National Radio Astronomy Observatory
Tech Transfer

Associated Universities, Inc.

Variable Frequency Coherent Hybrid Synthesizer

Frequency Synthesizer Step Sizes as Small as One Hz

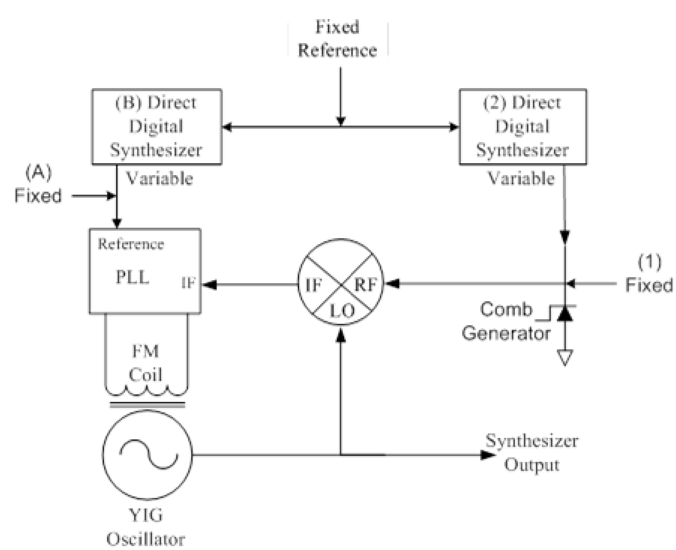
Value Proposition

The new synthesizer design (originally designed for radio telescopes) is used for local oscillators (LO) with increased tuning resolution and smaller synthesizer steps sizes that will provide greater flexibility and increased capability of existing hardware.

Previous synthesizer designs relied on comb generators that provided a picket fence of frequencies with fixed spacing between pickets. The flexibility of this synthesizer is obtained through the application of variable frequency comb lines where the difference between pickets is allowed to vary in order to provide tuning coverage over the full frequency range.

The evolution of synthesizers for radio astronomy has been to smaller and smaller synthesizer step sizes. The original synthesizers for the NRAO Very Large Baseline Array (VLBA) that this design replaces provided 200/300 MHz step sizes. Synthesizers designed by NRAO and used for the Atacama Large Millimeter-submillimeter Array (ALMA) second LO had step sizes of 62.5 MHz. By comparison, this new type of synthesizer can easily provide step sizes of 10 kHz. Additionally, these new synthesizers can provide step sizes of one hertz or less with only a small increase in complexity.

US Patent 8,779,814 as implemented at NRAO, which is a composite of all four types from the chart to the right.



A New Synthesizer for when close is not *exactly* enough

Frequency synthesis results in the generation of one or more frequencies from one or a few reference sources.

A new type of NRAO synthesizer can be described as a Coherent Hybrid (direct/indirect) type. The direct portion consists of a Fine Tune Synthesizer (FTS) realized in the form of a Direct Digital Synthesizer (DDS) that allows precise digital control of the frequency and phase of the synthesized frequency. The indirect portion includes other elements including a Phase Lock Loop (PLL) and a comb generator which allow the synthesized frequency to maintain coherence in conjunction with the FTS.

Existing synthesizers utilizing fixed (or near fixed) comb lines can use an FTS to tune to a small range of offset frequencies around the fixed comb lines. However, this results in tuning holes in the output frequency range due to limitations in the FTS tuning and frequency range limitations of the PLL.

The new NRAO type of synthesizer has no tuning hole limitations and is further capable of almost limitless output frequency tuning resolution (often referred to as synthesizer step size). An additional advantage is that any particular desired frequency can be achieved in multiple ways by simply changing the settings thus avoiding combinations that might otherwise generate deleterious spurious responses and spectral degradation.

Synthesizer types A1 and B1 are well known, while types A2 and B2 are the newly patented intellectual property.

		Intermediate Frequency (IF)	
		Fixed (A)	Variable (B)
Comb Lines	Fixed (1)	Advantages: Simple, Reliable. Disadvantages: Discrete frequencies, 200/300MHz steps	Advantages: Small tuning range around comb lines. Disadvantages: Frequency tuning holes, <50% tuning coverage
	Variable (2)	Advantages: Complete tuning over entire frequency range. Disadvantages: ~10kHz step size, Practical limit	Advantages: Capable of sub-Hz step sizes. Disadvantages: Requires 2nd DDS, Complexity

Additional Background

The signal source for an existing synthesizer is an oscillator capable of tuning directly to approximately the correct frequency. However, most oscillators are incoherent until phase locked to a reference frequency. There is a large frequency difference between the desired frequency and the reference frequency to consider.

Some synthesizer designs solve the large frequency difference issue using a reference signal to drive a comb generator. In simple terms, the output frequencies of a comb generator are all harmonically related to the reference frequency. Typically, a frequency comb spans the entire frequency band required of the synthesizer and has evenly spaced frequency teeth. The teeth can be used like a ruler to measure other frequency sources with very high precision.

Some frequency synthesizers rely on fixed inputs or in some cases either a couple of harmonics or sub-harmonics of the input frequency to drive the comb generator. By allowing the comb generator frequency to vary continuously over some frequency range, the comb ruler can be controllably *stretched or compressed*. The stretchable comb lines can then be compared to the oscillator output frequency. A frequency mixer produces the sum of (or difference between) the oscillator frequency and all the comb lines. This new NRAO synthesizer uses the difference between the oscillator and the closest comb line frequencies.

The phase of the difference frequency and a reference frequency are compared in the PLL. An error signal is generated and used to tune the oscillator and correct the phase error. Thus, the loop is locked and oscillator output is coherent to the references.

Shortcoming of DDS

A shortcoming of Direct Digital Synthesis is the generated frequency is usually not *exactly* the desired frequency. As a hypothetical example, suppose a 500 MHz reference is used to clock a 32 bit DDS and the desired output frequency is 100 MHz. It is easy to find the frequency tuning word (FTW) for the DDS as,

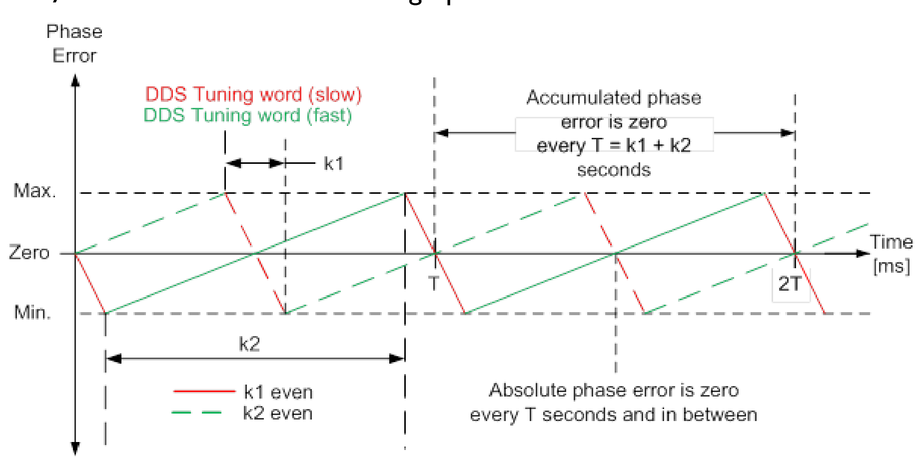
$$FTW = \text{Int}\left(\frac{100}{500} x\, 2^{32}\right) = 858993459$$

However, when we use this tuning word we find the DDS output frequency is 99.9999999765 MHz instead of 100.000000 MHz an error of about -0.0233 Hz. Even though the error seems small it will continue to accumulate over time, and in this example, 21,012 cycles will be missed during a one day period.

Eliminating the Shortcoming

The 100 MHz out of the DDS of the example is running slow. The accumulation error can be eliminated by using the frequency tuning word 858993459 for four clock cycles and 858993459+1 for one clock cycle. The maximum non-accumulating error is 1.9×10^{-10} cycles (a very small error).

In the new synthesizer, this solution is complicated by the fact the DDS output frequency is multiplied by the comb generator. The frequency error only has to be eliminated at the particular comb line number used in the PLL. This complicates the solution but the complication is not too great that it cannot be easily dealt with, as shown in the graphic below.



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