# Enhancement to the TRACKER™ System - the provision of an uplink path

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## SYNOPSIS

The TRACKER system was originally conceived as a very simple and cost-effective covert in-car unit which would transmit an identification and location signal to tracking equipment fitted in a Police car when instructed to do so, over a proprietary radio network, after a report of the vehicle's theft.

This concept has now been augmented by the provision of an uplink (i.e. vehicle to base station) capability. Because of the in-car unit's limited complexity and low transmitted power (about 18mW) this has only been successfully achieved only through the addition of a number of novel processing features, both in the in-car unit and the base stations.

The in-car features are implemented in additional software, having been foreseen during a previous UK redesign. The base station receiver algorithms are implemented in a single-chip Digital Signal Processor (DSP) on a deceptively simple PC card.

One use for such an uplink is position reporting. A commercially available OEM Global Positioning System (GPS) receiver unit has been integrated into the in-car unit system for this purpose. Considerable effort has gone into maintaining low power consumption and fitting the necessary additional messages, data structures and processing algorithms into the limited bandwidth, storage and processing power available.

## AUTHOR'S BIOGRAPHICAL DETAILS

David Spreadbury graduated from The City University in 1971 with a first class honours degree in Electrical and Electronic Engineering. An experienced hardware designer, he has spent twenty years "doing DSP", in both military and commercial environments using a range of technologies. For the last four years he has been a Senior Technology Consultant at Plextek Ltd., specialising in DSP for digital radio communication. David is married, with two secondary-school aged children. He is actively involved in his local church and enjoys fixing things, reading, origami, computing, and a strictly limited amount of sport.

Ralph Kanter has been Chairman and Chief Executive of TRACKER Network (UK) plc since 1991, and spent three years and £500,000 bringing the product to the UK market, where it was launched in 1993. He was one of the three founders of Britannia Security Group plc in 1983, and before that spent twenty five years in general management in large corporations including Carreras Rothmans and Thomas Cook, where he was Group Managing Director. Ralph Kanter is also a non-executive director of a number of other public and private companies.

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## 1 INTRODUCTION

### 1.1 The Original System

The original system operates in a single VHF channel with one way network communication only, i.e. from the network to the vehicle. The covert vehicular unit only transmits a signal for short-range identification and location purposes, and then only when instructed to do so by a command from the network. This command is usually issued when a vehicle owner reports the vehicle missing. The vehicle's transmission is detected by suitably equipped Police vehicles which are subsequently able to track and locate the vehicle.

The advantages of this approach, which have been confirmed in operation, are:

- a low cost vehicular unit,
- a low network bandwidth requirement,
- a zero false alarm rate, and
- high precision location.

### 1.2 The Desirability of an Uplink

There are two aspects of the original system which can be improved:

- the potential long delay before an owner discovers a vehicle theft, and
- the necessity for an equipped Police vehicle to pass, unguided, within tracking range.

The provision of an uplink radio link can address these requirements and significantly enhance system performance and usefulness by enabling:

- the status of installed vehicular units to be monitored,
- the performance of the overall system to be monitored, and
- an automatic theft alert to be generated.

With additional hardware, like a GPS receiver, an uplink would enable:

- a vehicle's geographic position to be reported,
- a driver to summon assistance, and
- another vehicle to be guided within tracking or visible range.

## 1.3 Technical Considerations

The provision of the uplink radio path is complicated by the following considerations:

- it should ideally fit into the existing allocated VHF channel,
- the vehicle’s Effective Radiated Power (ERP) is only about 1% of that of the base station, due to a 1 Watt in-car transmitter and a covert and hence inefficient (15dB loss) antenna,
- the high levels of interference visible by most base station receivers, and
- the simplicity of the in-car transmitter, resulting in incoherent frequency modulation along with a carrier frequency uncertainty of about ±1.5 kHz.

# 2 UPLINK TRANSMISSION FORMAT

## 2.1 Bit Level

The normal transmission format is 1200 bits per second (bps) Minimum Shift Keying (MSK), where “1” is represented by a single cycle of a 1200Hz sinewave and “0” by 1.5 cycles of an 1800Hz sinewave, as illustrated in Fig. 1:

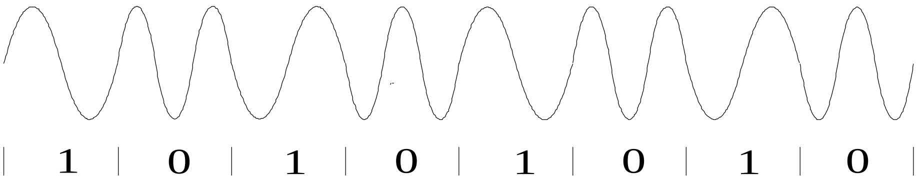

Fig. 1: MSK Modulation

This is used to frequency modulate the carrier with a peak deviation of about ±2kHz.

The circuitry to generate this waveform was provided at the UK redesign in a mixed mode Application Specific Integrated Circuit (ASIC), using digital synthesis and a simple Digital-to-Analogue Converter (DAC).

The uplink transmission format is a modification of this, with the data rate reduced to about 56 bps and the data being represented by a fixed +2kHz or -2kHz deviation for the duration of each bit, with a half cycle of the 1800Hz sinewave used for bit transitions, as in Fig. 2:

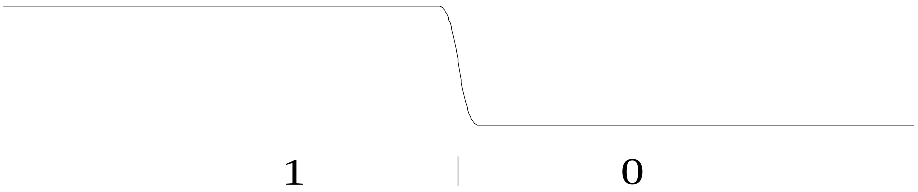

Fig. 2: Uplink Modulation

Because the carrier now dwells on either +2kHz or -2kHz deviation for long periods, this effectively results in a pair of narrow band signals, with complementary amplitude modulation. The advantages of this approach are:

- a very narrow band linear receiver can be employed on each signal, minimising noise and maximising the chance of successful reception, and
- the existence of the two signals spaced by some 4kHz gives a useful diversity against interferers.

The carrier frequency uncertainty, augmented by about 500Hz agility applied randomly between transmissions, provides useful additional diversity (about ±1.75kHz) against fixed interferers and other vehicles which happen to be transmitting simultaneously.

### 2.2 Message Level

Each message is arranged into a number of 63 bit blocks. At the beginning and end of each transmission and between multiple blocks of a transmission a synchronising pattern is inserted. This pattern comprises the dotting sequence “0101”, the flag sequence “10001101” and the null sequence “0000”, in that order.

Vehicular units are able to detect the presence of an identification and locating signal being transmitted from another vehicle, and will postpone the transmission of their own uplink message transmission until this is complete.

## 3 RECEIVER PROCESSING

### 3.1 Analogue Circuitry

The base station radio receiver accepts the useful 8kHz band, attenuating anything more than 500Hz away from this band by at least 80dB. This band is mixed down to a final Intermediate Frequency (IF) of about 14kHz, so that it fits into a range which can digitised by a commercial Audio Frequency Analogue-to-Digital Converter (ADC), operating at 56 kilosamples per second (ksps), or 1024 times the bit rate. These digital samples are sent by twisted pair cable to the DSP card in the PC.

### 3.2 Digital Filtering

The first digital operation, after conversion to floating point format, is a complex mixing and filtering operation which generates two complex data streams, relating to the upper and lower components of the signal pairs respectively, each with a signal content of ±1.75kHz, sampled at 7kHz, or 128 times the bit rate. This first stage of reduction in bandwidth will reduce the noise. The linear processing means that signals not too far into the noise can be brought out of it by such means.

Each of these streams is processed by a 512 point Fast Fourier Transform (FFT) every 4.5ms (one quarter of the bit period), which efficiently estimates the power of the received signal spectrum at 14Hz intervals. Windowing at the FFT input ensures that the bandwidth of each of these estimates is limited to approximately 33Hz (see Fig. 3), thus reducing the noise even further. A linear phase FIR filter is used so as to prevent any phase distortion of the signal.

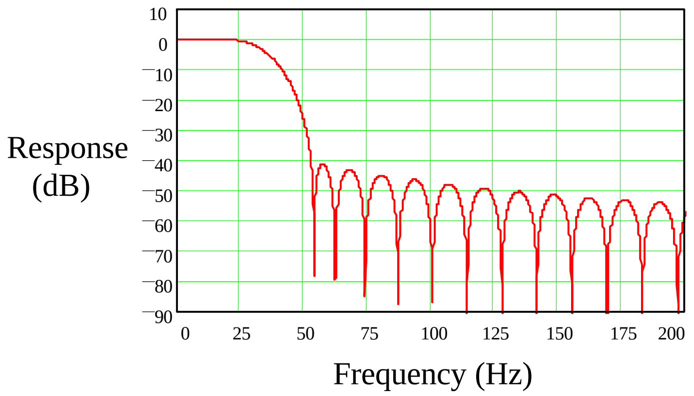

Fig. 3: FFT Point response

The signal sequences out of each of the 256 central points out of the FFT (corresponding to the ±1.75kHz signal band) are examined to see if a transmission can be detected. This effectively creates 512 simultaneous 33Hz bandwidth radio receivers, tuned at 14Hz intervals over the wanted signal band, thus satisfying the twin criteria of optimal signal to noise ratio and insensitivity to carrier offset.

## 3.3 Detection

Detection is accomplished by looking for the pattern “1100011010” in the points of one stream, and, independently, “0011100101” in the other. In many systems this would be done by correlating the received signal with the wanted pattern, and detecting the peak response at a match, even with a noisy signal. Here, because of the incoherent nature of the simple vehicular transmitter, such correlation gain is not available. Rather, the processing gain necessary is achieved by keeping the bandwidth of each individual receiver very low, with the detection processes looking directly for the required patterns.

Because of the wide dynamic range expected, this is not done by comparing with a fixed threshold but by looking for the presence of an eye, that is seeing what range of threshold (if any) could be applied to the received signal to give the required data pattern.

Fig. 4 below shows the ideal noise-free pattern out of one FFT point:

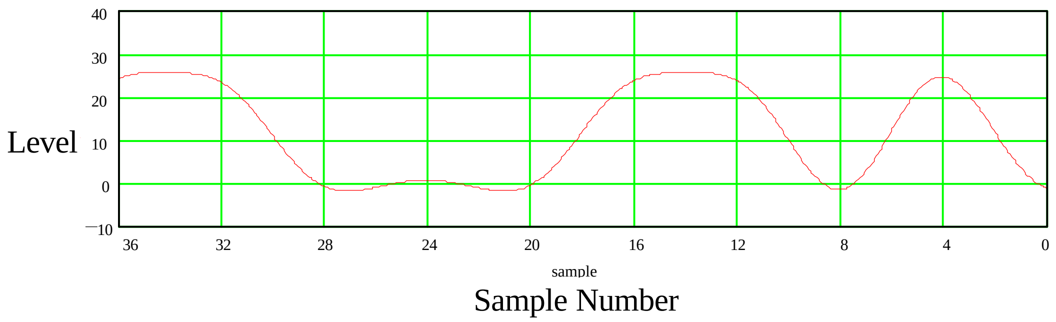

Fig. 4: Noise-free Detection Pattern.

The eye opening measure is computed by subtracting the highest value of those samples which should be low (samples 0, 8, 20, 22, 24, 26 and 28 above) from the lowest value of those samples which should be high (samples 4, 12, 14, 16, 32, 34 and 36 above).

If this result is zero or negative, no eye is present and the value zero is output. If the result is positive, it is divided by the highest value of all the samples used to generate a normalised “eye quality” measure between zero and 1. Note that the pattern has an equal number of “1”s and “0”s, so that the probability of detection of the two streams is equal.

This computation is carried out at quarter bit intervals for each of the 256 FFT points for each of the two streams. As the received signal samples move through this process, the oversampling in time and the overlap of the FFT point responses mean that any real signal inevitably gives rise to a cluster of contiguous non-zero measures in both time and frequency. A typical set of such measures, recorded during laboratory trials, is shown in Table 1:

| Sample Number | FFT Point | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0.070249 | 0.080866 | 0.042759 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0.445905 | 0.643595 | 0.622750 | 0.657230 | 0.477270 | 0 |
| 26 | 0 | 0.121496 | 0.491645 | 0.628440 | 0.753539 | 0.815201 | 0.584730 | 0 |
| 27 | 0 | 0 | 0.305885 | 0.341721 | 0.341811 | 0.416611 | 0.327406 | 0 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 1: Typical Cluster of Non-zero Eye Measures.

These clusters are defined as adjacent non-zero values, surrounded by zero values, and are readily detectable. They give a fuller picture of the signal, and allow a simple Centre Of Gravity (COG) to be computed in both dimensions to give a more accurate value for the carrier frequency and bit position of the underlying signal. In this example, the computed frequency is at FFT point 9.998 and the bit centre is at sample 25.816.

During the course of this COG computation the sum of the detection values within the cluster is determined. This sum is thresholded to make a final decision on the presence of a signal (note that since all the values passed to the COG algorithm are scaled “eye quality” values, this threshold is related to the detectability rather than the strength of the signal).

### 3.4 Demodulation

The demodulation process operates on the original data coming from the converter into memory, the last three zeroes of the null sequence which was input to the FFT, and is still held in memory. The precise frequency from the COG algorithm is used to construct a “personalised” local oscillator tuned accurately to the detected signal. In addition, the COG bit centre time is used to set up the addressing of the samples (to the nearest 1/32 of a bit) to give sampling accurately at the bit centres. Following mixing, a 33Hz low pass filter maximises the signal to noise ratio to allow conventional detection.

If the processor detects the presence of both signal streams from a single vehicle (by their separation in frequency, complimentary modulation and simultaneous arrival) it combines them in proportion to their quality measures in order to further improve the demodulation performance. The local oscillator and bit timing are held constant for the duration of each 63 bit block. Long multi-block messages will be automatically resynchronised at block boundaries, allowing changes in radio channel propagation to be accommodated.

# 4 IMPLEMENTATION

## 4.1 In the Vehicle

Since the provision of some kind of uplink was anticipated at the time of the UK redesign, flexibility was incorporated into the digital modulation circuitry at negligible cost, with the bulk of the functionality being provided by a micrcontroller and a mixed-mode ASIC. Provision of the uplink has been effected through additional microcontroller software only, with no increase in per-unit cost. Subsequently, additional features (like a key fob and GPS receiver) have caused the migration to another microcontroller in the same family but with more on-board memory.

In addition, an inexpensive commercially available OEM GPS receiver (not described here), has been engineered into an optional package, compatible with the basic vehicular unit, to provide geographic data to support additional features which the uplink enables.

## 4.2 At the Base Station

All the base station digital processing is performed in a single Analog Devices SHARC DSP Processor running at 33MHz. A major feature of this device is that it contains a large, fast on-chip memory which can hold enough signal and program data to run the processes above without any external device except a single low speed (and hence low cost) Programmable Read-Only memory (PROM) from which the program is read at power-on. This results in a small cost-effective half-size PC card.

At 33MHz the processor can perform seven simultaneous demodulation processes in addition to the 512 filtering and detection processes described above. This means that up to seven transmissions which overlap in time but not in frequency can be resolved. In addition, the odd false detection (which will subsequently be rejected when the data content is checked) will not completely blind the receiver to other valid messages.

# 5 PERFORMANCE

During recent uplink trials, the base station in-band noise levels were found to vary significantly from site to site, a common problem being co-sited transmitters for other services. In spite of this, and the vehicle’s ERP of only about 18mW, the up and down links have been confirmed to be essentially reciprocal, and successful operation has been recorded over ranges from 30 to 70 miles.

## 6 APPLICATION

The uplink described will be used to implement the following features:

- the transmission of theft alert messages, in response to an integrated movement detector, either in conjunction with a car immobiliser, or an additional radio beacon (either in a key fob to indicate an authorised driver or on a designated site to indicate an authorised location). These will enable the registered owner to be contacted for rapid confirmation of the suspected theft. This confirmation will maintain the system's zero false alarm rate.

- the transmission of a driver-initiated alert message to summon assistance.

- the transmission of a geographic position from an integrated OEM GPS unit (engineered for inclusion in the covert vehicular installation at low cost), either on demand from the network or in conjunction with a theft or driver alert, to allow guided deployment of a search or assisting vehicle.

- the transmission of a warning message when a vehicle enters or leaves one or more defined geographic areas. These areas will include some that are fixed (e.g. country boundaries and sea ports) and others that can be downloaded over the network (e.g. user-definable transport corridors, rental areas and plant sites).

- the transmission of a geographic position at regular intervals or in response to a request from the network, to allow a vehicle owner to monitor the activity of a vehicle.

- the transmission of vehicular status, in response to a request from the network, to allow all system aspects from installation through radio communication, message handling and high level efficiency to be monitored.

- the transmission of other vehicle status, related either to the owner's business (e.g. cargo temperature) or safety (e.g. impact or fire detection).

## 7 SUMMARY

The use of the latest DSP technology and novel processing algorithms have made possible the addition of a radio uplink in an extremely simple and cost-effective (patented) manner to an already simple vehicle recovery system, in a difficult environment, without any extra radio channel assignment or punitive vehicle or base station cost.

This will not only improve the way that existing features operate but will open the way for a number of new features, all highly desirable but previously only available in systems involving considerably more complex and expensive installation and infrastructure.