An Economical Dual Vector SDR with Optional 2 GHz Extension for Amateur Radio and Citizen Science Applications

[n6gn 1 August 2023]

This article describes a strawman proposal for an economical, moderately high dynamic range, two path receiver/measurement system that can operate up to 30 MHz or optionally up to 2 GHz. The two paths accurately track one another in both amplitude and phase, having the same relative time reference to within [ten's] of nanoseconds, good absolute amplitude accuracy with tracking perhaps better than [.1]dB between them. Furthermore the time reference may be accurately synchronized with a GNSS absolute time reference. This accuracy is achieved by way of a novel calibration scheme performed using an included calibrator and digital signal processing (DSP). Fequency accuracy, better than .1 parts per billion (ppb) is achieved through external disciplining, either from the GNSS constellations or local 10 MHz quartz or rubidium frequency standards. In GNSS mode, absolute time is also available.

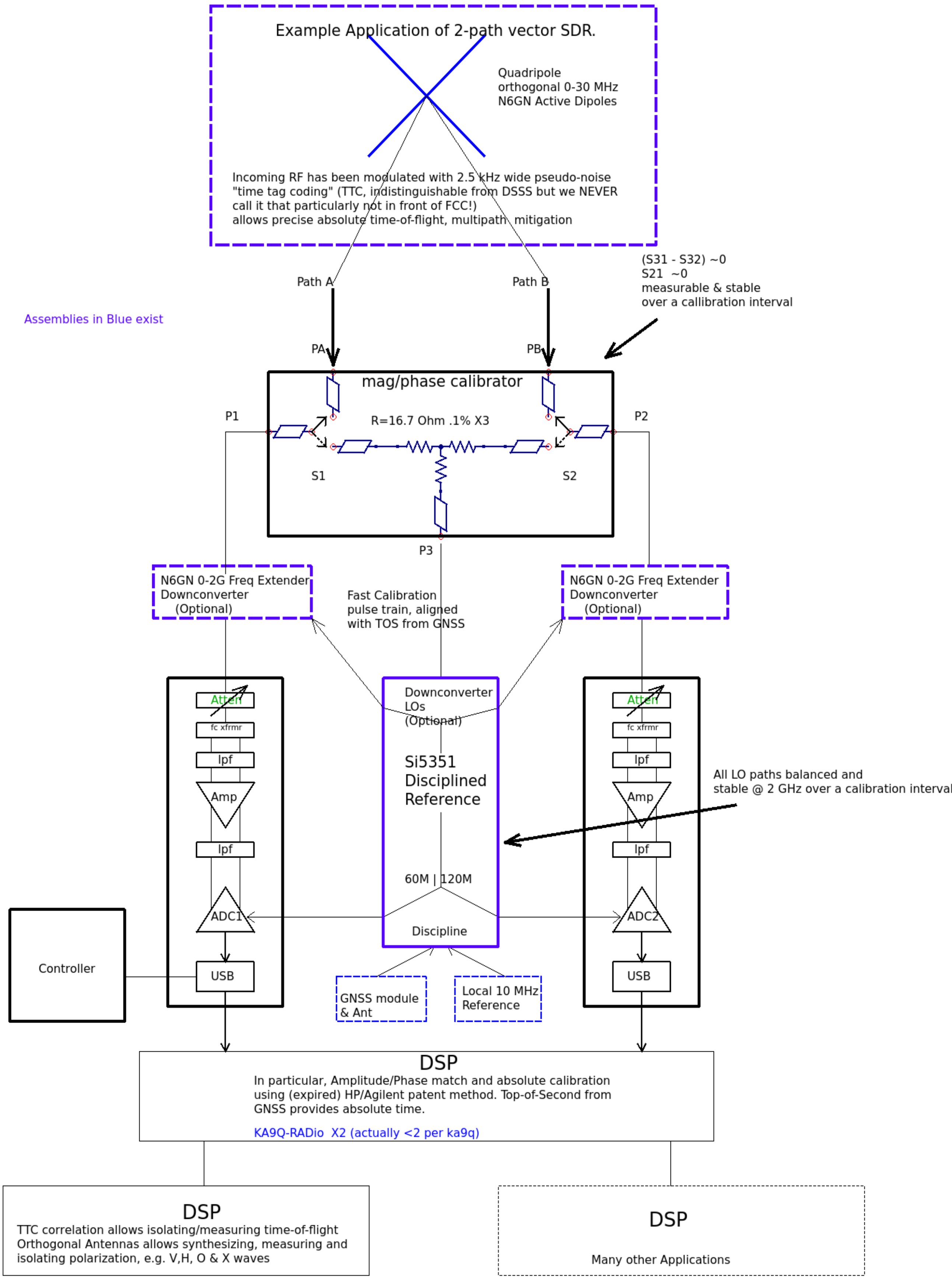
Within a 30 MHz bandwidth multiple individual 'receive' data streams are available from either port's (ADC) path. This is achieved through use of ka9q-radio DSP software which digitizes each port's ADC and further provides for the streams as well as some limited application interfaces. Additional interfaces might include provision for 30 MHz wide spectrum display, as well as a generality of amateur analog and digital coding protocols such as AM, FM, SSB and PSK, FSK etc.

Because the two paths make complex (vector) measurements, their outputs can be combined to produce an additional variety of useful applications. For example, when combined with inputs from orthogonal antenna systems, beam forming and wave polarization synthesis make separation of different ioospheric propagation mechanisms possible, not least O and X waves. Apart from use with antenna systems, by combining with relatively simple directional devices very accurate vector nework analyzer (VNA) measurements are possible. Similarly, combined with appropriate reference antennas or noise sources the good absolute amplitude accuracy makes electric field measurements and noise figure measurements possible.

Creating two isolated paths, accurately aligned to one another and accurately calibrated in both amplitude and time/phase requires special effort – far more than just providing common local oscillators and clocking to two ADCs. Absolute time alignment referenced to defined measurement planes are required for accurate tracking of the ADC samples. Extending the useful range of the ADCs to low microwave frequencies by way of an optional frequency extender requires further care in design.

This design attempts to create a relatively low cost set of hardware which along with suitable DSP in an associated computer can accomplish all of this.

A block diagram of this proposed system, with an example antenna application is shown below. Separate items within the block are described next.



Example Application of 2-path vector SDR.
Quadripole
orthogonal 0-30 MHz
N6GN Active Dipoles
Incoming RF has been modulated with 2.5 kHz wide pseudo-noise
"time tag coding" (TTC, indistinguishable from DSSS but we NEVER
call it that particularly not in front of FCC!)
allows precise absolute time-of-flight, multipath mitigation
(S31 - S32) ~0
S21 ~0
measurable & stable
over a callibration interval
Path A
Path B
Assemblies in Blue exist
PA
PB
mag/phase calibrator
P1
P2
R=16.7 Ohm .1% X3
S1
S2
P3
N6GN 0-2G Freq Extender
Downconverter
(Optional)
Fast Calibration
pulse train, aligned
with TOS from GNSS
N6GN 0-2G Freq Extender
Downconverter
(Optional)
Atten
fc xfrmr
lpf
Amp
lpf
ADC1
USB
Downconverter
LOs
(Optional)
Si5351
Disciplined
Reference
60M | 120M
Discipline
Atten
fc xfrmr
lpf
Amp
lpf
ADC2
USB
All LO paths balanced and
stable @ 2 GHz over a calibration interval.
Controller
GNSS module
& Ant
Local 10 MHz
Reference
DSP
In particular, Amplitude/Phase match and absolute calibration
using (expired) HP/Agilent patent method. Top-of-Second from
GNSS provides absolute time.
KA9Q-RADio X2 (actually <2 per ka9q)
DSP
TTC correlation allows isolating/measuring time-of-flight
Orthogonal Antennas allows synthesizing, measuring and
isolating polarization, e.g. V,H, O & X waves
DSP
Many other Applications

Calibrator

As shown in the block diagram the calibrator assembly is essentially a broadband 5-port approximately 50 ohm device which switches the entire system between measurement and calibration modes. By design its parameters are stable over time and frequency. In calibrate mode a nearly identical pulse train common to both paths is processed in order to provide amplitude and phase corrections for each. In measurement mode, each of the two separate inputs are presented to the associated frequency converter(s) and ADC. In measurement mode, there is high isolation between the two paths.

Its role is to provide a fast rise time pulse train presented on Port 3 to Ports and Port 2. Although careful VNA measurement of this assembly can be performed and applied to further improve calibration and accurately define a measurement plane, symmetry of paths and simplicity may keep this from being required for many measurement purposes.

Timebase

The timebase provides accurate frequency conversion and clocking for the ADCs. Although symmetry of design creates nearly identical conversion signals at similar points along the two paths, this is not sufficient to acquire and maintain the accurate alignment required for vector operations at the maximum measurement frequencies. This greater precision is enabled by DSP performed during a calibration which corrects for differences and variations in the paths both for absolute amplitude and relative time/phase. Furthermore this correction can produces high frequency accuracy for both frequency and analog-to-digital data conversions.

Additionally, absolute time referencing is available by way of the GNSS disciplining path. Top-of-second alignment of the calibration pulse train can provide a quite precise reference to satellite constellation time. This can become useful for measuring time-of-flight of ionospherically propagated signals for geolocation as well as measurement of the ionosphere itself.

Hardware exists.

2 GHz Frequency Extender (Optional)

The frequency extender is essentially a dual channel 20 MHz wide block downconverter. It can convert separate paths of any contiguous frequency block between 10 kHz and 2 GHz to an IF frequency of 10-30 MHz. A single set of accurately synchronized and disciplined LO’s is common to two different frequency conversion paths. It is optional to extend the range of the basic ADC systems.

Hardware exists.

HF Analog Front End

The HF front end provides conditioning and protection for each ADC path. It is identical for each path. Anti-alias filtering as well as signal preamplification and attenuation is provided in order to optimize dynamic range while providing a relatively low system noise floor. Operation is from near-DC to somewhat less than half the ADC sampling frequency as is common for convetional HF SDRs.

ADC

Each ADC samples the conditioned, broadband analog RF and provides a very high speed digital stream to the USB for transport to the associated computer where DSP is performed.

USB

The high speed data stream from the ADC is transported across the USB link to a host computer at as much as several Gbs.

Controller

The controller interfaces with control applications in the host computer to configure and calibrate the hardware and to set up the USB stream, as required.

DSP

DSP provides the bulk of the capability and precision of this system as well as its flexibility for various applications. In particular, there are two pieces: the ka9q-radio package and an implementation of newly expired US patent #6600438 is used for path calibration and tracking.

A description of ka9q-radio as applied to a single ADC SDR is here:
http://www.sdrutah.org/info/using_ka9q_radio_with_the_rx888.html

while Broadband IF conversion using two ADCs https://patents.justia.com/patent/6600438 gives a description of the correction algorithm.