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# WWVB BPSK Modulation Remover – the “Dephaser”

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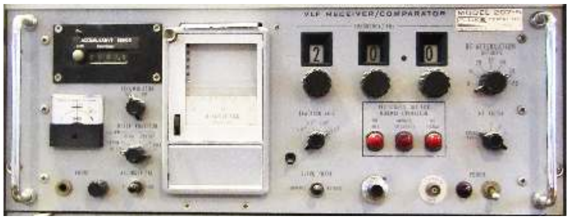
WWV transmits standard frequencies on 2.5, 5, 10, 15, 20 and, experimentally, 25 MHz, derived from an ensemble of cesium-beam stabilized clocks. Doppler shifts of the skywave results in received frequency error of up to 1 Hz or more, or 1 part in $10^7$.

WWVB reduces this error by several orders of magnitude by transmitting a 60 kHz signal, which propagates by ducting through the atmosphere, rather by skywave. Over 24-hour integration times, comparisons to local standards with accuracy on the order of 1 part in $10^{11}$ or better can be obtained.

Receivers that receive the WWVB signal phase lock a local oscillator to the 60 kHz carrier. This was the situation until October 2012 when a new binary phase-shift keying (BPSK) modulation pattern containing the time codes was instituted. All the phase-lock receivers were then rendered inoperable and obsolete. The new modulation scheme resulted in a more robust signal in the presence of noise and fading, while still allowing “atomic clocks” that demodulated the retained amplitude modulation of the time code on the carrier, but did not need to phase lock onto the carrier.

## Solution

This note describes a “dephaser” that removes the BPSK modulation from the WWVB signal, keeping the accuracy of the transmitted signal, so that it can be compared to a local GPS frequency standard. Therefore, my two phase-locked receivers, the Fluke 207-5 and the Tracor 900 VLF/LF receivers would again be operational to measure the diurnal time variation of the received 60 kHz signal.



An accompanying note describes experiments comparing the diurnal phase and amplitude variation of the WWVB signal, using local GPS as the reference.

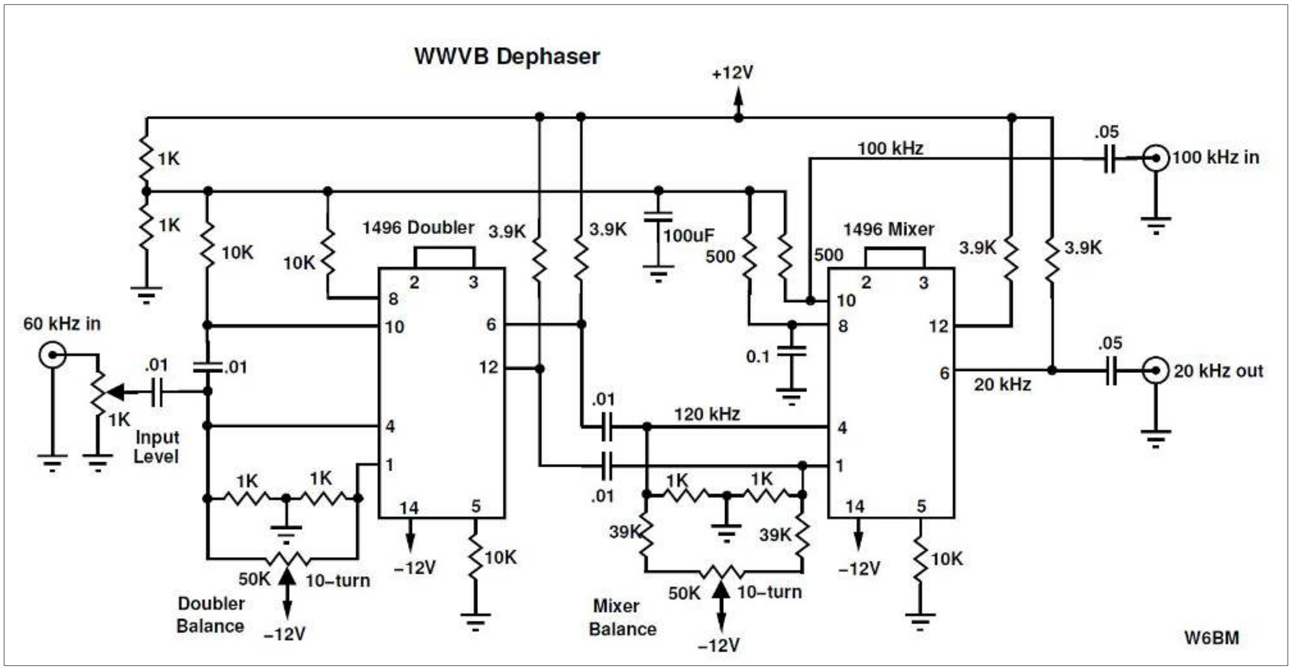
One technique of removing the modulation is to double the 60 kHz carrier frequency with a circuit that multiplies the signal by itself. The product of a signal V = sin(ωt) by itself contains a cos(2ωt) component, or the second harmonic. (Remember your trig identities?) The phase of the 120 kHz signal remains constant, as a 0 or 180 degree phase shift translates to 0 and 360 degrees at 120 kHz.

This multiplication is carried out with a 1496 multiplier chip with the same signal introduced in both inputs. The output signal is 120 kHz, which is out of the range of the Fluke and Tracor receivers. However, these receivers, beside accepting a 60 kHz signal, can also tune to a number of VLF frequencies, including 20 kHz.

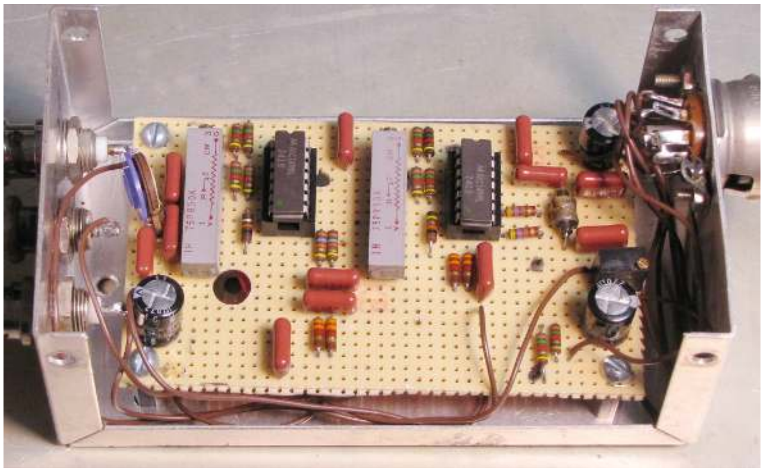
To produce a phase-coherent 20 kHz signal, the 120 kHz signal is heterodyned to 20 kHz with the 100 kHz signal derived from the GPS standard. Propagation phase errors in the original 60 kHz signal are doubled in the 120 kHz signal, and then are coherently translated to 20 kHz by the heterodyne process. Therefore, the phase variation of the original 60 kHz signal is mapped to phase variation of the 20 kHz signal.

## Implementation

The dephaser circuit is deceptively simple. No tuned circuits are required.



An amplitude-leveled 60 kHz signal from an external antenna, narrow filter and AGC-controlled amplifier is introduced to both inputs, pin 4 and 10 of the first 1496 doubly-balanced mixer. The mixer products, including the 120 kHz signal appear on the push-pull output lines 6 and 12. The 50K 10-turn trimpot balances the mixer so no 60 kHz component appears at the output.



The push-pull 120 kHz signal is applied to pins 4 and 1 of the second 1496 mixer, along with a 100 kHz local oscillator signal derived from the GPS frequency standard to pin 10. The second 50K trimpot is adjusted to minimize the 120 and 100 kHz direct-through signals, leaving the 20 and 220 kHz mixer products in the output on pins 6 and 12.

The tracking receiver responds only to the 20 kHz component using its own set of filters. The tracking receiver uses the GPS frequency standard as its reference, so the phase difference represents the phase difference between the WWVB signal and the GPS signal. As phase variations in the WWVB signal are much larger than those of the 100 kHz GPS-derived reference, the GPS signal is assumed to be an absolute reference.

As a multiplier is a square-law device, the output amplitude of the doubler goes as the square of the input level. Thus, it is important to maintain a near-constant input level. The rest of the circuit is linear, and the VLF tracking receiver operates over a wide variation of input signal, so strict control of the 60 kHz input level is not mandatory, but helps as it is found that the WWVB signal exhibits a strong diurnal variation.

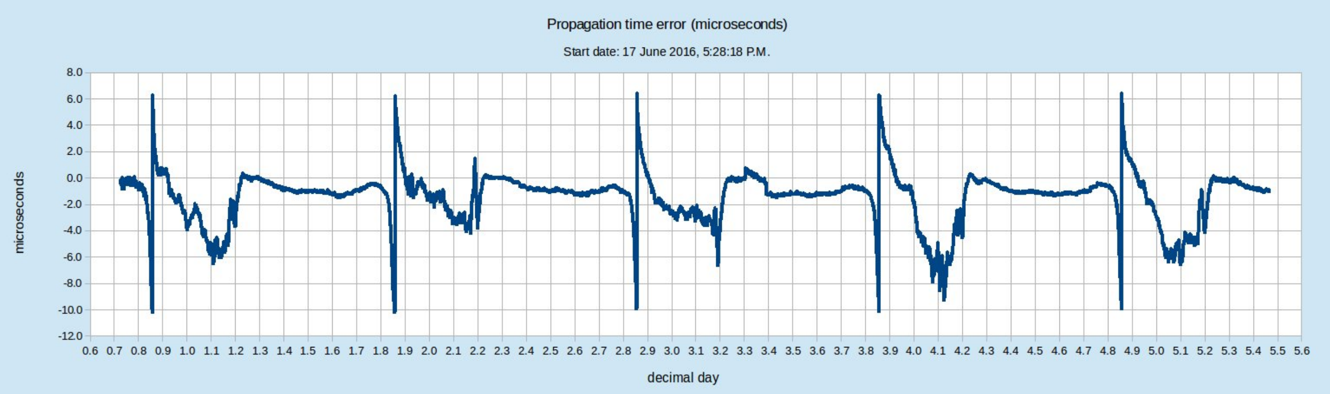
The input signal conditioner is the Spectracom Netclock / 2, which is a device that receives and decodes the amplitude time code of the WWVB signal and displays the time on an LED readout.  It does not phase-lock to the carrier.

The Spectracom comprises a 1-meter amplified whip antenna, a narrow 60 kHz crystal filter, and an AGC-leveled amplifier producing a near-constant 60 kHz output.   This signal is tapped off before the clock decode circuitry and applied to the dephaser.  The ±12 volt power is also “borrowed” from the Spectracom.

As the Spectracom uses a narrow-band crystal filter, changes in temperature may result in a phase shift through the Spectracom, it should be in a temperature-stable environment.

## Results

The plot shows a five-day recording of the microsecond time shift of the WWVB signal.  The complete analysis is presented in an accompanying note.



The smooth segments occurred during the day, when paradoxically, the signal was weakest.  At sunup and sundown, large phase variations occurred.   When the smooth segments are correlated over 24-hour distances, the day-to-day phase stability of the WWVB signal phase is on the order of 2 parts in $10^{12}$. This shows that, given a long comparison time, that stable comparisons can be made of local frequency standards, which was the case before GPS-stabilized standards were available.  This also shows that the older technology receivers can be again be made operational with a simple dephaser circuit.

The dephaser exhibited flawless behavior over the 5-day experiment, showing that the design concept and implementation is robust.