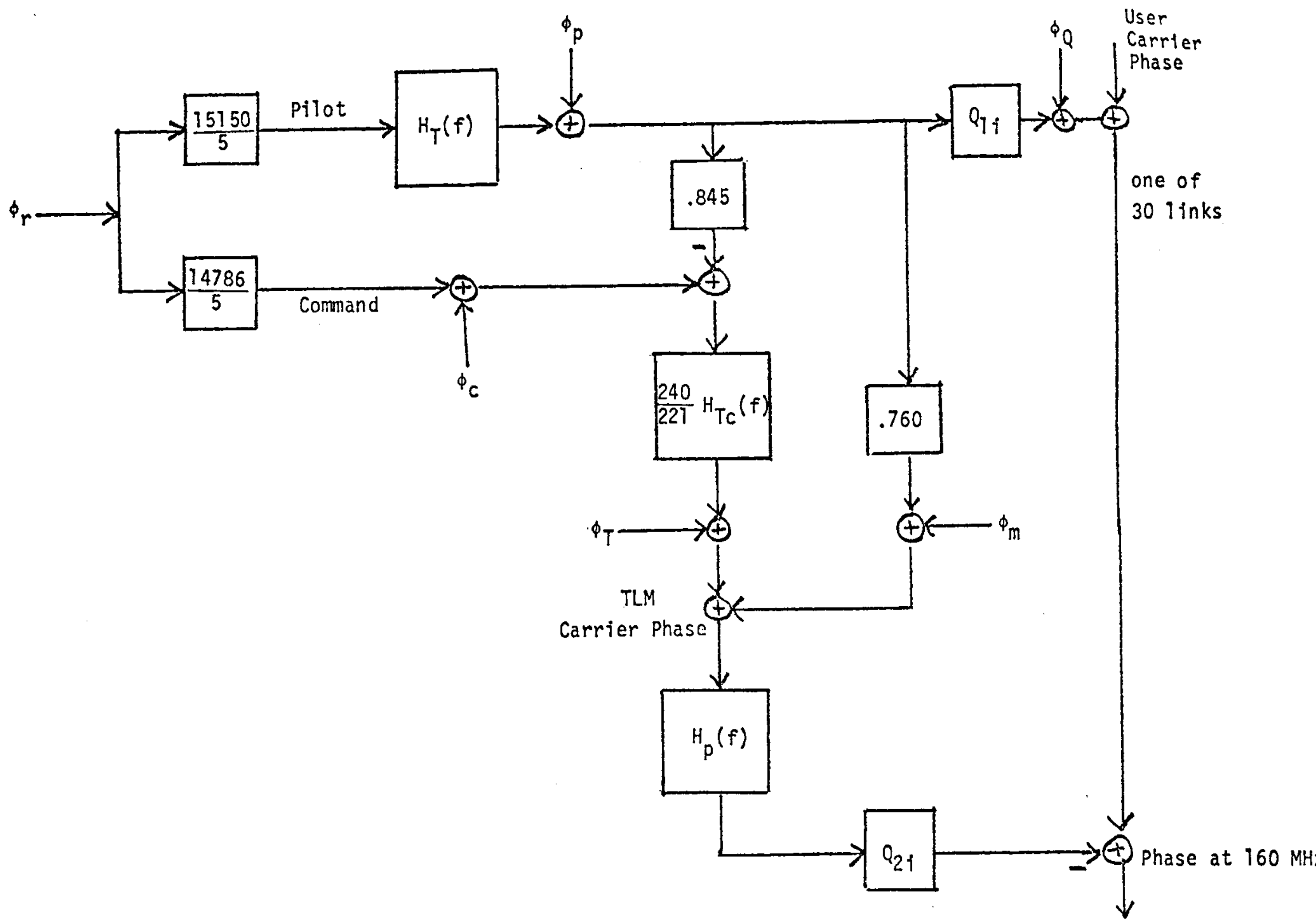

Figure 2. Equivalent Phase Noise Diagram