SIDI, the SImple Digital Interferometer

Introduction and FAQ

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Background:

The ERAC (European Radio Astronomy Club) has a project to build an amateur VLBI system called ALLBIN. While several amateur radio astronomers have done classic (non-VLBI) interferometry before, they all did it using analog techniques, see for example:

Hans Michlmayr's phase switched interferometer (EXTERNAL LINK)

IRO interferometer (EXTERNAL LINK)

However, VLBI requires many operations like correlation search and delay equalization, fringe stopping, etc... that are very hard to do with analog circuits. Therefore I decided to try designing a digital interferometer as one of the first steps toward the ALLBIN project. In the 21st century it is probably not necessary to explain the advantages of going digital, but let me mention only one: it allows things to be done in software. It is much easier for amateurs to develop software than hardware, since it requires much less of a material basis, like instrumentation etc.

My goal is to publish here all the gory details needed to reproduce various versions of SIDI - with all schematics, software sources etc - so anybody can build and use it.

Usually I announce any new developments of SIDI at the ERAC-VLBI Yahoo group (EXTERNAL

LINK)

Design goals:

To design a digital radio interferometer for radio astronomy accessible to amateurs, suitable for both connected and disconnected (VLBI) interferometry.

Design guidelines:

Design guideline #1: Keep everything as simple and cheap as possible, so that as many amateurs as possible can build it, while also keeping it flexible and open for future improvements.

Design guideline #2: The design should be modular, so that many different interferometers can be built from the standard modules and upgrades and changes can be made one module at a time.

Design guideline #3: Avoid the use of exotic hardware and software components that are hard to get or prone to obsolescence. The design should be fully open, no proprietary IP etc.

Basic design choices:

Two basic choices were made for SIDI, mainly to comply with the design guideline #1: direct conversion receivers and one bit sampling.

In an interferometer where correlation is done after frequency conversions, all local oscillators must be coherent. In VLBI, this can only be achieved by phase locking the LO's. Phase locking is a tricky business, so it is advisable to reduce it to a minimum in an amateur setup. That is one reason for choosing a direct conversion receiver, which only has a single LO. Another is that it is one of the simplest receivers to build and tune up.

Radio astronomy signals are usually well below the receiver noise, so sampling them with high precision makes no sense, since most of the bits will only contain receiver noise. Using single (yes, ONE) bit sampling looses only cca 2dB in this case, of which one can be reclaimed by oversampling. Bandwidth is much more important for sensitivity here than number of bits, and single bit sampling makes very fast circuitry qiute simple. Single bit sampling brings so much simplification (like no AGC etc) at so little cost that I think it is the only sensible choice for an amateur interferometer at this point. Many professional VLBI systems have used 1-bit sampling, and most of them use only two bits.

Incarnations of SIDI

SIDI version 1.0
For the first version of SIDI, I used modules from Matjaz S53MV's 23cm megabit PSK packet radio transceivers. The data goes into the PC via the parallel port, using software sample timing. Software runs under DOS / Borland C 3.0.

This was meant mostly as a proof-of-concept prototype, and I probably won't do any improvement work on it in the future. Therefore I do not recommend it for construction.

For a description of hardware, software and the results obtained, click here: SIDI 1.0

SIDI version 1.1
This version is currently under development. It uses tuners from digital satellite TV receivers and simplified IF amplifiers. It still uses the LPT port and DOS software.

Its main advantages compared to v 1.0 are frequency agility and much easier construction - no microwave skills required.

For a description of hardware, software and the results obtained, click here: SIDI 1.1

SIDI version 1.2
This version is currently under planning.
The main difference compared to v 1.1 will be a USB 2 interface and migration to GNU/LINUX.

For a description of hardware, software and the results obtained, click here: SIDI 1.2

FAQ:

I've just published this, and people haven't yet asked many questions, so this is just a list of "Fearlessly Anticipated Questions"!

Q1: Why not use the (Icom, Yaesu, Kenwood....) commercial general purpose communication receiver?

A1: There are two main reasons for this: 1. you cannot phase lock their many internal oscillators 2. their bandwidth is WAY to small for serious work. Currently there is no way around building your own receivers. Because of modularity, it could become possible to use slightly adapted modules from surplus cellular, satellite and similar equipment.

In the meantime, somebody notified me of the fact that some new model has a master clock reference input and an wideband IF output. Well, that probably solves the locking problem, (is it possible to know the exact division ratios used in the internal synthesizers?) but in the future I would like to use 10 and

more MHz of bandwidth, which a 10.7 MHz IF output certainly does not have.
And of course, to convert that 10.7MHz output to I and Q would require another locked oscillator and mixers that you would still have to provide... That is not much less hardware than a microwave direct conversion RX!

And of course, these stupid big boxes with all their bells and whistles and the QRM their CPUs produce would be a nightmare to use...

For an interferometer you need at least two of them - so their price is even less attractive!

Q2: Why didn't you use a sound card as input device?

A2: The reasons are almost identical as above: 1. you have no control over the sampling clock 2. their bandwidth is too small. There probably are some high-end sound cards that allow external smapling clocks, but these aren't cheap and easily available, so the design guidelines rule them out. And they will NEVER have the bandwidths I plan for the future versions of SIDI.
External clocking is essential for VLBI work where the data must be coherently sampled and recorded on separate computers.

Q3: Why do you use the printer port?

A3: Mainly to comply with design guideline #1 above. The LPT port offers cca a MHz of bandwidth with only very simple dumb hardware. New standards like USB, IEEE1394, SCSI etc all require intelligent hardware that can identify itself, negotiate bus bandwidth etc. There are some interface chips available that will do most of those chores, but using them would go against design guideline #3 above - the standards in the PC world change so quickly that a design published using chips available today would be useles in a few years. However because bandwidth is so important it would also be stupid to limit oneself in this respect, so I DO plan switching to a more powerful way of getting bits into the computer, probably using FPGA's and open IP.

But since getting bits into the PC faster and under external clock is so important, I still do think about USB 2.0 - currently I'm looking into Cypress FX2 chips. Hopefully at least a compatible family will be available for some years....

Q4: Do you plan to write a Windows version of the programs?

A4: WINDOWS?? Didn't know that funny thing was still around!
The answer is no.

Q5: What does an interferometer actually measure?

A5: It measures the **correlation** between signals from antenas at different locations. This is a measure of how similar two signals are.

For example, if the two antennas do not see a common source of signal, there will be no similarity

between their signals, because the signals will come from independent sources (mostly LNA noise), and the correlation will be zero.
On the other hand, if the antennas see a comon source, their signals will have a common part in addition to the independent part caused by preamplifier noise etc. The common part will in general arrive at different times to the two antenas (because of the geometry - different path lengths from the source to each antenna) and will therefore have a relative delay (time offset) between the two antennas, This delay is also measured by the interferometer and is partly reflected in that the correlation is a complex number.

Obviously, the amount of correlation depends on the power of the source: a brighter source will produce a bigger common component (compared to receiver noise) so the correlation will be higher.

But the correlation also depends on the angular brightness distribution of the source and the antenna spacing (baseline). By recording the correlation with many different baselines, it is even possible to reconstruct an image of the source.

The most popular output of an interferometer are the "fringes".They are just the real (or imaginary) part of the correlation, plotted versus time. As the Earth rotates, the delays change and the phase of the correlation rotates, so its real and imaginary parts change periodically.

Q6: How does an interferometer compare to a classic radio telescope?

A6: Hmmmm? Counter question: what is a "classic radio telescope"? :-)
OK, I'll suppose it is an total power radiometer as used by many amateurs.
Maybe the question was meant more as: what do I gain with the extra complication? (second antenna, and in the case of a digital interferometer, a second receiver too...)

First, in one aspect, an interferometer can be simpler than a radiometer: to get good sensitivity with a radiometer, one needs to control the gain very precisely, otherwise the gain fluctuations will easily swamp the few hundreths of a dB produced by a weak source.
With an interferometer (except with an additive one) gain control is not so important, so one can get good sensitivity without temperature control, Dicke switching etc.

Second, and most important, in terms of angular resolution, the interferometer can sometimes simulate the performance of an antenna of the size equal to the distance between the interferometer antennas.

On the down side, to get full performance from an interferometer, one needs precise knowledge and control of the phase. With longer baselines this can be even harder than gain control.

Qx:

Ax:

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