# Recording VSOP Data (Mode 128-2-2) on VLBA Tapes

**Version 3.0**

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## 1. Introduction

This document provides the details of recording parameters for VSOP data which are recorded using VLBA data acquisition systems. Specifically, it gives the track assignments, including the fan-out of the observing channels to tracks, and the sequence of head positions to be used in the recording on the longitudinal tape recorders used as part of the VLBA system. The specified recording details are consistent with the VLBA formatter, with the defaults currently in use at the VLBA, and with the current understanding of the implementation of the U.S. and Japanese tracking stations and correlators. Possible exceptions are discussed in the last section of this document, but generally should not cause tracking stations and ground radio telescopes to deviate from the conventions specified herein.

The VLBA tape recorder has a total of 36 write heads, so each tape is divided into 36 tracks per head position. Thirty-two tracks (numbered 2 through 33) are normally used to write VLBI data, while four tracks (numbered 0, 1, 34, and 35) are system tracks which may be used to substitute for known dead tracks (see Section 5.1). There are 14 allowed head positions across the width of the tape, permitting data to be written in multiple passes through the tape. The seven "negative" head positions are normally allocated for writing on forward tape passes, while the seven "positive" head positions are allocated for writing during the reverse tape passes. (Head positions are specified by location relative to the center of the 1-inch wide tape, in micrometers.) The nominal bit density is currently 33,333 bits per inch, but 56,000 bits per inch will be used routinely (on "thin" tapes) by the time of VSOP launch. At that time, the maximum tape speed normally employed will be 160 inches per second, which corresponds to writing at the maximum rate of 8 Mbit/s per track (not counting overhead).

## 2. VSOP Observing Modes

The VSOP spacecraft has several different VLBI observing modes, all of which involve a total data rate of 128 Mbit/s. These modes are given in Table 1 below, with each specified according to the standard VLBA conventions of (Data Rate-Channels-Bits per Sample). In this table, it should be noted that mode 128-2-2 is the only entry that is compatible with the VLBA data acquisition system, and is the only mode addressed in this document. The other modes can be recorded at tracking stations (but not VLBA-equipped ground radio telescopes); the method of recording those modes should be specified elsewhere.

**Table 1. Possible VSOP Observing Modes**

| Mode | Channels | Channel BW | Bits/Sample |
|---|---|---|---|
| 128-2-2 | 2 | 16 MHz | 2 |
| 128-2-1 | 2 | 32 MHz | 1 |
| 128-1-2 | 1 | 32 MHz | 2 |

VSOP has only Left Circular Polarization (LCP) reception. During some polarization experiments, it may be desirable for ground radio telescopes to record four 16-MHz channels, two each at LCP and RCP, with either 1-bit or 2-bit sampling. Thus, in these special cases, the ground telescopes would observe in mode 128-4-1 or in mode 256-4-2. Since very little discussion has been held to determine the operation of ground telescopes in these cases, this document does not attempt to set corresponding recording standards.

## 3. 16-Track Recording

The VLBA data-acquisition system has a maximum fan-out of 1:4. In other words, a single data stream can be fanned out onto a maximum of 4 write heads and written to 4 tracks on the tape. In mode 128-2-2, there actually are two data streams per 16-MHz channel (one stream of "Most Significant Bits," or MSB, and one stream of "Least Significant Bits," or LSB), or a total of four data streams overall. Therefore, at a telescope with a VLBA data acquisition system, the maximum number of tracks that can be used at any one time is 16 tracks, and it takes two passes through the tape to fill up all the tracks at a given head position. Since the maximum fan-in ratio of the VLBA correlator is 4:1, all data destined for that correlator *must* be written to 16 tracks. The accepted procedure is to write half the tracks using a single head position during a forward pass, move the heads, write half the tracks in a different position during a reverse pass, then return the heads to the original position and write the other half of the tracks in the forward direction. This process continues until the entire tape is filled.

### 3.1 Sequence of Head Positions for 16-Track Case

The sequence of head positions that should be used for VSOP recording, involving a total of 14 complete passes (*i.e.,* 14 forward and 14 in reverse) through the VLBA tape, is given in Table 2 below. Although it is possible to deviate from this sequence in a number of ways, there is no logical reason to do so, and we view this sequence as a **required** sequence for both radio telescopes and ground tracking stations.

**Table 2. Head Positions for 16-Track Recording**

| Pass | Direction | Head Position | Direction | Head Position |
|---|---|---|---|---|
| 1 | Forward | −319 | Reverse | +31 |
| 2 | Forward | −319 | Reverse | +31 |
| 3 | Forward | −271 | Reverse | +79 |
| 4 | Forward | −271 | Reverse | +79 |
| 5 | Forward | −223 | Reverse | +127 |
| 6 | Forward | −223 | Reverse | +127 |
| 7 | Forward | −175 | Reverse | +175 |
| 8 | Forward | −175 | Reverse | +175 |
| 9 | Forward | −127 | Reverse | +223 |
| 10 | Forward | −127 | Reverse | +223 |
| 11 | Forward | −79 | Reverse | +271 |
| 12 | Forward | −79 | Reverse | +271 |
| 13 | Forward | −31 | Reverse | +319 |
| 14 | Forward | −31 | Reverse | +319 |

### 3.2 Assignment of Data to 16 Recorder Tracks

The next step is to specify the assignment of data to recording tracks. As stated previously, the tracks 0, 1, 34, and 35 are used for system information. The remaining 32 tracks can be divided into 4 sets. The even-numbered tracks comprise two sets, from 2 through 16 ("low-even") and from 18 through 32 ("high-even"). The odd-numbered tracks comprise two similar sets, from 3 through 17 ("low-odd") and from 19 through 33 ("high-odd"). There are two passes through the tape at each head position; the even-numbered tracks will be written on the first pass at a given position, while the odd-numbered tracks will be written during the second pass at the same position. The two VSOP channels will be numbered "1" and "2" here to conform with VLBA conventions (although they are called Channels A and B in the Space Radio Telescope Schedule File). In each pass, Channel 1 will be recorded on the lower-numbered set of tracks while Channel 2 will be recorded on the higher-numbered set of tracks.

The description above can be summarized in a compact notation used by the VLBA. This notation is defined as follows:

track=(1st-Channel,Lowest-Track),(2nd-Channel,Lowest-Track)

Only two sets of track assignments are needed for recording the VSOP mode 128-2-2, and only these track assignments should be used except in extraordinary circumstances. These assignments are specified as follows:

| | |
|---|---|
| EVEN Tracks | track=(1,2),(2,18) |
| ODD Tracks | track=(1,3),(2,19) |

In each case, only the lowest-numbered track of a set is given. Therefore, "track=(1,2),(2,18)" indicates that Channel 1 is written on the "low-even" tracks 2,4,6,8,10,12,14,16, while Channel 2 is written on the "high-even" tracks 18,20,22,24,26,28,30,32. The notation "track=(1,3),(2,19)" indicates that Channel 1 is written on the "low-odd" tracks 3,5,7,9,11,13,15,17, while Channel 2 is written on the "high-odd" tracks 19,21,23,25,27,29,31,33.

Given the above notation, it now is possible to summarize the recording sequence by expanding Table 2, giving the result shown below in Table 3.

**Table 3. Head Positions and Track Sequences for 16-Track Recording**

| Pass | Direction | Heads | Tracks | Direction | Heads | Tracks |
|---|---|---|---|---|---|---|
| 1 | Forward | −319 | (1,2),(2,18) | Reverse | +31 | (1,2),(2,18) |
| 2 | Forward | −319 | (1,3),(2,19) | Reverse | +31 | (1,3),(2,19) |
| 3 | Forward | −271 | (1,2),(2,18) | Reverse | +79 | (1,2),(2,18) |
| 4 | Forward | −271 | (1,3),(2,19) | Reverse | +79 | (1,3),(2,19) |
| 5 | Forward | −223 | (1,2),(2,18) | Reverse | +127 | (1,2),(2,18) |
| 6 | Forward | −223 | (1,3),(2,19) | Reverse | +127 | (1,3),(2,19) |
| 7 | Forward | −175 | (1,2),(2,18) | Reverse | +175 | (1,2),(2,18) |
| 8 | Forward | −175 | (1,3),(2,19) | Reverse | +175 | (1,3),(2,19) |
| 9 | Forward | −127 | (1,2),(2,18) | Reverse | +223 | (1,2),(2,18) |
| 10 | Forward | −127 | (1,3),(2,19) | Reverse | +223 | (1,3),(2,19) |
| 11 | Forward | −79 | (1,2),(2,18) | Reverse | +271 | (1,2),(2,18) |
| 12 | Forward | −79 | (1,3),(2,19) | Reverse | +271 | (1,3),(2,19) |
| 13 | Forward | −31 | (1,2),(2,18) | Reverse | +319 | (1,2),(2,18) |
| 14 | Forward | −31 | (1,3),(2,19) | Reverse | +319 | (1,3),(2,19) |

The next detail that must be specified is the functional assignment of sample bits to the eight tracks in each set. Although the VLBA formatter provides the flexibility to fan out the bits to tape tracks in a number of ways, the straightforward method that corresponds to VLBA conventions is fairly simple to specify, and is **required** except in extraordinary circumstances. In the following, we will define $t_1$ through $t_4$ to be the times at which four consecutive samples are received. At each time, the signal from each channel is 2-bit sampled, resulting in a Most Significant Bit (MSB) and a Least Significant Bit (LSB). Then, for the four sets of tracks specified above, the data should be written to the tracks in the time sequence given below in Table 4, which repeats for each set of four samples.

**Table 4. 16-Track Fan-out of Sample Bits**

| Sample | Bit | Track Ch. 1 Pass 1 | Track Ch. 1 Pass 2 | Track Ch. 2 Pass 1 | Track Ch. 2 Pass 2 |
|---|---|---|---|---|---|
| $t_1$ | MSB | 2 | 3 | 18 | 19 |
| $t_2$ | MSB | 4 | 5 | 20 | 21 |
| $t_3$ | MSB | 6 | 7 | 22 | 23 |
| $t_4$ | MSB | 8 | 9 | 24 | 25 |
| $t_1$ | LSB | 10 | 11 | 26 | 27 |
| $t_2$ | LSB | 12 | 13 | 28 | 29 |
| $t_3$ | LSB | 14 | 15 | 30 | 31 |
| $t_4$ | LSB | 16 | 17 | 32 | 33 |

### 3.3 Barrel Roll for 16-Track Recording

The next parameter to be specified is the barrel roll. This is the periodic reassignment of the bit streams from a group of channels to particular heads and tape tracks in a cyclic pattern, advancing by one step each tape frame. Its purpose is to minimize susceptibility to a single bad head or track, either on the recording system or on the playback system at the correlator. The normal VLBA convention is that a 16-track barrel roll is used for data recorded on 16 tracks. (Note that 8-track barrel roll is useless for data in which only 2 channels are recorded on 16 tracks, as is the case for 128-2-2 mode.) In the VSOP case, if there is a single bad track on the recorder, the effect of the barrel roll would be to cause each of the two original data channels to be lost 50% of the time, instead of having one channel be good 100% of the time, while the other channel is bad 100% of the time. However, the 16-track barrel roll also is incompatible with a 2048-point Fast Fourier Transform, which is needed for the highest spectral resolution or for the greatest delay range in fringe searching. Furthermore, there may be difficulties in aligning the two VSOP channels for spacecraft data, in view of problems with aliasing and harmonics in extracting the spacecraft phase-calibration tones at tracking stations. This implies that, for continuum observations, it is preferable to have one channel that is good 100% of the time rather than two channels that are each good 50% of the time.

Since most tracking stations will find it difficult to turn barrel roll on and off for individual tracking passes, this specification should have the same value of barrel roll for all VSOP experiments recorded on 16 tape tracks. Because of the arguments given above, the default specified here will be to turn the barrel roll **OFF** for all 16-track recording of VSOP experiments.

It may be that a decision is made later to turn the barrel roll on for some or all VSOP experiments recorded on 16 tracks. Therefore, for completeness, we include in Table 5 the exact track sequence for the even-numbered tracks that should be followed in that case (information supplied by N. Kawaguchi and confirmed by G. Peck). A similar sequence would be followed for the odd-numbered tracks, by letting $2n \rightarrow 2n - 1$ for $n$ from 1 through 16.

| Table 5. Hypothetical 16-Track Barrel-Roll Sequence | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Output track | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
| | input tracks | | | | | | | | | | | | | | | |
| 1st frame | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
| 2nd frame | 16 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 32 | 18 | 20 | 22 | 24 | 26 | 28 | 30 |
| 3rd frame | 14 | 16 | 2 | 4 | 6 | 8 | 10 | 12 | 30 | 32 | 18 | 20 | 22 | 24 | 26 | 28 |
| 4th frame | 12 | 14 | 16 | 2 | 4 | 6 | 8 | 10 | 28 | 30 | 32 | 18 | 20 | 22 | 24 | 26 |
| 5th frame | 10 | 12 | 14 | 16 | 2 | 4 | 6 | 8 | 26 | 28 | 30 | 32 | 18 | 20 | 22 | 24 |
| 6th frame | 8 | 10 | 12 | 14 | 16 | 2 | 4 | 6 | 24 | 26 | 28 | 30 | 32 | 18 | 20 | 22 |
| 7th frame | 6 | 8 | 10 | 12 | 14 | 16 | 2 | 4 | 22 | 24 | 26 | 28 | 30 | 32 | 18 | 20 |
| 8th frame | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 2 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 18 |
| 9th frame | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |
| 10th frame | 32 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 16 | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
| 11th frame | 30 | 32 | 18 | 20 | 22 | 24 | 26 | 28 | 14 | 16 | 2 | 4 | 6 | 8 | 10 | 12 |
| 12th frame | 28 | 30 | 32 | 18 | 20 | 22 | 24 | 26 | 12 | 14 | 16 | 2 | 4 | 6 | 8 | 10 |
| 13th frame | 26 | 28 | 30 | 32 | 18 | 20 | 22 | 24 | 10 | 12 | 14 | 16 | 2 | 4 | 6 | 8 |
| 14th frame | 24 | 26 | 28 | 30 | 32 | 18 | 20 | 22 | 8 | 10 | 12 | 14 | 16 | 2 | 4 | 6 |
| 15th frame | 22 | 24 | 26 | 28 | 30 | 32 | 18 | 20 | 6 | 8 | 10 | 12 | 14 | 16 | 2 | 4 |
| 16th frame | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 18 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 2 |

### 3.4 Data Modulation

The VLBA formatter normally modulates data by multiplying the bitstream by a pseudo-random sequence of bits in order to produce an equal number of 0 and 1 bits. This modulation then is removed at the VLBA correlator in order to recover the original bitstream. Data modulation should always be **ON** for data destined for the VLBA correlator. If data are to be sent to the VSOP correlator, the tape-copy facility has been designed only to cope with unmodulated data, although the default in the software and firmware of the VLBA formatter is to have the modulation applied to all data. This inconsistency in designs has not yet been resolved.

## 4. 32-Track Recording

It is not possible to record ground radio telescope data taken in Mode 128-2-2 on 32 tracks, because there is no 1:8 fan-out for the VLBA data acquisition system. However, U.S. tracking stations may record data in this format. This will be desirable when the tapes are to be sent to the VSOP correlator, because it will enable double-speed copying to VSOP cassettes. (Recording at the Usuda tracking station is not relevant, because data to be sent to the VSOP correlator will be recorded directly on VSOP cassettes, not on VLBA tapes.)

### 4.1 Sequence of Head Positions for 32-Track Case

In the case of 32-track recording at tracking stations, there will be seven forward and seven reverse passes through each tape, with 32 tracks being recorded at a tape speed of 80 inches per second (4 Mbit/s per track). The sequence of head positions is given in Table 6.

**Table 6. Head Positions for 32-Track Recording**

| Pass | Direction | Head Position | Direction | Head Position |
|---|---|---|---|---|
| 1 | Forward | −319 | Reverse | +31 |
| 2 | Forward | −271 | Reverse | +79 |
| 3 | Forward | −223 | Reverse | +127 |
| 4 | Forward | −175 | Reverse | +175 |
| 5 | Forward | −127 | Reverse | +223 |
| 6 | Forward | −79 | Reverse | +271 |
| 7 | Forward | −31 | Reverse | +319 |

### 4.2 Assignment of Data to 32 Recorder Tracks

All U.S. tracking stations receiving VSOP data share a design in which the decoder outputs the data on 16 parallel wires. These data are input to the VLBA formatter, where a 1:2 fan-out is used to put the data to the tape. This implies that there are certain constraints in the track assignments. A 32-track assignment that should be used as the standard for VSOP has been suggested by L. D'Addario and N. Kawaguchi. It has been confirmed that all tracking stations can write data using this assignment, and that the tape copier at the VSOP correlator can read such data (32-track recordings will not go to the VLBA correlator). Since all 32 tracks are written at the same time, this formatter mode need never change; each pass through the tape will have the same track assignment. Then, a sequence of eight consecutive samples, from time $t_1$ to time $t_8$, would be written as shown below, in Table 7. This sequence repeats for every eight samples.

**Table 7. 32-Track Fan-out**

| Sample | Bit | Track Ch. 1 | Track Ch. 2 |
|---|---|---|---|
| $t_1$ | MSB | 2 | 18 |
| $t_2$ | MSB | 6 | 22 |
| $t_3$ | MSB | 10 | 26 |
| $t_4$ | MSB | 14 | 30 |
| $t_5$ | MSB | 4 | 20 |
| $t_6$ | MSB | 8 | 24 |
| $t_7$ | MSB | 12 | 28 |
| $t_8$ | MSB | 16 | 32 |
| $t_1$ | LSB | 3 | 19 |
| $t_2$ | LSB | 7 | 23 |
| $t_3$ | LSB | 11 | 27 |
| $t_4$ | LSB | 15 | 31 |
| $t_5$ | LSB | 5 | 21 |
| $t_6$ | LSB | 9 | 25 |
| $t_7$ | LSB | 13 | 29 |
| $t_8$ | LSB | 17 | 33 |

### 4.3 Barrel Roll

The tape copier at the VSOP correlator has been designed to receive data for which no barrel roll has been applied. Therefore, the barrel roll should be **OFF** for all tracking data simultaneously recorded on the 32 tracks of a VLBA tape.

### 4.4 Data Modulation

The only data to be recorded on 32 tracks of VLBA tapes will come from U.S. tracking stations; all the 32-track data will be sent to the VSOP correlator for copying. As for 16-track recording, the normal formatter default is to modulate all the data, while the VSOP tape copier can copy only unmodulated data (see Section 3.4). This inconsistency still must be resolved.

## 5. Extraordinary Circumstances

Exceptions to the allowed rules about recording should take place only in extraordinary circumstances. Below, we give what may be the most likely faults, and the action that should be taken at the tracking station or ground telescope.

### 5.1 Single Bad Head or Track

If a single head/track is not working, the preferred option should be to substitute one of the system tracks for the non-working track. This process must be enabled by an operator, on a track-specific basis, so it is only of use after the fault actually has been discovered. The normal track assignments would be specified in the correlator input log, with a separate item specifying the substitution. If a second recorder is present, as it will be at all U.S. tracking stations, another option is to use the second recorder and retain the standard track assignments.

### 5.2 Multiple Bad Heads or Tracks

If there are only a few ($\leq 4$) known bad tracks, the actions taken should be the same as for a single bad track. However, having multiple bad tracks may be a sign of a significant problem with recorder or formatter, so diagnosis and maintenance should be performed as soon as possible. In the case where a large number of the tracks is bad, the station should consider halting support until the data acquisition system can be repaired.

### 5.3 Headstack Positioning Failure

The possibility that a subset of the headstack positions might be non-functional is extremely unlikely. It is more likely that the complete headstack positioner mechanism might fail. In this case, the only recourse is to switch to the other recorder and to repair the faulty mechanism as soon as possible.

### 5.4 Formatter Problems

It may be possible to have formatter problems causing one or more of the data streams to include data that are bad or only intermittently useful. Changing the recording track assignments cannot improve this situation. One might regularly change the assignment of data to formatter channels at some periodic interval in order to share the errors among different observing channels. In practice, this does not seem optimal, and a better course of action would be to remove the station from service and repair or replace the formatter immediately.

### 5.5 Summary of Response to Anomalous Conditions

The cases described above seem to be the main situations in which one might envision changing the way in which data are fanned out and written to VLBA tapes. They do not provide any compelling reason to use non-standard recording options, with the sole exception of substituting system tracks for known, non-functional tracks. Therefore, in most circumstances, there should be no need to deviate from the single preferred sequence for head positions or from the assignment of tracks specified in the above sections.