IRCA Technical Column

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A Precision Frequency Measurement System

by Albert Lehr

(*editor's note*: Precision Frequency Measurement (PFM) of received radio signals goes back quite a long way in the medium wave DXing hobby. In the early '70s, Gordon Nelson and Ron Schatz among a few others were able to derive fairly exact frequencies of received MW signals using a signal generator, a digital frequency counter accurate to one hertz or better, a receiver and some interfacing circuitry. Charles Taylor describes such a system in IRCA reprint T31. An accurate measurement of a received signal can provide a "fingerprint" which along with a direction-finding antenna such as a loop, can allow a DXer to identify a signal even before it delivers audio, and long before any audio includes an ID. Al's system is a considerable improvement on the older designs, as it allows measurement of frequencies to better than 0.01 Hz, and provides a synchronously demodulated output as well.

The original designs for PFM of a received signal used a separate signal generator that was carefully tuned to the same frequency as the signal which one was trying to measure (see figure 1). First one heard an audible heterodyne between the signal generator's output and the received signal, which became lower in pitch as the generator approached the received signal's frequency. This would be followed by a "subaudible heterodyne" (SAH), a pulsating sound in which the number of pulses per second indicated the separation between the two frequencies in hertz. Finally, the generator's frequency would be exactly the same as the received signal's, and there would be no interference between the two signals. At this point, the signal generator's frequency would be read on the frequency counter which would also indicate the exact frequency of the received signal.

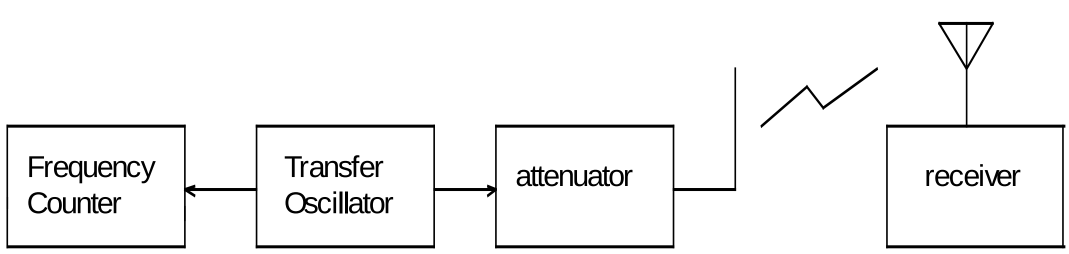

Figure 1

If you read Charles Taylor's article you will discover that PFM is not quite so simple, but the basics are as described above. Now, on to Al's set-up:)

My Precision Frequency Measurement system may be more capable than the systems of 25 years ago, but it is also more complex. Unless you own a receiver which provides an output from its local oscillator, as well as an output from the final IF amplifier, you will need to modify a receiver to provide these outputs (as I did with my Allied A-2515) to enable you to perform accurate PFM. In addition, if you want to define signals very precisely, you will need either a very accurate frequency counter or one that will accept an accurate external timebase signal, which you will provide. Finally, there is some construction involved in providing an interface between the receiver and the frequency counter, but the interface provides the bonus of a synchronously demodulated output from the receiver.

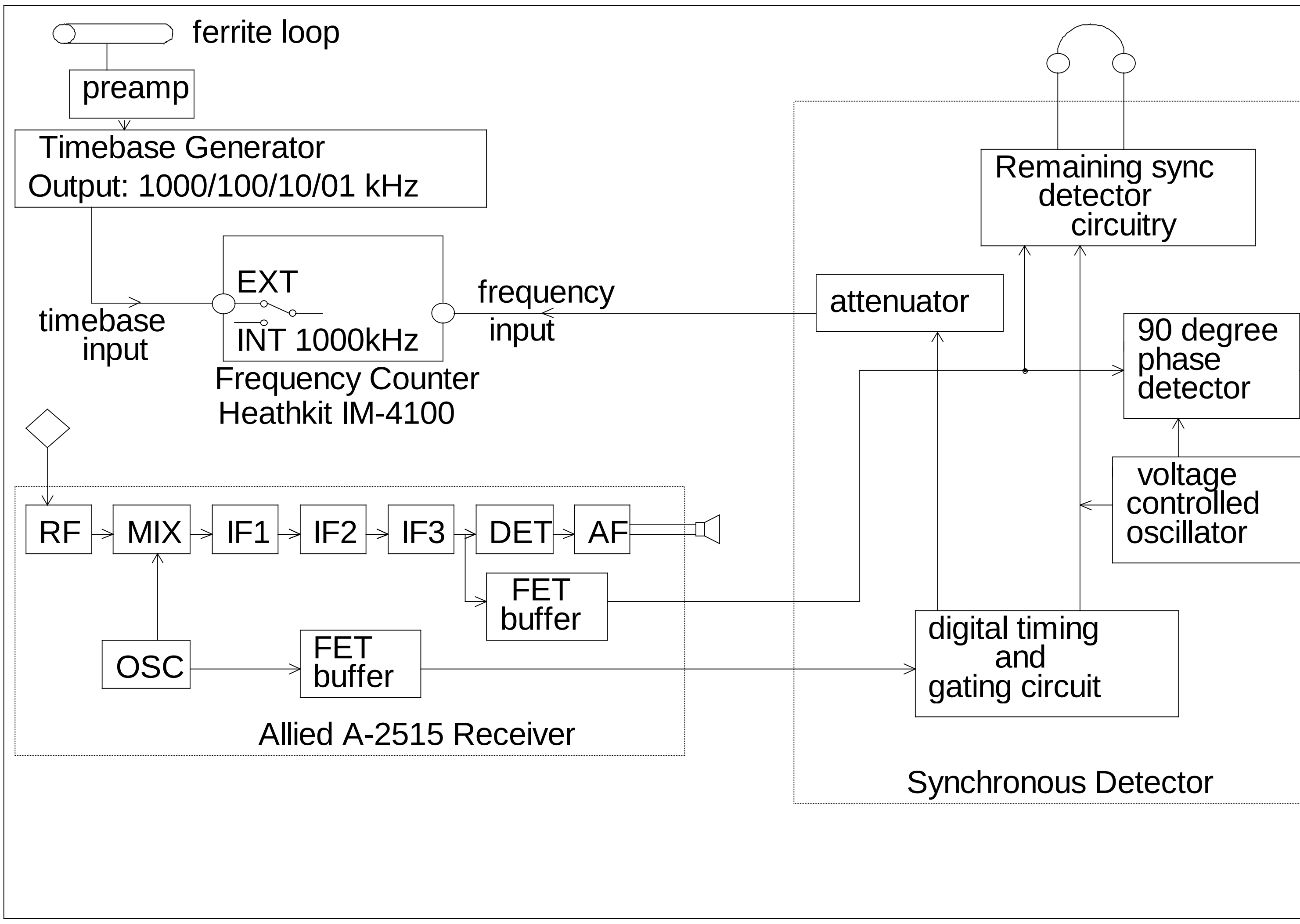

Figure 2

Figure 2 shows a block diagram of the overall system. There you will see that FET buffers have been added to my A-2515 receiver to provide the required local oscillator and IF outputs. Such buffers may be added to other types of receivers if you have the expertise. You will also note that my receiver is a single conversion model; the system described is usable only on a single conversion receiver with an IF below the tuning range, and the local oscillator frequency must be at least twice that of the VCO frequency. Unfortunately, this requirement eliminates most modern day communications receivers, but the diehard experimenter may have an older receiver put aside which will fill the bill.

The timebase generator The timebase for the frequency counter is my own design, and derives its accuracy from reception of the time and frequency standard station WWVB on 60 kHz. Its carrier frequency is referenced to the National Institute of Standards and Technology frequency standard, and, due to its low frequency, suffers very little from propagation induced disturbances. My generator consists of a 6 MHz crystal oscillator which is divided down to 60 kHz and phase-locked to WWVB's signal which is received using a ferrite loop and preamplifier.

As noted in figure 2, the output of the timebase generator consists of several frequencies. Each frequency provides a different gating period for the frequency counter (the gating period is the time it takes to count the frequency displayed by the counter). The longer the gating period used, the more precise is the measured frequency. The various timebase frequencies and their related gating periods are:

1 kHz (gating period of 1000 seconds) - It is very seldom that I want to wait for a minimum of 16 minutes and 40 seconds for a frequency reading. The first reading will almost always be wrong, meaning that it could be over a half-hour wait for a valid readout. I don't think that this gating period isof much practical use to a DXer, although it does give a precision of 0.001 Hertz.

10 kHz (gating period of 100 seconds) - Not too long a wait, so it is usable if the VCO can hang on to the carrier long enough. Not very good on crowded channels or on fading signals, but I was able to measure CKXM on 1200.01156 kHz.

100 kHz (gating period of 10 seconds) - Probably the best combination of resolution and practicality. I used this to measure Norway on 1313.9990 kHz and Denmark (?) on 1062.0000 kHz in December 1997.

1000 kHz (gating period of 1 second) - Used when changing frequencies, for scanning across the band, or when conditions on the channel make a longer gating period useless.

The remainder of the block diagram includes PLL (phase locked loop) components (phase detector, low pass filter and voltage controlled oscillator), a digital timing and gating (DTG) circuit, some additional synchronous detector circuitry, and a fine tuning control and zero-center tuning meter to aid in getting the PLL to lock on the IF output.

DTG A pulse synchronization circuit using a 74LS74, (described in Don Lancaster's TTL Cookbook) is used in the DTG circuit to produce a 455 kHz gating pulse that is delayed until it coincides with the arrival of a pulse from the conversion (local) oscillator of the receiver. This gating pulse then removes pulses (one pulse at a time) periodically from the conversion oscillator pulse train to produce the frequency that is to be measured, which is exactly the same as the frequency received at the antenna.

As an example, let's say that you tune to a station on exactly 1000 kHz. In the period of one second, the conversion oscillator will put out 1,455,000 pulses. The gating circuit will remove 455,000 of them, leaving 1,000,000 for the frequency counter to count. Suppose that the conversion oscillator drifts to 1455.025 kHz. The station carrier in the IF channel moves to 455.025 kHz. The VCO will track it, the gating circuit will remove 455,025 pulses per second and the counter will still count 1,000,000 pulses.

PLL and synchronous detector Although one could still accurately measure stronger received signals by simply running the IF FET buffer output through a limiter and using its output as the 455 kHz input to the DTG circuit, a carefully tuned PLL is required to lock onto very weak IF signals. Besides providing switching pulses for the DTG circuit and the 90 degree phase detector, the voltage controlled oscillator (VCO) also switches a zero degree phase detector that produces audio for the headphones. I use 4066 CMOS analog switches as the phase detectors, and the demodulation is definitely better than what comes from the receiver.

Tuning Meter and Fine Tuning Control The tuning meter's primary function is to indicate whether the VCO is in the center of its lock range. The meter is useful only after the VCO is locked, or on the verge of locking. I try to get within a few Hz with the receiver main tuning by listening to the heterodyne between the signal carrier and the VCO output. When it approaches zero, the meter will flutter as the VCO control voltage from the phase detector begins to capture the signal. If the meter reads off-center after the VCO locks, it means that the phase difference between the VCO and the signal is more or less than the desired 90 degrees. Then I can use the fine tuning to adjust the VCO to the center of its lock range.

I have found that this system does pretty well with fading signals and also handles sideband splatter reasonably well as long as the VCO is in the center of its lock range. The low-pass filter eliminates most of the effects of splatter from the PLL circuit, but any splatter that affects the receiver AGC system may cause some problems with measuring weak signals. My A-2515 has no AGC on/off switch, but it seems likely that it would help the PLL further if the gain could be adjusted manually, or if a faster AGC decay was available.

This system is still experimental and I don't consider it to be a finished product. Some portions of the synchronous detector don't yet work as well as I would like and I have several revisions in mind. For example, I have breadboarded an improved VCO circuit that I plan to install soon. Since I like to have my sync detector operational for DXing, I keep putting off taking it "off-line" for modification. If this article inspires others to try out something similar, I can be reached at ALehr@compuserve.com

(*ed. note*: although PFM is "precise", i.e. the frequencies read are the same for each and every sample, even with a resolution such as 0.01 Hertz, frequencies read really need to be "accurate" for the measurement to be of most use. An accurate measurement is one which indicates the true frequency of the monitored station. Unless the timebase of the frequency counter is both stable and accurate in itself (i.e. a 1 MHz timebase is really 1000000.000 Hertz, and doesn't drift), then a measurement made with a PFM system may have a high frequency resolution and be precise, but not be a true representation of the actual frequency of the monitored station.)