A 10MHz reference locked to CHU

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I live about 11km from the CHU time standard transmitter in Southern Ottawa. CHU transmits at three frequencies: 3.33MHz, 7.85MHz, and 14.67MHz at a power of 3kW, 5kW and 3kW respectively. (https://en.wikipedia.org/wiki/CHU_(radio_station)) So, at my home location, CHU is received with excellent signal strength at all hours without any fading. The carrier frequency is tied to the National Research Council's time laboratory and is accurate to 5 X 10E-12. I decided to design a 10MHz frequency reference standard that is disciplined to CHU.

Now, when it comes to phase locked loops (PLLs), crystal oscillators (VCXO) , and radio system designs, I am at best a "hack", so I do not claim that this is the ultimate reference standard. I am not a "Time Nut" http://www.leapsecond.com/ . However, it does certainly lock, and stay locked after warm-up and I therefore have no concern that the long-term stability is excellent, as good as CHU's. Using this reference with my other pieces of test equipment that have 10MHz inputs certainly improves frequency measurement accuracy.

System Design:

The 3.33MHz frequency that CHU uses lends itself to a particularly elegant receiver architecture. The incoming CHU signal at 3.33MHz (from a long-wire antenna, with an antenna tuner and some amplification) is mixed with a 3.33333… MHz Local Oscillator (LO) signal, which is the 10MHz VCXO divided down by 3. The resulting IF frequency is 3.3333… kHz. The IF filter is a narrow band active filter that strips away all the audio modulation from the CHU signal. This signal is compared to a 3.3333… kHz signal derived from the 10MHz oscillator by dividing it by 3000. The output of the phase comparator is filtered with a loop filter, and drives the voltage control port of the VCXO. This may sound incestuous at first glance, but the math works out. If we let *Fosc* represent the VCXO frequency, and *Fchu* represent the frequency of the incoming CHU signal, then the frequency of the error signal in the loop filter, *Ferr*, is:

$$Ferr = \frac{Fosc}{3000} - \left(\frac{Fosc}{3} - Fchu\right)$$

$$Ferr = Fchu - Fosc\frac{999}{3000}$$

The conditions for the PLL to lock occur when Ferr=0, so:

$$Fchu = Fosc\frac{999}{3000}$$

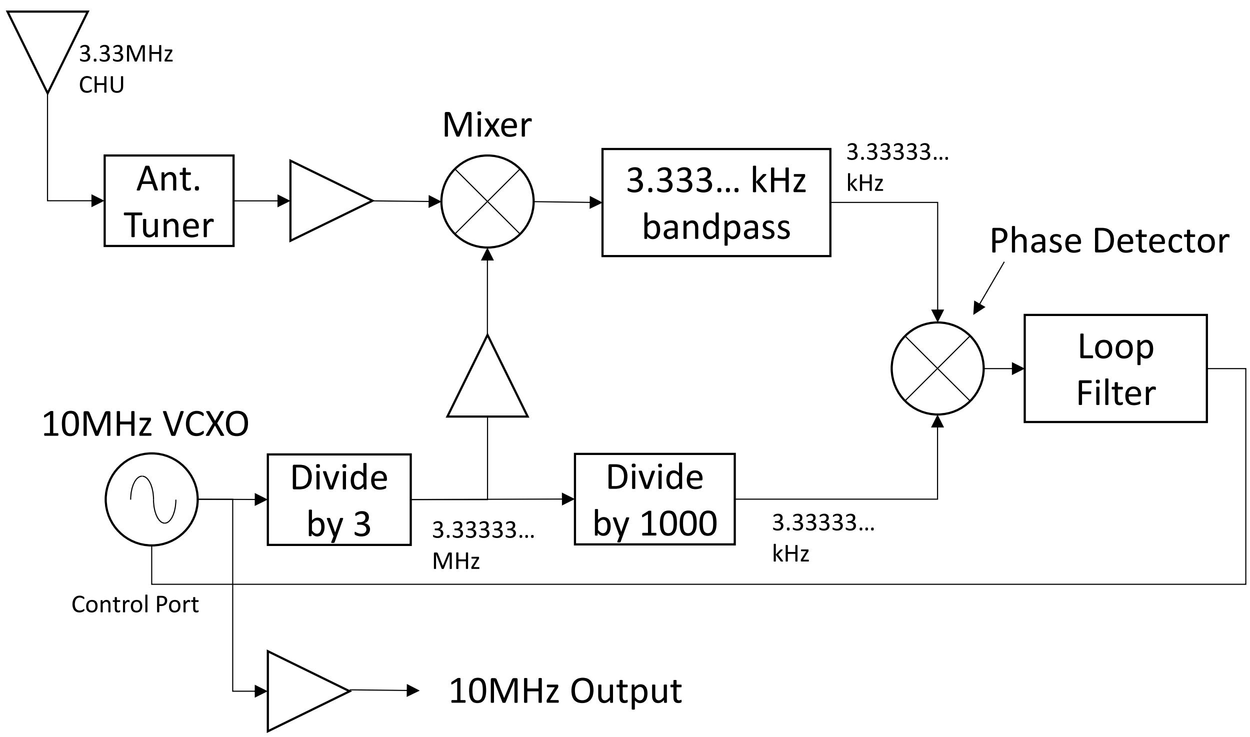
Since CHU operates at 3.33MHz, the crystal oscillator will lock to:

$$Fosc = 3.33\frac{3000}{999}$$

Which equals *exactly* 10MHz. Note that the receiver also has an image response 6.66kHz away, but as long as the VCXO range is limited, it will not lock onto that frequency. However, the receiver will be sensitive to noise at that frequency, so an image reject mixer at the front-end would be beneficial.

Implementation:

I show the block diagram below. I won't go into the details simply because I am lazy, but if you are interested, I can dig them up if you contact me. The antenna is tuned with a L-C circuit which optimizes CHU and rejects the AM band. This is fed into a JFET amplifier, and then into a Minicircuits mixer (SRA, as I recall). The mixer output feeds an active (op-amp based) narrow-band filter. From there, the phase detector on the CMOS 4046B PLL chip is used (there are three; I used the charge pump, I think). I hacked together a loop filter. The crystal oscillator is probably the weakest element in the design; a simple Colpitts design with coarse mechanical tuning and fine varactor tuning, with an electronic tuning range of a few 10's of Hz. The output of the oscillator is buffered and presented to the outside world as a sine wave. Not shown in the diagram is a metering circuit that can monitor the received signal strength (which assists in tuning the antenna), and the voltage to the VCXO. These can also be sent to a speaker, and you can hear the PLL lock-in as the coarse tuning on the VCXO is adjusted.



Will this work for you? Well, if you live in the Ottawa Valley, certainly. If you live in an area that receives the 3.33MHz CHU signal clearly and without fades, sure. A good antenna would help. But the receiver as I implemented it is fairly crude (it has no image rejection, low gain, no AGC), so if you are farther away, then you would need a more sophisticated front-end. And, keep in mind that propagation can impart significant phase changes to the carrier, and the loop might fight to track it properly. In my location, CHU is the dominant signal in that band, so interference is of little concern. If CHU is just one of many similar signals, then I don't know how well it will work.