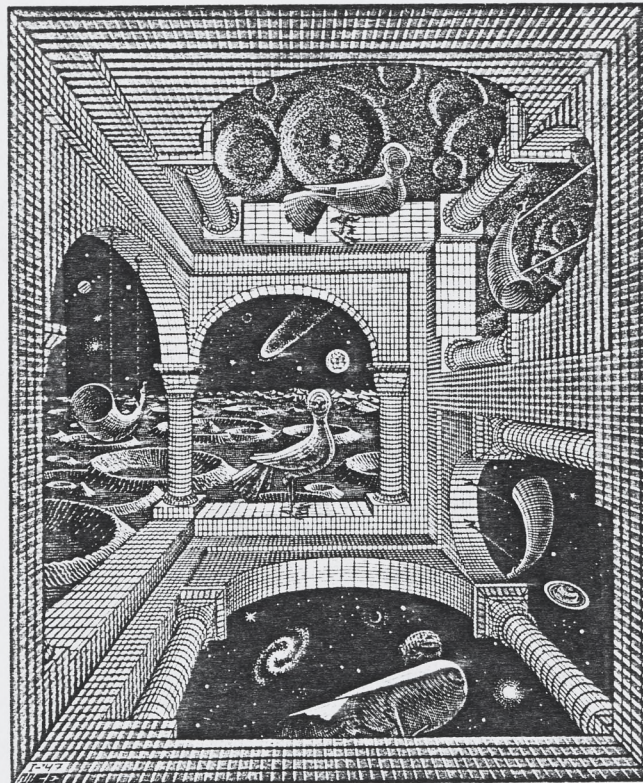


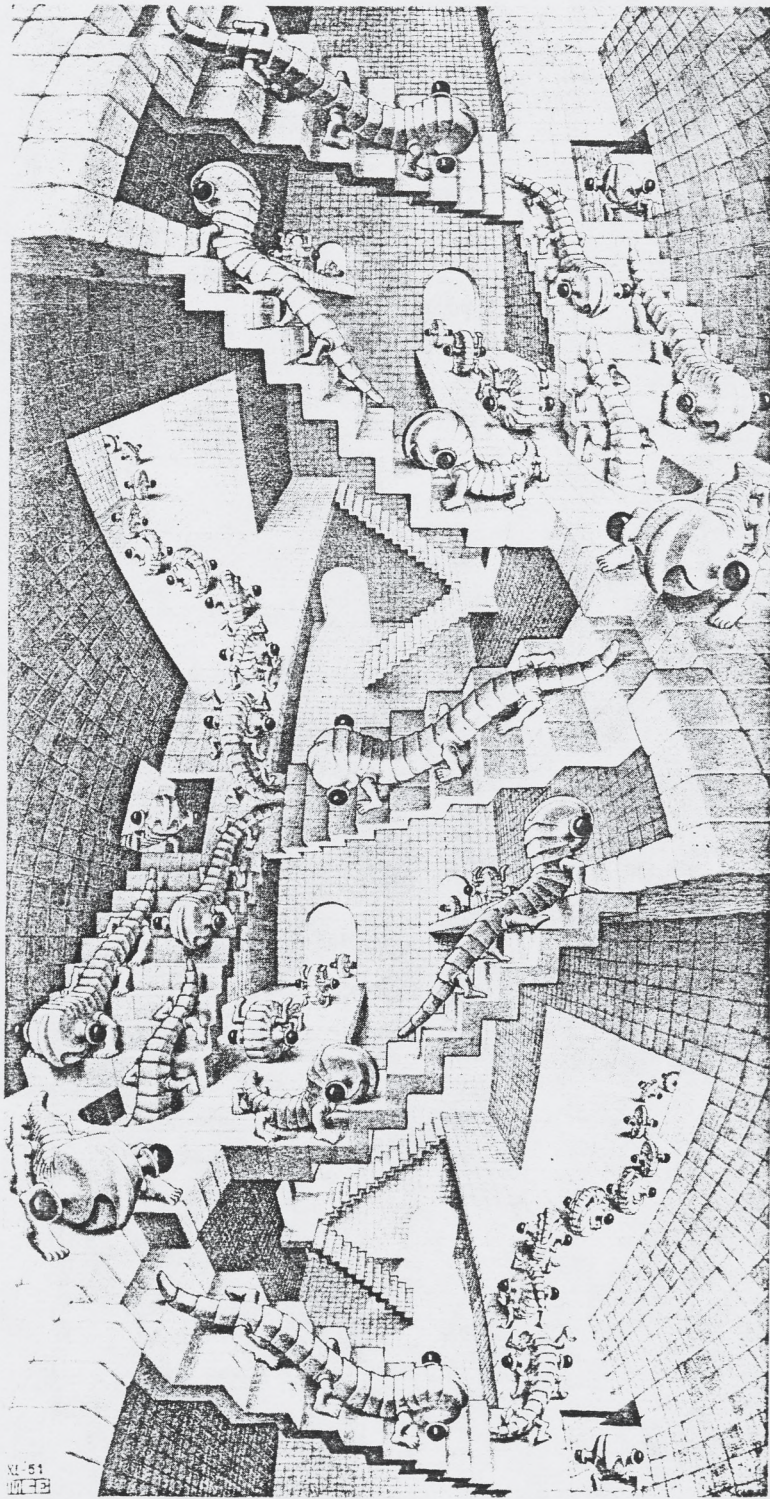
A SHORT GUIDE FOR VLA SPECTRAL LINE OBSERVERS

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This new edition of the "Short Guide" has a slightly different format. It attempts to be more complete so that users do not have to collect documentation from umpteen different places to get the complete picture; it is hoped that this document and the Observer's Reference Manual suffice. All sections and subsections of this Guide are dated so that it should be possible for the user to find out what has been changed since he ran off his copy three visits to the VLA ago.

The first two chapters give some basic information on the VLA spectral line reduction process and the philosophy of the DEC-10 software, and are essentially meant for novices. The rest of the chapters goes through the whole reduction process step-by-step, all the way from preparing for observing to display of the results. The discussion in these sections is on the fundamental level; for details on the mechanics of specific programs (inputs, examples, etc.) the user be referred to the Observer's Reference Manual (ORM). Additional background reading may be found in chapters 8 and 15 of "Synthesis Mapping", the proceedings of the NRAO-VLA workshop.

Appendix D documents some MIC files, canned procedures to perform particularly boring jobs like running SPECTR a dozen times.

Appendix E gives temporary update notes and a list of known specific spectral line bugs.

It is very important to realize that the VLA Spectral Line System is still in an experimental state; there are a number of pitfalls, but almost anything can be done - although not all of it is easy. The three most important ingredients for success are READ, ASK, and RELAX. Make sure you are familiar with the system (e.g., by reading and trying to understand this document) before you start; it does save time in the end. If you are, at any point, not sure of what you are doing, try to find the answer in the documentation and, if you can't find it there, ask a VLA staff member or an experienced user; they are happy to give you advice. Finally, allow yourself ample time to reduce your data; a typical line observer collects 40 million bytes of information, several orders of magnitude more than during a typical single dish run, and one cannot expect to reduce and digest that much in just a few days; besides, although the rush and panic just before leaving the VLA site is probably unavoidable, one should not build it in from the start since it definitely increases the error rate and, hence, decreases your efficiency.

This section only means to give an overview of the various steps involved in the reduction process. First, the various VLA computers are described, then the reduction flow.

2.1. The Computers at the VLA Site

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The computers at the VLA fall into four major categories: the MODCOMPs, the DEC-10, the PDP-11s, and the VAXes.

The MODCOMPs constitute the on-line computer system, taking care of array control, monitoring, and data collection. Usually, the user never interacts with them; they are the domain of the array operator. The Observe File, made by the user on the DEC-10, is brought over to the MODCOMPs by the operator and the observations are carried out by the MODCOMPs following the instructions contained in this file. Some on-line display of the data (single integration-single base line total fluxes and spectra) is available upon request to the operator. The data are written onto magnetic tape and passed on to the DEC-10 via a fixed head disk.

The DEC-10 is the general-purpose mainframe computer used for inspection, calibration, and editing of the data. The user's data base is filled from the fixed head disk or tape, and there is a large number of programs available - all using the same user interface - to perform these three basic tasks. In addition, the visibility data can be sent to one of the PDP-11s for mapping or written onto an Export Tape for processing on one of the VAXes or elsewhere. Also all observing preparation is done on the DEC-10. All user terminals are connected to the DEC-10.

The PDP-11s are special-purpose computers in the map and post-map domain, and are being wrought into the "pipeline" mapping system. They appear as slaves of the DEC-10. The most important ones for the user are MAPPER (PDP-11/70) which does self-cal, mapping, and cleaning from continuum data bases, SORTER (PDP-11/70) which does quick-look mapping from spectral line data bases, and DISPLY (PDP-11/44) which does map display and analysis (single, two-dimensional maps only). Maps can be moved from MAPPER or SORTER to DISPLY by the program GETMAP or by FITS tape; maps can be taken from all PDP-11s by FITS tape. DISPLY is sometimes called IMPS, after the name of the image display system that runs on it.

The VAXes are used for running AIPS, offering all data handling beyond the calibration (selfcal, mapping, cleaning, map display and analysis on two- or three-dimensional maps). They are equipped with an array processor and IIS image display computer. For data input they accept Export or FITS tapes.

All VAXes (including the one in Charlottesville) and PDP-11s are connected by DECNET; VAX #1 is the central VAX node, MAPPER the central PDP-11 node. The DEC-10 is also connected to MAPPER in a rather non-transparent way.

A flow diagram of VLA data reduction is shown in Appendix A.

The first thing to do is to run the program SPFINX. There are certain things about your spectral line data that the DEC-10 does not know. SPFINX enters these upon your specification into the data base.

Then it is time to worry about the system temperature corrections. These can range from no correction at all to a very involved operation, depending on the nature of the observations. Spectral line data are not corrected for system temperature on-line, as are continuum observations, since there may in some cases be a considerable line contribution in the narrow band single dish spectra. The programs to be used are GTBCOR or GTTSYS or (GTTSYS and MONLST).

Next, one has to assess the quality of the data. The tools available are: SPECPL (plots spectra of individual base lines), LISTER (listing of visibilities in various formats), and ANTSOL (closure errors are usually a very handy tool for detecting bad data).

Editing of the data is an iterative process between the inspection outlined in the previous paragraph and flagging of bad data by means of running the program FLAGER. Anomalously large values can be edited out with FILTER, but this program has to be run on fully calibrated data.

Absolute flux information is entered into the data base by SETJY. One can either enter the flux for all calibrators (and possibly later correct the flux of some by analyzing the gain solutions found by ANTSOL) or just the flux of a primary flux calibrator (such as 3C286) and bootstrap the fluxes of the others using ANTSOL. Some care has to be exercised if no system temperature correction was applied because of elevation effects.

Calibration of the overall complex gains is a two-step process. First ANTSOL reads the visibilities of the specified calibrator(s) and makes an least squares solution of the individual complex antenna gains; it prints out closure errors above a certain level and some more editing may have to be done at this stage. The results are stored in a separate file, the .CAL file, which gets overwritten every time ANTSOL is run. When one is satisfied with the ANTSOL solution, GTBCAL can be run which multiplies the gain table entries by the solutions it finds in the .CAL file after doing some averaging or interpolation; this multiplication means that GTBCAL should be run only once on the same data; if one has goofed, the gain table has to be reset by GTBCAL (which may mean redoing the system temperature correction) before proceeding any further. These operations are usually done on spectral channel 0; however, it is possible to tie the phases to a particular (strong) spectral feature at this point.

If the band passes have to be calibrated one has to create a passfile by running that function of the program SPECTR.

One is now ready for mapping. GRIDER can make maps directly from the spectral line data base. MAKMAP and EXPVIS (VAXes and beyond) require continuum-type data bases; to split the spectral line data base up into a number of pseudo continuum data bases run SPECTR. GRIDER maps are not presently suitable for further processing; instead, they provide a quick-look facility.

Selfcal, mapping, and cleaning are available in MAPPER and the VAXes (AIPS), limited image display and analysis in DISPLY (IMPS), and more extensive image display and analysis in the VAXes (AIPS).

This section is intended to clarify the way things work on the DEC-10, not to tell how to attack specific programs. For a comprehensive list of DEC-10 monitor commands see Table 7-1 of the Green Book (pages 6-18,19,20). Detailed documentation of the monitor commands can be found in Volume 2 of the "white note books", the set of DEC-10 manuals.

3.1. Data Base Structure

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A DEC-10 data base is a collection of files with the same name but different extensions in your [14,useno.] area. The name can be any string of up to six alphanumeric characters but the default is 1MMMDD, where MMM is a three letter mnemonic for the month and DD the day of observation. The three basic files in the data base are the Index (extension .INX), Visibility (.VIn, where 2**n is the number of spectral line channels; .VIS for continuum), and Gain (.GAI) files. In addition there may be History (.HST), Calibration (.CAL), Antennas (.ANT), and Band Pass (.PAn) files. The Band Pass file does not necessarily have the same name as the other files in the data base.

The Index file has a record for each scan (corresponding to a single source card in the Observe file) containing basic information about the scan: start and stop times and dates, position, source name, various other things, and pointers to the Visibility and Gain files. These pointers indicate where the first and last record belonging to that scan can be found in those files.

The Visibility file contains a record for each base line and each integration time during the observing run; it is strictly in time order but there is no scan information. A record contains a time stamp, a base line identification, the (u,v,w) coordinates, flagging bits, and a complex spectrum. Nothing in the Visibility file, with the exception of the flagging bits reserved for the DEC-10, is ever changed; all corrections are put into the Gain file.

The Gain file contains records for the beginning of each scan, thereafter at each gain interval (set in FILLER; default 10 minutes), and at the end of each scan. Each record contains, among other things, the complex gains of all IFs for all antennae; these are initially set to ones and zeroes. Calibration is effected by taking a visibility record and multiplying it with the complex gains of the antennae involved as interpolated between the two bracketing (in time) gain records.

In the following SLDB stands for Spectral Line Data Base, PCDB for Pseudo Continuum Data Base. Some programs have not been adapted to accept data from SLDBs; to patch this incompatibility the program SPECTR has been written to select two channels or the average of two groups of consecutive channels, and write their visibilities into the AA and CC channels of a continuum data base which we will refer to as a PCDB.

All DEC-10 programs that are written in SAIL (not the ones written in FORTRAN, like DOPSET) use the same user interface. To activate the program XXXXXX one types:

```
r xxxxxx
```

XXXXXX will identify itself and come back with its prompt, an asterisk (*, as opposed to the DEC-10 monitor level prompt, a period, .). At this point one can enter commands; minimum match applies. There are a number of different types of commands: executable commands, help commands, commands manipulating the inputs file, and commands editing the inputs file (changing input parameters); the inputs file being edited is XXXXXX.0nn, where nn is the number of the terminal one is working from.

XXXXXX.0nn is an ASCII file containing the input parameters by keyword and their present values specific to XXXXXX. If XXXXXX.0nn did not exist previously, it is created and all input parameters are set to their default values. If it did exist (i.e.: if XXXXXX has been run by the same user from the same terminal nn) XXXXXX.0nn is in the state it was left in when last exiting from XXXXXX at terminal nn. A modified file XXXXXX.0nn may be reset to its default values by typing:

```
setdef
```

Input parameter values may be fetched from a file XXXXXX.0mm (previously created by working on terminal mm) by typing:

```
get .0mm
```

XXXXXX.0nn may be "saved" into a file YYYYYY.DDD by typing:

```
save YYYYYY.DDD
```

The present contents of XXXXXX.0nn may be inspected by typing:

```
inputs
```

or:

```
inputs <category>
```

if the input parameters for XXXXXX are divided into categories (this is especially handy for programs that have many - more than a screen full - input parameters, like MAKMAP and the MAKOBS phase of OBSERV). Parameter values are changed by typing:

```
<keyword> <value>
```

The minimum matching also works on <keyword>. An asterisk may be given as <value> for many keywords, indicating "all". A special word about the parameter OUTFILE, common to many programs: the name for OUTFILE may be prefixed with the device where the file is supposed to go to, followed by a colon. So, LPT:ANTSOL will print the output on the line printer under the name ANTSOL; TTY: stands for the terminal, DSK: for storing in a disk file. In some cases (e.g.: SPECPL, VISPLT) the program needs to derive some characteristics from this name for plotting results, and it needs to know the type of terminal; ADDS: then refers to a regular text terminal, TEK: to a graphics terminal.

When one is satisfied with the inputs, the program is activated by typing:

```
go
```

or, if the program can perform more than one task, a specific function is activated by typing:

```
go <option>
```

At this point the program will collect the values for whatever input parameters it needs from XXXXXX.0nn and do its thing.

One can exit from a program and return to the monitor level by typing any of the following:

```
exit
finish
quit
```

For all but one or two programs a single "q" will do the job.

All programs are documented in considerable detail in the Observer's Reference Manual (the Blue Book). At the terminal help can be obtained by answering the asterisk prompt by:

```
help
```

or:

```
explain
```

3.3. Batch Jobs and MIC Files

830105

Especially for things that take a long time to execute it is not always profitable to sit and stare at the terminal until the prompt reappears. A control file (extension .CTL) can be made with the editor (SOS) and submitted to the Batch Queue. That control file contains all instruction one would normally type on the terminal. Each command may be preceded by the prompt (. at monitor level, * at program command level) that would precede it.

Let's say you want to create a control file XXXXXX.CTL to run the program XXXXXX. It would look something like this:

```
.run xxxxxx
*db 1jan05
*ant 1 w *
*inp
*go
*q
%ERR
%CERR
%TERR
%FIN
```

The last four instructions are to ensure elegant exiting.

Submission to the batch queue is effected by typing:

```
su xxxxxx
```

or, if it is expected to take more than 5 minutes CPU time:

```
su xxxxxx/time:mmnn
```

where mm is the number of minutes, nn the number of seconds of CPU time. The batch queue can be inspected by typing:

```
su
```

The batch job will produce a log file, XXXXXX.LOG, which will be printed out upon completion. Be sure to delete it before you submit XXXXXX again, or it will keep appending to the original one.

MIC files (extension .MIC) are like control files, but they are executed interactively and allow parameters to be passed on. They are activated by typing:

```
do xxxxxx par1,par2,...,parn
```

A number of canned MIC files are described in Appendix D.

The DEC-10 Editor is activated by typing:

```
sos xxxxxx.ddd
```

where xxxxxx.ddd is the file one wants to edit. If the file does not exist it is created and one enters input mode immediately; otherwise one ends up in command mode (asterisk prompt). Here we will just give an abbreviated summary of the most important commands.

```

p          print the next 16 lines
p <range> print the lines in <range>
<esc>     print the previous line
i <line>   insert after <line>
i <line>,<inc> insert after <line> with line increment <inc>
c <line>,<range> copy <range> after <line>
d <range>  delete <range>
. <line>   shift pointer to <line>
a <range>  enter alter mode for <range>
f<string><esc> find <string>
s<string1><esc><string2><esc><range> substitute <string2> for
<string1> in <range>
n          renumber lines

```

The following definitions apply:

```

<line>    line number; special symbols:
           . current line
           ↑ top of page
           * end of page
<range>   <line> or <line1>:<line2>
<esc>     escape key

```

One can exit the input mode by hitting the escape key. In alter mode the following key definitions are valid:

```

<space>   go to next character in the line
w         go to next word in the line
d         delete the current character
c<key>    change the current character to <key>
<delete>  back up one character
<cntl>i   go to end of line
-<cntl>i   go back to beginning of line
i         insert characters
<esc>     exit from inserting
<new line> leave rest of line unchanged; go to next line

```

Exiting from SOS is effected by typing at command level the letter e, optionally followed by one or more of the following letters:

```

q         do not replace the original file by the new
         one; the new file is lost
b         do not create a back up; the old file is lost
s         strip lines of line numbers (needed for
         FORTRAN input files)

```

If b is not specified, the old file will be kept under the name XXXXXX.QDD.

Several things have to be thought through and others have to be done before one starts observing. This section outlines the most common ones. It is generally a good idea to arrive at the VLA site a few days early in order not to have to rush the preparation. One should also consider that there is no guaranteed assistance in setting up spectral line programs from Friday 3 pm till Monday 9 am.

4.1. Present System Specifications

830111

At the moment there is still an upper limit to the product of the number of base lines and the number of frequency channels retained in the MODCOMPs. What this means in terms of the number of antennae one can employ is shown in Appendix B.

There are presently 6 spectral line observing modes available: 1A, 1C, 2A, 2C, 4A, and 4. The digit indicates how many IFs go into the correlator, the letter which IF will be used (only one IF can be extracted at the time; A is right, C left circular polarization). Modes 4 and 4A are equivalent although they represent different implementations in the correlator.

The available spectral resolutions and total band widths are given in Appendix C. The table actually gives the channel separation; the frequency half width of the synthesized sinc function is 1.2 times the channel separation. The noise-equivalent width is equal to the separation, though. Hanning smoothing will increase the resolution to 2 times the separation and the noise equivalent width to 2.67 times the channel separation. The number of channels ($2^{**}n$) shown in the table is the maximum for each particular combination of total band width and observing mode. Channels are numbered 0 through ($2^{**}n - 1$), and channel 0 is always replaced by the average of the central 75% of the originally available band as defined by the band width code. The center of the band is at channel $2^{**}(n-1)$.

Channels may be traded for antennae, however (i.e., less frequency coverage for more antennae). The number of channels chosen ($2^{**}m$) has to be a power of 2, not less than 8, and not greater than 256. A beginning channel (k) may be specified. The new channels 0 through ($2^{**}m - 1$) correspond to the original channels k through ($k + 2^{**}m - 1$) and the center of the original band is now at channel ($2^{**}(n-1) - k$). However the zeroth channel in the new band (original channel k) will be replaced by the original channel 0.

The r.m.s. noise can be expressed as follows:

$$\sigma = \frac{a}{\sqrt{n(n-1)\tau\Delta\nu}} \text{ mJy} \quad (1)$$

n is the number of antennae involved, τ the integration time (in hours), and $\Delta\nu$ the band width (in kHz). a depends on the observing band and is tabulated below:

Band	Wave Length	a
L	20 cm	620
C	6 cm	420
U	2 cm	1100
K	1.3 cm	4500

The values are based on average maps produced with uniform weighting and only apply to point sources; the sensitivity for an extended source cannot be given since it depends on the source structure and the (u,v) plane coverage. Additional degradation of the sensitivity can be caused by non-ideal data (e.g., due to bad atmospheric conditions), tapering of the visibility data, non-optimum data reduction, and observing at frequencies far removed from the standard continuum frequencies (for which the receivers are optimized).

The U-band number applies to antennae equipped with the new 2-cm FETs. For the other antennae it is a factor 3 higher.

More detailed information on current system characteristics may be found in the Observational Status Report.

The calibration of spectral line data can be split into two orthogonal components: the overall complex gain calibration and the band pass calibration. The former is predominantly a function of time, the latter of frequency. Calibrators and their characteristics can be found in the Calibrator Manual.

The overall complex gain calibration is very much like the one performed on continuum data and is determined from channel 0. One has to be aware, however, that the band width of channel 0 is usually quite a bit narrower than in the continuum case, while also the number of base lines is smaller. One therefore has to look more carefully at the signal-to-noise ratio. Typically, one would want a signal-to-noise ratio on a single base line of at least 30 for a calibrator scan; but this is not always attainable at the higher frequencies. The length of the calibration cycle can be of the order of half an hour at L and C band, 10 to 15 minutes at U and K band. Calibration has to be done at the same frequency as the observations although there is a few MHz leeway. However, if one is using two polarizations, both have to be calibrated separately. It is suggested to discriminate between different frequency/polarization observations by using different qualifiers in the observe file.

For the band pass calibration one has the choice between 1) no band pass calibration at all, 2) dividing the cross correlation spectra by the geometric mean of the auto correlation spectra of the antennae involved, 3) a proper band pass calibration, and 4) a combination of the last two. The "auto correlation normalization", which is done on-line and cannot be undone, takes care of the amplitude part of the band passes to a few per cent. Phase slopes of up to 5 or 10 degrees across the band of individual base lines may be left. This is usually adequate for cases where weak continuum signals are to be expected. Auto correlation normalization should not be used if lines are expected to show up in the single dish spectra (strong masers, strong absorption, Galactic HI emission, interference). In the case of strong maser lines often no band pass calibration is necessary; especially at total band widths smaller than 10 MHz, the central part of the band is reasonably flat (to about 10%). If very high spectral dynamic range is required (e.g., weak line emission in the presence of strong continuum) an accurate band pass calibration is mandatory. This is effected by observing a very strong calibrator (does not have to be unresolved) for a sufficiently long period such that the signal-to-noise ratio in a single channel on a single base line is adequate. This does not have to be done in one scan; as a matter of fact, when it is split up into scans well apart in time, one has a check on time-variability in the band passes. Again, however, it has to be done for each frequency/polarization combination and the restriction on frequency differences is more strict than for the overall gain calibration; in cases where one cannot observe the band pass calibrator at the same frequency as the source one is advised to make two band pass calibration observations, symmetrically shifted by the same amount to both sides and average them. When selecting a band pass calibrator one should consider whether Galactic HI absorption in its spectrum would hurt.

Finally a word on Gibbs phenomenon (see page 8-6 of the Workshop Proceedings). It shows up as a ringing in alternate channels, most

noticeably in the lower channels, in the presence of an appreciable amount of continuum radiation. It cannot be calibrated out; its only cure is Hanning smoothing. Hanning smoothing is to be recommended for all observations requiring high spectral dynamic range.

4.3. Selecting Antennae

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For most spectral line observing not all antennae can be used. To optimize the (u,v)-coverage some care should be exercised in choosing which ones one wants to use. One can be aided in this decision by the program LUVN that makes plots of (u,v)-coverage on the ZETA pen plotter. Documentation can be found in the documentation folder at the plotter and in the plot section of the ORM. If you are tempted to use the outer antennae consider carefully whether your project really warrants the highest possible resolution and whether the coverage in the center of the (u,v)-plane is adequate for your object(s). The plots are made with the u-axis running along the length of the paper and looking down at the earth; hence East is at the right.

Information on shadowing can be found in VLA Scientific Memorandum No. 134. The program OBSERV will perform checks on shadowing. More accurate information on the shadowing can be obtained from GTBCOR, but in order for that to be complete it is necessary that all antennae are pointed (even though not collecting data) during the observations.

4.4. Interference

830209

Especially in L-band there are numerous interference signals, some external, some internally generated, and some generated by mixing of external interference with an internal LO signal.

For a complete table, see VLA Test Memorandum No. 139.

The worst ones in the second class are at multiples of 50 MHz; they should be avoided at all times, but they are very narrow (however, they may cause "ringing" if not exactly centered at a channel). Minor ones occur at irregular and unpredictable multiples of 5 MHz (± 0.1 MHz); these are just frequencies to watch out for after observing.

The worst one in the third class is at 1404 MHz (± 1 to 2 MHz); this one does not occur in antennae equipped with the L-band FETs and will, therefore, gradually disappear from the system.

1465 MHz should be avoided.

Solar interference can be quite serious, even at distances of several tens of degrees, especially at short base lines. It shows up in spectral line observations as a sinusoidal disturbance on the spectra of continuum sources.

Doppler tracking is not yet implemented in the on-line system, so one has to do all the LO setting activities "by hand". The first step in this process is to run the program DOPSET. It takes as inputs a source name, RA and Dec, rest frequency, velocity, velocity definition (optical or radio), velocity rest frame (heliocentric or l.s.r.), an hour angle range, a time interval to do the calculations, and a date range (in LST days since the beginning of the year). It defaults to the geographic coordinates of the VLA and the current year, although these parameters can also be set.

The output gives a large amount of interesting information, but the crucial numbers are the calculated sky frequencies.

It is a non-standard FORTRAN program that requires an input file under the name FOR20.DAT made up beforehand (exit from SOS with ES or EBS) and starts running immediately when you start it after asking for some specifics on the output file (disk or line printer). See the ORM for detailed documentation.

The program LOSER is the second step in the process. Take the sky frequencies from DOPSET and the total band width (corresponding to the band width code) that you plan to use and run LOSER with those as inputs. It will calculate the LO settings and display an image of the LO-card in the observe file with the values that should go in.

The line shows: two values for firstlo, four for synthesizer, and two for flukesynthesizer. A description of the VLA LO chain can be found in Chapter 8 of the Workshop Proceedings.

For a band width of 50 MHz only certain frequencies can be chosen ($n \times 50 \pm 10.1$ MHz), for 25 MHz some frequencies are inaccessible, while for narrower band widths there often are several choices. If at all possible, chose such a combination of LO settings that firstlo and synthesizer are not changing during the observing run if you are observing at more than one frequency. Aside from that, there is no reason to prefer one setting over another.

LOSER is a standard program and is documented in the ORM.

OBSERV is a conglomerate of four programs: OBSERV, SETDEF, MAKOBS, and CHKOBS. Its purpose is to produce an observe file (the file that - after transfer to the MODCOMPs by the operator - specifies the observations to the on-line program). It is activated by typing:

```
r observ
```

By typing:

```
go <name>
```

one can get from one program of the conglomerate to another. Before starting, one may want to generate a source file (extension .SOU) with SOS that contains the sources that one is planning to observe. The format of each line in this file is:

```
<source name> <RA (hh mm ss.sss)> <Dec (dd ' ' "".'''')> <gain codes>
```

(<gain codes> consists of four integers from 0 through 9 for each of the four observing bands, separated by spaces). The visibilities are calculated in the correlator-cum-AP in 24 bits, normalized to a correlation coefficient of 1.0. The MODCOMPs allow only 16 bits, and the gain code indicates how many least significant bits should be dropped. The directions for calculating the gain code apply to the highest flux expected in any one spectral channel at any one base line; one should therefore take into account continuum as well as line signal and the source structure (the visibility function at the shortest base line). The minimum gain code to be used should be 3.

Useful RA/Dec-Az/El plots may be found on pp.6-5,6 of the Green Book. Full documentation may be found in the ORM under OBSERV.

4.7.1. OBSERV

This program sets some basic input parameters and can be used for listing. Set PROGRAM to LINE and enter the names of your source and observe files. Note that your source file will be appended to the master source list. These lists will be searched in that order; if you insist on your own position for a calibrator (not to be encouraged) you should give it a different name so that it will not be picked up from the master source list.

The in- and outfile are for listing purposes; this way one can list one's observe file as well as one's source list.

Next, go to SETDEF.

4.7.2. SETDEF

SETDEF allows setting defaults for the parameters on the various types of cards. For spectral line observing the main ones are the the source, LO, and LI card. The defaults can be viewed by typing:

```
inp <card type>
```

If a source file is present the parameters for the source card that may need setting are: durations, mode, band, and widths; the three durations just allow multiple defaults. For the LO-card they are: firstlo (have to be set or entered later on for U- and K-band, may be left out for L- and C-band), synthesizer, and flukesynthesizer. Note that the numbers for these parameters have to be preceded by a band designation (e.g., LL); this again allows multiple defaults. For U- and K-band observations biasdigits may be added; these allow wide band tuning of the first LO mixer:

Bias Digit	Band	First LO Peak Frequency (GHz)	
		U-Band	K-Band
0	Broad	19.6	17.6
1	Lower	19.3	18.2
2	Middle	19.7	18.4
3	Upper	20.0	19.0

For the LI-card the parameters to be set are: beginning channel, number of channels (the power of 2; hence an integer between 3 and 8), the integration time in the MODCOMPs (in seconds; a multiple of 10), and, if so desired, the normalization option (B or blank; see section 4.2.). For the integration time, see section 4.8.

For any parameters that are going to change from scan to scan there is no point in entering them in SETDEF; they will come up in the next section. Now go to MAKOBS.

4.7.3. MAKOBS

MAKOBS is essentially an editing program for the observe file. First enter the start date (found on the VLA schedule sheet) and time (in LST). Then specify the "adformat"; this contains the list of parameters that you want to enter for each scan. Usually, these will be at least name and duration; if needed, qualifier; if Doppler tracking is necessary, the flukesynthesizer; if both polarizations are used, the mode; etc. Then by typing

add *

it will start adding cards at the end of the list, prompting the user for input for the specified parameters. It will automatically pick up the defaults set in SETDEF. If the band is among the input parameters, the appropriate LO settings, as set in SETDEF, will be used. Durations can be abbreviated to "c" or "o" to get the duration or oduration defaults. Exiting from the add-mode is accomplished by pressing the <escape> key. Copying of certain lines can be done with the "copy" command, listing with the "list" command, and the parameters specified in the "chformat" can be changed to a different value for a line or range of lines with the "change" command. The "stop" command changes all durations to stop times, and the "durations" command changes stop times back to durations. The operators prefer to have an observe file in stop times.

Next, go to CHKOBS.

4.7.4. CHKOBS

CHKOBS performs five basic checking operations: elevation hardware limit (8°), zenith passing, shadowing, proximity to the sun, and move times. The summary checkoption gives enough information (fitting on the tty: screen) to detect any serious errors; the detailed option gives full information on shadowing and move times.

After the observe file has been found to be in good order, make a line printer listing for the operator.

The Program FILLER fills the DEC-10 data base either in real time from the fixed head disk, or later from MODCOMP Archive Tape. Usually, FILLER is run by the array operator, but the user has to specify the integration time, so we will just discuss that subject here.

A rule of thumb for determining the integration time (τ) that one can get away with is:

$$\tau = \frac{150 \times \lambda}{\vartheta \times L} \text{ sec} \quad (2)$$

where λ is the observing wave length, in cm, ϑ the size of the area of interest centered on the field center, in arcmin, and L the longest base line, in km.

Usually, the MODCOMP integration time is set to 20 or 30 seconds; this can be longer, but then one is likely to lose some observing time - not much, but it can be a fair percentage of short scans. The FILLER integration time is usually an integer multiple of it, up to 1 or 2 minutes. FILLER can always be re-run with a shorter integration time, the MODCOMP integration time cannot be changed after the fact.

Still, it is to everybody's advantage to choose the integration times reasonably long: a longer MODCOMP integration time reduces the amount of tape that is used and the time it takes to run FILLER; a longer FILLER integration time reduces the amount of disk space used and the time it takes to run the data reduction programs.

If a MODCOMP integration time of 10 seconds has to be used, it is not possible to run the real time FILLER; the data have to be filled afterwards from tape.

The default gain table entry interval is 10 minutes. This is usually quite adequate, but if one intends to obtain detailed shadowing information from GTBCOR one is advised to make it shorter.

There are two things that have to be done to the data before one starts on the rest of the reduction. This is not to say that one has not touched the data before; in general one will have done some data inspection before one gets to this stage, since it is recommended that the operations described in this chapter not be performed until the data base is complete, to avoid confusion and errors.

5.1. SPFINX

830111

There are certain things that FILLER (and hence the DEC-10 data base) does not know about your observations: the data selection parameters (i.e., the beginning channel) on the LI-card, the velocities, and the rest frequency; without further information, it will be assumed that that the beginning channel was 0, so the frequencies may be off.

To run SPFINX type:

```
r spfinx[11,364,spect]
```

SPFINX is a standard program, but is undocumented; however, it is exceedingly simple. Put in a rest frequency and beginning channel and it will correct the frequencies in the data base and calculate velocities using a reverse DOPSET.

5.2. System Temperature Correction

830201

For spectral line data the system temperature correction is not automatically applied. The reason is that the system temperature measurement in the front end pertains to the full 50 MHz band, whereas the relevant figure is that in the narrow band that comes through the base band filters. This quantity is actually measured, but, unfortunately, has all the compression and temporal instability of the wave guide communication system in it. The system temperature correction serves, generally speaking, two purposes: elimination of elevation effects, and a correction of the source contribution to the system temperature. Three cases can be distinguished:

1. Source and calibrator are close together in the sky and neither has enough flux to noticeably increase the system temperature.
2. Either source or calibrator (or both) emits enough continuum radiation to affect the system temperature.
3. Either source or calibrator (or both) have strong line radiation that affects the narrow-band system temperature.

In case (1) the elevation effects will be calibrated out; no system temperature correction is necessary. However, one should be very careful about bootstrapping fluxes in ANTSOL when data are taken at rather different elevations. Applying the standard system temperature correction certainly does not hurt (but it means waiting until the monitor data base is dumped onto disk). In principle, the elevation effects can also be taken out by applying a sec-z correction in GTBCOR, but there is no certainty over the correct coefficients.

In case (2) the standard system temperature correction HAS to be applied (run GTTSYS).

Case (3) is the tricky one. The following recipe applies:

- 1). Run GTTSYS to apply the regular Tsys correction.
- 2). List for each antenna used the following two monitor points from the monitor data base by running MONLST: Xcal and IFXSD, where X stands for the IF (A, B, C, or D) used. The DCS addresses for these monitor points are listed below:

Monitor Point DCS Addresses

X	Xcal	IFXSD
A	1: 0	5:120
B	1: 4	5:121
C	1:20	5:122
D	1:24	5:123

- 3). Read these two quantities off as closely together in time as possible, both during a source and during a calibrator scan. Then calculate for each antenna the correction factor T:

$$T = \left[\frac{Xcal_{source} \times IFXSD_{cal}}{IFXSD_{source} \times Xcal_{cal}} \right]^{\frac{1}{2}} \quad (3)$$

- 4). Put the correction factors T for each antenna individually into the data base gain table, using the parameter AMPFACTOR and the GO AMPCOR option in GTBCOR - FOR THE SOURCE ONLY!
- 5). Correct the calibrator flux (if necessary) for the line contribution (averaged over the narrow band) when inserting the flux into the data base index records with SETJY.
- 6). Calibrate the data in the normal way, taking care that CALIBRATION is set to APPLY in ANTSOL. If the gain table has to be reset in GTBCAL for some reason or other, start again from the beginning.

By going through this exercise one enters the system temperature corrections due to elevation effects and continuum radiation with the aid of GTTSYS, while steps 2 through 5 take care of the narrow band to wide band ratio.

While the data are coming in, some checks on their integrity and quality can be performed. For this purpose several of the DEC-10 programs can be used as tools, each with its own specialty. Particularly, if the observing run starts with a scan on a strong calibrator one can check whether all selected antennae work properly (use SPECPL). As mentioned in section 2.1. one can request some on-line display from the operator.

6.1. SPECPL

830117

This program can plot spectra (amplitude and phase), averaged in time, for single base lines. It is suggested to run it from the TEK-4012 terminal and to set the display file to TEK:. Options include the following:

Averaging can be done in time or over scans. A subset of spectral channels can be selected with the channel command. Spectra can be normalized to channel 0, and amplitude and phase scales can be set independently. The spectra may be Hanning smoothed. When you type "go", the program starts plotting spectra; typing a character after the plot is displayed, starts a new plot, unless the character is a "p" (numbers are printed in the outfile), a "q" (brings you back to command level), or a carriage return (acts as if two characters had been typed); when no more data can be found, any character (except "p") acts as "q". If averaging across scan boundaries is required, crossscans should be set to "yes", the averaging time to an appropriately large number, and typing a "c" after each plot has been displayed will add the next scan in to the average. Hard copies may be made on the Versatec by depressing the Hard Copy switch.

If normalization is set to "no", the amplitude scale is in arbitrary units, even if calibration is set to "apply".

6.2. PASSUM

830201

PASSUM averages all spectra within the boundaries set by its input parameters together, either by vector averaging (only useful for calibrated data) or by ampscalar averaging. In the latter case it averages all amplitudes that can be found (including noise), in the former case it is equivalent to making a map with natural weighting and displaying the spectrum at the center cell. For ampscalar averaging uvlimits may be set to eliminate long noisy base lines, for vector averaging it may be used to control the "beam size" of the spectrum. PASSUM is run by typing:

```
r passum[21,21]
```

It is still an undocumented and unsupported program.

6.3. LISTER

830117

LISTER lists data in a variety of formats: matrices or columns, amplitudes, phases, rms-es, real and imaginary. Particularly useful options at this stage are:

- go summary (prints a summary of the data, including the list of antennae in use)
- go scan (prints a list of all scans available in the data base)
- go matrix with list options scanheadings, amplitude, and rms and averaging over scans for calibrators (uncommonly high rms-es are indicative of problems)

6.4. ANTSOL

830117

ANTSOL takes the visibilities for calibrators, averaged over individual scans, and tries to determine the complex gains of each antenna by finding a least-squares, antenna-based solution; it is a good idea to first fill in the calibrator fluxes in the index file by running SETJY. It prints the closure errors (deviations from the antenna-based solution on individual base lines) above a certain limit (default 5% in amplitude, 5 degrees in phase). Many high closure errors are indicative of either trouble, or to a small signal-to-noise ratio; if single antennae show up consistently with high closure errors, they are likely to be the culprit.

The "go list" option lists the solutions; this is a good way to detect sudden jumps. Singularly low amplitude gains indicate that the antenna is not functioning properly, and are usually correlated with high closure errors. Phase jumps are to be avoided; unless you want to do some rather involved work, it is suggested that all data be deleted for the antenna(e) involved between the two calibrator scans where the jump occurred. Be careful, though: if all antennae show a phase jump, the real jump is likely to be in your reference antenna. When there are jumps, special care has to be taken regarding calibration across these jumps (see section 7.2.).

6.5. FLAGGER

830201

The data base contains two kinds of flags, each in two locations. There are MODCOMP and DEC flags, the former set by the on-line system (they cannot be changed by the user), the latter by the user who can also undo them. Single antennae can be flagged for entire scans; these flags are kept in the index record. Single base lines can be flagged for individual time stamps; these flags are kept in the visibility records. Single antennae can also be flagged for individual time stamps; the base lines involved are then individually flagged in the visibility records. Flagging is the way to remove bad data.

Among the input parameters governing data selection in most programs is "passflag". If set to "unflagged" it only passes on unflagged data; if set to "modcomp" it passes all data that is not flagged or is flagged by the MODCOMPs; if set to "dec" it passes all unflagged data and data flagged in the DEC-10; if set to "both" it passes all data and ignores the flags.

6.6. FILTER

830201

Occasionally, very large amplitudes appear in data bases. The program FILTER filters these out by flagging visibility records with anomalously large values (as defined by the user). FILTER has to be run on a fully calibrated data base, though; so one has to wait until GTBCAL has been run. This filtering can also be done in the VAXes with the AIPS task CLIP.

6.7. DBCON

830208

If data from different days have to be combined, the data bases can be concatenated by running DBCON. For running it one temporarily needs extra disk space. Make sure things are specified in the right time order. If one plans to run SPECTR, then the concatenation can also be done there; if a band pass correction is to be applied, a separate run of SPECTR for each day (band pass file) is required anyway. Finally, concatenation can also be done in AIPS if mapping is to be done there.

As mentioned in section 4.2., the calibration of spectral line observations can usually be split into a time dependent and a frequency dependent part. The present chapter discusses the time dependent part. This amounts to calibrating the overall complex gains of each antenna and one should use channel 0 for this purpose.

Before starting on the actual calibration, one has to insert the calibrator fluxes into the data base. This is done by running SETJY. When one plans to tie the fluxes to one of the standard flux calibrators (3C286 or 3C48), one should calculate the flux that is correct for the actual observing frequency, using the formulae in the introduction of the Calibrator Manual.

If the system temperature correction was applied and one does not want to have to repeat that when a mistake is made in the following, it is a good idea to make a back-up copy of the gain table:

```
copy <dbname>.qai[14,] _ <dbname>.gai[14,]
```

7.1. ANTSOL

830119

ANTSOL has been described in section 6.4. Three more things should be pointed out at this stage.

First, ANTSOL does not really calibrate the data base. It calculates the antenna-based gain solutions and puts them in a separate file, <dbname>.CAL. It is GTBCAL (see next section) that takes this information and actually enters it in the gain file. Hence, one can run ANTSOL as often as one wishes without affecting the data, as long as GTBCAL is not run. Every time ANTSOL's "go solve" option is run, the .CAL file is overwritten.

Second, if system temperature corrections were applied, one should make sure that "calibration" is set to "apply" in ANTSOL.

Third, there are two ways of bootstrapping calibrator fluxes from standard flux calibrators. One is to use the "go bootstrap" option in ANTSOL, the other is to put in an approximate flux for the calibrators, and compare the amplitude gain solutions that ANTSOL found for different calibrators; the fluxes should then be corrected by multiplying the approximate flux by the square of the ratio of average amplitude gains on the particular calibrator and on a standard one. With either method one has to be very careful about elevation effects if the data have not been corrected for the system temperature.

When you are satisfied with your ANTSOL solution time has come to enter the complex gain solutions into the data base's gain file. This task is performed by GTBCAL. It will either interpolate linearly between consecutive ANTSOL solutions or take a boxcar (in time) average. The linear interpolation is mainly to be used if you have very good signal-to-noise and/or sizeable but monotonic changes from one calibrator scan to the next.

If there are observations at different frequencies in the data base, you should ascertain that the right source gets calibrated by the right calibrator.

If there are phase jumps and boxcar averaging is being used, you should either calibrate the two parts separately, or ensure that the boxcar does not span the gap while calibrating valid data.

Just a reminder: if one wants to run FILTER, this is the time to do it.

7.3. Spectral Line Phase Selfcal

If there is a very strong, point-source-like spectral feature (e.g., a strong maser), one can effectively self-calibrate the data by tying the phases to this feature. Positions of spectral components in other channels will be very accurate with respect to the strong feature, but absolute position information will not improve.

It can be done by, after doing the regular calibration, running ANTSOL again (calibration apply!) on the source and on the appropriate channel with a judiciously chosen averaging time; then run GTBCAL on it, calibrating only the phase. The procedure has yielded very good results.

The band pass corrections are calculated by the "go passfile" option in the program SPECTR. For each base line the spectra, individually normalized by channel 0, are vector averaged over the source(s) designated. These averaged spectra are then written to a "passfile" with extension .PAn, where 2^{*n} is the number of spectral channels. Hanning smoothing is recommended unless one needs a very high channel-to-channel dynamic range; in the latter case smoothing of band pass and real data should be identical. The resulting band passes may be inspected with PASSPL which is very much like SPECPL and plots them for all base lines implied by the "antennas" command.

The actual correction is carried out later on in the "go newdb" option of SPECTR when the visibilities are divided by the values in the passfile. To activate this, "corrections" has then to be set to "apply".

There are three routes to make maps from the visibility data: in SORTER (program GRIDER), in MAPPER (MAKMAP), and in AIPS (UVMAP). The first works straight off the Spectral Line Data Base, but is still experimental; the second works off PCDBs on the DEC-10 and hence requires the user to run SPECTR; the third works off visibility data bases in AIPS (on the VAXes) and requires the user to run SPECTR as well as EXPVIS. When making maps on the machines SORTER or MAPPER the DEC-10 programs PROBE and CATLST will enable the user to monitor progress and inspect his catalog on these machines.

When making maps, be careful to specify them large enough to catch all the continuum radiation in the field and to make them with a sufficient number (at least three) points per beam to facilitate cleaning; remember that only one-fourth of the area of a map can be cleaned.

The coordinate grid in VLA maps corresponds to a parallel projection from a sphere onto a tangential plane with its tangent point at the field center specified in the observe file. Hence, distances from that field center are not really angles but the sines of such angles, although for most purposes these are identical. The conversion formulae from map coordinates (x,y) to (α , δ) and vice versa (where subscript 0 denotes the coordinates of the tangent point which also serves as the origin of the map coordinate system) are:

$$x = \cos \delta \sin \Delta\alpha \quad (4)$$

$$y = \cos \delta_0 \sin \delta - \sin \delta_0 \cos \delta \cos \Delta\alpha \quad (5)$$

$$\Delta\alpha = \arcsin \frac{x}{\cos \delta} \quad (6)$$

$$\delta = \arcsin (\sin \delta_0 \sqrt{1-x^2-y^2} + y \cos \delta_0) \quad (7)$$

$$\Delta\alpha = \alpha - \alpha_0 \quad (8)$$

One should be aware that, due to the fact that except for snapshot observations the VLA's coverage is really three-dimensional, there is a "w" term in the Fourier transform kernel. As a result, very large maps quickly deteriorate beyond the primary beam half-power point. The only solution at the moment is mosaicing such large maps, but here one also has to remember that, if cleaning is required, one can only use the inner quarter of maps for the mosaicing.

9.1. GRIDER

830209

GRIDER is, as far as its inputs are concerned, essentially a subset of MAKMAP; cleaning facilities are not guaranteed and selfcal is not included. One can specify a range of spectral channels to be mapped and GRIDER will fetch the visibility data from the SLDB. The maps are made in the PDP-11/70 SORTER and may be transferred to DISPLY by running GETMAP (on DISPLY) to be viewed with IMPS, or they may be written on FITS tape.

The program is still not fully debugged and may give phony results (usually quickly recognizable), while the maps cannot be cleaned (in any computer). However, it provides a good quick-look facility and it is appreciated if users use it once.

Run GRIDER by typing:

```
r new:grider
```

9.2. SPECTR

830209

All other mapping programs are designed to work off continuum data bases. Therefore, the SLDB has to be split up into PCDBs, each of which contains two spectral channels or averages of groups of channels. SPECTR performs this task in its "go newdb" option. Optionally it performs band pass correction and/or Hanning smoothing on the fly. If band pass corrections are required CORRECTIONS should be set to APPLY and APPLYQUICK to YES.

One spectral line channel (or the average over a range of adjacent channels) goes into the AA channel of the PCDB, another into the CC channel. Usually one only has to transfer the source to the PCDBs. Since it is a boring task, prone to typing errors, to run SPECTR for many channels, one is encouraged to use the MIC file SPECTR (see Appendix D).

9.3. MAKMAP

830119

MAKMAP makes maps from visibility data in PCDBs residing on the DEC-10; the maps are made in the PDP-11/70 MAPPER. The mapping requests are queued and progress can be monitored by running PROBE, while the user's catalog can be inspected with CATLST; both run on the DEC-10. Maps may be transferred to PDP-11/44 DISPLY by running GETMAP (on DISPLY) to be viewed in IMPS, or may be written onto FITS tape. MAKMAP is also capable of cleaning existing maps and of performing selfcal.

9.5. EXPVIS

830209

EXPVIS writes visibility data (only continuum data bases) onto an Export Tape. The process is rather straightforward, but the same remark applies as for SPECTR, and one is encouraged to use the MIC file EXPVIS (see Appendix D). Unless the gain codes in the observe file were chosen rather tightly, it is not necessary to run EXPREP; FILTER will take care of overflows.

9.6. UVMAP

830209

UVMAP is the mapping task in AIPS, running on the VAXes. After running SPECTR and EXPVIS, the visibility data are loaded into the VAX by UVLOD and sorted by UVSRT; UVMAP can then make maps. Only the AA channel frequency in the PCDB will be loaded; the CC channel frequency can be corrected by entering the CC minus AA difference by means of APARM(9) and APARM(10). As for all AIPS tasks, documentation may be found in its HELP file and in the AIPS Cookbook.

Limited analysis and display facilities are available in IMPS. Because of its limitations for spectral line work and the fact that this system is self-explanatory anyway, it will not be discussed here. The DEC-10 only has one program in this category that is of any use: PASSUM. For more powerful analysis and display the user has to turn to AIPS. The mechanics of running AIPS are explained in the AIPS Cookbook. In the following we shall only briefly describe AIPS tasks and verbs that have a specific spectral line function.

10.1. Global Profiles

830120

On the DEC-10 a global profile can be obtained by running PASSUM:
r passum[21,21]

Use vector averaging, set "calibration" to "apply", and choose your "uvlimits" such that the entire area of interest is covered. An APPROXIMATE band pass correction can be applied by first running PASSUM on the source with "outfile" "dsk:passum.dat", then on the band pass calibrator with "outfile" "bpass.dat", and then run bpc:

r bpc[21,21]

First, a continuum map has to be constructed. Usually this is done by averaging some spectral channels containing no line signal on either side of the spectrum. This can most easily be done by putting the two averages into the same PCDB and (assuming that the two averages have the same weight) constructing a Stokes I map from it. One has to take care that the noise in the continuum map is considerably lower than in the individual channel maps, since it will enter systematically in all the difference maps later on. If there are not enough continuum channels left and no band pass corrections were applied, one may consider using a carefully weighted difference between channel 0 and the average of all line channels, remembering that channel 0 contains the average of the center 75% of all originally (before data selection in the on-line system) available channels. This assumes, of course, that the user is certain there is no line radiation in channels covered by channel 0, but not in the selected spectrum.

Then, there are three stages at which the continuum may be subtracted: in the (u,v)-plane, in the dirty maps, and in the clean maps. For a discussion see Chapter 15 in the Workshop Proceedings.

If the subtraction is done in the dirty map domain, the continuum sidelobes should not be strong compared with the line signal. If this condition is fulfilled one should either make the subtraction in the (u,v)-plane or subtract the clean maps, provided the instructions for clean map subtraction are carefully adhered to.

If the subtraction is done with cleaned maps, the initial clean should be done on the continuum map and its clean components should be used to start the clean on the individual line channel maps; otherwise spurious results will follow.

Cleaned map subtraction is not feasible in AIPS. We would therefore recommend the following procedure:

1. Make a large continuum map
2. Clean the strong sources in this map
3. Subtract the clean components obtained in 2) from all (u,v) data sets (UVSUB)
4. Make maps of all line channels and the continuum at the desired size from the (u,v) data sets generated in 3)
5. Subtract the continuum map generated in 4) from all line maps

Selfcal is a powerful image analysis tool, but it is not a panacea. Specifically, it is only useful in spectral line work if one is either interested in the continuum radiation as well (provided there is enough continuum to self-calibrate on), or if one has a strong spectral feature (if it is point-like as well one may use the alternative ANTSOL route; see section 7.3). Whatever the case, if one wants to use selfcal, run it (ASCAL) on the appropriate channel and apply the solution to all other channels using ASCOR.

The statement that selfcal is not particularly useful in cases where one wants to subtract a sizeable continuum but is not interested in the continuum itself, is based on the fact that the largest errors are in that continuum and will be subtracted out. Admittedly, the selfcal will also affect the line residual, but the result is not expected to be dramatic as far as increasing the dynamic range is concerned except at U- and K-band where the phases are often fluctuating. For such cases we recommend the following procedure:

1. Determine whether the continuum map is dynamic range limited
2. Determine whether the line-minus-continuum map for the strongest line channel is dynamic range limited
3. Determine the dynamic range of a self-called continuum map
4. If 1) and 2) are true, if 3) is better than 1), and if 3) promises improvement for 2) apply the selfcal solution to all line channels

The problem of adding short base line information to aperture synthesis maps is still being studied and no "black box" recipes can be given yet. Several methods for solving the problem are known, but most of them either are clumsy or leave a rather unsatisfactory feeling behind.

One has to remember that CLEAN does a kind of least squares fit over the holes in the (u,v)-coverage, and hence is capable of restoring some of the missing information. If the spatial structure size spectrum in the brightness distribution is adequately covered by the observations, there is nothing to worry about. If that is not the case, one may want to try to add a "zero spacing flux" in AIPS's UVMAP; empirically it has been determined that it should be given a weight of approximately 30.

Another, more involved possibility is, if a single dish map is available, to follow this recipe: clean the single dish map, multiply the clean components by the VLA primary beam and convolve them with a Gaussian about the size of the single dish beam; smooth the VLA map to the same Gaussian beam, and add the difference (single dish minus VLA smoothed) to the full resolution map. Obviously, one has to be rather careful about the flux scales and the single dish should be large enough to fill the central hole in the VLA data: the 140 ft is barely adequate. This procedure can be applied to either dirty or clean maps. If applied to dirty maps and subsequent cleaning is required, the same procedure should be followed for the dirty beam. Alternatively, the clean component data from the single dish map could also be added in the central part of the (u,v)-plane before mapping, but this needs intervention in UVMAP and careful juggling of weights, which may be more trouble for the user.

More sophisticated iterative interpolation schemes, as well as "large component clean" are still under study.

10.5. Cleaning

There is not much more to be said about cleaning after the remarks made in sections 10.2. and 10.4. It should be added, however, that it is important to clean each map with its own beam, since the scale of the beam (and the sidelobes) changes with frequency; this is also the reason why subtracting continuum in dirty maps only works if the continuum sidelobes are not strong compared to the line signal. The reason for using the same clean components for continuum and line maps (if subtraction is to be done after cleaning) is that because of the differences in noise between the different channel maps, the clean program is bound to find slightly different solutions which may be devastating after subtraction if one is looking for weak line signals in the presence of strong continuum radiation. The situation is made worse by the fact that the differences will, in some way or other, be correlated with the continuum distribution.

To analyze spectral line data AIPS uses three-dimensional maps (cubes). Since the visibility data are still being brought in as pseudo continuum data, from which only single, two-dimensional maps can be made, it is necessary to combine those maps into a cube. The task MCUBE will do this. Since the frequency-velocity conversion is not yet completely implemented it is useful to change the third axis of the cube to velocity at this point using AXDEFINE.

Later on in the analysis one is often interested in how the spectral profiles change with position and since it is extremely inefficient to read many numbers in random order from a disk, there is the task TRANS to transpose a cube anyway one wants (e.g., change the order of the coordinate axes from (lmv) to (vlm), where l and m are the spatial coordinates and v is velocity). Some analysis tasks actually require the cubes to be transposed for reasons of efficiency.

10.7. Smoothing

Smoothing is an excellent tool to bring out large structures that may in full resolution be hidden in the noise, since it increases the signal-to-noise ratio (ONLY for large structures!). However, it also has its limitations. There are two kinds of smoothing: spectral and spatial.

For spectral smoothing there is the task HANSM which performs Hanning smoothing on a (vlm) cube (velocity or frequency being the first coordinate axis). Hanning smoothing decreases the spectral resolution by a factor 1.67, removes the high sidelobes of the sinc-function response, and decreases the noise by a factor 1.63.

For spatial smoothing one may use the tasks SMOTH or CONVL which will smooth each two-dimensional plane of a (lmv) cube to a specified resolution. One has to be aware, however, that the noise does not quite go down as fast as one might have expected, because the process is roughly equivalent to weighing down the long base lines and hence there are fewer data points used. Similarly, spatial smoothing can not bring out any structures that were not in the observations to begin with; i.e., one can not retrieve the 3 K background by excessive smoothing since there were no base lines in the array measuring that spatial component.

The basic problem in analysis of spectral line data is how to put the information in such a form that it is readily digestible, especially in view of the fact that the information is basically three-dimensional while everything is geared toward two-dimensional images. There are two ways to attack this problem: reduce the numbers and clever displays. This section will address the former approach, the next section the latter.

The traditional approach to reduce the number of bits of information is to try to describe each spectral profile with a limited number of parameters. Examples of this are fitting the profiles with Gaussian components (not yet implemented in AIPS) and calculating the profile moments numerically. Although there may be more descriptive ways of summarizing a profile (e.g., integral, peak, peak velocity, and full width at the 20% level), the moments have the virtue that they are mathematically well defined quantities (which does not necessarily mean that they are easy to extract). If somebody were therefore to model his observations (and took instrumental effects properly into account) those moments should provide a reasonably reliable check; how many moments one needs would depend on the particular problem at hand.

The reason that one cannot just sum the profiles to get the zeroth moment is that there are likely to be many points in the profile that cheerfully contribute to the noise but not to the signal; as a result the signal will be often buried in the noise. One therefore has to find a way to weed out the useless junk; on the other hand, one does not want to risk weeding out faint, extended (spectrally or spatially) structure with the real rubbish. This is why seemingly normal spectral line types often get unpredictably excited at the mentioning of this apparently innocent subject.

The approach chosen for the AIPS task MOMNT is to smooth the cube in all three directions, compare the smoothed intensity with some threshold value, and, depending on the outcome of that check, accept or reject the ORIGINAL value for inclusion in the moments summations. It is up to the user to judiciously choose the threshold and the parameters for the smoothing kernels; some hints are given in MOMNT's HELP file. In general, spatial smoothing to twice the beam, a three-point Hanning spectral smoothing, and a threshold of half the the r.m.s. noise in the maps should give reasonable results. Obviously, spatial smoothing will help spatially extended structures with small velocity gradients, spectral smoothing features with a large velocity width, and the combination regions with high velocity gradients.

For examples see Chapter 15 of the Workshop Proceedings.

The zeroth moment produced by MOMNT is in units of Jy/beam*km/s, the other moments (up to third moment - skewness) in units of km/s, provided the first axis is defined in units of km/s.

10.9.1. Three-Dimensional Displays

Two ways of viewing three-dimensional brightness distributions have been implemented in AIPS. One uses color as the third axis, the other time.

TVHUEINT makes an intensity-hue display on the TV screen, deriving the intensity information from one, and the hue information from another map. The obvious application to spectral line work is to load the zeroth moment into one TV channel and let it control intensity, and to load the first moment map into another and let it control the hue. The transfer functions for the two maps can be controlled independently.

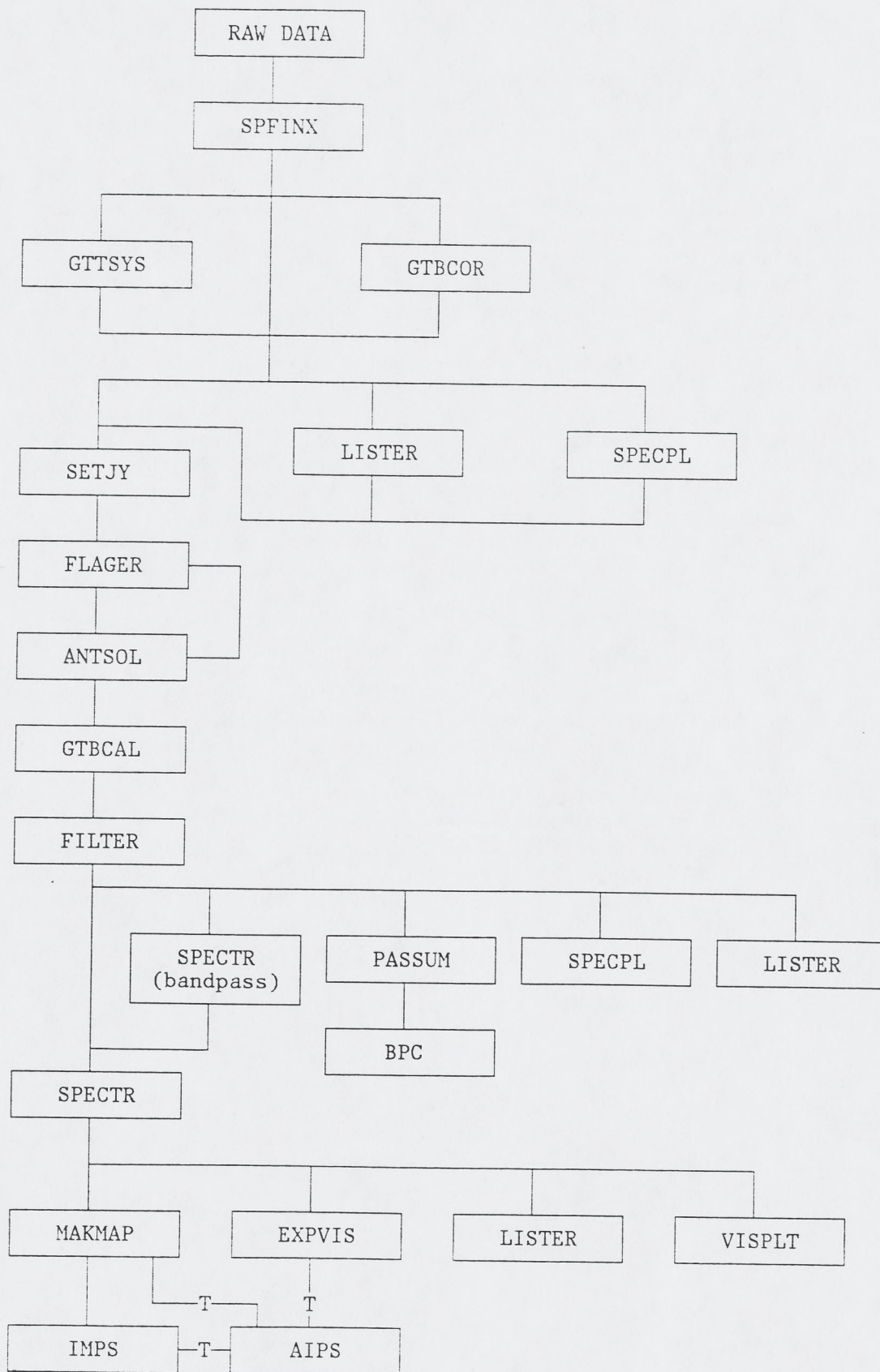
TVMOVIE loads 16 planes from a map cube into each TV channel and, by employing the zoom capability of the image computer, shows them as a movie. The frame rate can be controlled with the trackball while still image, single step, and reversal of direction are also possible. Time goes along the third axis, so this verb is not restricted to movies where velocity varies with time; by running it on transposed cubes, one can step through space-velocity maps in the other spatial coordinate. A spin-off of this verb is that it allows the user viewing 16 channels in one frame after exiting and unzooming.

10.9.2. Hard Copies

The Honeywell grey-scale hard copy unit will make useful working copies of the 16 channel map frames discussed in the previous paragraph. It is recommended to put the TV for this purpose in grey-scale, since the hard copy unit works, rather arbitrarily, off the green gun. Be aware that TVMOVIE reverses the order of the channel maps in even numbered TV channels.

For more permanent hard copies, the TV image can be sent to the DICOMED film recorder.

Regular, old-fashioned contour maps can be made with the AIPS tasks CNTR on the Versatec and KONTR on the ZETA pen plotter. KONTR has the advantage that it works faster and will plot a range of two-dimensional planes from a map cube in one call. Color coding of the contours is recommended when plotting velocity fields with KONTR.



Appendix B. Number of Antennae and Number of Frequency Channels 830105

Number of Frequency Channels	Number of Antennae Allowed
8	All
16	All
32	21
64	15
128	11
256	8

Appendix C. Available Band Widths and Number of Frequency Channels

830105

BW Code	Band Width MHZ	Single IF Mode(1) No. Channels(4) Freq. Separ. kHz	Two IF Mode(2) No. Channels(4) per IF Freq. Separ. kHz	Four IF Mode(3) No. Channels(4) per IF Freq. Separ. kHz
0	50	16 3125	8 6250	4 12500
1	25	32 781.25	16 1562.5	8 3125
2	12.5	64 195.313	32 390.625	16 781.25
3	6.25	128 48.828	64 97.656	32 195.313
4	3.125	256 12.207	128 24.414	64 48.828
5	1.5625	512(5) 3.052	256 6.104	128 12.207
6	0.78125	512(5) 1.526	256 3.052	128 6.104
8(6)	0.390625	512(5) 0.763	256 1.526	128 3.052
9	0.1953125	512(5) 0.381	256 0.763	128 1.526

Notes :

- (1) Observing Modes 1A and 1C.
- (2) Observing Modes 2A and 2C.
- (3) Observing Modes 4 and 4A.
- (4) These are the numbers of frequency channels produced in the AP. Any number of channels that is a power of 2, that is less than or equal to the number in the table (with a maximum of 256; see note (5)), and that is greater than or equal to 8 may be selected using the data selection parameters on the LI card.
- (5) Although 512 frequency channels are produced in the AP, only 256 channels may be sent to CORA. Data selection must be used to meet this limitation.
- (6) Only the upper half of the band is usable.

A number of canned MIC files are available in the system to perform some particularly boring and tedious jobs prone to typing errors and to provide simplified procedures for straightforward processes. They are activated by:

```
do xxxxxx par1,par2,...,parn
```

1. SPECTR

830209

Runs SPECTR on a range of spectral line channels.

Parameters:

1. Data base name of Spectral Line Data Base
2. Visibility type; number of spectral line channels in data base
3. Source name(s)
4. First spectral line channel to process; NO leading zeros
5. Last spectral line channel to process; NO leading zeros
6. Prefix (one or two characters) for Pseudo Continuum Data Bases
7. Disposition of Pseudo Continuum Data Bases ("overwrite" or "extend")

Any other input parameters to SPECTR (e.g., corrections, passfile) have to be set beforehand. Example:

```
r spectr
corrections apply
passfile ljan17
q
do spectr ljan17,32,m81,0,15,c,new
r spectr
passfile ljan18
q
do spectr ljan18,32,m81,0,15,c,over
```

This concatenates the data from two spectral line data bases, each with its own passfile, into PCDBs C0001 through C1415. The new PCDBs are created under the names <prefix>nnmm, where nn is the channel that goes into IFpair AA, mm the one in CC; if the first channel number is greater than 99, the name is <prefix>nnn. Before you start make sure there is enough disk space to hold the PCDBs; the size of the new .VIS files may be estimated as 7/(visibilitytype+3) times the size of the SLDB visibility file times the portion that is taken up by the specified sources in that file.

2. EXPVIS

830117

Runs EXPVIS on PCDBs generated by the SPECTR.MIC file.

Parameters:

1. Prefix to Pseudo Continuum Data Base names
2. First spectral line channel to be processed
3. Last spectral line channel to be processed

The definition of the parameters is the same as in the previous MIC file (SPECTR). Mounting and dismounting of the tape is included in this MIC file. EXPREP is not included.

Example:

```
do expvis c,0,15
```

This writes an export tape for the PCDBs created in the example under SPECTR. Approximately 35000 blocks fit on one tape; start with a new tape since this MIC file does not skip existing files.

When the mount message appears on the screen go to the DEC-10 secondary console, ascertain that your tape request is the one currently being handled, mount the tape on one of the drives, and type:

```
m-n
```

on the console, where n is the unit number of the drive (0-3) you used; make sure it responds with "Done" before returning to your terminal.

3. GAICPY

830117

Copies IF C gains to IF A. This is sometime necessary to overcome bugs in certain programs in applying the gains for mode 1C or 2C observations; normally one should not have to do this.

Parameter:

1. Data base name

Example:

```
do gaicpy ljan17
```

It also creates a backup copy of the gain table before starting the gain copying in case something happens, under the name <data base name>.qai[14,].

4. FILTER

830124

Runs FILTER on PCDBs generated by the SPECTR.MIC file.

Parameters:

1. Prefix to Pseudo Continuum Data Base names
2. First spectral line channel to be processed
3. Last spectral line channel to be processed
4. Maximum flux allowed (Jy)

The definition of the parameters is the same as in the MIC file SPECTR. The fourth parameter is the second element of "vislimits" (vismax) in FILTER; the first element (vismin) is assumed to be 0.

Example:

```
do filter c,0,15,1.0
```

1. IF C and Gain Application

830111

Unfortunately, whenever the calibration is applied to data taken in one of the C-modes, the A-gains are used. This affects the programs LISTER, PASSUM, and ANTSOL, ONLY if calibration is set to APPLY. SPECTR is NOT affected. The solution is to copy the gains from the C side to the A side before such operations. This can be done with CANDID; it is generally a good idea to make a safe place before embarking on the CANDID adventure. Type:

```
copy <dbname>.qai[14,] ← <dbname>.gai[14,]
r candid
g opens '<dbname>.gai[14,<uno.>]'
g[↑↑].corr[↑↑,1] ← x ← g[↑↑].corr[↑↑,2]
return
```

<uno.> is your user number. Do NOT type ahead; wait for the CANDID prompt (->). If this is done in batch or in a procedure, ↑↑ should be replaced by ↑↑↑↑.

There is also a MIC file doing exactly the same thing; it is described in Appendix D under 3. Users are encouraged to use this, rather than running CANDID themselves.

2. SPECPL

830111

SPECPL does not apply the calibration correctly (no matter which IF) to produce sensible amplitudes. Neither does it use the correct flags for IF C data.

3. FILTER

830124

FILTER still only works on continuum data bases. It is suggested to run it between SPECTR and EXPVIS or MAKMAP and to use the MIC file FILTER (see Appendix D).

4. More Interference

830209

Users are advised to avoid Fluke frequencies below 105.0 MHz; this is especially important if the autocorrelation normalization option is used.