SRT Memo #001

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To: SRT Group

From: Alan E.E. Rogers and Larry Kimball

Subject: Description of "phase 1" SRT - DRAFT

1] Characteristics

L.O. Frequency range	1370-1800 MHz
L.O. Tuning steps	40 kHz
L.O. settle time	<5 ms
Rejection of LSB image	>20 dB
3 dB bandwidth	56 kHz
I.F. center	40 kHz
6 dB I.F. range	10-70 kHz
Preamp frequency range	1400-1440 MHz
Typical system temperature	150 K
Typical L.O. leakage out of preamp input	-105 dBm
Preamp input for dB compression from out of band signals	-24 dBm
Preamp input for intermodulation interference	-30 dBm
Square law detector approx. max.	2000 K at 0 dB attenuation 20,000 K at 10 dB attenuation
Control	RS-232 2400 baud

2] Circuit description

A) Preamplifier

A TQ9122 provides a nominal 22 dB gain. The input is matched to the 50 Ω feed for lowest noise using a capacitor and inductor to approximate the T1 and T2 matching sections described in the 9122 data sheet. The output of the preamp is filtered with a 1420 MHz ceramic filter with 40 MHz 3 dB bandwidth to prevent out of band signals from producing intermodulation products in the mixers. To minimize connections the preamp is powered by +5v carried through the R.F. connector.

B) Image rejection mixer

A pair of mixers with 90° quadrature phased L.O. drive followed by a 90° I.F. phasing networks make a "phasing type" single sideband receiver. The lower sideband is only rejected by 20 dB but since the unwanted "image" sideband is adjacent to the wanted sideband we don't expect strong signals in the radio astronomy band to be present in the image. Both the preamp and the MAR-6SM amplifier provide a large amount of reverse isolation so that the level of L.O. radiation, which might interfere with others, is minimized. The unconventional use of the single conversion to a low "baseband" frequency I.F. has the advantage of avoiding a difficult image problem, allows simple active I.F. filtering, as well as allowing for easy future digital signal processing of the baseband. The disadvantage is that we need to rely on amplifier reverse isolation to prevent significant L.O. radiation. The AD8011 operational amplifiers are unit gain all_pass filters with 90 degree phase difference determined by c1 and c2. Since most of the radiometer's gain is in operational amplifiers it is very stable and requires only infrequent calibration.

C) Gain control

A 10 dB attenuation can be switched in to prevent overloading the power detector when observing strong signals like those from the sun when is in an active state.

D) Active I.F. filter/amplifiers

A pair of AD8011 operational amplifiers provide 53 dB of gain and high/low pass filtering. The high pass cuts-off frequencies below 10 kHz while the low pass cuts-off frequencies above 70 kHz. The high pass is a 4-pole Butterworth filter with 56 kHz 3 dB passband.

E) Square law detector

The conversion of the I.F. frequency voltage waveform to a voltage which is proportional to the I.F. signal power uses a back-diode or Schottky diode in the "squaring" region. Because the square law region is at a very low level the diode output is amplified by a factor of 100 using a OP-27 amplifier.

F) Analog to digital conversion

The I.F. power is an analog signal which is converted to a pulse whose duration is inversely proportional to the average power present during the pulse period. The AD654 and the stamp "pulsin" routine performs this "integrating" analog to digital conversion (ADC). The AD 654 output is a 12 ms positive pulse for a nominal 1 volt output from the OP-27 followed by a fixed 3 ms negative pulse. This negative pulse is shortened by the current through a diode when the output goes low. See the AD654 data sheet for the details of its operation. The stamp uses the pulsin routine to measure the duration of the positive pulses.

G) Local oscillator synthesizer

A voltage turned oscillator (JTOS-2000) is "phase locked" to the 8 MHz crystal oscillator using a LMX2325 synthesizer chip. The details of the LMX2325 and the principles of the phase lock are described in the data sheet. A MAR-4SM amplifier is used to isolate the oscillator from the mixers and an OP-27 is used to boost the LMX2325 phase detector voltage so that the oscillator can reach the OH frequencies at 1665 MHz which require a tuning voltage above +5v.

H) Serial communication

The D.C. power along with bi-directional serial communication are all multiplexed onto a single conductor coax cable which connects the "ground" electronics from the receiver electronics on the antenna. The voltage from the LM317T conveys the D.C. power and the "uplink" to the receiver all follows:

RS_232 input	LM317 out	Voltage on cable
+12v	22v	19v
-12v	17v	14v

A CMP402 comparator in the receiver is provided with at 16v threshold which converts the 19v (RS-232 high) to 0 volts and the 14v (RS2-232 low) to 5 volts. The cable voltages in the above table are for the "downlink" not transmitting state for which the receiver draws a 150 ma. When the downlink is active and a transmitted "one" is conveyed by drawing an additional 100 ma which drops the cable voltage by 2 volts so that a CMP402 on the "ground" with 13 v threshold can be used to drive the RS-232 output. [A 0 to 5 volt output is used to drive the serial COM port. This is not a true RS-232 signal but should work with all PCs]

I] Stamp controllers

The radiometer and antenna drives are controlled via stamp 1 controllers. The RS-232 serial port is used to talk to both stamps using a different "keyword" for each stamp and a wired logical "OR" for the response from each stamp. This method allows communication with one stamp at a time. Under most circumstances this is acceptable since we don't need the radiometry data while the antenna is in motion.

J] Biasing the operational amplifiers

Only a positive voltage is supplied to the radiometer. Since the operational amplifiers require both polarities the inputs are biased to a voltage above ground potential with resistor network. In addition there are many decoupling capacitors to filter the power and bias voltages.

K] Motor control

Uses power H-bridges (LMD-182000) to control and reverse the +24v D.C. power to the motors.

L] Vane calibrator

An H-bridge is also used to provide a reversible voltage to the motor which swings an absorber in front of the feed to provide an ambient load for calibration of the system temperature.

3] Stamp firmware

A] Radiometer stamp control firmware

The radiometer stamp communicates with the PC serial port, controls the L.O. frequency synthesizer, the 10 dB attenuator and measures the radiometer power.

a] L.O. frequency synthesizer

The reference divides (R register) is set to 200 to provide a 8 MHz/200 = 40 kHz reference. [This could be changed by small amounts for added frequency flexibility but large changes may require changing the loop filter capacitor values.] The prescalor is set to 64/65 by making S15 = 0. The A register is set by first calculating its value in the host PC

j = (freq/0.04) + 0.5;

Where freq = frequency in MHz
j = 32 bit unsigned integer

Then separating j into bytes

b11 = (j >> 14) & 0xFF
b10 = (j >> 6) & 0xFF
b 9 = j & 0x3F

because the synthesizer is quantized the actual frequency will be

freq = ((256 * b11 + b10) * 64 + b9) * 0.04

in the case that the frequency you selected is not a multiple of the 40 kHz reference frequency. The bytes b11, b10, b9 along with a byte b8 to control the attenuator are sent to the stamp following the keyword "freq".

b] Power measurement

The radiometer power is measured by using the pulsin routine (see stamp 1 manual) to count the stamp clock cycles in a pulse from the AD654 voltage to frequency converter. To enhance the accuracy we count up to 10000 10 microsecond cycles. During this time we may have several AD654 positive pulses so we return the total count w1 and the number of pulses counted w2. The host PC then calculates the power

Power = scalef*(w2/w1)

so that, for example, a 1 volt out of the OP-27 which produces a pulse length of 12 ms so that

w2 = 8 = b4
w1 = 9600 = b3 x 256 + b2
and power = 833.33 when scalef = 10^6

The scale factor of 10^6 is approximately the value which make the output in units of K but each individual radiometer needs to be calibrated if you want the power to be in units of Kelvins.

B] Antenna drive control stamp

The antenna azimuth and elevation drives are controlled one at a time with a stamp 1 in the power supply unit which is located near the control PC. The motors are activated when the stamp detects the keyword "move". The keyword is followed by a byte which gives the axis and direction to the move and the number of "counts" of the reed microswitch on the drive gear to move. The motors drive a magnetic disk with 12 poles giving 12 contact closures per rotation which in turn drive a sprocket gear with 8 teeth which chain drives a large 54 tooth sprocket gear which in turn drive a sector gear of 52 teeth via a worm gear. Thus the number of counts per degree is

$$12 \times 54 \times 52 / (8 \times 360) = 11.70$$

The stamp counts the positive pulses from the reed microswitch using the pulsin routine. The routine is repeated until the derived number of pulses have occurred or the pulsin routine times out and returns to zero. Only one axis can be moved at a time because the pulsin routine can only monitor one microswitch at a time.

4] Antenna feed

The radiometer is connected to a feed which illuminates a 10 foot diameter dish with f/D ratio of 0.4. The feed is made by adding a $\lambda/4$ probe to the C-band (4.2 GHz) feed. The outer diameter of the C-band (4.2 GHz) feed. The outer diameter of the C-band feed is about 8" which supports a TE_{11} circular waveguide mode with $a/\lambda \approx 0.5$ which is close to optimum for a $f/D \approx 0.4$ [see Methods of Experiment Physics, Astrophysics edited by Marton, vol. 12B page 32.] The aperture efficiency should be close to 60% (or 50% when the feed and feed support blockage is taken into account.) so that

$$T_A = \frac{FA\eta}{2k}$$

where A = area of the reflector
F = radio source flux density in Jy
η = aperture efficiency ≈ 0.5
k = Boltzmann's constant 1.38×10^{-23} $wHz^{-1}K^{-1}$

with the illumination fo the feed the antenna beamwidth should be

$$\theta_B = 1.22\lambda/D = 5 \text{ degrees (10 foot at1.4 GHz)}$$

5] Calibration

The radiometer can be calibrated using the "vane cal" method in which the antenna is pointed at cold sky, the power noted, and then an absorbing vane is placed over the feed aperture and the power measured again. In this case

$$\frac{T_R + T_{vane}}{T_R + T_{spill} + T_{sky}} = P_{vane} / P_{sky}$$

where T_s = system temperature - includes receiver, sky background, atmosphere and spill-over

T_{vane} = ambient temperature of the vane (nominally 300 K)

P_{vane}/P_{sky} = power ratio

T_{spill} = feed spill-over ≈ 20 K

T_{sky} = cosmic background 3K plus atmosphere ≈ 1K

A T_s value of around 150 K should be measured. The antenna efficiency can then be measured by observing the temperature increase when the antenna is pointed at a radio source of known strength. The sun can be used if the flux density is obtained from www.drao.nrc.ca [its value at 1420 MHz can be approximately extrapolated from the data at 2800 MHz assuming a linear dependence on frequency.] For the observing frequency. The sun's flux density at 1420 MHz can vary from 2×10^5 Jy to 2×10^6 Jy depending on the sunspot activity which brightens the sun at radio wavelengths.

5] Projects for SRT -

A] Evaluate radiometer performance

a) measure system temperature using vane calibration
   - check at various frequencies in 1420 MHz radio astronomy band.

b) test antenna spill-over by doing tipping scans (see discussion of attenuation in atmosphere).

c) measure antenna beamwidth using the sun as a signal source.

d) Evaluate pointing errors using the sun using 25 point mapping

e) Measure aperture efficiency using automated on/offs on Cas A, Moon and Cygnus X

SRT continuum flux calibrators

Source	Flux density Jy	Expected Ta K	Comments
Moon	710	1	Very weak
Cassiopeia A	2000	2.6†	
Cygnus X	~ 5000	7	Extended
Sun	2×10^5 - 2×10^6	264 - 2640	variable

†10 foot dish with 50 % aperture efficiency

To avoid confusion with the hydrogen line, continuum measurements can be made at a frequency of 1422 MHz.

B] Solar observations

a) measure sun's flux density - a time history of the 28 day solar rotation would be especially interesting.

C] Galactic hydrogen line projects

a) periodically observe several points in the galactic plane over a period of 1 year and solve for the earth's orbit from the frequency shifts in the spectra.
b) Map the sky in 21 cm H I emission. The entire sky can be mapped in 24 hours with about 10 seconds integration per beam. A deeper more sensitive survey can be made by parking the antenna at one declination for 24 hours and letting the earth's rotation map out one swath each day. With the 4 degree beamwidth this will take more than a month to cover the sky visible from the Boston area.

D] Extragalactic hydrogen line - in Andromeda

Perform an experiment to detect HI emission from the nearby Andromeda galaxy. This experiment will require long integrations using beamwidth "on/off mode Andromeda. In addition data editing may be required to remove interference. Several days of data should result in a significant detection and a determination of the average velocity and velocity spread. If 128 40 kHz frequencies are observed for a total of 24 hours the theoretical noise level in each frequency bin should be

$$2 \text{ x } T_s / (BT/128)^{½}$$

$$\approx 0.1 \text{ k for } T_s = 200 \text{ K}, B = 40 \text{ kHz}, T = 86400$$

The factor of results from taking the difference between the "signal" and "comparison" and only half the integration being one source.

E] Atmospheric attenuation

The attenuation of radio signals in the path through the atmosphere is about 0.005 dB/km at 1.4 GHz. This attenuation results in an increase in antenna temperature of approximately 2 cosec (elevation) Kelvin or an attenuation of about 8% at 5 degrees elevation. The elevation dependence of the system temperature can be measured by it is difficult to separate the spillover effects from the atmospheric temperature dependence. However it might be possible to measure the cosecant dependence of the setting sun provided the horizon is clear and there is no blockage to low elevation. While it may be difficult to measure the atmosphere attenuation it should be straight forward to show that rain has little or no measurable effect on radio signals at 1.4 GHz.

6] <u>PC control software</u>

We provide 2 software packages, one written in C and another in JAVA.

<u>C version</u>

The SRT "C" program is not glamorous but is quite functional and will run on virtually any IBM compatible new or old. It will run in a DOS window under windows 95/98 or under DOS 3.1 or later. It uses the serial port to control the SRT and doesn't require a mouse as all the control is keyboard driven.

a) Catalog file

The program reads a catalog file (srt.cat) which contains the source catalog, antenna limits and site specific data. It is an ASCII file in a fairly obvious format which can be edited with any text editor. The first word on each line is a "keyword", which is used by the software to determine the nature of data which follows the keyword. For example the right ascension, declination and epoch follow the SOURCE keyword. The convention chosen for the antenna set-up and its limits are as follows:

1] The mid-point of the azimuth rotation points due south. (azimuth = 180 degrees)
2] The mid-point of the elevation rotation is the zenith (elevation = 90 degrees).
3] The azimuth limit known as the "stow" position is close to the east normally around azimuth = 104 degrees.
4] The elevation stow limit is normally about 15 degrees.
5] When pointed south the antenna will be in its normal elevation range.
6] When pointed north the antenna will be rotated all the way past the zenith in elevation.
7] The limits are normally symmetrical (but are not assumed to be) so that the azimuth range with the antenna elevation before the zenith will be from 104 to (360-104) = 256 and the azimuth range with the antenna "on its back" will be 180 + 104 = 284 through north to (180 - 104) = 76.

b) Antenna position

The antenna axis angles are sensed by counting pulses produced by the microswitch contact closure from the "stow" position. The gear ratios set the scale to 11.7 pulses per degree. Only one axis is moved at a time because the stamp can only sense pulses on one axis at a time. If the power is interrupted or the program restarted the software drives the antenna to the stow limits so it can reinitialize the pulse counting to regain a knowledge of the antenna pointing angles.

c) Pointing modes:

The program supports several simple modes:

1) Fixed azimuth and elevation

The software moves the antenna to a fixed azimuth and elevation by typing "d" the computer will prompt for entry of the desired angles. This mode might be used to gather spectra as the earth's rotation sweeps the antenna beam in right ascension keeping the declination fixed. The software continuously communicates with the receiver, displays the spectrum for each scan of frequencies and displays the average spectrum.

2) Tracking

The antenna is pointed at a source selected from the catalog by typing "s" to select the source and "t" to track. [This is a line on the screen which prompts the user with the available keyboard commands] The tracking mode is useful if you want to average the radiometer output to reduce the noise in the spectrum.

3) Raster scan

You can go from the tracking mode to the scan mode by typing "n". The software moves the antenna to each of 25 points making a raster scan of the radio source. At each point it takes one complete radiometer frequency scan. At the end of the raster the software uses a 2-D dimensional convolution to contour plot the interpolated beampattern, measure the offset pointing angles for the peak signal, and the peak signal. This mode is used to check the pointing and measure the flux density on a strong source like the sun.

4) Beamswitching or "on/offs"

Since the radiometer is a total power spectrometer without any electronic "Dicke" switch the only way to measure weak signals is to move the antenna on and off the source and synchronously detect the signal by subtracting the "off source" comparison spectra from those "on source" signal spectra. The comparison spectra are taken on alternate sides of the signal spectra by moving the antenna in azimuth while continuing to track the source. In this mode the average spectrum display is the average signal minus comparison.

5) Drift

In this mode the antenna is driven to the position the selected source would have at a future time 1 beamwidth in advance. Radiometer data is then taken as the source slowly drifts through the antenna beam. This mode might be used to map the antenna beam or measure the flux density of a strong source without the effects of antenna gear backlash.

d] Radiometer modes

The current radiometer is a very simple single frequency total power detector. The desired frequency is sent to the radiometer which tunes to that frequency (see details in section) , integrates the power for approximately 100 ms and replies with power measurement. When the program is not moving the antenna it is constantly sending and receiving data from the radiometer. The software treats a sequence of frequencies as a "scan". A scan can be single frequency or as many as 1024. The received power is "binned" into a signal and comparison array. The program allows you to select the frequency by typing "f" at which it will prompt you for the center frequency and the number of frequencies. The software spaces the frequencies 40 kHz apart which is the frequency synthesizer quantization. If you select a frequency which cannot be exactly synthesized the nearest possible frequency will be commanded and displayed. By convention the frequency is the local oscillator frequency which is about 40 kHz below the center of the passband.

e] Radiometer output file

The radiometer output can be recorded in a data file for off-line processing. Each scan is recorded as a single line of an ASCII file. The line starts with the UT time, antenna pointing angles, pointing offsets, center frequency and is followed by the radiometer power. The pointing angles as those calculated from the counters on the axes. When the output data is processed the antenna beam location in right ascension and declination can be recalculated. The files are named yydddhh.rad and for continuous radiometry are about 2.5 MB but can compressed fit on one 1.4 MB floppy. The data file recording can be turned on and off by typing "r".

F] Command file

The C and JAVA program will schedule the SRT using a command file srt.cmd to that you can acquire data unattended. The each line in the file should have the following:

Stop time Source mode

Where stoptime = yr:day:hr:min:sec 1998:232:12:00:00
source = source name - same as in srt.cat
mode = t = track; n=25 point raster; b = beamwidth

The command file mode is activated by typing "R". The program reads a line and activates the desired mode until the stop time is reached when it reads the next line. More details of the command syntax are given in the on-line help.

G] JAVA

The JAVA version must run under Windows either from bytecode (java srt) or using the compiled JAVA srt.exe. In either case the jsp*.dll (dynamic link libraries) are required. Program control uses the mouse, keyboard for manual data entry or command file. For example a source can now be selected by clicking on the display.