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(54) **MULTIMODE RECEIVER ARCHITECTURE**

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H04B 1/7117 (2011.01)
H04B 1/712 (2011.01)

(52) **U.S. Cl.**

CPC ***H04B 1/7117*** (2013.01); *H04B 1/712* (2013.01)

(58) **Field of Classification Search**

USPC 375/347, 350, 148, 152, 147
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,570,918	B1 *	5/2003	Rademacher	375/232
7,082,174	B1	7/2006	Smee et al.	
7,646,802	B2 *	1/2010	Black et al.	375/147
7,746,917	B2 *	6/2010	Horneman et al.	375/144
2008/0159373	A1 *	7/2008	Taha et al.	375/232

OTHER PUBLICATIONS

Valadon, Cyril, WO 2008/012522 A1, "Reconfiguration Signal Processing Scheme".*

* cited by examiner

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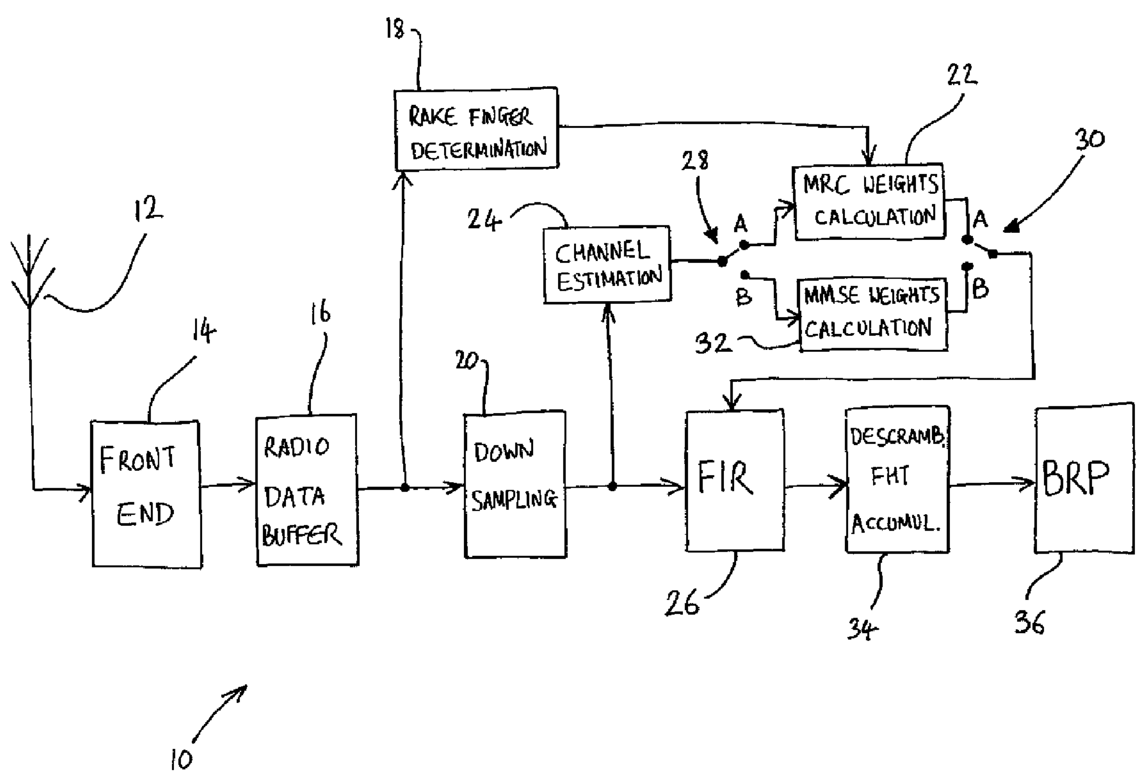
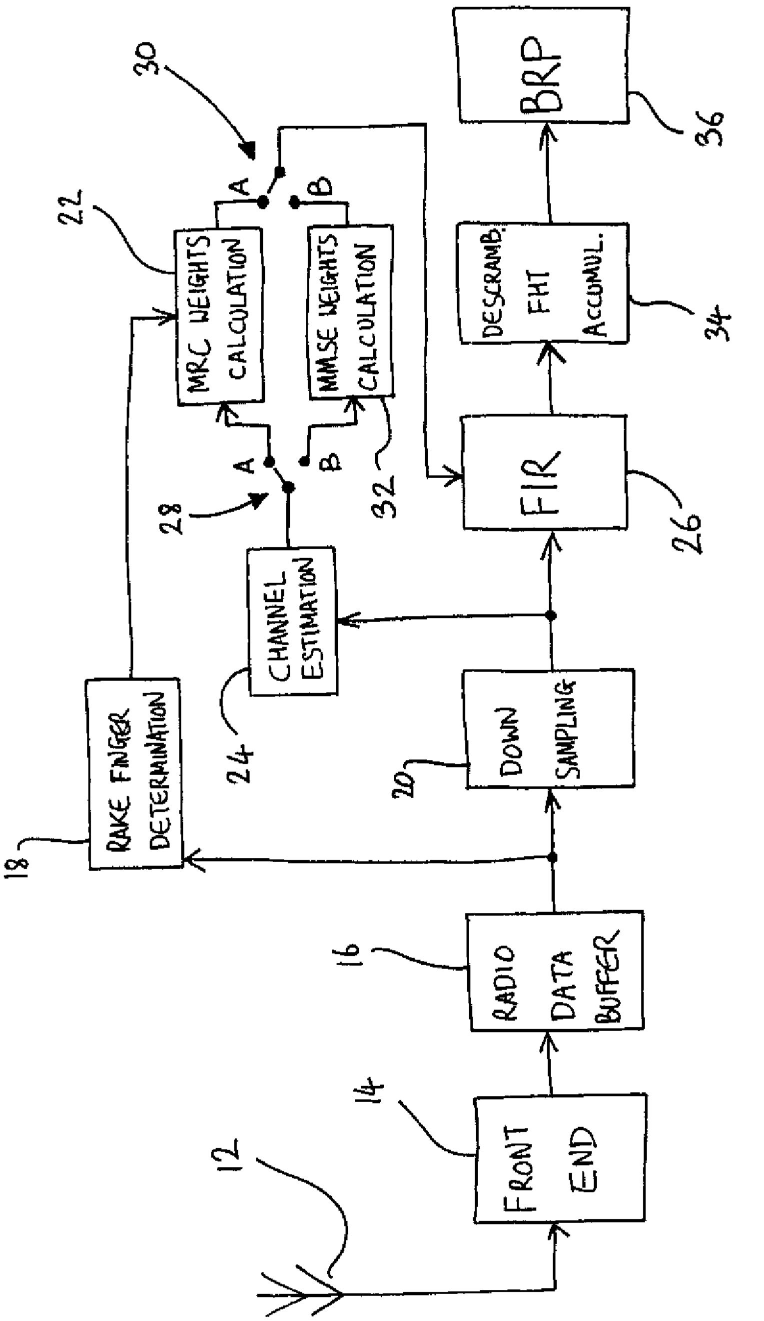
(57) **ABSTRACT**

A radio receiver comprising a compensator arranged to compensate for intersymbol interference in a signal received at the receiver and a configurator arranged to configure the compensator, wherein the compensator comprises a programmable filter and the configurator is capable of configuring the filter in a first mode to operate as an ISI equaliser or in a second mode to implement a RAKE finger set.

18 Claims, 4 Drawing Sheets





FRONT END
RADIO DATA BUFFER
DOWN SAMPLING
RAKE FINGER DETERMINATION
CHANNEL ESTIMATION
MRC WEIGHTS CALCULATION
MMSE WEIGHTS CALCULATION
FIR
DESCRAMB. FHT ACCUMUL.
BRP
A
B
A
B
12
14
16
18
20
22
24
26
28
30
32
34
36

Figure 1

10

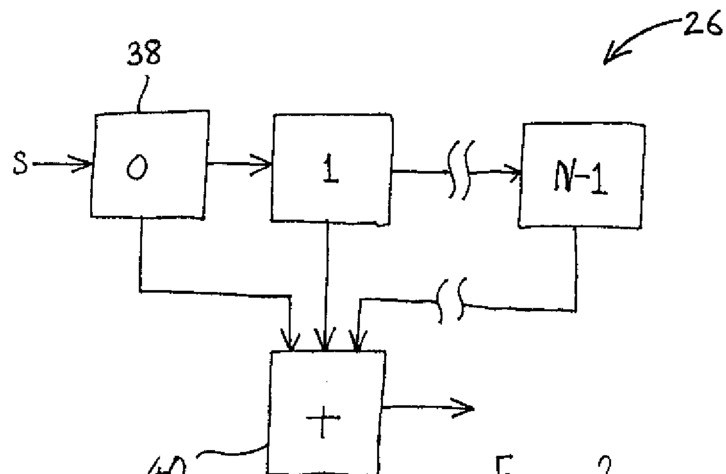


Figure 2

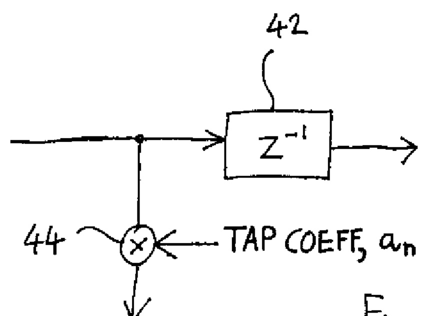


Figure 3

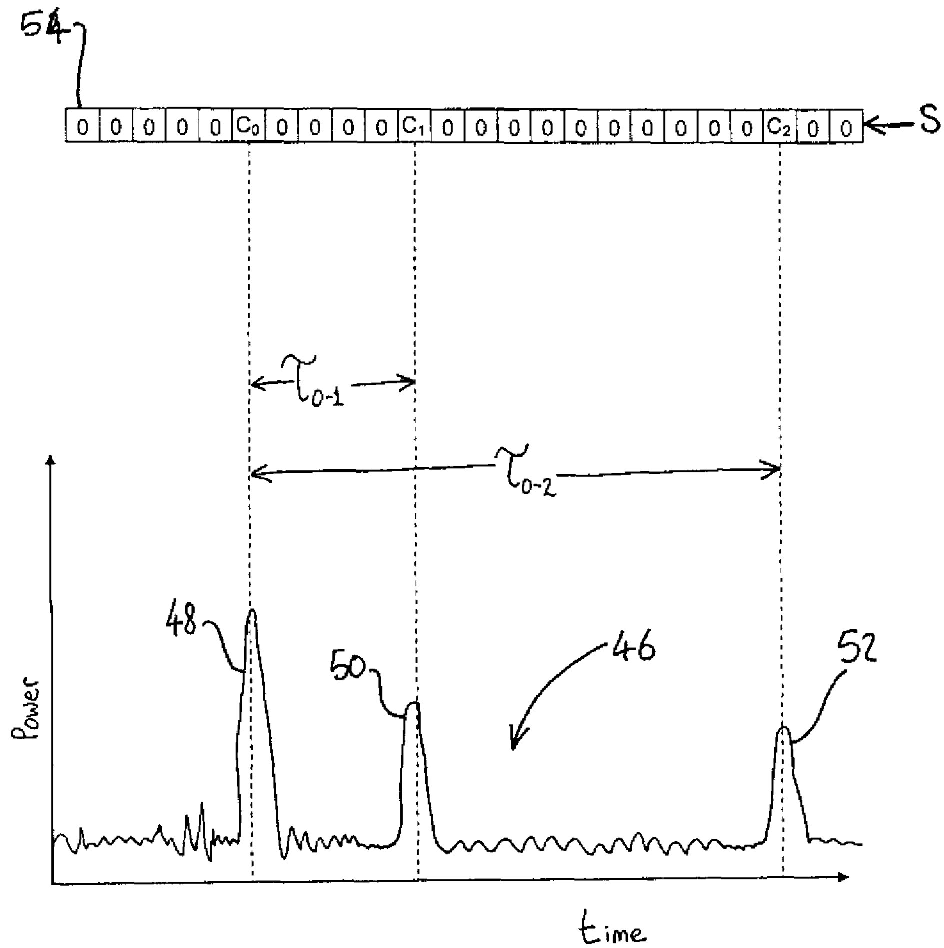

54
0
0
0
0
0
C0
0
0
0
0
C1
0
0
0
0
0
0
0
0
0
0
C2
0
0
S
τ0-1
τ0-2
48
50
46
52
Power
time

Figure 4

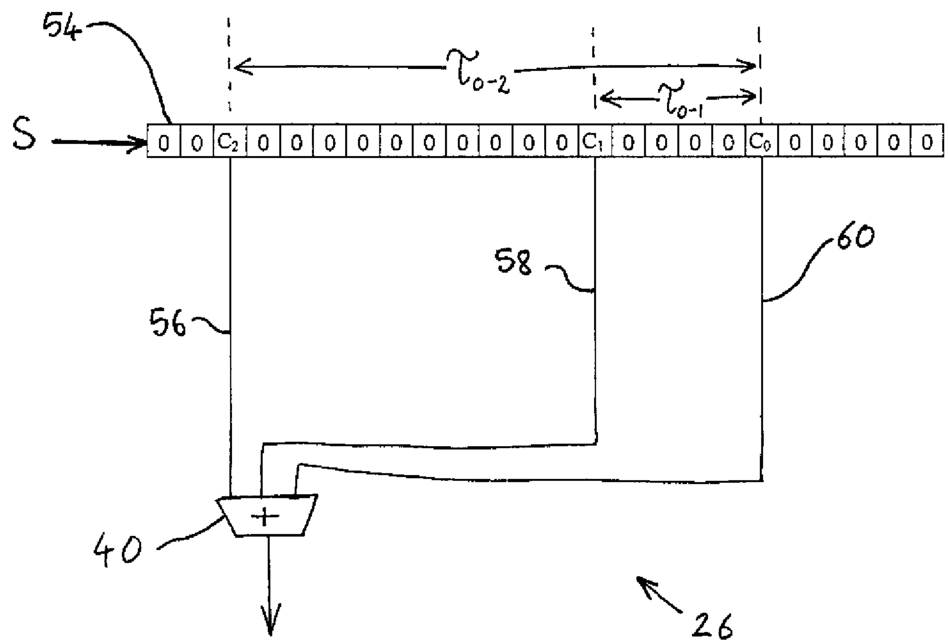

54
τ_{o-2}
τ_{o-1}
S
0 0 C2 0 0 0 0 0 0 0 0 0 0 C1 0 0 0 0 C0 0 0 0 0 0
58
60
56
+
40
26

Figure 5

MULTIMODE RECEIVER ARCHITECTURE

FIELD OF THE INVENTION

The invention relates to the field of digital communications conducted by means of radio frequency (RF) carrier signals.

BACKGROUND OF THE INVENTION

In normal practice, digital signals are converted into streams of modulation symbols, for example using a modulation scheme such as QPSK, and then modulated onto RF carrier signals. Receivers that are configured to handle signals that have been modulated in this way attempt to isolate a wanted received carrier signal and then demodulate the stream of symbols from the RF carrier signal. However, it is likely that the carrier signal will reach the receiver via a number of different paths, with the result that a number of versions of the carrier signal arrive at the receiver, all at different delays. This is the well known phenomenon of multipath propagation, which gives rise to intersymbol interference (ISI) in the demodulated signal. That is to say, the delay between two multipath components can be such that at some given instant, the receiver experiences different symbols from the two paths. It is well known to use an equaliser or a RAKE receiver to compensate or correct for intersymbol interference.

SUMMARY OF THE INVENTION

According to one aspect, the invention provides a radio receiver comprising a compensator arranged to compensate for intersymbol interference in a signal received at the receiver and a configurator arranged to configure the compensator, wherein the compensator comprises a programmable filter and the configurator is capable of configuring the filter in a first mode to operate as an ISI equaliser or in a second mode to implement a RAKE finger set. The invention also consists in a method of compensating for intersymbol interference in a signal received at a receiver, the method comprising configuring a programmable filter and applying the filter to the signal in the compensation of ISI, wherein the configuring step comprises selecting a configuration for the filter from a set including a first filter configuration in which the filter operates as an ISI equaliser and a second filter configuration in which the filter implements a RAKE finger set.

Thus, the invention provides a relatively compact architecture that can change between RAKE and equaliser solutions to the ISI problem as conditions dictate.

The radio receiver may be compliant with the WCDMA standards that are maintained by 3GPP.

The radio receiver may, for example, form part of a handset of a mobile telephone or part of a base station in a cellular telecommunications network.

Although the invention involves a selection between RAKE and equaliser solutions to the ISI problem, it is to be understood that the invention also extends to the case where an ISI solution is selected from a larger group of available solutions, of which the RAKE and equaliser solutions are two.

BRIEF DESCRIPTION OF THE DRAWINGS

By way of example only, certain embodiments of the invention will now be described with reference to the accompanying drawings, in which:

FIG. **1** is a block diagram schematically illustrating a mobile telephone handset from the perspective of its role as a radio receiver;

FIG. **2** is a block diagram schematically illustrating the structure of a finite impulse response filter;

FIG. **3** is a block diagram schematically illustrating the structure of a cell of the FIR filter depicted in FIG. **2**;

FIG. **4** is a diagram showing a channel impulse response and a chain of cells in an FIR filter that is being configured for use as part of a RAKE receiver; and

FIG. **5** shows the chain of FIR filter cells as configured in FIG. **4** feeding into the adder unit of the filter.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Various of the diagrams in this document illustrate circuits and systems and it will be understood by persons skilled in the field of digital communications that the elements appearing in these figures serve to illustrate functions that are performed in the various circuits and systems and do not necessarily correspond to actual components.

In general terms, a data signal, comprising a series of bits, that is to be transmitted over the air interface in a WCDMA network is first subjected to forward error correction (FEC) coding. The resulting signal, again comprising a series of bits, is then encoded as a series of constellation symbols belonging to a modulation scheme (and there may be multiple bits of the FEC-encoded signal represented by each modulation symbol), with the symbols then being divided into shorter duration chips by spreading and scrambling processes. The details of this sequence of processes will be familiar to engineers skilled in the field of digital communications and this sequence of processes must be retraced in a receiver in order to recover the transmitted data signal.

FIG. **1** illustrates schematically a WCDMA handset **10** from the perspective of its role as a wireless signal receiver and shows only those elements necessary for describing the invention. It will be understood by engineers skilled in the field of digital communications that, in practice, the handset **10** will contain other elements besides those shown in FIG. **1**.

The handset **10** has an antenna **12** for receiving wireless communications. The antenna **12** picks up radio signals in the vicinity of the handset **10** and supplies them to an RF front end module **14** for processing. The RF front end module **14** uses filtering to isolate an RF signal in a wanted channel of the WCDMA network to which the handset **10** belongs. The RF front end module **14** is also tasked with amplifying the isolated RF signal and demodulating it, for example by direct downconversion, to produce a baseband signal, representing the chip rate signal that was modulated onto an RF carrier in the transmitter. The RF front end module **14** then digitises this baseband signal with a sampling rate that is eight times higher than the chip rate that resulted when the data signal was scrambled and spread during preparation for its transmission. This ×8 oversampled chip rate signal is then fed into a radio data buffer **16**. The ×8 oversampled baseband signal from the radio data buffer **16** is delivered to a finger determination unit **18** and to a downsampling unit **20**.

The finger determination unit **18** identifies in a known manner a predetermined number of the strongest multipath components within the signal supplied from the radio data buffer **16**. The finger determination unit **18** calculates the RAKE finger positions to a ⅛ chip resolution from the ×8 oversampled baseband signal. The finger determination unit **18** then provides an MRC weights calculation unit **22** with the RAKE finger positions for a purpose that will be described later. In the main signal path, the downsampling unit **20** reduces the degree of oversampling of the signal provided by the radio data buffer **16** from ×8 to ×2. The ×2 oversampled signal provided by the downsampling unit **20** is then supplied to both a channel estimation unit **24** and to a finite impulse response (FIR) filter **26**.

The channel estimation unit **24** calculates a ×2 oversampled channel impulse response from the ×2 oversampled signal provided by the downsampling unit **20**. Schemes for calculating a channel impulse response from the baseband signal will be well known to engineers skilled in the field of digital communications. The channel impulse response estimate is delivered to a switch **28**. The switch **28** introduces two parallel processing paths that converge in a further switch **30**. These parallel paths provide alternative mechanisms for calculating a set of complex-valued filter coefficients to configure the FIR **26**.

Switch **28** has A and B outputs and switch **30** has A and B inputs. The switches **28** and **30** operate as a pair and together can assume one of two states. In one state, the switch **28** connects its input to its A output and switch **30** connects its output to its A input. When the switches **28** and **30** are in this state, the handset **10** shall be said to be in RAKE receiver mode. The other state that can be adopted by the switches **28** and **30** is when switch **28** connects its input to its B output and switch **30** connects its output to its B input. When the switches are in this state, the handset **10** shall be said to be in equaliser mode.

The operation of the handset **10** in equaliser mode shall now be described.

Equaliser Mode

In equaliser mode, the channel impulse response estimate produced by channel estimation unit **24** is supplied via switch **28** to an MMSE weights calculation unit **32**. MMSE weights calculation unit performs the calculations that are necessary to produce the set of filter coefficients that will configure the FIR filter **26** to operate as a minimum mean-square error (MMSE) equaliser. The calculations that are needed to deduce this set of filter coefficients from the channel impulse response estimate provided by channel estimation unit **24**, which include a relatively computationally intensive matrix inversion step, will be known to engineers skilled in the field of digital communications and so will not be described in detail here.

With the FIR **26** thus programmed, the output of the FIR filter is an equalised version of the ×2 oversampled baseband signal. The equalised ×2 oversampled baseband signal produced by the FIR filter **26** is then supplied to symbol rate conversion unit **34** where the signal undergoes various operations such as despreading, descrambling, fast Hadamard transformation (FHT) and symbol-length accumulation to produce a complex-valued digital signal comprising a stream of symbols. The stream of symbols produced by symbol conversion unit **34** is supplied to a bit rate processor (BRP) **36** where any forward error correction (FEC) coding is decoded to recover a data signal which is then put to its intended use, such as conversion to an analogue audio signal that is played through a loud speaker or rendition as a web page that is shown on an LCD display.

RAKE Mode

In RAKE mode, the ×2 oversampled channel impulse response estimate is provided to the MRC weights calculation unit **22**. It will be recalled that the MRC weights calculation unit **22** also receives as an input the set of finger positions deduced by finger determination unit **18**. The MRC weights calculation unit **22** maps the finger positions onto the channel impulse response estimate. The finger positions are specified to a ⅛ chip resolution but the MRC weights calculation unit **22** nevertheless identifies the samples within the ½ chip resolution channel impulse response estimate that best correspond to the finger positions. Thus, for each finger position, the MRC weights calculation unit **22** identifies a corresponding channel impulse response estimate value. Next, the MRC weights calculation unit **22** deduces a RAKE finger coefficient for each finger position by calculating the complex conjugate of the channel impulse response estimate value that has been mapped to the finger. Thus, a RAKE finger coefficient is deduced for each member of the set of RAKE finger positions. The set of RAKE finger positions, each with its corresponding RAKE finger coefficient, is then deployed in the FIR filter **26** to cause the FIR filter to operate in conjunction with symbol rate conversion unit **34** as a RAKE receiver. Before describing this configuration of the FIR filter **26** in more detail, a brief discussion of the structure of the FIR filter will first be provided.

FIG. **2** shows the structure of FIR filter **26**. The ×2 oversampled baseband signal s is supplied to a chain of N cells, e.g. **38**. The samples of signal s shift one place to the right along the chain of cells with every clock cycle. Also, each cell in the chain sends an output to an adder **40**. The sum value produced by adder **40** represents the sample of the digital output signal that the FIR filter **26** presents to unit **34** in the current clock cycle.

FIG. **3** illustrates a typical cell of the chain shown in FIG. **2**. The sample of signal s that is received from the preceding cell in the chain (or which is presented at the filter's input in the case of cell **38**) is supplied both to a one clock cycle delay element **42** and to a multiplier **44**. The output of the delay element provides the input to the next element in the chain. In the multiplier **44**, the input to the cell is multiplied with a so-called "tap coefficient" to produce the output that is passed to the adder **40**. All the cells have this configuration, except the cell numbered N-**1** which does not require the delay element. Each cell in the FIR filter **26** has its own tap coefficient, the tap coefficient of the n^{th} cell being denoted a_n. It is well known that the characteristics of an FIR filter, e.g. its pass band, can be determined by setting these tap coefficients appropriately.

Returning now to the discussion of RAKE mode operation, the MRC weights calculation unit **22** sets the tap coefficients along the chain to zero except at the positions where RAKE fingers are specified in the aforementioned RAKE finger allocation. At each position along the chain where a RAKE finger falls, the cell is given as its tap coefficient the RAKE finger coefficient deduced for the respective finger. This configuration of the tap coefficients will now be explained further with the help of an example involving FIG. **4**.

The bottom part of FIG. **4** shows a channel impulse response **46** plotting power (vertically) versus time (horizontally). The channel impulse response plot contains three prominent peaks **48**, **50** and **42**. The time delay between peaks **48** and **50** is τ_{0-1} and the time delay between peaks **48** and **52** is τ_{0-2}. Consider now the case where the handset **10** is operating in RAKE mode and the MRC weights calculation unit **22** is required to configure the tap coefficients of the FIR filter **26** for RAKE mode operation given the channel impulse response **46** and that RAKE fingers have been allocated to peaks **48**, **50** and **52** only (fingers **0** to **2**, respectively).

The strip **54** at the top of FIG. **4** represents a part of the chain of cells in the FIR filter **26**. It is to be carefully noted, however, that in this figure the chain of cells is shown with signal s flowing through the chain from right to left and not left to right as in FIGS. **3** and **5**. Each rectangle in the strip **54** represents a cell in the chain. The value shown in each cell represents the tap coefficient of that cell. The MRC weights calculation unit **22** deduces finger coefficients C_0, C_1 and C_2 for fingers **0**, **1** and **2** respectively. These finger coefficients are loaded into the chain of cells such that the time offset between the cells containing C_0 and C_1 is τ_{0-1} and such that the time offset between the cells containing C_0 and C_2 is τ_{0-2}. Besides these cells, all of the FIR filter's tap coefficients are set to zero. In this way, the FIR filter **26** functions like three RAKE fingers. That this configuration of the FIR filter **26** results in RAKE mode operation will be clearer when FIG. **5** is considered.

In FIG. **5** the chain of cells **54** is shown together with the adder **40** that makes up the FIR filter **26**. In FIG. **5**, the signal s flows from left to right through the chain **54** of filter cells. As in FIG. **4**, the values shown in these cells denote the tap coefficients of the cells. Only the paths from the cells containing coefficients C_2, C_1 and C_0 are shown as feeding into the adder **40** since the paths from the other cells are effectively switched off by their zero-valued tap coefficients. The paths **56**, **58** and **60** are, in effect, RAKE fingers: each of these paths conveys the ×2 oversampled baseband signal at a time offset relative to the other two paths and each path contains a multiplier, in its respective cell of chain **54**, that applies a respective RAKE finger coefficient to derotate the version of the ×2 oversampled baseband signal s that is travelling along the respective path. The only difference between the representation shown in FIG. **5** and a traditional RAKE receiver layout is that the symbol rate conversion process is not replicated in each of the paths **56**, **58** and **60** but is instead performed singly, at a point downstream from the adder **40**, in the symbol rate conversion unit **34**.

The path **60** represents the earliest RAKE finger, which corresponds to peak **48** in FIG. **4** and for which RAKE finger coefficient C_0 has been deduced by the MRC weights calculation unit **22**. Path **58** represents a RAKE finger allocated to the next significant multipath component to arrive at the antenna **12**, which is indicated by peak **50** in FIG. **4**. The RAKE finger of path **58** is delayed by an interval τ_{0-1} relative to path **60**. Path **56** represents a RAKE finger allocated to the third, and latest arriving, significant multipath component, which is represented by peak **52** in FIG. **4** and for which RAKE finger coefficient C_2 was calculated. The version of signal S that travels along the RAKE finger represented by path **56** is delayed by an interval τ_{0-2} relative to the leading RAKE finger represented by path **60**.

The output of the adder **40** of the FIR filter **26** is supplied to the symbol rate conversion unit **34** where the descrambling despreading and accumulation processes that are required to complete the RAKE processing are performed. The stream of symbols produced by symbol conversion unit **34** is supplied to a bit rate processor (BRP) **36** where any forward error correction (FEC) coding is decoded to recover a data signal which is then put to its intended use, such as conversion to an analogue audio signal that is played through a loud speaker or rendition as a web page that is shown on an LCD display.

In the embodiment described above, the finger determination unit **18** calculates the finger positions for use by the MRC weights calculation unit **22** from the ×8 oversampled baseband signal from the radio data buffer **16**. In one alternative embodiment, the finger determination unit **18** calculates the finger positions by applying a peak detection algorithm to the ×2 oversampled channel impulse response estimate provided by the channel estimation unit **24**.

The invention claimed is:

1. A radio receiver, comprising:

a radio frequency (RF) front end configured to convert a radio signal received at the radio receiver to a baseband signal at a first oversampling rate;

a downsampling unit configured to downsample the baseband signal from the first oversampling rate to a second oversampling rate;

a filter configured to produce a filtered signal by filtering the baseband signal at the second oversampling rate using configurable filter coefficients;

a symbol rate conversion unit configured to convert the filtered signal to a symbol-rate signal;

a channel estimation unit configured to calculate a channel impulse response estimate based on the baseband signal at the second oversampling rate;

a minimum mean-square error (MMSE) weights calculation unit configured to calculate a first set of filter coefficients for minimum mean-square error (MMSE) equalization, the first set of filter coefficients being based on the channel impulse response estimate;

a finger determination unit configured to identify a set of RAKE finger positions based on the baseband signal at the first oversampling rate; and

a maximum ratio combining (MRC) weights calculation unit configured to calculate a second set of filter coefficients based on the channel impulse response estimate and the set of RAKE finger positions, the second set of filter coefficients causing the filter in conjunction with symbol rate conversion unit to operate as a RAKE receiver,

wherein the filter uses the first set of filter coefficients as the configurable filter coefficients during a first mode and uses the second set of filter coefficients as the configurable filter coefficients during a second mode.

2. A radio receiver according to claim **1**, wherein, in the second mode, the radio receiver is operable to time align and combine several multipath components of the radio signal for collective conversion from chip rate to symbol rate.

3. A radio receiver according to claim **1**, wherein calculation of the second set of filter coefficients in the MRC weights calculation unit includes mapping each finger position in the set of RAKE finger positions onto the channel impulse response estimate.

4. A radio receiver according to claim **3**, wherein calculation of the second set of filter coefficients in the MRC weights calculation unit further includes, for each finger position in the set of RAKE finger positions, calculating the complex conjugate of the channel impulse response estimate value that has been mapped to that finger position.

5. A radio receiver according to claim **1**, that is compatible with Wideband Code Division Multiple Access (WCDMA).

6. A radio receiver according to claim **1**, wherein conversion of the filtered signal to the symbol-rate signal in the symbol rate conversion unit includes despreading the filtered signal.

7. A radio receiver according to claim **6**, wherein conversion of the filtered signal to the symbol-rate signal in the symbol rate conversion unit further includes descrambling the filtered signal.

8. A radio receiver according to claim **1**, wherein calculating the first set of filter coefficients in the MMSE weights calculation unit includes matrix inversion.

9. A radio receiver according to claim **1**, wherein the filter is a finite impulse response (FIR) filter and the configurable filter coefficients are tap weights.

10. A method for use in a radio receiver, the method comprising

converting a received radio signal to a baseband signal at a first oversampling rate;

downsampling the baseband signal from the first oversampling rate to a second oversampling rate;

filtering the baseband signal at the second oversampling rate using configurable filter coefficients to produce a filtered signal, the filtering using a first set of filter coefficients as the configurable filter coefficients during a first mode and using a second set of filter coefficients as the configurable filter coefficients during a second mode;

converting the filtered signal to a symbol-rate signal;

calculating a channel impulse response estimate based on the baseband signal at the second oversampling rate;

calculating the first set of filter coefficients for minimum mean-square error (MMSE) equalization, the first set of filter coefficients being based on the channel impulse response estimate;

identifying a set of RAKE finger positions based on the baseband signal at the first oversampling rate; and

the second set of filter coefficients based on the channel impulse response estimate and the set of RAKE finger positions, the second set of filter coefficients causing the filtering in conjunction with the converting to provide RAKE receiver processing.

11. A method according to claim **10**, wherein, in the second mode, the method is operable to time align and combine several multipath components of the radio signal for collective conversion from chip rate to symbol rate.

12. A method according to claim **10**, wherein calculating the second set of filter coefficients includes mapping the each finger position in the set of RAKE finger positions onto the channel impulse response estimate.

13. A method according to claim **12**, wherein calculating the second set of filter coefficients further includes, for each finger position in the set of RAKE finger positions, calculating the complex conjugate of the channel impulse response estimate value that has been mapped to that finger position.

14. A method according to claim **10**, wherein the method is compatible with Wideband Code Division Multiple Access (WCDMA).

15. A method according to claim **10**, wherein converting the filtered signal to the symbol-rate signal includes despreading the filtered signal.

16. A method according to claim **15**, wherein converting the filtered signal to the symbol-rate signal further includes descrambling the filtered signal.

17. A method according to claim **10**, wherein calculating the first set of filter coefficients includes matrix inversion.

18. A method according to claim **10**, wherein the filtering is finite impulse response (FIR) filtering and the configurable filter coefficients are tap weights.

* * * * *