CALIBRATION TECHNIQUES FOR ACROSS-THE-ROAD TRAFFIC RADARS[*]

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ABSTRACT

We discuss simulator units for calibrating across-the-road Doppler traffic radar transceivers used in enforcement of highway speed limits. Two units of very similar design were developed, one operating at K-band (24 GHz) and the other at Ka-band (35 GHz). The signal received from the radar transmitter is frequency-modulated at rates that correspond to the expected Doppler shift for approaching and receding vehicles travelling at speeds of 25 to 200 km/h. The modulated signal is subsequently retransmitted back to the radar receiver, which demodulates it and then displays the simulated speed . The required calibration accuracy is 1.6 km/h at 90 km/h.

INTRODUCTION

Across-the-road traffic radars systems, in which the radar antenna is typically pointed across the highway at a 20° angle to the highway axis , rather than down the highway, are widely used in Europe for monitoring and enforcing highway speed limits and are finding increasing use in the U.S. and other parts of the world [1-4]. The advantage of this configuration, from a law-enforcement viewpoint, is that the radar can better differentiate between vehicles in dense traffic and is able to provide fast and automated identification of offenders using photographic methods (hence the terminology photo radar for these systems). In addition, virtually no advance warning of the radar's presence is given to drivers with radar detectors.

In the traditional down-the-road configuration, the Doppler frequency shift f_d, which is directly proportional to the speed of the target vehicle v being monitored, remains approximately constant. In the across-the-road configuration, this is no longer true. As the vehicle passes through the radar beam, the Doppler shift varies with time as the cosine of the angle *?* between the direction of fixed target motion and the varying direction of target return (see Fig. 1):

$$f_d = \pm \frac{2f\,v}{c}\cos\theta \ , \qquad (1)$$

where f is the radar frequency, c denotes the velocity of light, and the positive and negative signs apply respectively to an approaching and receding vehicle.

For a small point scatterer passing through the radar beam, equation (1) states that the Doppler shift f_d measured by the radar exhibits a monotonic decrease with time for an approaching (increasing *?*) scatterer (termed, by some, as the downward frequency “chirp”) [5]. For a receding (decreasing *?*) scatterer, a monotonic increase in Doppler shift with time results. However, for a real vehicle passing through the radar beam, there are multiple and interacting scattering centers on the vehicle that return energy to the radar at incident angles *?* that vary randomly with time. Consequently, the resulting Doppler spectrum is very complex (see Fig. 2). The manner in which traffic radars derive the vehicle speed from this spectrum differs between manufacturers. Some simply measure the Doppler shift registered when the target vehicle first enters the radar beam, while others derive a mean value of several sequential Doppler shift measurements obtained as the vehicle passes through the radar beam. Because of these problems, a somewhat greater uncertainty exists in speed measurements performed by across-the-road radars relative to the down-the-road type.

In the United States, developing techniques for accurate calibration of such radars is considered essential in order to ensure that citations issued to motorists for exceeding highway speed limits are legally enforceable in local courts of law. The U.S. National

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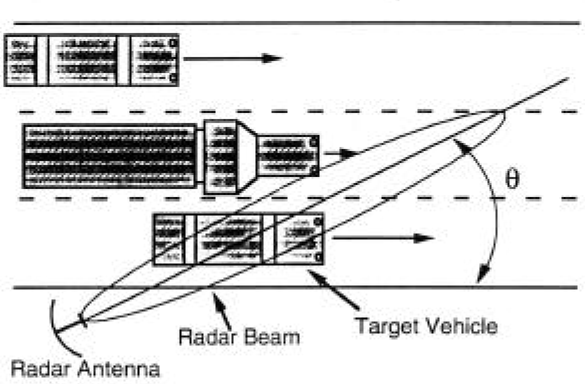

Fig. 1. Across-the-road traffic radar configuration for monitoring speed of a receding vehicle.

Institute of Standards and Technology (NIST) was therefore asked to develop suitable calibrator/simulators for this purpose. We developed two units of essentially the same design, one operating at K-band (24 GHz) and the other at Ka-band (35 GHz). The units were required to simulate Doppler shifts that correspond to both approaching and receding vehicles moving at speeds in the range 25 to 200 km/h. The specified calibration accuracy was 1.6 km/h at 90 km/h. The K-band calibrator was initially designed as a self-contained unit, with its own batteries and internal circuitry, and was intended to calibrate photo radars in the field. The unit provided radar calibration at only one vehicle speed, namely 88 km/h [5]. Later, this unit was modified so that it could also be used in a type-certification laboratory, where it can be driven by an external analog function generator capable of providing radar calibration over vehicle speeds in the range (25 to 200) km/h. The Ka-Band calibrator is intended solely for use in a type-certification laboratory and is driven by an external digital-based function generator capable of simulating Doppler shifts over the same range of vehicle speeds.

CALIBRATOR DESIGN

In both NIST calibrators, the radar signal is received through a pyramidal horn antenna, frequency-modulated at rates that correspond to the Doppler shifts typically measured by the radar system, and subsequently retransmitted back to the radar receiver. The modulation is achieved by means of a 5-pole electronic coaxial switch in which each pole is terminated by an open coaxial line (see Fig. 3). The lengths of the five terminating lines are adjusted such that their phase shifts, as measured at the

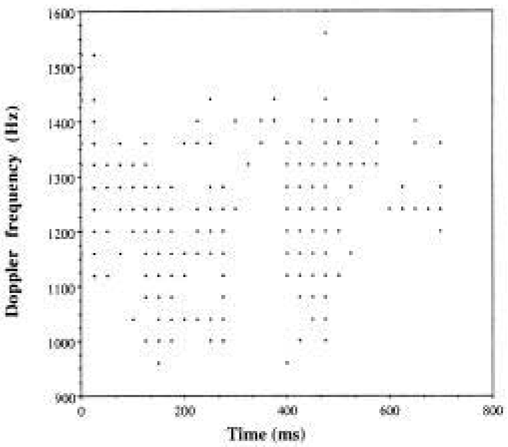

Fig. 2. Doppler-shift spectrum for a vehicle receding at 32 km/h, as measured by a K-band traffic radar aligned 20^0 to the highway direction (beamwidth of radar is 5^0).

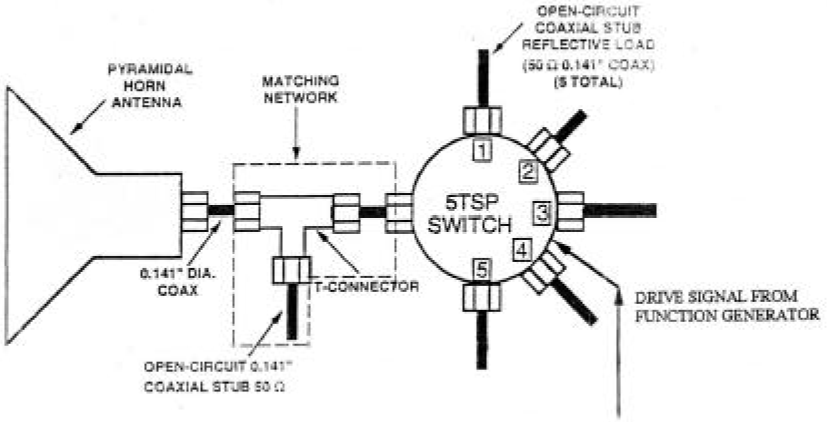

Fig. 3. Microwave Design of NIST Calibrator.

switch input, are approximately -144, -72, 0, 72 and 144 degrees. The input signal then becomes modulated at the desired Doppler shift if the switch is driven at a rate five times this shift. A single stub tuner is required to match the impedance of the horn antenna to that of the switch plus waveguide-to-coax adapter. A coaxial open-circuit stub is used for the K-band unit (see Fig. 3), while a waveguide T-junction terminated with a sliding short is used in the Ka-band unit.

The internal or external function generator that drives the electronic switch provides the various calibration capabilities of the simulator unit. In order to simulate any required vehicle speed *v*, the analog or digitally-controlled function generator is set to drive the switch at a rate five times that given by (1), where clockwise rotation of the switch creates a positive Doppler shift, corresponding to an approaching vehicle, and anticlockwise rotation creates a negative Doppler shift, corresponding to a receding vehicle. The manner in which the *cos ?* factor of (1) is handled differs for each calibrator. In the K-band field unit, the output waveform of the internal function generator includes a downward or upward frequency change ("chirp") with time corresponding to the change in Doppler shift created by an approaching- or receding-point scatterer as it moves through the radar beam at 88 km/s. This capability was intended to accurately calibrate any photo radar that derives vehicle speed by fitting this mean curve to the measured Doppler spectral data. For the Ka-band unit, the external function generator is programmed to operate at frequencies corresponding to the average Doppler shift exhibited when a point scatterer passes through the radar beam. The *?* value corresponding to the average Doppler shift can be readily derived by integrating (1) over the radar beamwidth and was found to lie within 0.05^0 of the beam's center or "nose". In order to test the radar's abilities to accept or reject Doppler signals typically received from single or multiple vehicles moving in traffic, we also included a time-gate in the function generator which turns the calibrator on and off after an elapsed time duration. These duration values were chosen to simulate Doppler returns obtained from an automobile, a truck, two vehicles following closely and a motorbike. Most traffic radars are designed to discriminate between these various returns, rejecting the latter two categories as an unreliable measurement and accepting only the first two.

CALIBRATOR PERFORMANCE

We measured the spectral content of the calibrator signal using a simple laboratory test set-up consisting of a CW microwave generator feeding a pyramidal horn antenna through a reverse 20 dB directional coupler [5]. The horn antenna is mounted directly in front of the simulator's antenna. Using a spectrum analyzer connected to the coupled arm of the reverse coupler, we monitored the modulated signal from the calibrator unit. Fig. 4 shows the measured K-band calibrator spectrum for both increasing and decreasing phase sequences of the switch. Note that the dominant (desired) spectral sideband is spaced ±3620 Hz above and below the fundamental generator frequency of 24.1GHz, and that the next harmonically-related sideband (shown

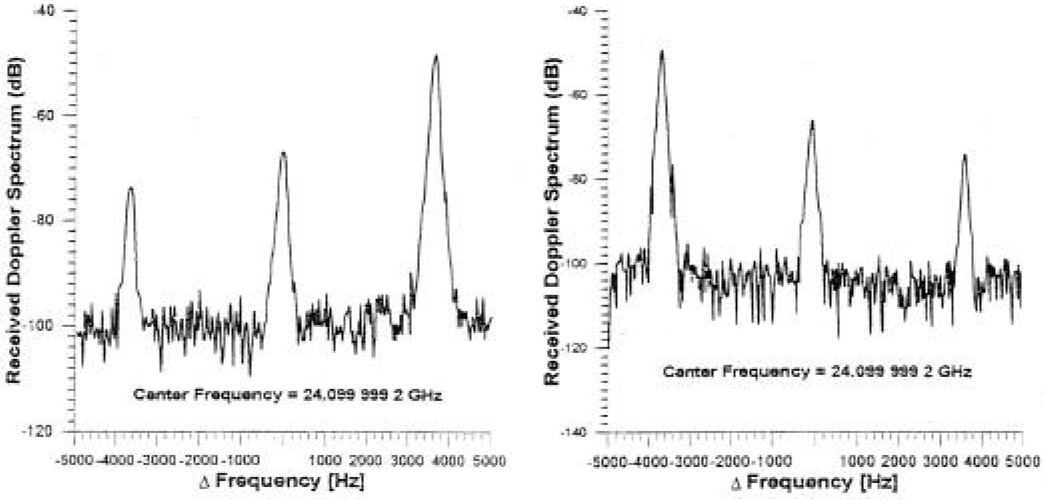

Fig. 4. Measured spectrum of NIST K-band (24.1 GHz) calibrator for clockwise (left) and anticlockwise (right) switch rotation.

respectively on the left and right of the fundamental frequency) is more than 20 dB below the dominant spectral sideband. This 20 dB difference in spectral component amplitude was found to be true for all simulated vehicle speeds and for both calibrator units. We measured the fifth-harmonic sideband at -12 dB below the dominant sideband. We also demonstrated the performance of both calibrator units against commercial K-band and Ka-band photo radars. We determined that the speed read-out of the radars usually agreed with the simulator speed setting within less than 1 km/h at 100 km/h, and that the radar correctly accepted or rejected the simulator signal according to the preset signal durations.

CONCLUSIONS

We have successfully developed and tested calibrator/simulator units to be used for certifying the performance and accuracy of across-the-road traffic radars in a laboratory setting. The units are of simple design and should prove very reliable. Although the developmental models are relatively costly to produce, the basic design readily lends itself to quantity production at low per-unit cost. We plan, in time, to incorporate additional circuitry in these units, which will improve their testing capabilities.

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