Introduction to VLBI Time Delay (VTD) package.

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Abstract:

This document provides an outlines of the package of subroutines for computation of VLBI Time Delay and the Doppler frequency shift for observations of objects in the Solar system.

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1 General remarks

VTD is a set of subroutines for computation of VLBI Time Delay, Doppler frequency shift for observations of objects in the Solar system and its partial derivatives. It does not have a built-in database handler, so it is adaptive enough to be incorporated in existing software packages. The options of the model are specified in the control file. At the high level, there are only five calls:

VTD_INIT -- for initialization of the internal data structures;
VTD_CONF -- for parsing configuration file;
VTD_LOAD -- for loading input catalogues, planetary ephemerides, Earth orientation parameter series and other apriori parameters of the model as well as the range of dates for which VLBI time delay is to be computed.
VTD_METEO -- for loading meteorological information. NB: meteorological information is not needed, if the path delay through the atmosphere is interpolated from the external time series of slanted path delays.
VTD_DELAY -- for computation of VLBI time delay and its partial derivatives.

or

VTD_READ_NZO -- read coordinates of the near zone object
VTD_LOAD_NZO -- compute coefficients of the B-spline expansion of coordinates of the near zone object and load them in the VTD object.
VTD_DOPPLER -- for computation of the Doppler frequency shift from a body in the Solar system.
VTD_LT_ORB -- for computation of light time from the ground station to the orbiting station
VTD_REL_ORB -- for computation of time dilation integral for a case when one of the stations is on the orbit.
VTD_QUIT -- for deallocation dynamic memory used by VTD

Internal data structures are defined in one object called VTD which is passed from one routine to another. All routines have integer universal

error handler parameter IUER. If the input value of IUER = -1, and the error is detected, the routine which detected the error prints the error message and returns non-zero output value of IUER. If the routine which has detected the error was called from the routine of upper level, the routine of the upper level prints its error message as well and returns non-zero value. Input value of IUER suppresses the error message. In the case of successful completion the output value of IUER = 0.

Inside VTD only SI units are allowed, except the date. Dates are specified in a pair of MJD,TAI.

VTD is written in Fortran90 was tested under Linux, HP-UX and Sun operating systems. VTD depends on petools library and optionally on cfitsio library.

2 Strategy of computation

Computation of time delay and/or Doppler frequency shift is highly parameterized. Apriori data, names of variants of the algorithms for astronomical reductions are specified in the control file.

After parsing control file VTD needs apriori files to be loaded in the slots of internal data structures. VTD_LOAD loads station description file, station coordinate file, station velocity file, site eccentricity file. During this step it transforms units. It computes for each station longitude, geocentric and geodetic latitude, matrix of transformation from crust-fixed terrestrial reference system to Up(vertical)-East-North topocentric reference system, local gravity acceleration and the height above the reference ellipsoid. Then it loads source coordinates catalogue. Then it load series of pole coordinates and UT1 angles and computes coefficients of cubic spline for interpolation. Then it reads the file with DE403 ephemerides and parses it. Then it computes time-independent intermediate variables for solid Earth tides computation. These parameters depends only on station coordinates. Then it parses files with position variation models. In the case of harmonic

site position variations model it loads parameters of the models into slots of internal data structure. In the case if time series of position variations it computes interpolating polynomials for these variations.

Reading all these input files and making some computations which are time-independent is done only once. All remaining work is done by VTD_DELAY or VTD_DOPPLER.

VTD first checks whether the time epochs passed to as an argument is the same as in the previous call. If not, then it calls VTD_MOMENT which computes site-independent intermediate variables. It computes positions of the celestial bodies: the Moon and the Sun and all planets, except the Pluto using DE403 ephemerides. It computes pole coordinates and UT1-TAI using interpolation polynomials created by VTD_LOAD. It computes site-independent sums over constituents of the tide-generating potential for solid Earth's tides displacements computations. Then VTD_MOMENT computes the matrix of transformation from the terrestrial reference system to the celestial reference system. It may use either the Newcomb-Andoyer formalism for precession, nutation and stellar angle (Greenwich true stellar time) or the Empirical Earth rotation model formalism. In addition to nutation expansion, it applies the small perturbation to the transformation matrix specified in the external file in for form of harmonic expansion with cross terms (t* sin (omega*t _phase), t* cos (omega*t _phase))

Then VTD_DELAY checks whether site-dependent parameters for this particular epoch have been computed for the first and the second station of the baseline. If not, then it computes for each site station-specific parameters. This includes computation of the contribution due to antenna axis offset, solid Earth tides, pole tide, position variation models specified in the external files, troposphere/axis offset coupling. It applies site eccentricity, transforms coordinates from the crust fixed terrestrial reference frame to the celestial reference frame. Then it computes elevation and azimuth of the observing source at each station and computes atmospheric zenith path delay and the mapping function. Using these quantities VTD_DELAY computes apriori path delay at each station.

After calculation of site- and time- specific intermediate variables

VTD_DELAY computes geometric path delay and VTD_DOPPLER computes the Doppler frequency shift parameter. VTD_DELAY computes small troposphere-geometric coupling contribution. VTD_DELAY computes (not implemented on 2007.01.01) the contribution to delay due to source structure and ionosphere.

3 Interface to the subroutines

The program which calls VTD should have definition of the object VTD which are kept in the include block vtd.i , i.e. should have a statement

INCLUDE 'vtd.i'

3.1 VTD_INIT

```
      SUBROUTINE VTD_INIT ( VTD, IUER )

! *   Routine VTD_INIT  initializes object VTD. It should be called      *
! *   before first used of package VLBI Time Delay (VTD).                *
! *                                                                      *
! * _____________________________ Modified parameters: _____________________ *
! *                                                                      *
! *      VTD ( RECORD    ) -- Object which keeps configuration and data  *
! *                           related to VLBI Theoretical Delay (VTD)    *
! *                           package.                                   *
! *    IUER ( INTEGER*4, OPT ) -- Universal error handler.               *
! *                      Input: IUER=0 -- no error message will be       *
! *                                     printed even in the case         *
! *                                     of error.                        *
! *                             IUER=-1,-2,-3 -- in the case of error    *
! *                                     the message will be put on       *
! *                                     stdout.                          *
```

```
! *                     IUER=-3 -- in the case of error after    *
! *                             printing the error message    *
! *                             the program will terminate.   *
! *                 Output:                                   *
! *                     if input value of IUER =-2,-3 -- IUER    *
! *                             is not modified.              *
! *                     otherwise, the output value of IUER is 0 *
! *                     in the case of successful and             *
! *                     positive non-zero in the vase of errors. *

extern void vtd_init (
            char * vtd,
            int  * iuer
          ) ;
```

3.2 VTD_CONF

```
! *   Routine  VTD_CONF  parses configuration file of the package for    *
! *   computation of VLBI Time Delay (VTD) and stores results of parsing *
! *   in the internal fields of the object VTD.                          *
! *                                                                      *
! * ____________________________ Input parameters: ____________________________ *
! *                                                                      *
! * CONFIG_FILE ( CHARACTER ) -- Full path name of the configuration     *
! *                          file.                                       *
! *                                                                      *
! * ____________________________ Modified parameters: ____________________________ *
! *                                                                      *
! *     VTD ( RECORD    ) -- Object which keeps configuration and data   *
! *                     related to VLBI Theoretical Delay (VTD)     *
! *                     package.                                    *
! *    IUER ( INTEGER*4 ) -- Universal error handler argument.          *
! *                     Input:  switch IUER=0 -- no error messages  *
! *                          will be generated even in the case  *
! *                          of error. IUER=-1 -- in the case of *
```

```
! *                        error the message will be put on    *
! *                        stdout.                             *
! *                    Output: 0 in the case of successful     *
! *                        completion and non-zero in the      *
! *                        case of error.                      *

extern void vtd_conf (
            char * vtd_config_file,
            char * vtd,
            int  * iuer,
            int    sizeof_vtd_config_file
          ) ;
```

3.3 VTD_LOAD

```
! *   Routine  VTD_LOAD  loads lists of stations participated in the     *
! *   observing session, list of observed sources, time of the first and *
! *   the last observation. It puts station and sources list in the      *
! *   internal field of VTD. VTD reads the catalogue specified in the    *
! *   control file, reads the Earth orientation parameters file, reads   *
! *   planetary ephemerides, computes time-independent quantities needed *
! *   for solid Earth tide computations, loads position variations       *
! *   modes,  computes interpolating coefficients of site displacements  *
! *   if needed. VTD_LOAD  should be called before computation of time   *
! *   delay for the first observation.                                   *
! *                                                                      *
! * _____________________________ Input parameters: _____________________ *
! *                                                                      *
! *    L_STA ( INTEGER*4 ) -- The number of stations participating in    *
! *                           the experiment.                            *
! *    C_STA ( CHARACTER ) -- List of statation names participating in   *
! *                           the experiment. Dimenstion: L_STA.         *
! *    L_SOU ( INTEGER*4 ) -- The number of observed sources.            *
! *    C_SOU ( CHARACTER ) -- List of source names participating in      *
! *                           the experiment. Dimenstion: L_SOU.         *
```

```
! *   MJD_BEG ( INTEGER*4 ) -- Modified Julian data on the midnight of   *
! *                        the first observation. Units: days.       *
! *   TAI_BEG ( REAL*8    ) -- Moment of time of the first observation.  *
! *                        Units: sec.                               *
! *   MJD_END ( INTEGER*4 ) -- Modified Julian data on the midnight of   *
! *                        the last observation. Units: days.        *
! *   TAI_END ( REAL*8    ) -- Moment of time of the last observation.   *
! *                        Units: sec.                               *
! *                                                                  *
! * _____________________________ Modified parameters: _____________________ *
! *                                                                  *
! *    VTD ( RECORD    ) -- Object which keeps configuration and data   *
! *                        related to VLBI Theoretical Delay (VTD)     *
! *                        package.                                  *
! *    IUER ( INTEGER*4, OPT ) -- Universal error handler.              *
! *                     Input: IUER=0 -- no error message will be       *
! *                                    printed even in the case       *
! *                                    of error.                      *
! *                            IUER=-1,-2,-3 -- in the case of error    *
! *                                    the message will be put on     *
! *                                    stdout.                        *
! *                            IUER=-3 -- in the case of error after    *
! *                                     printing the error message    *
! *                                     the program will terminate.   *
! *                     Output:                                      *
! *                            if input value of IUER =-2,-3 -- IUER    *
! *                                     is not modified.             *
! *                            otherwise, the output value of IUER is 0 *
! *                            in the case of successful and            *
! *                            positive non-zero in the vase of errors. *

extern void vtd_load (
            char   * vtd,
            int    * l_sta,
            char   * c_sta,
            int    * l_sou,
            char   * c_sou,
```

```
        int    * mjd_beg,
     double * tai_beg,
        int    * mjd_end,
     double * tai_end,
        int    * iuer,
        int      sizeof_c_sta_element,
        int      sizeof_c_sou_element
      ) ;
```

3.4 VTD_METEO_IN

```
! *   Routine VTD_METEO_IN inserts atmospheric pressure and air          *
! *   temperature for station STANAM in the object VTD.                  *
! *                                                                      *
! * _____________________________ Input parameters: _____________________________ *
! *                                                                      *
! *   STANAM ( CHARACTER ) -- Name of the station of the baseline.       *
! *                           The station should be in the input         *
! *                           catalogue defined in the control file.     *
! * ATM_PRES ( REAL*8    ) -- Atmospheric pressure at the station in     *
! *                           Pascals.                                   *
! * AIR_TEMP ( REAL*8    ) -- Air temperature at the station in Kelvins. *
! * AIR_TEMP_EFF ( REAL*8  ) -- Effective air temperature for taking     *
! *                             into account thermal expansion of the    *
! *                             antenna (in Kelvins). It is up to the    *
! *                             analyst to descide which effective       *
! *                             temperature is the best. It was found    *
! *                             that the station air temperature lagged  *
! *                             2-3 hours gives the best agreement with  *
! *                             the in situ measuremenets.               *
! *                                                                      *
! * _____________________________ Modified parameters: _____________________________ *
! *                                                                      *
! *     VTD ( RECORD    ) -- Object which keeps configuration and data   *
```

```
! *                    related to VLBI Theoretical Delay (VTD)     *
! *                    package.                                    *
! *    IUER ( INTEGER*4, OPT ) -- Universal error handler.         *
! *                  Input: IUER=0 -- no error message will be     *
! *                               printed even in the case         *
! *                               of error.                        *
! *                         IUER=-1,-2,-3 -- in the case of error  *
! *                               the message will be put on       *
! *                               stdout.                          *
! *                         IUER=-3 -- in the case of error after  *
! *                                printing the error message      *
! *                                the program will terminate.     *
! *                   Output:                                      *
! *                         if input value of IUER =-2,-3 -- IUER  *
! *                                is not modified.                *
! *                         otherwise, the output value of IUER is 0 *
! *                         in the case of successful and          *
! *                         positive non-zero in the vase of errors. *

extern void vtd_meteo_in (
            char   * vtd,
            char   * sta_nam,
            double * pres,
            double * temp,
            double * humid,
            int    * iuer,
            int      sizeof_sta_nam
          ) ;
```

3.5 VTD_DELAY

```
! *   Routine  VTD_DELAY  is the main routine of the package for       *
! *   computation of the VLBI Time Delay (VTD). It computes group delay  *
! *   and phase delay as well as partial derivatives of group delay and  *
```

```
! *   delay rate with respect to parameters of the model at the          *
! *   specified moment of time, for the specified pair of stations and   *
! *   for the specified source using the model specified from the        *
! *   control file previously loaded into the data structure VTD.        *
! *   It is assumed that routines VTD_INIT, VTD_CONF and VTD_LOAD were   *
! *   called before the call of VTD_DELAY.                               *
! *                                                                      *
! *   VLBI Time delay is defined as the difference of two intervals of   *
! *   proper time: 1) the interval of proper time of station #2 between  *
! *   events: coming the wave front to the reference point on the moving *
! *   axis and clock synchronization; 2) the interval of proper time of  *
! *   station #1 between events: coming the wave front to the reference  *
! *   point on the moving axis and clock synchronization. The time delay *
! *   is referred to the moment of coming the wave front to the          *
! *   reference point on the moving axis of the first antenna at time    *
! *   measured by the time scale TAI. The reference point of the station *
! *   for which modeling is done is defined as the point on the moving   *
! *   axes which has the minimal distance to the fixed axis. In the      *
! *   case if axes intersect, this is the point of intersection.         *
! *                                                                      *
! *   Precision of computation of VLBI time delay is deemed to be no     *
! *   worse than 1.D-12 seconds, precision of computation of delay rate  *
! *   is no worse than 1.D-15 . Accuracy of computation of time delay    *
! *   is limited by accuracy of a priori information. It can be as good  *
! *   as 1.0D-10 .                                                       *
! *                                                                      *
! * _____________________________ Input parameters: _____________________________ *
! *                                                                      *
! *  SOU_NAM ( CHARACTER ) -- Name of the source. The source should      *
! *                           be in the input catalogue defined in the   *
! *                           control file.                              *
! * STA1_NAM ( CHARACTER ) -- Name of the first station of the baseline. *
! *                           The station should be in the input         *
! *                           catalogue defined in the control file.     *
! * STA2_NAM ( CHARACTER ) -- Name of the second station of the baseline.*
! *                           The station should be in the input         *
! *                           catalogue defined in the control file.     *
```

```
! *     MJD ( INTEGER*4 ) -- Modified Julian date of the midnight of    *
! *                          the observation.                           *
! *     TAI ( INTEGER*4 ) -- Time of the observations in seconds at     *
! *                          time scale TAI elapsed from the midnight.  *
! *  OBS_TYP ( VTD__OBS_TYPE ) -- The object with information about     *
! *                               observation type, polarization and  *
! *                               frequency setup of the experiment.  *
! *                               It is used for                      *
! *                              1) computing source structure        *
! *                               contribution;                       *
! *                              2) computing ionospheric contribution; *
! *                              3) computing contribution to phase    *
! *                               caused by delay parallactic angle   *
! *                               rotation.                           *
! *    Fields of VTD__OBS_TYPE:                                       *
! *                                                                   *
! *    INTEGER*4   %L_FRQ  ! The number of frequency channels within the *
! *                        band                                       *
! *    CHARACTER*2 %PLRZ   ! Polarization at each band: RR, LL, RL or LR *
! *                        'RR' -- both antennas observed right       *
! *                             circular polarization;                *
! *                        'LL' -- both antennas observed right       *
! *                             circular polarization;                *
! *                        'LR' -- Reference antenna observed left    *
! *                             circular polarization and another     *
! *                             antenna observed right circular       *
! *                             polarization.                         *
! *                        'RL' -- Reference antenna observed left    *
! *                             circular polarization and another     *
! *                             antenna observed right circular       *
! *                             polarization.                         *
! *                        'NO' -- Contribution due to parallactic    *
! *                             angle correction is not computed.     *
! *    INTEGER*4   %STATUS  ! Status: VTD__UNDF, VTD__BND, VTD__CHN    *
! *                        VTD__UNDF -- ! Frequency setup is undefined. *
! *                                     This indicates that no        *
! *                                     information about frequencies *
```

```
! *                          and polarization is available.*
! *                  VTD__BND  -- ! Frequency channel setup is    *
! *                          undefined, but the reference  *
! *                          frequency, effective          *
! *                          ionospheric frequencies and   *
! *                          polarization are known.       *
! *                  VTD__CHN  -- ! Frequency channel setup is    *
! *                          known. Effective ionospheric  *
! *                          frequencies are computed on   *
! *                          the fly.                      *
! *   INTEGER*4   %N_BND ! Number of either bands or channel depending  *
! *                  on the status.                         *
! *   INTEGER*4   %DELAY_TYPE ! Delay type. Delay type depends on       *
! *                     band: low or high and on observable for *
! *                     each band: phase delay, multi-band      *
! *                     delay, narrow-band delay. The list of   *
! *                     supported combination is defined in     *
! *                     vtd.i                                   *
! *   CHARACTER   %EXP_NAME    ! Experiment name. Experiment name may   *
! *                     ! be used for gaining access to external *
! *                     ! calibration files.                    *
! *   CHARACTER   %SCAN_NAME   ! Scan name. Scan name may be used for   *
! *                     ! gaining access to external calibration *
! *                     ! files.                                *
! *   REAL*8      %FRQ ! Array of cyclic frequencies. Dimension %L_FRQ. *
! *   REAL*8      %WEI ! Array of channel weights. Dimension %L_FRQ.    *
! *   REAL*8      %FRQ_REF  ! Reference frequency per band.             *
! *   REAL*8      %FRQ_ION_EFF ! Effective cyclic ionosphere            *
! *                     ! frequency for this type of delay       *
! *                     ! contribution. Units: Herz.             *
! *                                                              *
! *   If no information about frequencies and polarization is          *
! *   available, set OBS_TYP%STATUS to VTD__UNDF. Then contents        *
! *   of  OBS_TYP will be ignored and contribution to delay caused     *
! *   by the ionosphere, source structure and parallactic anlge        *
! *   rotation will be set to zero.                                    *
! *                                                              *
```

```
! * _____ Output parameters: _____ *
! *                                                                *
! *    DELAY ( REAL*8    ) -- VLBI time delay. Units: seconds.       *
! *     RATE ( REAL*8    ) -- VLBI delay rate. Units: dimensionless. *
! *  DER_DEL ( REAL*8    ) -- Vector of partial derivatives of group *
! *                           delay with respect to parameters of the *
! *                           model or some important intermediate    *
! *                           quantities. Dimension: DER__NDER.       *
! *           Symbolic names of the indexes of the partial derivatives *
! *           in the array DER_DEL are defined in vtd.i .             *
! *           Their meaning:                                          *
! *                                                                   *
! *           VTD__DER_E1    -- Earth rotation Euler angle 1          *
! *           VTD__DER_E2    -- Earth rotation Euler angle 2          *
! *           VTD__DER_E3    -- Earth rotation Euler angle 3          *
! *           VTD__DER_ST1X  -- Station 1, X coordinate               *
! *           VTD__DER_ST1Y  -- Station 1, Y coordinate               *
! *           VTD__DER_ST1Z  -- Station 1, Z coordinate               *
! *           VTD__DER_ST2X  -- Station 2, X coordinate               *
! *           VTD__DER_ST2Y  -- Station 2, Y coordinate               *
! *           VTD__DER_ST2Z  -- Station 2, Z coordinate               *
! *           VTD__DER_RA    -- Right ascension of the far-zone source *
! *           VTD__DER_DL    -- Declination of the far-zone source    *
! *           VTD__DER_AT1   -- Station 1, atmospheric path delay     *
! *           VTD__DER_AT2   -- Station 2, atmospheric path delay     *
! *           VTD__DER_ATN1  -- Station 1, atmospheric north tilt     *
! *           VTD__DER_ATE1  -- Station 1, atmospheric east  tilt     *
! *           VTD__DER_ATN2  -- Station 2, atmospheric north tilt     *
! *           VTD__DER_ATE2  -- Station 2, atmospheric east  tilt     *
! *           VTD__DER_POS1  -- Position of near zone object, X coord. *
! *           VTD__DER_POS2  -- Position of near zone object, Y coord. *
! *           VTD__DER_POS3  -- Position of near zone object, Z coord. *
! *           VTD__DER_VEL1  -- Velocity of near zone object, X coord. *
! *           VTD__DER_VEL2  -- Velocity of near zone object, Y coord. *
! *           VTD__DER_VEL3  -- Velocity of near zone object, Z coord. *
! *           VTD__DER_AXF1  -- Antenna axis offset length 1st antenna. *
! *           VTD__DER_AXF2  -- Antenna axis offset length 2nd antenna. *
```

```
! *                                                    *
! *          VTD__ELEV1     -- Elevation angle of the 1st antenna      *
! *          VTD__ELEV2     -- Elevation angle of the 2nd antenna      *
! *          VTD__AZIM1     -- Aximuth angle of the 1st antenna        *
! *          VTD__AZIM2     -- Aximuth angle of the 2nd antenna        *
! *          VTD__TROP1      -- Slanted troposphere path at the        *
! *                     1st antenna.                    *
! *          VTD__TROP2     -- Slanted troposphere path at the         *
! *                     2nd antenna.                    *
! *          VTD__IONO1     -- Slanted ionosphere  path at the         *
! *                     1st antenna.                    *
! *          VTD__IONO2     -- Slanted ionosphere  path at the         *
! *                     2nd antenna.                    *
! *          VTD__TRP_HZD1  -- Hydrostatic troposphere path delay in   *
! *                     zentith at the 1st antenna.           *
! *          VTD__TRP_HZD2  -- Hydrostatic troposphere path delay in   *
! *                     zentith at the 2nd antenna.           *
! *          VTD__TRP_WZD1  -- Non-hydrostatic troposphere path delay  *
! *                     in zentith at the 1st antenna.        *
! *          VTD__TRP_WZD2  -- Non-hydrostatic troposphere path delay  *
! *                     in zentith at the 1nd antenna.        *
! *          VTD__PARAL1    -- Parallactic agle at the 1st antenna     *
! *          VTD__PARAL2    -- Parallactic agle at the 2nd antenna     *
! *          VTD__STRUC     -- Contribution of the source structure    *
! *                     to time delay.                  *
! *                                                    *
! *  DER_RAT ( REAL*8    ) -- Vector of partial derivatives of phase     *
! *                     delay rate with respect to parameters of   *
! *                     the model. Dimension: DER__NDER.          *
! *                                                    *
! * _____________________________ Modified parameters: _____________________ *
! *                                                    *
! *    VTD ( RECORD    ) -- Object which keeps configuration and data   *
! *                     related to VLBI Theoretical Delay (VTD)     *
! *                     package.                        *
! *    IUER ( INTEGER*4, OPT ) -- Universal error handler.             *
! *                   Input: IUER=0 -- no error message will be       *
```

```
! *                          printed even in the case       *
! *                          of error.                      *
! *                     IUER=-1,-2,-3 -- in the case of error    *
! *                          the message will be put on     *
! *                          stdout.                        *
! *                     IUER=-3 -- in the case of error after    *
! *                           printing the error message    *
! *                           the program will terminate.   *
! *                Output:                                   *
! *                     if input value of IUER =-2,-3 -- IUER    *
! *                           is not modified.              *
! *                     otherwise, the output value of IUER is 0 *
! *                     in the case of successful and          *
! *                     positive non-zero in the vase of errors. *
! *                                                           *

extern void vtd_delay (
            char         * sou_nam,
            char         * sta_nam1,
            char         * sta_nam2,
            int          * mjd_obs,
            double       * tai_obs,
      vtd__obs_type * obs_typ,
            char         * vtd,
            double       * tau,
            double       * rate_ph,
            double       * der_del,
            double       * der_rat,
            int          * iuer,
            int            sizeof_sou_nam,
            int            sizeof_sta_nam1,
            int            sizeof_sta_nam2
           ) ;
```

3.6 VTD_DOPPLER

```
! ************************************************************************
! *                                                                      *
! *   Routine  VTD_DOPPLER is the main routine of the package VTD for    *
! *   computation of the Doppler frequency shift parameter. It computes  *
! *   also partial derivatives of the Doppler frequency shift parameter  *
! *   with respect to parameters of the model at the specified moment of *
! *   time, for the specified stations and for the specified near zone    *
! *   source using the model specified from the control file previously  *
! *   loaded into the data structure VTD. It is assumed that routines    *
! *   VTD_INIT, VTD_CONF and VTD_LOAD were called before the call        *
! *   of VTD_DO.                                                         *
! *                                                                      *
! *   The Doppler frequency shift parameter is defined as a ratio of     *
! *   the observed frequency to the emitted frequency minus 1.           *
! *                                                                      *
! *   Precision of computation of VLBI time delay is deemed to be no     *
! *   worse than 1.D-11 .                                                *
! *                                                                      *
! *   CAVEAT: as of 2007.01.11, computation of partial derivatives is    *
! *         not implemented.                                             *
! *                                                                      *
! *                                                                      *
! * _____________________________ Input parameters: _____________________ *
! *                                                                      *
! *  SOU_NAM ( CHARACTER ) -- Name of the source. The source should      *
! *                           be in the input catalogue defined in the   *
! *                           control file.                              *
! *  STA_NAM ( CHARACTER ) -- Name of the station. The station name      *
! *                           should be in the input catalogue defined   *
! *                           in the control file.                       *
! *     MJD ( INTEGER*4 ) -- Modified Julian date of the midnight of     *
! *                           the observation.                           *
! *     TAI ( INTEGER*4 ) -- Time of the observations in seconds at      *
! *                           time scale TAI elapsed from the midnight.  *
! *                                                                      *
```

```
! * _____________________________ Output parameters: _____________________________ *
! *                                                                               *
! *    D_FRQ ( REAL*8    ) -- The Doppler frequency shift parameter      *
! *                           defined as a ratio of the observed         *
! *                           frequency to the emitted frequency minus 1.*
! *  DER_DEL ( REAL*8    ) -- Vector of partial derivatives of the       *
! *                           Doppler frequency ratio with respect       *
! *                           to parameters of the model. Dimension:     *
!                            DER__NDER.                                  *
! *           Symbolic names of the indexes of the partial derivatives  *
! *           in the array DER_DEL are defined in vtd.i .               *
! *           Their meaning:                                            *
! *                                                                     *
! *           VTD__DER_E1    -- Earth rotation Euler angle 1            *
! *           VTD__DER_E2    -- Earth rotation Euler angle 2            *
! *           VTD__DER_E3    -- Earth rotation Euler angle 3            *
! *           VTD__DER_ST1X  -- Station, X coordinate                   *
! *           VTD__DER_ST1Y  -- Station, Y coordinate                   *
! *           VTD__DER_ST1Z  -- Station, Z coordinate                   *
! *           VTD__DER_RA    -- Right ascension of the far-zone source  *
! *           VTD__DER_DL    -- Declination of the far-zone source      *
! *           VTD__DER_POS1  -- Position of near zone object, X coord.  *
! *           VTD__DER_POS2  -- Position of near zone object, Y coord.  *
! *           VTD__DER_POS3  -- Position of near zone object, Z coord.  *
! *           VTD__DER_VEL1  -- Velocity of near zone object, X coord.  *
! *           VTD__DER_VEL2  -- Velocity of near zone object, Y coord.  *
! *           VTD__DER_VEL3  -- Velocity of near zone object, Z coord.  *
! *                                                                     *
! *  DER_FRQ ( REAL*8    ) -- Vector of partial derivatives of phase     *
! *                           delay rate with respect to parameters of   *
! *                           the model. Dimension: DER__NDER.           *
! *                                                                     *
! * _____________________________ Modified parameters: _____________________________ *
! *                                                                               *
! *     VTD ( RECORD    ) -- Object which keeps configuration and data   *
! *                          related to VLBI Theoretical Delay (VTD)     *
! *                          package.                                    *
```

```
! *    IUER ( INTEGER*4, OPT ) -- Universal error handler.              *
! *                  Input: IUER=0 -- no error message will be       *
! *                                 printed even in the case       *
! *                                 of error.                      *
! *                         IUER=-1,-2,-3 -- in the case of error    *
! *                                 the message will be put on     *
! *                                 stdout.                        *
! *                         IUER=-3 -- in the case of error after    *
! *                                  printing the error message    *
! *                                  the program will terminate.   *
! *                  Output:                                         *
! *                         if input value of IUER =-2,-3 -- IUER    *
! *                                  is not modified.              *
! *                         otherwise, the output value of IUER is 0 *
! *                         in the case of successful and           *
! *                         positive non-zero in the vase of errors. *
! *                                                                 *
```

3.7 VTD_READ_NZO

```
! *   Routine  VTD_READ_NZO  reads the input file FILNZO with           *
! *   coordinates of the near zone object, parses it and return arrays   *
! *   of coordinates of the near zone object and time tags associated    *
! *   with these coordinates.                                           *
! *                                                                     *
! * _____________________________ Input parameters: _____________________________ *
! *                                                                     *
! *   FILNZO ( CHARACTER ) -- Name of the file with coordinates of the   *
! *                           the near zone objects. The file should     *
! *                           comply specifications of the              *
! *                           "Apriori positions of a near zone object". *
! * NZO_NAME ( CHARACTER ) -- Name of the near zone object.             *
! * OBJ_TYPE ( CHARACTER ) -- Type of the near zone object.             *
! *                           Support types:                            *
! *                           VTD__MG  -- Extra-galactic object         *
```

```
! *                    VTD__GAL -- Galactic object              *
! *                    VTD__ES  -- Near zone object near Earth  *
! *   M_ARR ( INTEGER*4 ) -- The maximal points in the output arrays  *
! *                    of near zone objects.                    *
! *                                                             *
! * _____________________________ Output parameters: _____________________________ *
! *                                                             *
! *   L_ARR ( INTEGER*4 ) -- The number of points in the array of     *
! *                    the near zone object positions.          *
! *  MJD_ARR ( INTEGER*4 ) -- Array of MJD dates of position arrays of  *
! *                    near zone objects. Dimension: L_ARR.     *
! *  TAI_ARR ( INTEGER*4 ) -- Array of TAU time tags of dates of       *
! *                    position arrays of near zone objects.    *
! *                    Dimension: L_ARR.                        *
! *  POS_ARR ( INTEGER*4 ) -- Array of positions of the near zone      *
! *                    object. Units: meters. Dimension: 3,L_ARR. *
! *  VEL_ARR ( INTEGER*4 ) -- Array of velocities of the near zone     *
! *                    object. Units: m/s. Dimension: 3,L_ARR.  *
! * CENTER_NAME ( CHARACTER ) -- Name of the center of the coordinate  *
! *                      system. Supported names:               *
! *                      "EARTH BARYCENTER"                     *
! *                      "SOLAR SYSTEM BARICENTER"              *
! *   REF_NAME ( CHARACTER ) -- Reference system name. Supported names: *
! *                      "EME2000"                              *
! * TIM_CODE ( INTEGER*4 ) -- Time code of time tags. One of          *
! *                    VTD__TDB, VTD__TDT .                     *
! * COO_CODE ( INTEGER*4 ) -- Code of the metric of the coordinate    *
! *                    system. Supported codes:                 *
! *                    VTD__BRS, VTD__IERS1992, VTD__GRS .      *
! *                                                             *
! * _____________________________ Modified parameters: _____________________________ *
! *                                                             *
! *  IUER ( INTEGER*4, OPT ) -- Universal error handler.              *
! *                    Input: switch IUER=0 -- no error messages  *
! *                         will be generated even in the case  *
! *                         of error. IUER=-1 -- in the case of *
! *                         error the message will be put on    *
```

```
! *                    stdout.                    *
! *                Output: 0 in the case of successful      *
! *                    completion and non-zero in the    *
! *                    case of error.                *
! *                                                  *
! * ### 02-JAN-2006  VTD_READ_NZO   v2.0 (c) L. Petrov  11-JUN-2012 ###  *
```

3.8 VTD_LOAD_NZO

```
! *   Routine  VTD_LOAD_NZO  computes coefficients of the B-spline      *
! *   expansion of coordinates of the near zone object and loads them    *
! *   in the appropriate fields of the VTD object. Coordinates of the    *
! *   near-zone objects are supposed to be read by VTD_READ_NZO. These   *
! *   coordinates and time tags are passed to VTD_LOAD_NZO.             *
! *                                                  *
! *   The coefficients of the expansion will be used by other routines   *
! *   of the VTD library for computation of position, velocity and       *
! *   acceleration of the near zone object for calculation of VLBI       *
! *   path delay and/or Doppler frequency shift.                         *
! *                                                  *
! * ____________________________ Input parameters: ____________________________ *
! *                                                  *
! * NZO_NAME ( CHARACTER ) -- Name of the near zone object.            *
! * OBJ_TYPE ( CHARACTER ) -- Type of the near zone object.            *
! *                Support types:                    *
! *                VTD__MG  -- Extra-galactic object.        *
! *                VTD__GAL -- Galactic object.              *
! *                VTD__SS  -- Solar system object.          *
! *                VTD__ES  -- Near Earth object.            *
! * OBJ_USED ( CHARACTER ) -- Type of the near zone object.            *
! *                VTD__EM  -- Observed emitter.             *
! *                VTD__OR  -- Observing orbiting antenna.   *
! * TIM_CODE ( INTEGER*4 ) -- Time code of time tags. One of           *
! *                VTD__TDB, VTD__TDT, VTD__UTC, VTD__TAI.   *
! *    L_ARR ( INTEGER*4 ) -- The number of points in the array of      *
```

```
! *                     the near zone object positions.           *
! *  MJD_ARR ( INTEGER*4 ) -- Array of MJD dates of position arrays of   *
! *                     near zone objects. Dimension: L_ARR.      *
! *  TAI_ARR ( INTEGER*4 ) -- Array of TAU time tags of dates of        *
! *                     position arrays of near zone objects.     *
! *                     Dimension: L_ARR.                         *
! *  POS_ARR ( INTEGER*4 ) -- Array of positions of the near zone       *
! *                     object. Units: meters. Dimension: 3,L_ARR. *
! *    L_NOD ( INTEGER*4 ) -- The number of nodes for the B-spline basis *
! *                     of the expansion.                         *
! *    L_DEG ( INTEGER*4 ) -- The degree of the B-spline basis.         *
! *                                                               *
! * _____________________________ Modified parameters: _____________________________ *
! *                                                               *
! *       VTD ( RECORD    ) -- Object which keeps configuration and data *
! *                     related to VLBI Theoretical Delay (VTD)   *
! *                     package.                                  *
! *  IUER ( INTEGER*4, OPT ) -- Universal error handler.              *
! *                     Input: switch IUER=0 -- no error messages  *
! *                          will be generated even in the case   *
! *                          of error. IUER=-1 -- in the case of  *
! *                          error the message will be put on     *
! *                          stdout.                              *
! *                     Output: 0 in the case of successful       *
! *                          completion and non-zero in the       *
! *                          case of error.                       *
! *                                                               *
! *  ### 01-JAN-2006  VTD_LOAD_NZO  v2.0 (c) L. Petrov  13-JUN-2012  ### *
```

3.9 VTD_LT_ORB

```
! *   Routine VTD_LT_ORB computes the light time between the ground      *
! *   station STA_GRO and orbiting station STA_ORB at the moment of time *
! *   MJD,TAI on the clock synchronized with TAI for the ground station. *
! *   It is assumed that the ephemeride of the orbiting station and the  *
```

```
! *   catalogue of ground stations has already been loaded.           *
! *                                                                   *
! * _____________________________ Input parameters: _____________________________ *
! *                                                                   *
! *     VTD ( RECORD    ) -- Object which keeps configuration and data   *
! *                          related to VLBI Theoretical Delay (VTD)     *
! *                          package.                                    *
! * STA_GRO ( CHARACTER ) -- Name of the ground station.                 *
! * STA_ORB ( CHARACTER ) -- Name of the orbiting station.               *
! *                          The station should be in the input          *
! *                          catalogue defined in the control file.      *
! *     MJD ( INTEGER*4 ) -- Modified Julian date of the midnight of     *
! *                          the observation.                            *
! *     TAI ( INTEGER*4 ) -- Time of the observations in seconds at      *
! *                          time scale TAI elapsed from the midnight.   *
! *                                                                   *
! * _____________________________ Output parameters: _____________________________ *
! *                                                                   *
! *      LT ( REAL*8    ) -- time for propagation of light in vacuum     *
! *                          from the ground station to the orbiting     *
! *                          station.                                    *
! *                                                                   *
! * _____________________________ Modified parameters: _____________________________ *
! *                                                                   *
! *    IUER ( INTEGER*4, OPT ) -- Universal error handler.              *
! *                      Input: IUER=0 -- no error message will be      *
! *                                       printed even in the case      *
! *                                       of error.                     *
! *                             IUER=-1,-2,-3 -- in the case of error   *
! *                                       the message will be put on    *
! *                                       stdout.                       *
! *                             IUER=-3 -- in the case of error after   *
! *                                       printing the error message    *
! *                                       the program will terminate.   *
! *                      Output:                                        *
! *                             if input value of IUER =-2,-3 -- IUER   *
! *                                       is not modified.              *
```

```
! *                    otherwise, the output value of IUER is 0 *
! *                    in the case of successful and           *
! *                    positive non-zero in the vase of errors. *
! *                                                            *
! *  ### 14-JUN-2012   VTD_LT_ORB  v1.0 (c)  L. Petrov  14-OCT-2012 ###  *
```

3.10 VTD_REL_ORB

```
! *   Routine VTD_REL_ORB computes the time dilation for a VLBI station  *
! *   which is on the orbit. The dilation is computed for interval       *
! *   of geocentric time coordinates MJD_BEG/TCG_BEG, MJD_END/TCG_END.   *
! *   It does this computation by evaluating the integral using          *
! *   coefficients of spline interpolation which were computed by        *
! *   routine VTD_LOAD_NZO.                                              *
! *                                                                      *
! * _____________________________ Input parameters: _____________________________ *
! *                                                                      *
! *    VTD ( VTD__TYPE ) -- Object which keeps configuration and data    *
! *                    related to VLBI Theoretical Delay (VTD)           *
! *                    package.                                          *
! * STA_ORB ( CHARACTER ) -- Name of the orbiting station.               *
! *                    The station should be in the input                *
! *                    catalogue defined in the control file.            *
! * MJD_BEG ( INTEGER*4 ) -- Modified Julian date of the midnight of     *
! *                    the beginning of the interval.                    *
! * TCG_BEG ( REAL*8    ) -- Geocentric time coordinate for beginning of *
! *                    the interval.                                     *
! * MJD_END ( INTEGER*4 ) -- Modified Julian date of the midnight of     *
! *                    the end of the interval.                          *
! * TCG_END ( REAL*8    ) -- Geocentric time coordinate for end of       *
! *                    the interval.                                     *
! *                                                                      *
! * _____________________________ Modified parameters: ____________________________ *
! *                                                                      *
! *    IUER ( INTEGER*4, OPT ) -- Universal error handler.               *
```

```
! *                  Input: IUER=0 -- no error message will be      *
! *                              printed even in the case       *
! *                              of error.                      *
! *                         IUER=-1,-2,-3 -- in the case of error    *
! *                              the message will be put on     *
! *                              stdout.                        *
! *                         IUER=-3 -- in the case of error after    *
! *                               printing the error message    *
! *                               the program will terminate.   *
! *                  Output:                                     *
! *                         if input value of IUER =-2,-3 -- IUER    *
! *                               is not modified.              *
! *                         otherwise, the output value of IUER is 0 *
! *                         in the case of successful and           *
! *                         positive non-zero in the vase of errors. *
```

3.11 VTD_QUIT

```
! *   Routine VTD_QUIT  releases memory allocated by internal data       *
! *   structures of package VLBI Time Delay (VTD).                       *
! *                                                                      *
! * _____________________________ Modified parameters: _____________________________ *
! *                                                                      *
! *      VTD ( RECORD    ) -- Object which keeps configuration and data *
! *                           related to VLBI Theoretical Delay (VTD)   *
! *                           package.                                  *
! *  IUER ( INTEGER*4, OPT ) -- Universal error handler.                 *
! *                          Input: switch IUER=0 -- no error messages  *
! *                               will be generated even in the case  *
! *                               of error. IUER=-1 -- in the case of *
! *                               error the message will be put on    *
! *                               stdout.                             *
! *                          Output: 0 in the case of successful        *
! *                                completion and non-zero in the     *
! *                                case of error.                     *
```

```
! *                                                    *
! *  ### 14-APR-2006    VTD_QUIT   v1.6 (c)  L. Petrov  29-APR-2008 ###  *

extern void vtd_quit (
            char * vtd,
            int  * iuer
           ) ;
```

3.12 VTD_GET_VERSION

```
! *   Returns the VTD label with version.                    *
! *                                                          *
! * _____________________________ Modified parameters: _____________________________ *
! *                                                          *
! *       STR ( CHARACTER ) -- Version name of the VTD.              *

extern void   vtd_get_version (
              char * vtd_version,
              int    sizeof_vtd_version
             ) ;
```

Questions and comments about this guide should be directed to:

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