

Railway Signalling Receiver

5 The present invention relates to a railway signalling receiver for electrical signals carried by railway lines, which receiver performs a discrete Fourier transform. Such a receiver is useful, for example, for track circuit signals utilised for determining the presence and location of trains and automatic train protection systems which relay safe maximum speed
10 information to moving trains.

Discrete Fourier Transform techniques provide a quantitative analysis of the frequency spectrum of signal by sampling the signal in the time domain and
15 transforming those time-domain samples into the frequency domain. The process involves the collection of a set of time domain data samples which form an initial set of data points, a multiplicity of elementary calculations are then carried out to
20 produce a new set of intermediate results and proceeding through a series of levels or iterations to a final new set of outputs results in the frequency domain.

25 The initial set of data samples have real values in the time domain and the final set of results have real values in the frequency domain although the intermediate results may well be complex. However there is a substantial amount of redundancy among
30 these intermediate terms due to the periodicity exhibited by the exponential function in the transform equation.

In order to reduce the number of individual calculations involved in the transformation to a realistic level various algorithms or families of algorithms have been proposed. The Winograd algorithm is one, another is the Cooley-Tukey algorithm and another is Bergland's algorithm, which is a modification based on the Cooley-Tukey, and with which the particular examples described below will be concerned.

As in other fields discrimination against noise and interference is a constantly present problem which if not effectively dealt with in the railway context can seriously affect the safety of the railway system. Analogue electronic equipment designs possess the inherent disadvantage that "universal designs" are difficult if not impossible to achieve so that each application requires at least freshly calculated design values. Also they are liable to drift with temperature and age and each set of equipment needs individual alignment initially which is a time consuming and costly procedure.

Objects of the present invention include providing equipment which in addition to overcoming these difficulties is useful in different systems with different operating parameters but requires minimum modification and is useful as the basis of equipment for different purposes to which specialised peripheral items may be connected.

According to the present invention there is provided a railway signalling receiver for electrical signals carried by railway lines comprising sensing means for co-operation with the railway lines to sense the signals, sampling means operative in the time domain to continuously sample a sensed signal, data memory



means for storing a plurality of sample values,
means for performing a discrete Fourier transform on
said stored sample values, data memory means for
storing the results of the transformation, means
5 responsive to the final results of the transformation
in the frequency domain to identify the sensed signal,
means for discrimination between a frequency shift
keyed or frequency modulated signal comprising means
for calculating from information stored in the final
10 transformation results memory the phase angle relative
to the carrier signal of the resultant sideband vector
and means for discriminating against signals for which
said angle is substantially 0° or 180° whereby to
15 distinguish a frequency modulated signal from a
confusingly similar amplitude shift keyed signal.

In an embodiment for receiving and detecting a
frequency shift keyed transmission the receiver is
20 connected to a heterodyne circuit, a low-pass filter
means is arranged to pass the difference frequency
components and to exclude the sum frequency components
in the heterodyned output which is connected to the
means for performing a discrete Fourier transform on
25 said difference frequency components.

In one application of the invention to a railway
jointless track circuit receiver, a combination of
alternative carrier frequencies are employed as an
30 identification signal by the associated track circuit
transmitter thus defining between them the track
section. The modulation frequency may be employed as
an additional identification further increasing the
number of possible track circuit identifying
35 combinations or, as a means of encoding, for example,
a maximum speed limit for transmission to a train in
the track section.

In another application of the invention to an automatic train protection system a carrier signal is modulated by a speed limit designating signal and is communicated to a train, on board the train the signal is sensed and sampled, the sample values are temporarily stored and used as input values for a discrete Fourier transform process, the final results of which yield, inter alia, the modulation frequency which indicates a speed limit.

The invention, and how it may be carried into practice, will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 shows a schematic diagram of a jointless track circuit,

Fig. 2 shows a block diagram of apparatus according to the invention for performing a discrete Fourier transform to identify a received signal,

Fig. 3 shows a flow chart of the operational cycle of the apparatus of Fig. 2 used in a track circuit receiver,

Fig. 4 shows a flow chart of the operational cycle of the apparatus of Fig. 2 used in an Automatic Train Protection System,

Fig. 5 shows a graphic representation of the frequency domain output of the discrete Fourier transform apparatus in an A.T.P. system.



The present invention utilizes one of the most efficient discrete Fourier transform algorithms so far proposed, i.e. that by Cooley and Tukey which can be found published in "Mathematical Computing 19 (April 1965)." A further refinement of this algorithm which has been found particularly useful with real-valued series was subsequently described by Bergland in "Communications of the ACM (Vol. 11, No. 10 October 1968)." The algorithm takes as an initial input a real-valued time series comprising the N discrete sample values and, through a series of iterations which makes repeated use of a standardised calculation, computes the real and imaginary parts of the final Fourier coefficients of $(\frac{N}{2})$ frequency terms. Full theoretical descriptions of these algorithms can be found elsewhere, as noted above, and reference should be had to these publications for rigorous exposition of the theoretical basis of the algorithms.

The process of evaluating the Discrete Fourier Transform according to the Cooley-Tukey algorithm involves setting-up an initial array of data points, in time sequential or natural order. The algorithm then proceeds to calculate successive arrays in a series of iterations until eventually the final level array is obtained in which the calculated frequency domain results are in a scrambled order. All of the intermediate data calculated for the intermediate iteration and final arrays are the result of computations using only two data values from the previous array. These calculations are performed in a "butterfly" operation. Since each calculation produces two results

_____ from two input data points and as each is only used once it is convenient to write the results back into the same memory address locations thus, saving greatly on memory size. It is not intended to give further or more detailed mathematical analysis of Fast Fourier Transforms here but, the manner in which these basic tools are adapted and applied in practical use in embodiments of the invention will be described below.

Referring now to the accompanying drawings, Fig. 1 shows for a first example a schematic diagram of a jointless track circuit in which the running rails are referenced at 1 and 2 and track circuit receiver and transmitter transformers 3a and 4a, respectively, are connected between the rails 1, 2, at some distance apart, thereby defining the track section a monitored by the completed track circuit. Transformer units 3b and 4c, which form part of the track circuits of track sections b and c on either side of track section a, are connected adjacent transformers 4a and 3a, respectively, at a relatively short distance therefrom. The theory and practical design and positioning of these track circuit transformers is well-understood in the art and for present purposes the units referred to will be assumed to be according to the prior art.

The transmitted signal comprises a Frequency Shift-Keyed (FSK) signal employing up to four carrier frequencies at 1700, 2000, 2300 and 2600 Hz. with up to ten low frequency modulation rates, in this example

there are three modulation rates at 12.5, 15.0 and 20.0 Hz. The chosen combination of keyed carrier frequencies identify a particular track section/circuit, that is, a particular pair of track circuit transmitters and receivers is arranged to operate with a particular combination of carrier frequencies. This does not permit a large number of track circuit identifications, but does ensure that two track sections having the same identification are sufficiently far apart to prevent any possibility of the receiver in one section "picking-up" and positively responding to the transmitter in another and wrong section.

The transmitter 5 feeding into the track section through transformer 4a in Fig. 1, may thus be of such known type according to the prior art and will not be further described.

At the opposite end of the section, the transformer 3a feeds the FSK signal into a track circuit receiver 6 which "detects" the signal in a safe manner and energises track section relay 7 providing the signal is present and correct.

Fig. 2 shows in block diagram form the hardware of the track circuit receiver 6 comprising at 11 a pair of analogue input terminals to which the received track circuit signal is connected. The input signal path feeds through a noise and overload protection circuit 12 through an anti-alias filter 13 comprising a low-pass analogue filter, the object of which is to eliminate signals above half the Nyquist frequency of $f_s/2$.

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The theoretical dynamic detection range of the receiver is 42 dB but is restricted to 30dB by digital noise arising in the arithmetic processing of the FFT. Thus anti-alias filter 13 has a flat transfer characteristic from DC to 2 KHz which then falls by more than -30 dB at 5 kHz so that no signals above half the sampling frequency will be detected.

The input signal is then fed to a sample and hold circuit 14, operated by a sample control signal on line 15, for sampling in the time domain at a frequency of 9.6 kHz. Sampled values are then digitised by an 8-bit analogue to digital converter 16. The 8-bit binary output of the converter gives a lowest detectable amplitude of $\frac{1}{128}$ th (or -42dB) of the highest amplitude, thus providing the receiver with its previously mentioned dynamic range of 42dB.

Converter 16 generates eight parallel binary digital data bits at its output 17 which has to be "logged", i.e. temporarily stored, for later retrieval in preparation for evaluation of the FFT algorithm. The parallel data is received by digital input and address latch circuit 18 the output of which feeds into an 8-bit parallel multiplexed data bus 19 which interconnects a microprocessor Central Processing Unit (CPU) 20 and various co-operating units (11, 12, 13, 14 and 17.) The sampled data is "logged" in a Random Access Memory (RAM) 21. The control program for controlling operation of the CPU 20 is stored in a Read Only Memory (ROM) 22.

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Also connected to the data bus 19 are two peripheral interface adaptors 23 and 24, the former providing an interface with a "signed 2's Complement Multiplier" 25 which is used to perform multiplications at the command of CPU 20 during execution of the FFT algorithm. The interface 24 is that through which the final digital output is delivered. The operating frequency of the CPU is derived from a crystal oscillator 26 resonant at 6.147 MHz. The timing signals which control operation and synchronisation of all the co-operating units is provided by timer 27 via the multiplexed databus 29. This also controls operation of the sample and hold circuit 24 through control signal 25 and also operation of the A to D converter 26 and address latch 28.

The control program stored in ROM 22 is directly written as a set of program instructions in "machine code" thus making it possible for the programmer to compose the program instructions so as to execute the FFT algorithm in the most efficient way possible having regard for the capabilities and restrictions of the particular microprocessor.

The programmable read-only memory 22 contains a set of digital instructions specifically adapted to control the microprocessor in a sequence of operations which, when taken as a whole and in sequence, implement a discrete Fourier transform on the analogue input signal 11.

In a complete cycle of operations in one such transform, the digitised waveform samples are stored

and used as data-points in an initial level of calculations, the results of these calculations then form the data-points for a further level of calculations. This process is repeated several times through a succession of intermediate levels of calculation which descend to the final set of results in the completed transformation. As the initial samples and each level of results are only used in the next level of calculations, only one memory, 21, is used as temporary storage which need only be large enough to store the largest amount of data produced in any one level. Thus, data is discarded when no longer further required. Finally, the final results of the discrete Fourier transform are read-out through output circuits, generally referenced at 24.

The discrete Fourier transform effectively produces, as a final result, a digitised spectrum analysis of the received input waveform 11. When correctly interpreted, the final set of output data points represents a measure of the component frequencies of adjacent "frequency bins" spanning a frequency spectrum starting at 0 Hz. The required signal detection is achieved by monitoring or applying a discrimination function to the appropriate frequency bin. The lowest frequency component in the output results of a Fourier transform has to be zero Hertz. For the detection of FSK signals the need to detect a relatively high frequency has thus required a large number of samples and very long computation times in order to achieve adequate frequency resolution. A smaller number of samples speeds-up the computations, but causes a consequent loss of frequency resolution.

Therefore, the transforms have usually been performed "at leisure" on recorded data rather than "in real time".

5 To overcome this problem the FSK input signal is "heterodyned down" to produce a lower intermediate frequency sideband at very low frequencies, which sideband is then operated upon by the discrete Fourier transform to produce the required spectrum analysis to enable "detection" of the original carrier and modulation frequencies to be carried out. Fig. 3 shows a flow chart of the sequence of events in this operation.

15 In the particular embodiment being described, the "heterodyning" operation is carried out digitally by steps described below. The received track circuit signal is modulated by frequency shift-keying, therefore, it contains a band of frequencies centred about the carrier frequency f_c . The input signal is passed through an input noise filter, of band-pass type, which has the effect of limiting the frequencies present to a well-defined band.

25 Consider an example in which a carrier frequency f_c of nominally 1600 Hz. is keyed between $1600 \text{ Hz.} \pm 10 \text{ Hz.}$ at a modulation rate of 12.5 Hz., 15.0 Hz., or 20.0 Hz. In this example, where the modulation index is less than 1, it can be shown that the signal frequency spectrum consists of a component at f_c (1600 Hz.) and pairs of sidebands spaced at multiples of the modulation frequency f_m e.g., if $f_m = 20 \text{ Hz.}$, the sidebands are $1600 \pm 40 \text{ Hz.}$ etc. the amplitudes of the

higher order sidebands decrease progressively away from the centre frequency in accordance with values predicted by Bessel function mathematics. Frequency resolution, i.e. Δf , must be 2.5 Hz. or better, in order to provide discrimination between sidebands at 12.5 Hz. and 15.0 Hz. Sidebands of higher order than the first are attenuated by the track bonds; sampling theory specifies that the minimum sampling frequency can be twice the highest frequency component, so that:

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10 $f_{\max} = 1600 + 20.0 \text{ Hz.} = 1620 \text{ Hz.}$

therefore: $f_s = 2 \cdot f_{\max} = 3240 \text{ Hz.}$

Also, if Δf is the Fourier frequency bin width and N is the number of transform points,

15 then, $f_s = N \cdot \Delta f$
and $N = 3240 / 2.5 = 1296$.

Thus, if the input waveform is operated on directly, then a minimum of 1296 transform points has to be calculated, and computation time of the discrete Fourier transform is proportional to $N^2 \log_2 N$ but the FFT algorithm is proportional to $N \log_2 N$.

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However, if a heterodyne operation is carried out using a local oscillator frequency f_h of 1280, then in the difference frequencies sideband

25 $f_c - f_h = 1600 \text{ Hz.} - 1280 \text{ Hz.} = 320 \text{ Hz.}$

The highest frequency present is now 320 Hz. + 20 Hz. which yields $f_s = 680 \text{ Hz.}$ and $N = 272$. Therefore, the computation time for a transform of the heterodyned waveform with the same frequency resolution is considerably less than for a transform of the unmodified input waveform.

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A digital heterodyning operation is accomplished by multiplying the sampled input waveform with a sampled equivalent of the local oscillator frequency. By specifying a local oscillator signal having a cosine waveform and a frequency exactly four times the digital sampling rate, the sampled input signal can be digitally heterodyned merely by multiplying each sample by the appropriate co-efficient of the cosine waveform. A normalised waveform may be assumed for the simplest multiplication that is, the first sample is multiplied by +1, the second sample is set to zero, the third sample multiplied by -1, the fourth sample is set to zero, and the cycle is repeated again and again in that sequence. The operations involving +1 and -1 are trivial multiplications, that is, for multiplication by +1, the sample is unaltered, and for multiplication by -1, only the sign is changed. The calculated values of those heterodyned samples are then stored in the temporary memory 27 ready for use in the discrete Fourier transform. When completed, these results represent the levels of frequency components found in each of the corresponding frequency bins. By applying a straightforward amplitude discriminator or threshold detector to each bin, in turn, the frequency profile of a received input waveform can be checked for presence of carrier and modulation frequencies at the end of each complete transform cycle.

One of the dangers in safety equipment employing signal transmissions which has to be guarded against is accidental interference from other sources. One type of interfering signal difficult to discriminate

against in this class of system is the Amplitude Shift Keyed, or ASK, signal which may be generated by some types of electric-driven train traction control equipment and, as the running rails can be used as earth return, the additional current is superimposed on the track circuit signal. A problem arises because the spectral response of an ASK signal and confusion can arise when the amplitude of the received input signal is variable so that despite the differences between ASK and FSK signals of the sideband to carrier amplitude ratio it may not always be certain which is received. One way of distinguishing between the two signals is therefore to measure the ratio of the carrier and sideband amplitudes.

However, there is another difference between the signals, which is potentially more reliably detected. In the FSK signal the sideband vectors always produce a resultant orthogonal with respect to the carrier vector, in contrast, in the ASK signal, the sideband vectors produce a resultant in-phase or anti-phase with the carrier vector. The final results yielded by the Fourier analysis contain both phase and amplitude information for all frequency components. Thus, by using trigonometric formulae, the angle of a sideband resultant vector can be calculated.

So, as a final safety check, the magnitude of the resultants are calculated from the final Fourier transform results; if the resultant is too small (so that errors are no longer insignificant), the results may be inverted and the "opposite" vector calculated; the angle information is calculated and a

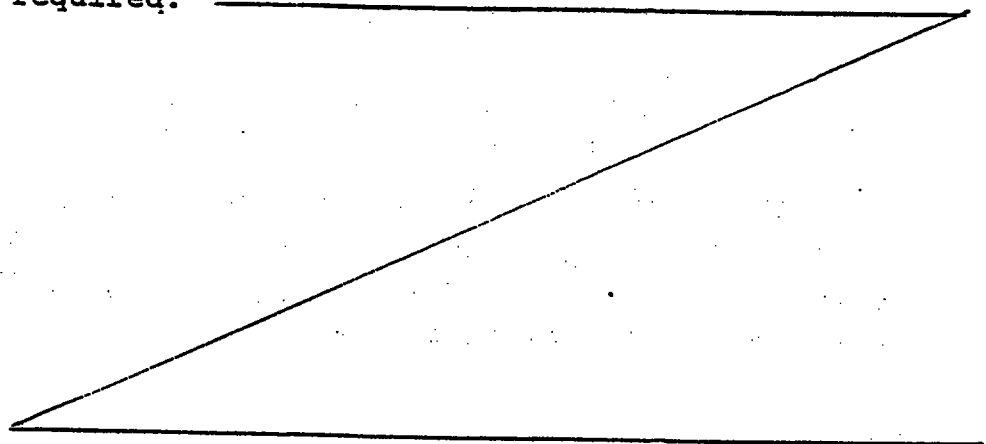
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5 discrimination check applied to positively locate an FSK signal. If this check fails, then it is assumed that the received signal is ASK and the calculated information is rejected, that is, the track circuit receiver reacts as if no track circuit signal was received and the track relay is de-energised.

10 In a second embodiment the invention forms part of an Automatic Train Protection (hereinafter ATP) system which involves the transmission to a moving train of a frequency signal which represents a maximum safe speed limit, the comparison of the actual train speed with that limit and, if it is exceeded, automatic operation of the train's brakes. Speed limit information is
15 transmitted to the train by means of amplitude-modulated carrier signals in which the speed limit signals are used as carrier modulators. Prior art ATP systems have employed analogue filters for decoding the ATP signal but these require one filter
20 for each frequency signal of interest. This embodiment of the invention is effectively an FFT digital filter of non-recursive type, i.e. it has an open loop design which processes only sampled values of an input waveform. Execution of single FFT
25 algorithm performs all the code frequency filtering required.

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In the non-recursive filter the same FFT algorithm is used to process different frequency allocations in different ATP systems with only minor changes to the software. Thus, the digital filter hardware described below is suitable for quantity production. The same basic hardware illustrated in Fig. 2 is used with differences only in the software program contained in the Read only Memory 22.

The ATP digital filter has to perform two functions, as outlined in the flow chart of Fig. 4. Firstly it has to determine that a received carrier signal is within its permitted frequency band and above minimum threshold amplitude and, second that there is a code modulation signal present, it is above minimum threshold amplitude, what is its frequency and, that there is only one modulation signal present. In the arrangement being described the carrier signal has a frequency of 1953 Hz. and there are four alternative modulation codes as follows:

Code 1 = 23.3 Hz representing 15 Kph

Code 2 = 27.6 Hz representing 40 Kph

Code 3 = 32.6 Hz representing 65 Kph

Code 4 = 38.6 Hz representing 80 Kph.

A carrier frequency resolution of approximately 150 Hz is demanded of the system: Shannon's sampling theorem suggests a minimum sampling frequency equal to twice the highest frequency component and, in practice four

or five times is found to be advisable. Thus for a carrier frequency of about 2 KHz a sampling frequency of 9.6 KHz was chosen. To achieve a frequency resolution Δf of 150 Hz with a sampling frequency f_s of 9.6 KHz the number N of time domain sample in the FFT must be therefore, $N = f_s / \Delta f = 64$. As the FFT algorithm is a radix 2 algorithm the number of samples has to be a binary multiple number. In view of the close spacing of the code frequencies a code frequency resolution capability of approximately 2.5 Hz is necessary. The filter being described is intended for use in an existing ATP system, in a completely fresh design the code frequencies could be more conveniently chosen.

Also in order to achieve minimum computation time and maximum efficiency it is preferable to use the same FFT algorithm and, as far as possible, the same sampled data points. By using every 65th sample starting with the first sample all 64 samples for use in the FFT are collected in a total sample acquisition time of 442 ms.

With reference to operation of the digital filter the sequence of events of one operational cycle is illustrated by the flow chart of Fig. 4. In normal train operation a coded ATP signal will be received by the train; at some time in a continuous series of events the digital filter of Fig. 2 will commence an operational cycle. The received signal is sampled at the 9.6 KHz sampling frequency, the first 64 of these time domain samples are digitised by ADC 16 and saved in RAM 21. When sufficient data, i.e. the 64 samples,

has been collected CPU 10 initiates execution of the 64 point FFT program stored in ROM 22. As the iterative process of the program progresses the digitised sample values are retrieved from RAM 21 and used in calculating intermediate results which are temporarily stored in the same memory locations in RAM 11. In the last iteration the final results are again temporarily stored in the same locations in preparation for retrieval by the output interface unit 24.

Identification of both carrier and modulation frequency may be by means of sequential operations in which the first operation searches for the carrier and execution of the second operation to find the modulation frequency is subject to positive detection of the carrier. Alternatively the two transform search operations may be performed simultaneously but the results are examined for the carrier first and only for the modulation frequency if successful.

As the carrier signal has 100% square wave modulation at the selected code signal frequency it is necessary to sample the ATP waveform for a time period equal to the maximum modulation period and perform 64 point transforms on consecutive blocks of 64 time domain samples starting with the first time domain sample. For the modulation frequencies quoted this corresponds to sampling the ATP carrier ($8 \times 64 =$) 512 times at a sampling frequency of 9.6 KHz. Providing at least one of these FFT computations produces a valid carrier spectrum the digital filter program moves on to its modulation code detection phase.

If no carrier signal is found a "carrier out of band" alarm is raised and the carrier search cycle is repeated. On the other hand if the carrier is detected the digital filter program moves into its modulation code detection phase. As the effective sampling rate now needs to be much lower only every 65th digitised sample is saved in RAM 21. When 64 of such samples have been collected the 64 point FFT algorithm program is again executed and the frequency spectrum provided by the final results is examined for a modulation code signal which, if found, sets the maximum speed limit for the ATP system. This interpretation is graphically represented in Fig. 5 in which signal amplitude is the vertical axis and the adjacent frequency bins are laid out along the horizontal axis. For completeness the results for signals containing each of the modulation codes are superimposed on each other in the drawing.

20. The frequency spectrum is also checked to determine if only one modulation code is present in the received signal. If two or more codes are detected a "mixed modulation" alarm is energised and the ATP system reacts in a fail-safe manner by adopting the lowest speed limit indicated by the detected codes or calling for the train to be halted.

In the carrier search phases data sample collection occupies 53.3mS and execution of the FFT program 25mS. Thus, the filter detects and identifies a received carrier in not more than 196mS. Further data collection for code identification occupies 442mS in total, if some of the carrier search data points are

retained, this period would be total elapsed time. However to economise on memory size fresh data is collected as all the earlier data points are discarded in the FFT program. The FFT program again takes 25mS to execute so that a code signal is identified in not more than 800mS. This permits a total operational cycle time of approximately one second during which data is collected, stored internally and analysed by the filter which is able to complete all these tasks as cyclically contiguous operational phases.

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CLAIMS

1. A railway signalling receiver for electrical signals carried by railway lines comprising sensing means for co-operation with the railway lines to sense the signals, sampling means operative in the time domain to continuously sample a sensed signal, data memory means for storing a plurality of sample values, means for performing a discrete Fourier transform on said stored sample values, data memory means for storing the results of the transformation, means responsive to the final results of the transformation in the frequency domain to identify the sensed signal, means for discrimination between a frequency shift keyed or frequency modulated signal comprising means for calculating from information stored in the final transformation results memory the phase angle relative to the carrier signal of the resultant sideband vector and means for discriminating against signals for which said angle is substantially 0° or 180° whereby to distinguish a frequency modulated signal from a confusingly similar amplitude shift keyed signal.
2. A receiver as claimed in claim 1 including means for performing a heterodyning operation on a sensed signal and means for selecting the lower heterodyne sideband frequencies.
3. A receiver as claimed in claim 2 wherein the means for performing the heterodyning operation comprises means to multiply the sampled values of the received signal by a factor equal to the corresponding values of a cosine curve of four times the sampling frequency.
4. A receiver as claimed in claim 3 wherein the multiplication factor is equal to the value of a normalised cosine curve at its quadrature points.



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5. A receiver as claimed in any preceding claim wherein the means responsive to the final result of the transformation is operative to identify the frequency of a carrier signal and a modulation frequency.

6. A receiver as claimed in claim 5 including means for performing a first transformation operation for identifying the carrier signal and a second transformation operation for identifying the modulation frequency conditional upon said identifying a carrier signal in the first operation.

7. A receiver as claimed in any preceding claim adapted for use as a railway track circuit receiver.

8. A receiver as claimed in any one of claims 1 to 6 adapted for use as a train borne receiver in an automatic train protection system.

9. A receiver substantially as hereinbefore described with reference to the accompanying drawings.

