# IMPROVED DISCRIMINATION OF MICROWAVE VEHICLE PROFILES

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## ABSTRACT

An FMCW microwave system is described which can separate traffic into five classes. Profiles derived from speed and range data are characteritstic but not immediately recognisable. Explanations are given and suggestions are made for a system with greater accuracy and a wider range of classification capability.

## BACKGROUND

Congestion is becoming a serious problem worldwide, not only does it incur time penalties but the pollution produced is becoming increasingly important. Road traffic engineers can benefit from low cost and portable equipment to classify road vehicles in busy urban areas in order to plan new routes and alleviate congestion and hence reduce pollution. Existing systems which use inductive loops have the disadvantages that they are expensive to install and are liable to damage by tarmac subsidence and by utility companies unearthing them. Initially planners are interested in dividing traffic into six classes:

Bicycles
Cars
Light goods
Medium goods
Heavy goods
Buses.

Previous work by Hobson et al [1], with a Doppler system to derive lengths of vehicles separated traffic into three groups to an accuracy of about 85%. In order to increase the discrimination a second dimension was required. This paper briefly describes a combined FMCW (Frequency Modulated Continuous Wave) and Doppler radar system which can separate traffic into five groups to accuracies of about 75% using length and height criteria and discusses the possibility of increased discrimination using the more detailed profile information.

## THE MICROWAVE TECHNIQUE

Doppler radar is used to determine the speed of moving targets since the beat frequency is proportional to speed. FMCW radar is used in aircraft as an altimeter, where the frequency of the received signal is proportional to the range of the target. However, if a target is moving relative to the signal source the reflected FMCW signal will be shifted by the Doppler beat frequency. If a triangular sweep waveform is used, it can be shown that the Doppler beat frequency will add on the upsweep and subtract on the downsweep for a receding target. Thus, by synchronising the signal processing with the sweep waveform and counting the number of cycles in the upsweep and downsweep, the Doppler speed signal can be separated from the FMCW range signal provided that the range is large enough to make the range beat frequency significantly larger than the Doppler frequency. This condition has been satisfied by our operating parameters.

The speed and range information forms a microwave profile which can be changed to a "lookalike" profile with cartesian coordinates x and y by the following transformation:

$$x = l_n.\sin\Theta + n.v_n.t, \quad y = H - l_n.\cos\Theta \qquad [1]$$

Where:

- $l_n$ = instantaneous range,
- $\Theta$ = angle to the vertical,
- $n$ = sweep sample number,
- $v_n$ = instantaneous speed,
- $t$ = sweep time,
- $H$ = height of antenna above road.

Initially we expected these coordinates to show the actual vehicle shape.

## THE SYSTEM HEAD

The system used an FMCW radar with a centre frequency of 10.5 GHz and a bandwidth of 120 MHz. Half beat cycles were counted so that the range resolution was 62.5 cm. To ensure that the FMCW beat frequency would always be greater than the Doppler beat frequency and assuming that the

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fastest urban vehicle would travel at 40 mph, a sweep time of 5 ms was chosen.

A 10 inch dish antenna with a 3 dB beamwidth of 10 degrees was used to give single lane discrimination when mounted on an overhead bridge about 9 metres above the road. The antenna was aligned at an angle of 45 degrees to optimise the mix of horizontal and vertical FMCW and Doppler signals.

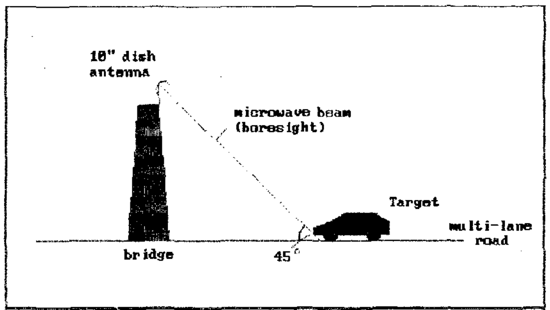


**Fig. 1. Field Trials for Microwave Classification.**

## FIELD TRIALS

Field trials were carried out viewing traffic on a busy three lane road near the bus and railway stations in Sheffield. The system head was mounted on an overhead footbridge at a height of 9 metres above the road, as shown in Fig. 1. The reflected signals were amplified and filtered to reduce noise and recorded onto the audio tracks of the video tape simultaneously with a view of the target vehicles passing underneath. The sweep waveform of the FMCW signal was recorded onto the second audio channel for synchronisation in later processing. The VTR caused a limitation on the bandwidth of the recorded signals of 50 Hz to 12 kHz.

Unfortunately, bicycles were too infrequent along the road viewed to be included in the assessment so the number of possible classifications was reduced to five.

## SIGNAL PROCESSING

After conditioning the reflected signal a TMS320C25 Digital Signal Processing board with stereo D/A and A/D channels was used. The reflected signal was fed to one A/D converter with the sweep synchronisation signal input to the other. This synchronisation made it possible to count the beat cycles on the upsweep and downsweep so that it provided the basis of sampled data profile information. Speed and range data are derived for each sweep cycle and used to calculate points on a vehicle profile at an instant in time.

## PROFILE DISCONTINUITIES

Fig. 2 shows typical derived FMCW and Doppler signals reflected from an approaching double-decker bus. The upper, FMCW trace consists of a sloping line and a flat section corresponding to the roof. It would be expected that the sloping line would meet the flat section since on a bus the front face smoothly joins the roof. However, there is a discontinuity - the front appears to be higher than the roof.

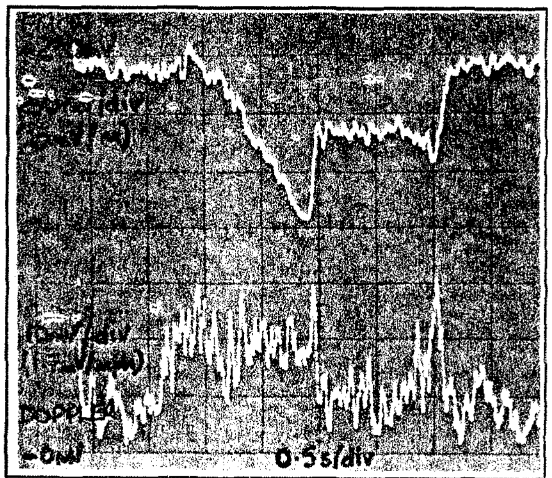


**Fig. 2. Typical FMCW and Doppler Signals Reflected from a Double-decker Bus.**

This can be explained by considering the points of reflection and the finite beamwidth of the antenna. As the bus approaches the beam boresight moves up the front of the bus, tracking the strongest reflecting points. However, when it reaches the top corner this feature is a much stronger reflector than the roof and although it is in a weaker part of the beam the corner is still tracked at an angle of less than 45 degrees to the vertical and the range reduces. When the reflection from the roof in the boresight becomes stronger than the corner reflection there is a sudden increase in range as the tracking angle returns to 45 degrees and a corresponding discontinuity in the profile. This discontinuity could be reduced by a narrowing the beamwidth, but this would imply using a larger antenna or moving to a higher frequency, which is discussed later.

## DIFFICULTIES WITH DOPPLER

Observation of the extracted Doppler signals, given in the lower trace of Fig. 2, showed that they were not giving a consistent speed indication for the whole length of the vehicle. This can be explained by considering the centre of reflection of the target vehicle. Doppler radar theory assumes that the reflecting centre is from an invariant target, which is true when the target is illuminated head-on. However, if an alignment angle of 45 degrees is used the centre of reflection moves over the vehicle as it passes through the beam, although this is not always the case as will be shown later. The strongest, most consistent Doppler signal occurred, as may be expected, at the front of the vehicle since the radiator grille, bonnet and corner of the roof would be the best reflectors. However, when the boresight beam is incident upon the roof of the vehicle there are no strong reflectors and the reflecting centre moves along the roof as the vehicle moves, giving a spurious interference signal rather than a true Doppler signal. This implies that the speed of the vehicle should be sampled from the leading part of the waveform.

## AUTOMATIC PROCESSING

In order to operate the system in real time a second processor was required. The TMS320C25 extracted the FMCW and Doppler data from the received signal and stored the data in a shared memory area. This data was retrieved by a program running on the host PC and the lookalike profile was derived and displayed on the computer monitor. It was catalogued into one of the five classes of car, light goods, medium goods, heavy goods and bus according to length and height criteria. Typical accuracies of 75% were achieved.

## DETERMINING THE TRUE SPEED

The next question to be answered is what is the true speed of the vehicle along the road? Since the illuminating beam is at 45 degrees it would be natural to assume the true speed is the resolved speed, where:

$$\text{resolved speed} = \text{indicated speed} \times \cos 45$$

Fig. 3 shows the lookalike profile of a double-decker bus. The upper trace using indicated speed sampled from the leading part of the Doppler waveform and the lower using resolved speed. Both profiles show the expected discontinuity as the front meets the roof.

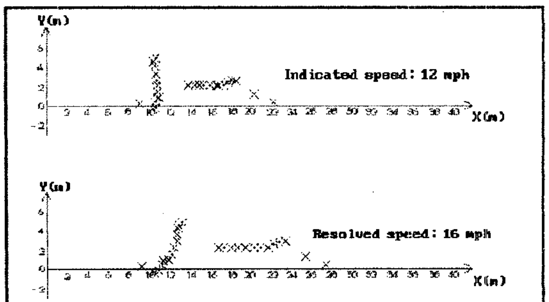


**Fig. 3. Profiles of a Double-decker Bus.**

The vertical front face of the indicated speed profile suggests that the indicated speed is correct but the length obtained from the resolved speed is more representative of a double-decker bus. This implies that the reflecting point must be carefully considered on the front of a bus since the roof of the bus only gives a spurious interference signal. Two possible explanations are: the beam smoothly traces the front of the bus, which implies the true speed is indicated speed/cos 45; or the beam jumps from one strong reflector to another and effectively tracks a fixed point, giving true speed is indicated speed x cos45. These extremes might also suggest why the Doppler trace is not more constant at the front of a vehicle if it oscillates between the two extremes to give an effective average of 1.1 x true speed.

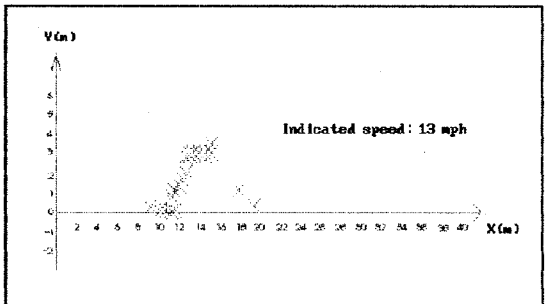


**Fig. 4. A Transit Van.**

## CHARACTERISTIC SHAPES

Although it is possible to explain the differences between the microwave profile and the actual shape the differences are not necessarily a disadvantage in classification. Overall the profiles obtained seemed to be highly representative of the vehicles they were derived from. Fig. 4 shows the profile of a Transit van in which a bonnet can be seen. The open-backed lorry in Fig. 5 has two vertical faces corresponding to the front of the cab and the back corner, whilst the articulated lorry in Fig. 6 shows an increase in height between the cab and the trailer. Fig. 7 is a car towing a caravan. The car has a rectangular outline with the suggestion of a bonnet followed by the roof and the coupling. The caravan appears as a vertical face and then a flat part for the roof. It was also possible to distinguish single-decker buses from double-decker buses, which would allow at least one extra class to be included.

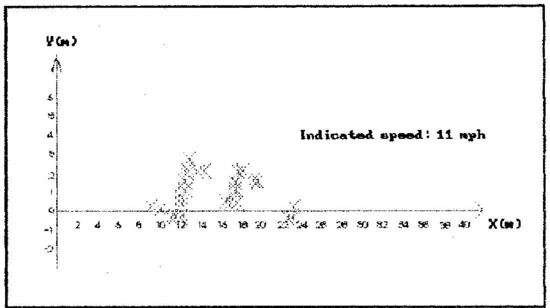


Fig. 5. An Open-backed Lorry.

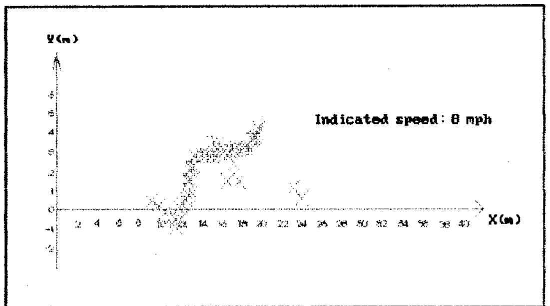


Fig. 6. An Articulated Lorry.

## CONCLUSIONS

In addition to the length and height data found in the Doppler and FMCW techniques it is possible to extract shape information for a vehicle. This shape has certain characteristics important for classification. It has been shown that the vertical face of vehicles such as buses can be identified and distinguished from other vehicles such as Transit vans whch have bonnets or sloping fronts. Another important feature is the segmentation of the profile which occurs for lorries, which tend to have cabs and trailers, but not for buses which are flat and continuous.

Overall the characteristic shapes suggest that with further development it should be possible to separate traffic into more than the six classes initially desired.

Further development would probably include moving to a higher centre frequency to reduce the effect of the discontinuity seen on double-decker buses by reducing the beamwidth. A frequency between 63GHz and 64GHz would be in line with current CEPT frequency allocations for Europeam Road Transport applications. The increased frequency is likely to give more detailed information both in the form of useful shape information and useless noise-clutter.

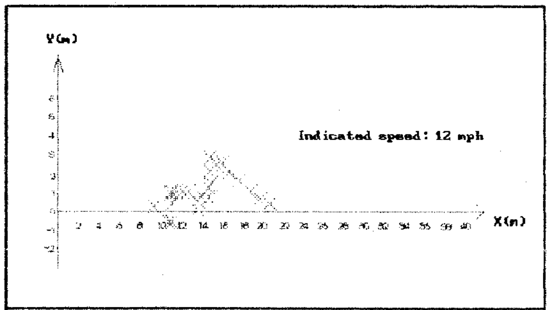


Fig. 7. A Car Towing a Caravan.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] G. S. Hobson, H. Roe, J. P. Hawley, Microwave Classification of Road Vehicles, 1991, Proc. 20th European Microwave Conference, Vol. 2, pp.996-1001.