Reprinted from NBS Special Publication 442,
"Report of the 60th National Conference on
Weights and Measures 1975," May 1976, pp.42-
47.

CALIBRATION OF POLICE RADAR INSTRUMENTS

by DAVID W. ALLAN, Frequency and Time Standards Section, Time and Frequency Division, Institute for Basic Standards, National Bureau of Standards, Boulder, Colorado *

and

FRANK H. BRZOTICKY, Metrologist
Weights and Measures Section, Department of Agriculture
State of Colorado

In common use for traffic speed control is a Doppler radar gun. The basic principle of operation of these guns is that the radar signal reflected from a moving vehicle is shifted in frequency by an amount directly proportional to the speed of the vehicle relative to the radar gun. Intrinsically one sees that such a radar gun is a frequency measuring device. The typical way of calibrating these radar guns is to place in front of the gun a vibrating tuning fork which produces a reflected signal to which the radar responds as though it were a moving vehicle. There exists a well-known relationship between this signal and the speed of the vehicle provided the radar frequency is known.

A question raised by the judiciary system is how does one know that a tuning fork used to calibrate a radar gun is at that certain

* Presentation was made by Mr. Allan.

specified frequency. Because of this question, several of these tuning forks have been brought to the Frequency & Time Standards Section of the National Bureau of Standards (NBS) in Boulder, Colorado for calibration. For example, the radar guns now operating, using the Federal Communication Commission (FCC) allocated frequency of 10 525 MHz (a "Hz" historically was designated cycle per second), have a 50 miles per hour calibration point using a tuning fork with a vibration frequency of 1569.54 Hz.

The demand for this calibration has increased to the point where it has become quite clear that it should be set up as an ongoing service. It seemed out of the context of the NBS mission and logistically difficult to provide this service nationwide. However, a reasonable alternative seemed to be to have the states' standards laboratories provide this service. A pilot program was set up with the Colorado State Standards Laboratory to demonstrate feasibility of a measurement system which would have traceability to NBS.

However, the possession of even an NBS calibrated tuning fork is not enough. Some of the available FCC allocated frequencies for law enforcement radar include 10 525 MHz and 24 150 MHz; the vast majority of current radar guns use the 10 525 MHz allocation. Suppose, for example, that a radar instrument which was designed for 10 525 MHz had a microwave oscillator which was detuned (outside the FCC allocation) to 12 000 MHz; then that radar instrument would measure a vehicle which was actually traveling 50 mph as traveling 57 mph even though a 50 mph tuning fork made for that gun would cause it to read 50 mph. Similarly, if a 50 mph tuning fork made for a 24 150 MHz type radar gun were used to calibrate a properly functioning 10 525 MHz type radar gun it would cause the latter to read 115 mph! For the protection of all parties, it is essential that both the frequency of the radar signal as well as that of the radar instrument's accompanying tuning fork be certified as correct within accepted accuracies. To directly measure the frequency of the radar signal is a nontrivial problem requiring sophisticated equipment; however, an indirect measurement of the radar frequency which can be easily implemented in the field is outlined below.

Fortunately, the microwave oscillators typically used in most radar guns have proven to be very stable, and being solid state devices they endure the rigors of field usage (e.g., shock, vibration, large temperature and car battery voltage variations) and still read accurately, i.e., ± 1 mph. The FCC allocation tolerance is comparable to an accuracy of ± 0.1 mph at 50 mph, and two of the major vendors in this country, which have sold about 20,000 radar guns, report that of the ones returned for repairs and maintenance almost none of them were outside the FCC allocation tolerance. It is still recommended, however, that the law enforcement officer using the radar gun occasionally check the radar frequency by transporting the gun in a vehicle with a calibrated speedometer, and while pointing the gun at a stationary object compare the radar gun's reading with that of the calibrated speedometer. The readings should agree within 2 percent ($\pm$ 1 mph at 50 mph) if the radar frequency is correct within 1 percent, the angle of pointing of the radar gun is within about 8° of the direction of motion of the vehicle, and the speedometer is calibrated to within $\pm$ 1 mph.

The above procedure or one equivalent to it is mandatory for completeness because of the way the Doppler equation is used in most speed radar instruments. The Doppler equation may be written:

$$\frac{\Delta\nu}{\nu} = \frac{2\,v\cos\Theta}{c},$$

where ν is the radar microwave carrier frequency transmitted by the gun, $\Delta\nu$ is the radar signal received by the gun as reflected back from the moving vehicle minus ν. v is the approach velocity of the moving vehicle relative to the ground. Θ is the angle between the pointing direction of the gun and the direction of travel of the vehicle, and c is the propagation velocity of the radar signal. Most, if not all, radar guns are constructed to simply measure $\Delta\nu$ under the assumption that Θ is zero (0), and that ν is within the Federal Communication Commission (FCC) frequency allocation. Under these assumptions the gun can be made to directly calculate and display the value of v well within a 1 percent error. The tuning fork placed in front of a properly operating radar gun simply generates the signal $\Delta\nu$ commensurate for some velocity v under the same assumption that if the tuning fork's frequency is right the radar gun's reading will be right. However, if a gun's radar signal ν is off in frequency (outside the FCC allocation) then this radar gun's indicated velocity of a vehicle will be off by an amount directly proportional to the amount ν is off from the allocation assumed in the design of that gun, even though a tuning fork used to calibrate the gun gave the right gun velocity indication. The probability of being outside the FCC allocation seems quite remote and hence the assumption made above is very reasonable—making the tuning fork method a more convenient method in the field of checking the radar gun. All that remains is to determine a procedure which will assure that the tuning fork's frequency is right.

NBS recommended an equipment configuration for calibrating the radar gun's tuning fork that would be relatively easy to set up and operate, reasonably inexpensive, and yet with sufficient accuracy traceable to the primary frequency reference operated by NBS. The following is our first effort to achieve the above goals.

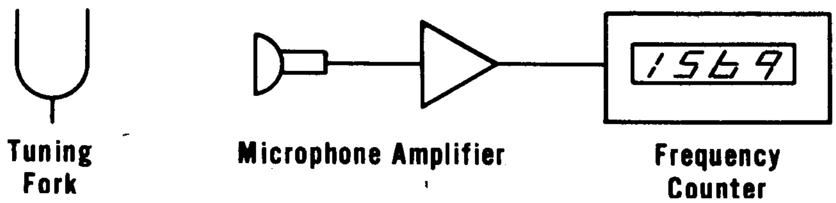

FIGURE 1

In figure 1 there remains the unresolved question of how does one know the reference frequency standard in the frequency counter is correct? Figure 2 shows a relatively inexpensive answer to this question:

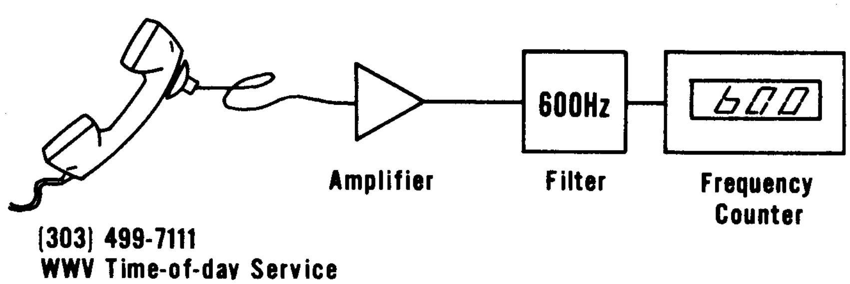

FIGURE 2

The format for the Standard Time and Frequncy broadcasts of NBS radio station WWV provides a continuous 600 Hz tone during every odd minute from 0 seconds to 45 seconds except for a 0.04 second hole where the second's tick occurs, and except for minutes 9, 45, 47, 49, and 51 of every hour. Using this method with the frequency counter set at a sample time of 1 second or a multiple of one second, one can calibrate the frequency counter to better than 0.4 percent as limited by current telephone frequency fidelity specifications. Only 1 percent accuracy is required for the tuning forks.

The equipment configurations in figures 1 and 2 have been tested for ease of use and for cross country telephone signal-to-noise problems on the telephone and were very satisfactory. The equipment cost of the components we used was about $500.00. A number of other, different equipment configurations are possible and acceptable if they guarantee traceability to NBS; e.g., by use of the

NBS Time Services either via telephone (figure 2) or via the radio station WWV.

The pilot program began in September 1974. Since that time over 200 forks have been tested for more than 40 law enforcement agencies in Colorado and from Wyoming. All of the tuning forks tested were found to oscillate within 5 Hz of the calculated (correct) frequency (less than 0.2 mph error).

The acceptance by the enforcement agencies is enthusiastic, particularly for those police departments having court difficulties. About 40 percent of all agencies contacted quickly responded and have had their tuning forks calibrated. About 10 percent of the departments have indicated interest and their forks are slowly coming in. Forty-eight percent either did not have radar units or did not have tuning forks for the radar units. Two percent did not find it important to have the forks calibrated.

Tolerances have not been developed for tuning forks as of this writing. A tolerance of about ± 1 mph seems acceptable which corresponds to ± 31 Hz for a 10 525 MHz radar gun. Most of the tuning forks tested had a frequency averaging 2/10 of 1 percent in excess of the calculated frequency for that particular speed. Note: this slightly higher frequency is shaded to be a slight advantage to the violator.

Reports have been received from several police officers that attorneys in court are starting to question the accuracy of tuning forks that appear to be damaged, referring to the scars appearing on the forks from striking the unit to make it "ring." Nearly all the forks tested by the Colorado laboratory bear these marks.

The frequencies of the Colorado tuning forks were within 5 Hz of the calculated frequencies (same as new forks).

Two forks were tested that appeared to have been run over or possibly dropped from a moving vehicle. Yet when testing the forks, the output of each was within 5 Hz of the correct frequency!

Several forks, when presented for test, did not bear serial numbers or identification. The units were tested and the frequencies recorded. Next, each fork was stenciled with appropriate identification. Markings were placed below the tines and just above the handle. The forks were retested under the same test conditions. The frequencies did not change even though this may be interpreted as a scarring of the forks.

Temperature tests were conducted on five different forks with temperatures ranging from 0° F to 110° F. The average change in miles per hour was only 0.69 mph for the 110° F span. The data for four of these is plotted in figure 3.

Overall, the tuning fork appears to be a very stable standard and suitable for the use intended.

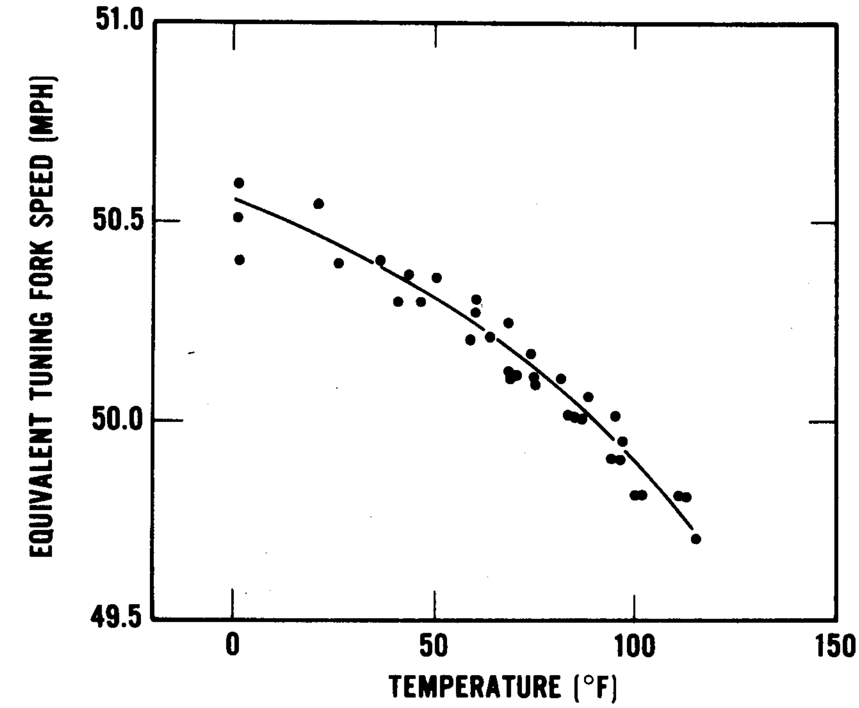

FIGURE 3. ***Equivalent radar gun speed versus temperature for 4 different 50 mph tuning forks. These were typical tuning forks which are used to check a radar gun.***

Calibration of the frequency counter using the 600 Hz tone derived from the NBS, WWV telephone line has proven itself totally adequate. The largest errors encountered have been ± 2 Hz (less than ± 0.1 mph). Note: the telephone signal automatically "hangs up" after 3 minutes, so one should carefully note the WWV format given in the text under figure 2 before calling (303) 499-7111.

We have received informal reports that significant litigation cost savings are realized when the law enforcement officer produces an official calibration certificate which has ultimate traceability to NBS.

USCOMM - ERL