(54) Title: RADIO FREQUENCY RANGING APPARATUS

(57) Abstract

Radio frequency ranging apparatus comprises a transmitter having a pseudorandom noise (PN) code generator (10) and a modulator (20) to modulate a carrier frequency with the re-generated PN code for transmission. A receiver comprises a processing means incorporating a correlator to correlate a PN code recovered from a radio signal received from the transmitter, with a similar reference PN code. The receiver provides a time signal dependent on a propagation time for the radio signal between the transmitter and the receiver. The PN code generator is arranged to generate a plurality of PN codes having the same number of chips and a common chip rate. The PN codes are equally time shifted one from the next within the period of a single chip of the PN codes. The modulator is arranged to modulate a corresponding plurality of carrier signals with respective codes for transmission as respective radio signals. The receiver is arranged to receive the respective radio signals. The processing means includes combining means to combine the received PN codes to recover a high rate PN code having a chip rate which is the product of the common chip rate and the number of the received PN codes. The correlator is arranged to correlate the recovered higher rate PN code with a similar reference PN code.

RADIO FREQUENCY RANGING APPARATUS

The present invention concerns radio frequency
ranging apparatus. The invention is particularly
applicable to radio frequency ranging apparatus used as
radio positioning apparatus, e.g. as a navigational aid.
However, the invention also has application in other forms
of ranging apparatus, such as radar, in which the
propagation time of radio signals is used to obtain a
range and/or a position. In radio positioning systems,
the position of a receiver relative to a number of
transmitters is determined. In radar systems, the
positions of the transmitter and receiver are generally
known (usually the same) and the radio signal propagation
time is employed to determine the range of a reflecting
target.

In radio positioning systems, spread-spectrum (SS)
are known and used particularly to reduce interference
between the transmitters of the radio positioning system
and other users of the radio frequency spectrum.
Spread-spectrum techniques permit the power spectral
density (psd) to be kept low whilst maintaining sufficient
total power in the transmitted signal for adequate
reception.

In some systems, such as radar, the radio signals
can be transmitted as short pulses of radio frequency
energy, but this is an inefficient method of ensuring
adequate mean power, and also generates high levels of
interference. For radio positioning systems, a commonly
employed technique is to measure the phase on reception of
unmodulated continuous wave (CW) narrow band carrier.
Systems employing this technique include the navigation
systems called Omega and Hyper-Fix. A problem with CW
systems is that a receiver cannot distinguish between

multiples of 2π in phase. In addition, the use of CW
does not permit discrimination between the wanted signal
propagated via the direct path between transmitter and
receiver, and interference propagated by other paths, such
as the so called "sky wave" signal reflected by the
ionosphere.

More recently, spread-spectrum techniques have
been introduced for radio positioning and current examples
include Geoloc, Syledis and Spot. In spread-spectrum
techniques for radio positioning employed hitherto, a
carrier wave is phase angle modulated by a digital code
sequence. The digital code sequence is typically a
pseudorandom noise (PN) code. In a PN code, the
individual elements of the binary code sequence are known
as chips, and the frequency of these code elements is
known as the chip rate. A particular PN code has a
predetermined number of chips before the code sequence
repeats and this represents the length of the code.

The presence of a defined time structure in the
transmitted signal, as determined by the chip rate,
permits acute time resolution of signals at a receiver.
On the other hand, the PN code can have a substantial
length before repeating, determined by the number of chips
in the code sequence, so that range ambiguities can be
avoided.

Importantly also, modulation of a carrier
frequency with a PN code distributes the transmitted power
over a band effectively corresponding to approximately
twice the chip rate, so that power spectral density within
the band can be reduced.

Nevertheless, with radio positioning systems
uitilising SS techniques, problems still remain of
interference with other users of the available spectrum.
Various techniques have been proposed of shaping the
transmitted spectrum of the SS signal but none have proved

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particularly effective or else involve substantial loss of performance.

According to the present invention, radio frequency ranging apparatus comprises a transmitter having a pseudorandom noise (PN) code generator and a modulator to modulate a carrier frequency with the generated PN code for transmission; and a receiver comprising processing means incorporating a correlator to correlate a PN code, recovered from a radio signal received from the transmitter, with a similar reference PN code and providing a time signal dependent on propagation time for said radio signal between the transmitter and the receiver, wherein said PN code generator is arranged to generate a plurality of PN codes having the same number of chips and a common chip rate, said PN codes being equally time shifted one from the next within the period of a single chip of said PN codes, and said modulator is arranged to modulate a corresponding plurality of carrier signals with respective said codes for transmission as respective radio signals, and wherein the receiver is arranged to receive said respective radio signals and said processing means includes combining means to combine the received PN codes to recover a higher rate PN code having a chip rate which is the product of said common chip rate and the number of said received PN codes, said correlator being arranged to correlate said recovered higher rate PN code with a similar reference PN code.

With the apparatus of the present invention, instead of transmitting a single carrier with a relatively high chip rate PN code, the transmitter is arranged to transmit several different carriers each modulated with a respective lower rate PN code. The different lower rate codes are all time shifted relative to one another by an equal fraction of one lower rate code period corresponding to the number of codes and carriers. On reception, a

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higher rate PN code is recreated by combining the received
lower rate codes. It has been shown that the recombined
higher rate code provides substantially as good time
correlation performance for signal to noise ratio in the
received signals, as would be provided by a single carrier
modulated with the higher rate PN code.

One advantage of the apparatus proposed above is
that each of the individual carrier signals can have a
different frequency and can be located as desired in the
available frequency spectrum, so as to produce minimum
interference with other users. Thus, for example, instead
of transmitting a single carrier with a band width of say
eight units, with the above described apparatus eight
carriers may be transmitted each with a band width of a
single unit and these eight carriers may be located in the
spectrum as desired. It can be shown that the performance
of the resulting apparatus is scarcely impaired.

In particular, the individual carriers may be
located in available gaps of the spectrum. The apparatus
is suitable for use in a frequency band in which multiple
spectral gaps are normally available but where there is no
continuously available gap adequate for the wide band SS
signal. Further, the apparatus may be modified to take
advantage of relatively narrow gaps available in the
spectrum for short periods of time. To this end, the
apparatus may include monitoring apparatus for monitoring
when gaps in a predetermined spectral region become
available and a control apparatus for controlling the
transmitter to generate carrier frequencies for
transmission in these gaps. The receivers may then
include seeker means for seeking the transmitted carrier
frequencies for reception.

In an alternative arrangement, each carrier signal
modulated by a lower rate PN code can have the same
frequency or different frequencies where the band widths

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of each carrier frequency overlaps. This is possible
since where four lower rate PN codes are used, only one
quarter of the available bandwidth is used. Each of the
PN codes are orthogonal and uncorrelated in time. Two
lower rate PN codes are identical except for a time shift
of one quarter of the lower rate chip period. 'In this
arrangement the receiver exploits the orthogonality
property to identify uniquely each lower rate PN code
modulated carrier signal. When one lower rate PN code
modulated carrier signal is being received the receiver is
locked onto and tracking the desired signal. The other
signals are all orthogonal to the desired signal and the
interference power contributed to these other signals is
sufficiently small that it can be neglected. It is of the
order of 1/L for each unwanted carrier signal and under
normal operating conditions will be significantly less
than the receivers thermal noise component and can thus be
neglected. This property is exploited by communication
systems and is commonly called
code-division-multiple-access (CDMA). This property has
also been exploited in navigation systems such as the
American military satellite navigation system GPS.

     One drawback with using the orthogonality of the
lower rate PN codes and using a single carrier frequency
or overlapping carrier frequency bands is that the power
spectral density presented to other uses of the same radio
band is increased. There is however a reduction in the
required bandwidth for the radio frequency ranging
apparatus compared to the use of separate carrier
frequencies.

     An additional advantage in using a single carrier
frequency is that there is no difference in propagation
delay for the carrier signals as can occur when the lower
rate PN codes modulate different frequencies.

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Conveniently, said PN code generator in the transmitter comprises means to generate a PN code having a higher chip rate and sampling means to sample the chips of said higher rate PN code sequentially to form said plurality of PN codes at a common lower chip rate which is equal to said higher rate divided by the number of said plurality of PN codes. The higher rate code may then correspond to the recovered higher rate code at the receiver. Alternatively, however, multiple lower rate PN codes may be generated independently with the required time spacing. Where the lower rate codes are generated by sampling a single higher rate code, the lower rate codes will normally have the same length (at the lower rate) as the original higher rate code, and will all in fact comprise the same code sequence but at different times in the sequence, provided that the number of lower rate codes is an integer power of two and relatively prime in number to the number of shift register stages (or code length) of the higher chip rate code. Where the lower rate codes are generated independently, the lower rate codes will be related to each other by time shifts and will also comprise the same code sequence but at different times in the sequence provided that the number of lower rate codes is an integer power of two and relatively prime in number to the code length of the higher chip rate sequence. This may be especially useful in radio positioning systems where the different carrier signals from a single transmitter of the system will be modulated with the same PN code for identification purposes.

In the receiver, said combining means may comprise adding means for performing modulo two addition of the received PN codes if they are (0,1). Alternatively, if the chips of the PN codes are represented as +1 and -1 in accordance with their binary state, the combining means may comprise multiplying means to multiply together the

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chips of the received PN codes. These two alternatives
represent coherent receivers where the receiver reference
signals have exactly the same frequency and phase as the
incoming signals and signal processing may be done
directly on the PN codes at baseband. This is the ideal
situation but in practice because of problems such as
propagation path effects, receiver oscillator
instabilities etc., the reference signals are not of
exactly the same frequency and phase. Thus a non coherent
receiver must be employed as standardly used in SS
sytems. In one such system the high rate clock correction
is recovered by adding error voltages of low rate delay
lock loops.

As contemplated above, the radio frequency ranging
apparatus may be configured as radio positioning
apparatus, wherein the apparatus includes at least three
said transmitters, and at least one said receiver, said
processing means thereof providing said time signals for
each of the transmitters from which radio signals are
received at the receiver and identifying a position for
the receiver relative to the transmitters from said time
signals. The transmitters may have respective different
carrier frequencies or sets of carrier frequencies.
Alteratively, in a time domain multiple access system
(TDMA) the transmitters use the same carrier frequencies
or sets of carrier frequencies and are assigned time slots
for transmission.

Where the carrier frequencies used by the or each
transmitter can vary, making use of gaps available in the
spectrum for limited periods of time, provision may be
made for encoding the transmitted carriers with frequency
information identifying the transmitted carrier
frequencies. Then such information can be decoded at a
receiver to assist in locating all the carrier frequencies
of a set for a particular transmitter.

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It will be appreciated that the present invention also provides a transmitter for use in radio frequency ranging apparatus as described above and comprises a pseudorandom noise (PN) code generator and a modulator to modulate a carrier frequency with the generated PN code for transmission, wherein said PN code generator is arranged to generate a plurality of PN codes having the same number of chips and a common chip rate, said PN codes being equally time shifted one from the next within the period of a single chip of said PN codes, and said modulator is arranged to modulate a corresponding plurality of carrier signals with respective said codes for transmission as respective radio signals.

The invention further provides a receiver for use in radio frequency ranging apparatus as described above which comprises processing means incorporating a correlator to correlate a received radio signal modulated with a PN code with a similar reference PN code and providing a time signal dependent on a propagation time for said radio signal between a transmitter and the receiver, wherein the receiver is arranged to receive a plurality of radio signals from a transmitter comprising respective carrier signals modulated by respective PN codes each having the same number of chips at a common chip rate, said PN codes being equally time shifted one from the next within the period of a single chip of said PN code, and the processing means includes combining means to combine the received PN codes to recover a higher rate PN code having a chip rate which is the product of said common chip rate and the number of said received PN codes, said correlator being arranged to correlate said recovered higher rate PN code with a similar reference PN code.

The present invention may also be regarded as a method of radio frequency ranging comprising the steps of generating a pseudorandom noise (PN) code, modulating a

carrier frequency with the generated code, transmitting
the modulated carrier frequency, receiving the modulated
carrier frequency signal at a receiver and processing the
received signal by correlating a PN code recovered from
the signal with a similar reference PN code and providing
a time signal dependent on a propagation time for the
radio signal between the transmitter and the receiver,
wherein a plurality of PN codes are generated at the
transmitter, the codes having the same number of chips and
a common chip rate, and being equally offset in time one
from the next within the period of a single chip of said
PN code, and respective said codes are modulated on
corresponding plurality of carrier signals which are then
transmitted, and wherein the respective transmitted radio
signals are received at a receiver and the received PN
codes thereof are combined to recover a higher rate PN
code having a chip rate which is the product of said
common chip rate and the number of said received PN codes,
said recovered higher PN code being then correlated with a
similar reference PN code.

Examples of the present invention will now be
described with reference to the accompanying drawings in
which:

Figure 1 is a block schematic diagram illustrating
a transmitter embodying features of the present invention;

Figure 2 is a timing diagram illustrating
splitting a higher rate PN code sequence into four lower
rate sequences;

Figure 3 is a block schematic diagram of a
receiver embodying features of the present invention;

Figure 4 is a graphical representation of the
distribution of power density with frequency of a higher
rate PN coded radio signal, for comparison with four lower
rate encoded radio signals at different carrier
frequencies;

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Figure 5 is a block diagram illustrating a signal
acquisition system for a direct sequence spread-spectrum
receiver;

Figure 6 is a block diagram illustrating a signal
tracking loop for a coherent direct sequence
spread-spectrum receiver;

Figure 7 is a graphical representation of the
correlation coefficients of a DS-SS receiver illustrating
the delayed reception of a sky wave signal;

Figure 8 is a block diagram illustrating a
computer model used to simulate operation of the present
invention;

Figure 9 is a graphical representation of range
uncertainty versus signal-to-noise power density for
different spread-spectrum systems and illustrating the
performance of an example of the present invention; and

Figure 10 is a further graphical representation of
range uncertainty versus signal-to-noise power density
illustrating the performance of another example of the
present invention.

Referring to Figure 1, a transmitter is
illustrated which embodies features of the present
invention and would be used in a radio positioning
system. In a radio positioning system, a number of such
transmitters will be provided to cover a geographical area
in which radio positioning using the system is required.
Generally, in radio positioning systems of this kind, a
vehicle requiring to identify its position carries a
suitable radio receiver for receiving signals transmitted
by the system transmitters. Although the system is not
normally capable of determining the propagation time
itself from any one transmitter to the vehicle, having no
reference time from which to work, the receiver can obtain
values for the difference in propagation time of the
signals from a pair of transmitters, using the signal

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received from one transmitter as a timing reference for
the other. A delay difference from the signals of a
single pair of transmitters establishes a line-of-position
(LOP), which is an hyperbolic curve on a map indicating
the locus of possible positions for the receiver
corresponding to the particular delay difference. By
obtaining a second LOP from a further pair of transmitters
(one of which may be a transmitter from the first pair),
the position of the receiver is then represented by the
intersection point of the two LOPS.

The transmitter illustrated in Figure 1, has a
generator 10 for generating a first PN code at a
relatively high rate, say 300 kHz. This high rate PN code
sequence is fed to a sampling block 11 in which successive
chips of the higher rate code are sampled onto four output
lines 12, 13, 14 and 15, to produce four lower rate PN
codes on these lines each having a chip rate which is a
quarter of the rate of the high rate code from generator
10. This sampling procedure is best understood by
referring to Figure 2 in which a simple fifteen chip PN
sequence is used for purposes of illustration. The higher
rate sequence is illustrated at 16 and as can be seen the
sequence repeats every fifteen chips.

A first low rate sequence, 17 is produced by
sampling every fourth chip of the higher rate sequence
starting with chip 0 and continuing with chips 4, 8 etc.
as shown by the arrows 18. The sampled level from the
higher rate sequence is maintained in the low rate
sequence until the next sample is taken to produce the
lower rate chip sequence as illustrated at 17.

Second, third and fourth lower rate sequences are
similarly obtained by sampling at the first, fifth, ninth
etc. chips, the second, sixth, tenth etc. chips, and the
third, seventh, eleventh etc. chips of the higher rate
sequence.

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Observing the form of the four low rate sequences
produced as illustrated in Figure 2, it can be seen that
these are in fact all fifteen chip sequences which
correspond to the chips of the higher rate sequence but at
one quarter of the rate. The four sequences are
sequentially spaced in time one from the next by one
quarter of a lower rate sequence period.

From the example mentioned above where the higher
rate sequence is 300 kHz, each of the lower rate sequences
has a chip rate of 75 kHz.

These four lower rate sequences are fed on lines
12, 13, 14 and 15 from the sampling block to respective
transmitter channels 20, 21, 22 and 23 as illustrated in
Figure 1. In each transmitter channel, the respective
lower rate PN code is phase modulated by means of a
balanced modulator 24 on a carrier signal from a carrier
oscillator 25. The resulting modulated carrier radio
frequency signal is then amplified in a power amplifier 26
for transmission from a common antenna 27.

The carrier oscillators 25 of the four transmitter
channels 20, 21, 22 and 23 can be arranged to provide
carrier frequencies which are sufficiently spaced in the
radio spectrum so that the spectra of the modulated radio
signals do not overlap. Alternatively, carrier
frequencies which overlap, or a single carrier frequency
can be used since the PN codes are orthogonal.

Referring now to Figure 3, for simplicity a
coherent receiver is shown for receiving signals
transmitted by a transmitter as shown in Figure 1. The
receiver has a corresponding number of receiver channels,
30, 31, 32 and 33 receiving radio frequency signals from a
common antenna 34. Each receiver channel includes an rf
amplifier 35 feeding a band pass filter 36 which is tuned
to pass a frequency band encompassing a selected one of
the modulated carrier frequencies from the particular

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transmitter to which the receiver is currently tuned.

The band pass filtered signal is then supplied to
an acquisition circuit 37 which acquires an initial lock
on the PN phase coded signal for use in controlling a
subsequent tracking loop 38 which controls a locally
generated lower rate PN code so as accurately ·to track the
PN code modulated in the received signal. The output from
the tracking loop 38 is a lower rate PN code having an
unknown delay relative to the same code as transmitted
from the antenna 27 of the transmitter. This delay is
accurately dependent on the propagation time from the
transmitter.

At the same time, receiver channels 31, 32 and 33
operate on the modulated carrier frequencies from
transmitter channels 21, 22 and 23 of the transmitter and
produce corresponding PN code sequences having
approximately the same delay representing the propagation
time from the transmitter. Ideally the delays for each
carrier frequency (if different frequencies are used) are
not the same and differential propagation effects will
lead to discrepancies which can be compensated.

The four PN code sequences on lines 40, 41, 42 and
43 are supplied to a multiplication circuit 44 in which
they are combined.

The multiplication circuit 44 combines the four
lower rate PN code sequences derived from the four
received rf signals to recover a higher rate sequence. In
the present example, the recovered higher rate sequence
corresponds to the original higher rate sequence from the
generator 10 in the receiver.

If the binary states of the four lower rate code
sequences are represented by +1 and -1, it can be seen
that multiplication together of the states pertaining from
time to time for the four lower rate sequences reproduces
the higher rate sequence. Considering again Figure 2, the

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recovered higher rate sequence is shown at 45 and it will
be observed that this is a PN code sequence corresponding
to the original higher rate sequence at 16 in the Figure.
As can be seen from Figure 2, the recovered sequence has
an inherent delay relative to the original higher rate
sequence of three chips of the original higher rate
sequence. This inherent delay will be in addition to the
delay corresponding to the propagation time from
transmitter to receiver, and it can be calculated for any
high rate sequence from which the low rate sequencies are
derived.

Reverting to Figure 3, the recovered high rate
sequence is supplied from the multiplication circuit 44 to
a range meter 46 in which it is correlated with a locally
generated corresponding high rate sequence so as to
generate a time signal which is accurately dependent on
the propagation time of the radio signals from the
transmitter to the receiver.

In an operative radio positioning system, there
will, as mentioned above, be at least three transmitters
such as shown in Figure 1 at different geographical
locations and the receiver of Figure 3 will be required to
receive the sets of radio signals from each of the three
transmitters, as well as any further transmitters within
range. Thus, the receiver of Figure 3 will be adapted to
tune successively to the predetermined carrier frequencies
from each of the transmitters providing radio positioning
coverage, and to generate therefrom appropriate time
signals. In order to determine the position of the
receiver, these time delay signals are compared relative
to each other to identify LOPs, and the receivers position.

In such a system each transmitter may use a
different set of carrier frequencies or all the
transmitters may use the same set of carrier frequencies
with allocated time slots (time doman multiple access

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TDMA).

Referring now to Figure 4, one advantage of the
above described radio positioning system embodying the
present invention is illustrated where different carrier
frequencies are used. In Figure 4, the upper graph
illustrates the frequency spectrum of a high rate PN code
phase modulated on a carrier frequency F. The band width
of the modulated carrier to the first null points on
either side of the central carrier frequency is $2f_c$,
where f_c is the chip rate of the PN code sequence. In
practice, for a PN code modulated carrier, the spectrum is
not continuous but comprises a set of lines as shown in
the drawing spaced by the rate of repetition of the PN
code sequence as a whole, i.e. f_c/L where L is the
number of chips in a code sequence before repeating. The
example in Figure 4 illustrates a fifteen chip sequence.

For radio positioning systems using PN code
spread-spectrum techniques, the chip rate of a single PN
coded transmission should be sufficient to permit the
required range resolution at the receiver. Obtaining a
range resolution of plus or minus 10 metres, with a timing
resolution within the duration of a single chip of 0.01,
implies a chip rate of say 300 kHz. In order to give an
unambiguous range for the radio positioning system of say
1,000 kilometre, the minimum sequence length for the PN
coded single signal should be 2,047. This figure assumes
that a maximal length PN code is employed generated by
feedback connected shift registers in the usual way.

Thus, reverting to the upper graph in Figure 4,
the band width for a single carrier signal phase modulated
with a PN code having a chip rate of 300 kHz is 600 kHz.
There may be substantial difficulties in finding a gap of
600 kHz within the available radio frequency sprectrum to
locate not only one but a number of transmitters having
different central frequencies and each with signal band

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widths of 600 kHz.

By splitting the single high rate PN code
illustrated in the upper graph of Figure 4, into a number,
say 4, lower rate codes, efficient utilisation of the
available band width can be maximised. In the example as
illustrated in Figures 1 and 3, the single high rate code
is sampled and split into four codes each having one
quarter of the higher chip rate. Thus in the above
described example where the band width of a single
modulated signal would be 600 kHz, the band width of each
of four carriers modulated with lower rate codes is
150 kHz. As shown in the lower graph of Figure 4, one of
the four lower rate encoded carrier signals may be
retained with the central carrier frequency F of the wide
band signal shown in the upper graph. The other three
carriers are distributed elsewhere in the frequency
spectrum with central carrier frequencies F_1, F_2 and
F_3. The frequencies F, F_1, F_2 and F_3 are selected
to make use of available gaps in the frequency spectrum so
as to minimise interference with other spectrum users. At
the receiver, all four signals are received, the lower
rate codes recovered and from these lower rate codes a
higher rate code is re-established, having all the
original timing information. Thus the higher rate code
may still be used to obtain the originally required range
resolution.

Although the examples of Figures 1 and 3 and as
illustrated in Figure 4 contemplate only dividing the
original higher rate PN code into four lower rate codes
each having one quarter the original chip rate, the
invention may of course be used to divide the original
code into many more lower rate codes of further reduced
chip rate as long as the code division is relatively prime
to the higher rate sequence, and the minimum chip rate is
greater than that required to discriminate a multipath sky

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wave signal. This enables each individual modulated
carrier signal to be relatively narrow band and to be
located in correspondingly small available gaps in the
spectrum.

Figures 5 and 6 illustrate conventional methods of
Spread-Spectrum signal acquisition and tracking. In
Figure 5, an incoming signal from antenna 50 is first
amplified in rf amplifier 51 before passing through a band
pass filter 52. A locally generated reference PN code is
produced by generator 53. The locally generated code at
this stage is at the lower chip rate of each individual
received radio frequency signal. The locally generated
code from the generator 53 is modulated on a local
oscillator signal at a frequency $f_0 + f_1$, where f_0
is the carrier frequency of the received radio signal.
The modulated local oscillator signal is then mixed in a
mixer 54 with the received radio signal and the resulting
difference frequency signal is filtered in a second band
pass filter 55 before detection in an envelope detector 56
before supply to an integrate and dump circuit 57 a
dismiss threshold circuit 58 and a search control circuit
59 which in turn controls the timing of the reference PN
code generator 53. The operation of the elements
illustrated in Figure 5 bring the generator 53 so that the
locally generated PN code is synchronised within plus or
minus one chip with the PN code detected from the received
radio signal.

Once the received code is acquired by the circuit
of Figure 5, fine synchronisation with the received PN
code is provided by the conventional signal tracking loop
illustrated in Figure 6. In the top right hand corner of
Figure 6 is illustrated a carrier tracking loop which
enables the central carrier frequency of the received
signal to be tracked over Doppler shifts corresponding to
movement between transmitter and receiver. The lower part

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of Figure 6 illustrates a PN code tracking loop known as a Delay-Lock-Loop. The local oscillators LO_1 and LO_2 are modulated by two PN reference sequences displaced in time by an amount less than one code chip. After mixing with the received signal and band pass filtering, the mixed signal is further mixed with the output of the carrier tracking loop, and the two mix signals, from the two time displaced PN reference sequences, are supplied to a different circuit and the result used to control the output frequency of a voltage controlled oscillator (VCO) which clocks the reference PN code generator. The output of this reference PN code generator constitutes the output of the respective receiver channel.

The output PN codes from the various receiver channels are multiplied together as described above to recover a high rate reference signal which is itself then correlated with a reference high rate signal to provide acute time resolution for the received signal.

Figure 7, illustrates the correlation coefficient of the receiver for the time difference between reference and received PN code signals. The time axis in Figure 7 is measured in units of lower rate code chip. In order to clearly discriminate between the direct signal from the transmitter and a multipath sky wave signal arriving after a delay of τ_d, it can be seen that this time delay must be longer than two chips, implying a minimum chip rate for the lower rate signals of $2/\tau_d$. The minimum sky wave delay likely to be experienced is about $70\mu S$ so that the lower rate chip rate should be significantly greater than 30 kHz.

Mathematical analysis and computer simulation of the described split signal system of spread-sprectrum radio positioning has demonstrated that under certain conditions for the same effective power at the receiver, the multiple relatively narrow band signals from a

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transmitter provide substantially the same range
resolution as a single wide band signal. Figure 8 is a
block diagram of a computer simulation of the split signal
system described above, making use of a communications
simulation software package known as COMDISCO from
Comdisco Systems Inc. This provides computer aided
engineering tools and a digital signal processing
building-block library. The software can be used to
develop and simulate digital signal processing algorithms
and to evaluate various architectural approaches to a
design.

Looking at Figure 8, a high rate PN sequence at 60
is sampled at 61 to provide four low rate signals. Noise
is added to each of these signals at 62, 63, 64 and 65 and
they are then subjected to controllable delays at 66 to 69
and then supplied to tracking loops 70 to 73. The outputs
of the tracking loops are multiplied together and then
correlated at 74 with the output of the original high rate
sequence and the result supplied for statistical analysis
at 75.

The simulations performed confirmed that the
correlation of the recovered high rate signal and
resulting time delay analysis closely followed that
predicted by theory.

Considering Figure 9, this illustrates graphically
the predicted rms range uncertainty in metres for a split
signal system employing four carriers each modulated with
PN code sequences at 75 kHz chip rate, with corresponding
wide band spread-spectrum signal with a chip rate of
300 kHz. The difference in range uncertainty of 12 metres
is due to the additional code self noise on the split
signals, which is $k^{3/2}$ times that for the wide band
signal, where k = 4 in this example. In fact when the
receivers of each system are locked and tracking, code
noise can be neglected so that the performances of the two

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systems are identical.

Figure 9 also illustrates the characteristics of existing known radio positioning systems which use similar wide band signals. The Spot navigation system is similar to a single one of the split signal carrier frequencies, since the chip rate of Spot is close to 75 kHz. Geoloc uses a wide band DS-SS signal of $2^{23} - 1$ chips at a chip rate 666 kHz. Thus a Geoloc like signal is broadly equivalent to an eight channel split signal embodying the present invention where each split signal has a chip rate of about 75 kHz. Figure 10 compares the range uncertainties of a Geoloc like signal with eight Spot-like signals each of 75 kHz embodying the present invention. The curves confirm the similarity of performance as predicted and the discrepancy illustrated tends to the self noise limit of 12 metres.

In practice, when thermal noise is dominant in the receiver, a split signal system can achieve the same performance as a conventional wide band system.

One advantage of the split signal system described is that it enables relatively narrow gaps in the radio frequency spectrum to be used flexibly, whilst retaining the attributes of wide band SS systems.

Because the signals from a single transmitter can comprise a number of carrier frequencies travelling over the same propagation path, channel differential delays between the different carriers could be measured at the receiver, these delays arising due to frequency dependent propagation effects. Such delays could then be used for correction purposes in the radio positioning process. It will be appreciated that the signals from different transmitters can also be at different carrier frequencies and might suffer from such differential delays. The receiver could use estimates of such delays derived from the signals from any one transmitter for correcting for

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frequency dependent differential delays in the signals
from different transmitters. In order to achieve a range
resolution of better than ± 10 metres, the PN code itself
might be employed to provide only a relatively coarse
range measurement and to use measurements of carrier phase
for fine resolution. The presence of multiple·carriers in
a split signal system from the same transmitter permits
the phase differences between carriers to be measured in a
manner corresponding to the Omega or Hyper-Fix navigation
systems, as well as measuring the phases of single
carriers.

Further, the relatively narrow band of each
individual carrier in the split signal technique should
minimise the effects of differential phase distortion due
to propagation over inhomogeneous media. In wide band
spread-spectrum techniques, when the fractional band width
exceeds 10% of the carrier, complex phase-group delay
compensation circuits are needed in the receiver.

As mentioned, the split signal technique
illustrated above enables multiple narrow band signals to
be transmitted from each transmitter instead of a single
wide band single. These narrow band signals can be
located in available gaps in the radio frequency spectrum
and can utilise such gaps which are available only for a
limited time. Techniques may be employed at the receiver
for searching for the various carrier frequencies in
operation from each transmitter. With the above described
technique in which a single high rate PN code is sampled
at the transmitter to create the lower rate codes, the
code sequence in each of the lower rate codes is
identical, though at the lower rate, to the original
sequence of the higher rate code. This is convenient for
identifying the signals from each transmitter.

Where signal identification is not a problem, the
multiple lower rate codes generated at each transmitter

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could be different code sequences having the same overall
code length and a common chip rate.

The preceding description has concentrated on an
application of the invention involving radio positioning.
The invention may also be applicable to other techniques
where the propagation time of radio signals is used for
ranging or positioning purposes. For example in radar
techniques, multiple carriers could be transmitted each
encoded with lower rate signals for reflection by a target
and reception back at the transmitting position. The
regenerated high rate code signal could then be used for
accurate ranging. The use of multiple transmitted carrier
frequencies could be an advantage in providing immunity to
jamming and other counter measures.

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CLAIMS

1.   Radio frequency ranging apparatus comprising a
transmitter having a pseudorandom noise (PN) code
generator and a modulator to modulate a carrier frequency
with the generated PN code for transmission; and a
receiver comprising a processing means incorporating a
correlator to correlate a PN code, recovered from a radio
signal received from the transmitter, with a similar
reference PN code and providing a time signal dependent on
a propagration time for said radio signal between the
transmitter and the receiver, wherein said PN code
generator is arranged to generate a plurality of PN codes
having the same number of chips and a common chip rate,
said PN codes being equally time shifted one from the next
within the period of a single chip of said PN codes, and
said modulator is arranged to modulate a corresponding
plurality of carrier signals with respective said codes
for transmission as respective radio signals, and wherein
the receiver is arranged to receive said respective radio
signals and said processing means includes combining means
to combine the received PN codes to recover a higher rate
PN code having a chip rate which is the product of said
common chip rate and the number of said received PN codes,
said correlator being arranged to correlate said recovered
higher rate PN code with a similar reference PN code.

2.   Radio frequency ranging apparatus as claimed in
Claim 1, wherein said PN code generator in the transmitter
comprises means to generate a PN code having a higher chip
rate and sampling means to sample the chips of said higher
rate PN code sequentially to form said plurality of PN
codes at a common lower chip rate which is equal to said

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higher rate divided by the number of said plurality of PN
codes.

3.   Radio frequency ranging apparatus as claimed in
Claim 1 or Claim 2 wherein said modulator is arranged to
modulate a corresponding plurality of carrier signals each
having a different frequency, such that the band widths of
each carrier signal does not substantially overlap.

4.   Radio frequency ranging apparatus as claimed in
Claim 1 or Claim 2 wherein said modulator is arranged to
modulate a corresponding plurality of carrier signals each
having substantially the same frequency.

5.   Radio frequency ranging apparatus as claimed in
Claim 1 or Claim 2 wherein said modulator is arranged to
modulate a corresponding plurality of carrier signals,
each having a different frequency such that the band
widths of each carrier signal substantially overlap.

6.   Radio frequency ranging apparatus as claimed in
any preceding Claim, wherein said combining means
comprises adding means for performing modulo two addition
of the received PN codes.

7.   Radio frequency ranging apparatus as claimed in
Claim 6 wherein the chips of the PN codes are represented
as +1 and -1 in accordance with their binary state, and
the combining means comprises multiplying means to
multiply together the chips of the received PN codes.

8.   Radio frequency ranging apparatus as claimed in
any preceding claim and configured as radio positioning
apparatus, wherein the apparatus includes at least three

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said transmitters and at least one said receiver, said
processing means thereof providing said time signals for
each of the transmitters from which radio signals are
received at the receiver and identifying a position for
the receiver relative to the transmitters from·said time
signals.

9.   Radio frequency ranging apparatus as claimed in
Claim 8, wherein each said transmitter has different sets
of carrier frequencies.

10.   Radio frequency ranging apparatus as claimed in
Claim 8, wherein each said transmitter has the same set of
carrier frequencies and transmits for a predetermined time
period on the set of carrier frequencies.

11.   A receiver for use in radio frequency ranging
apparatus as claimed in any preceding claim wherein the
receiver comprises processing means incorporating a
correlator to correlate a received radio signal modulated
with a PN code with a similar reference PN code and
providing a time signal dependent on a progagation time
for said radio signal between a transmitter and the
receiver, wherein the receiver is arranged to receive a
plurality of radio signals from a transmitter comprising
respective carrier signals modulated by respective
PN codes each having the same number of chips and a common
chip rate, said PN codes being equally offset in time one
from the next within the period of a single chip of said
PN codes, and the processing means includes combining
means to combine the received PN codes to recover a higher
rate PN code having a chip rate which is the product of
said common chip rate and the number of said received PN
codes, said correlator being arranged to correlate said

recovered higher rate PN code with a similar reference PN code.

12.   A receiver as claimed in Claim 11, wherein said receiver is arranged to receive a plurality of radio signals comprising a plurality of carrier signals each having a different frequency, the band widths of each carrier signal not substantially overlapping.

13.   A receiver as claimed in Claim 11, wherein said receiver is arranged to receive a plurality of radio signals comprising a plurality of carrier signals each having substantially the same frequency.

14.   A receiver as claimed in Claim 11, wherein said receiver is arranged to receive a plurality of radio signals comprising a plurality of carrier signals each having a different frequency the band widths of each carrier signal substantially overlapping.

15.   A transmitter for use in radio frequency ranging apparatus as claimed in any preceding claim wherein the transmitter comprises a pseudorandom noise (PN) code generator and a modulator to modulate a carrier frequency with the generated PN code for transmission, wherein said PN code generator is arranged to generate a plurality of PN codes having the same number of chips and a common chip rate, said PN codes being equally offset in time one from the next within the period of a single chip of said PN codes, and said modulator is arranged to modulate a corresponding plurality of carrier signals with respective said codes for transmission as respective radio signals.

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16.   A transmitter as claimed in Claim 15 wherein said
modulator is arranged to modulate a corresponding
plurality of carrier signals each having a different
frequency, such that the band widths of each carrier
signal does not substantially overlap.

17.   A transmitter as claimed in Claim 15, wherein said
modulator is arranged to modulate a corresponding
plurality of carrier signals each having substantially the
same frequency.

18.   A transmitter as claimed in Claim 15, wherein said
modulator is arranged to modulate a corresponding
plurality of carrier signals each having a different
frequency, such that the band width of each carrier signal
substantially overlaps.

19.   Radio frequency ranging apparatus substantially as
hereinbefore described with reference to and as
illustrated in the accompanying drawings.

20.   Radio positioning apparatus substantially as
hereinbefore described with reference to and as
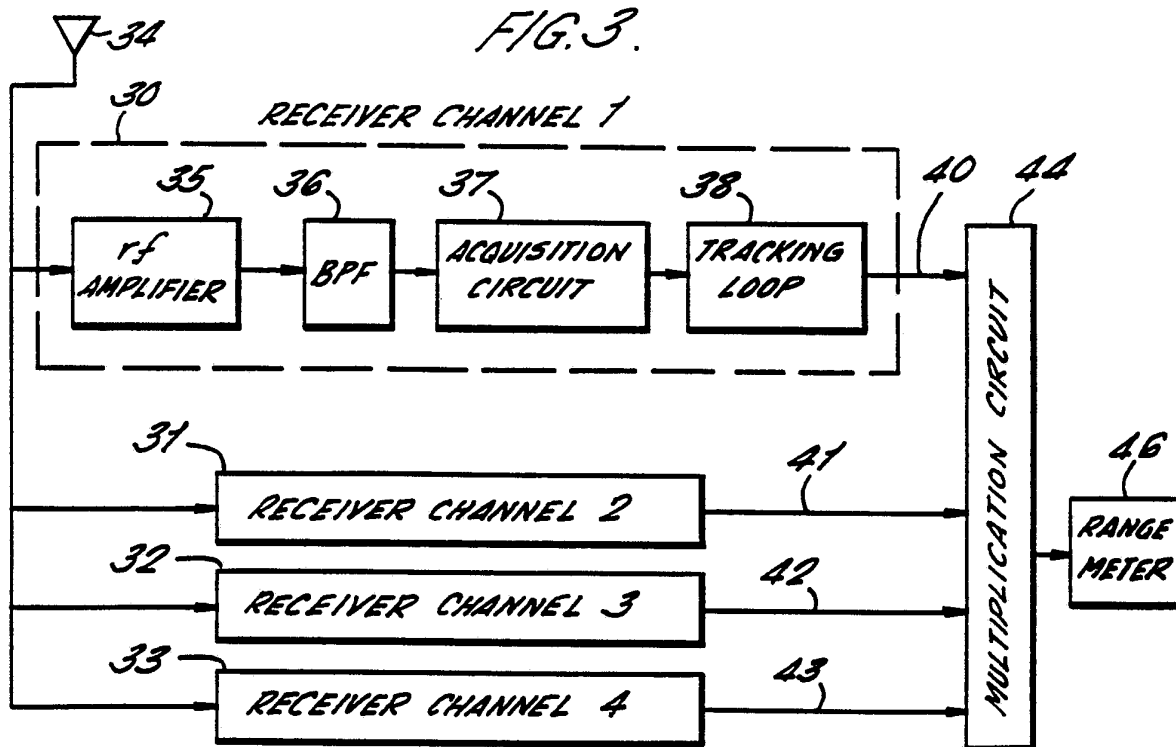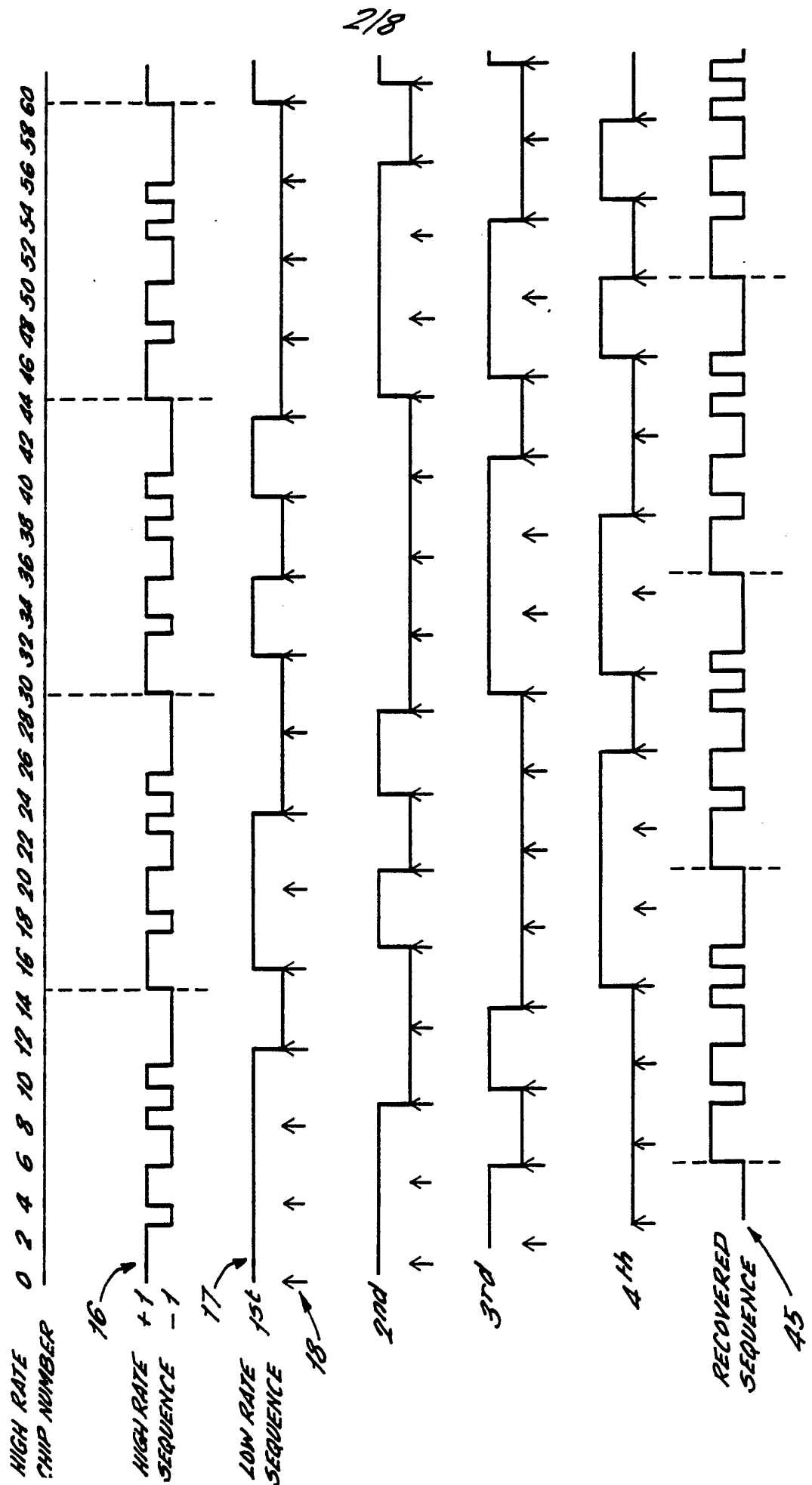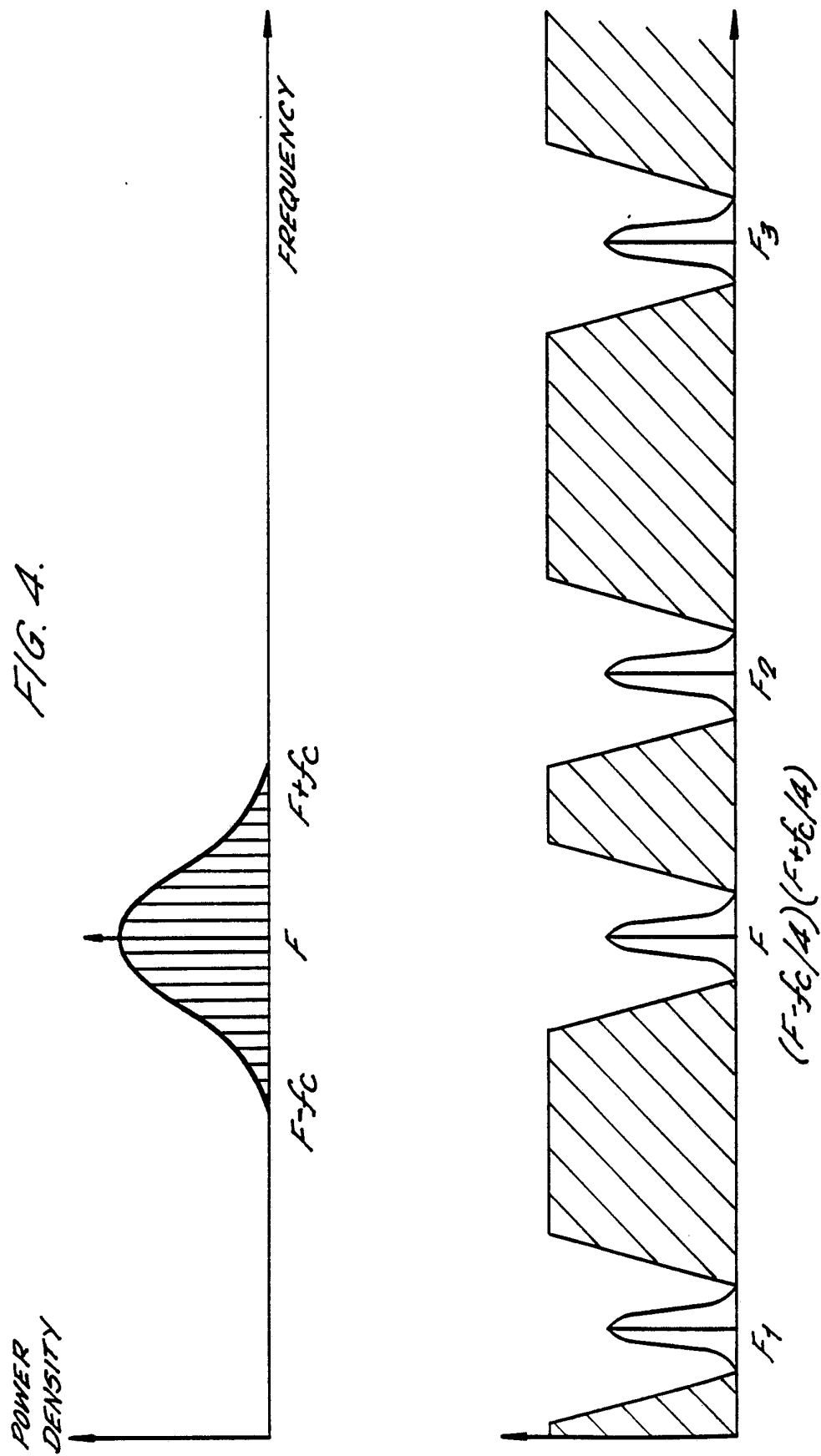illustrated in the accompanying drawings.

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FIG. 1.

FIG. 3.

FIG. 2.

FIG. 4.

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FIG. 5.

RECEIVED SIGNAL, FREQUENCY f_0

FIG. 6.

RECEIVED SIGNAL, FREQUENCY f_0
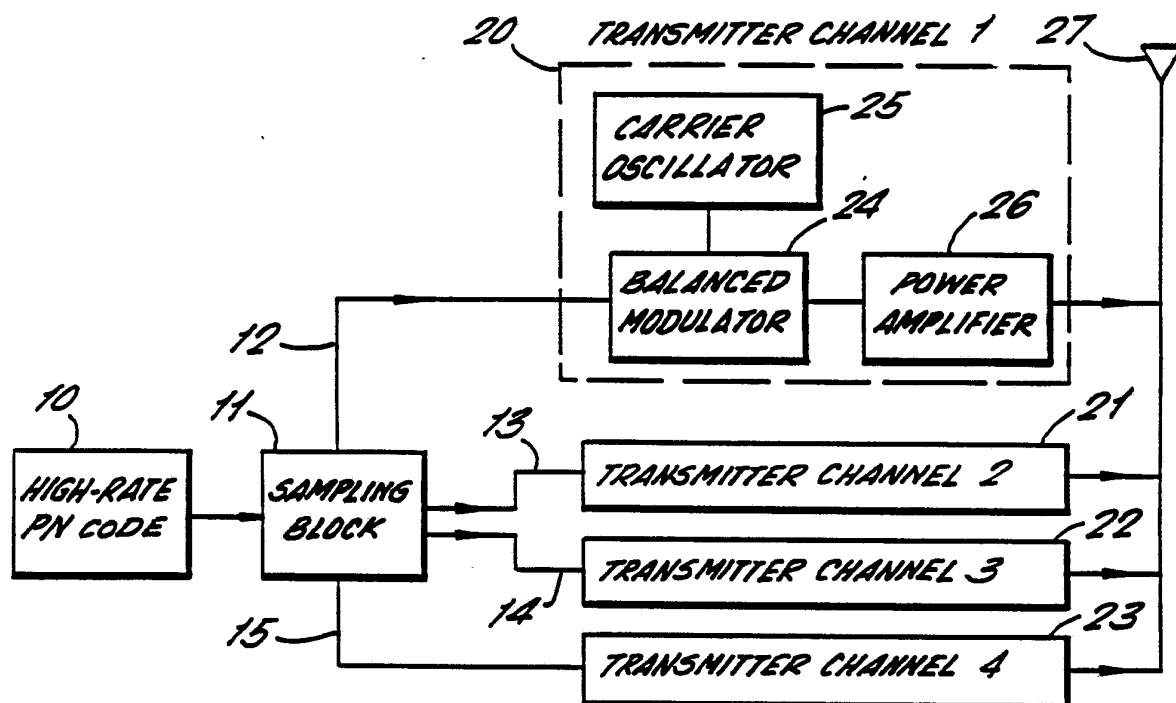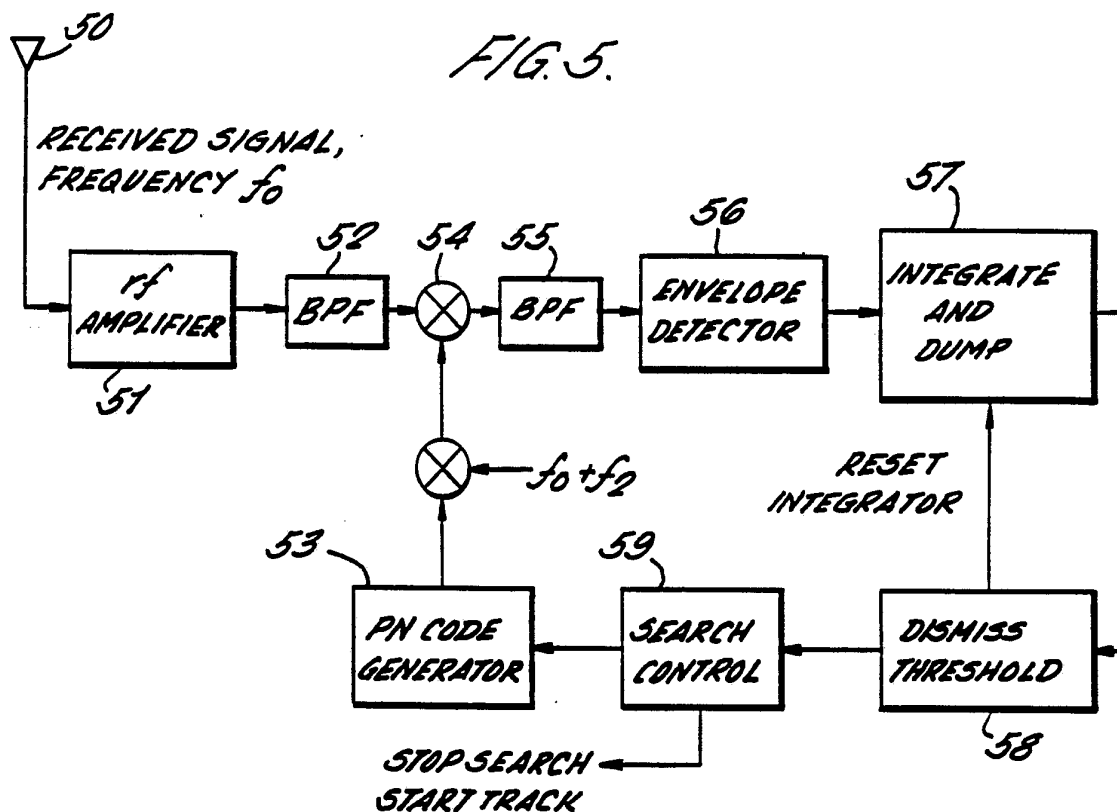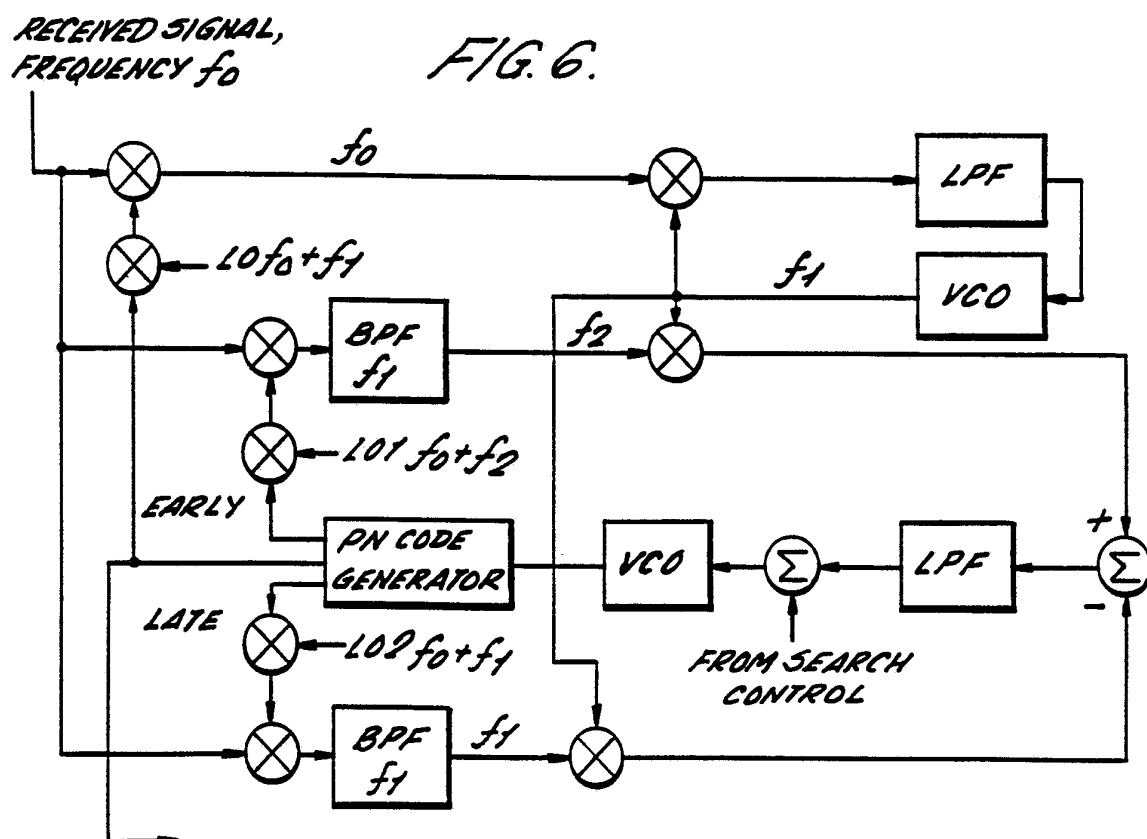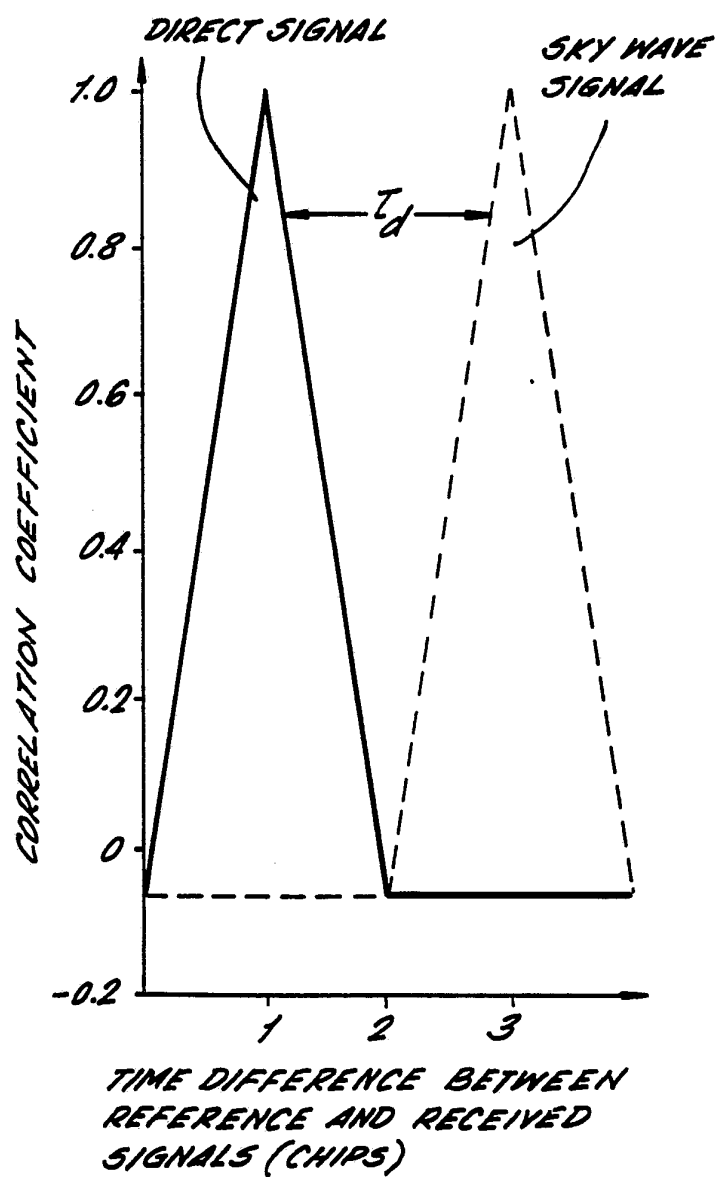
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FIG. 7.

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FIG. 8.

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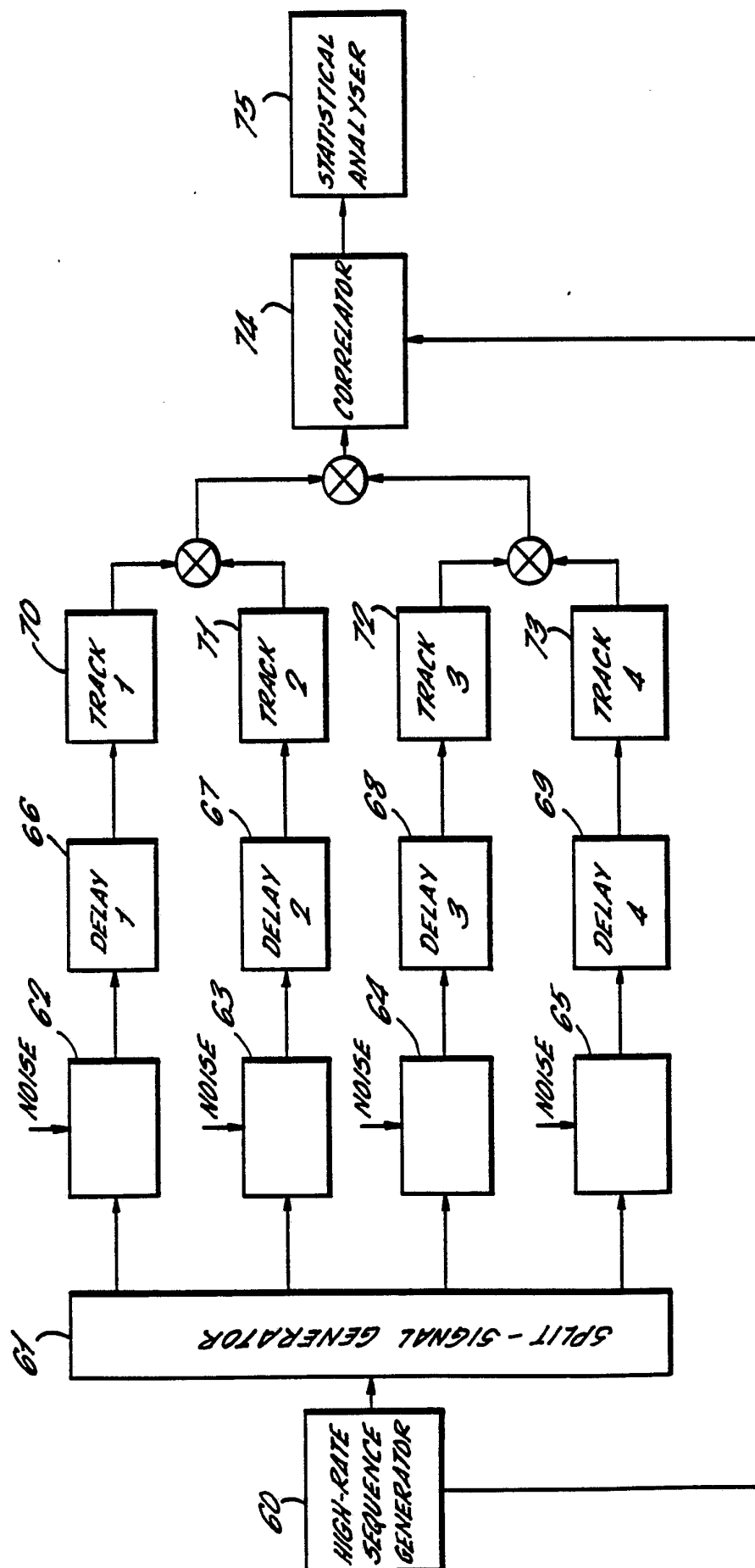
FIG. 9.
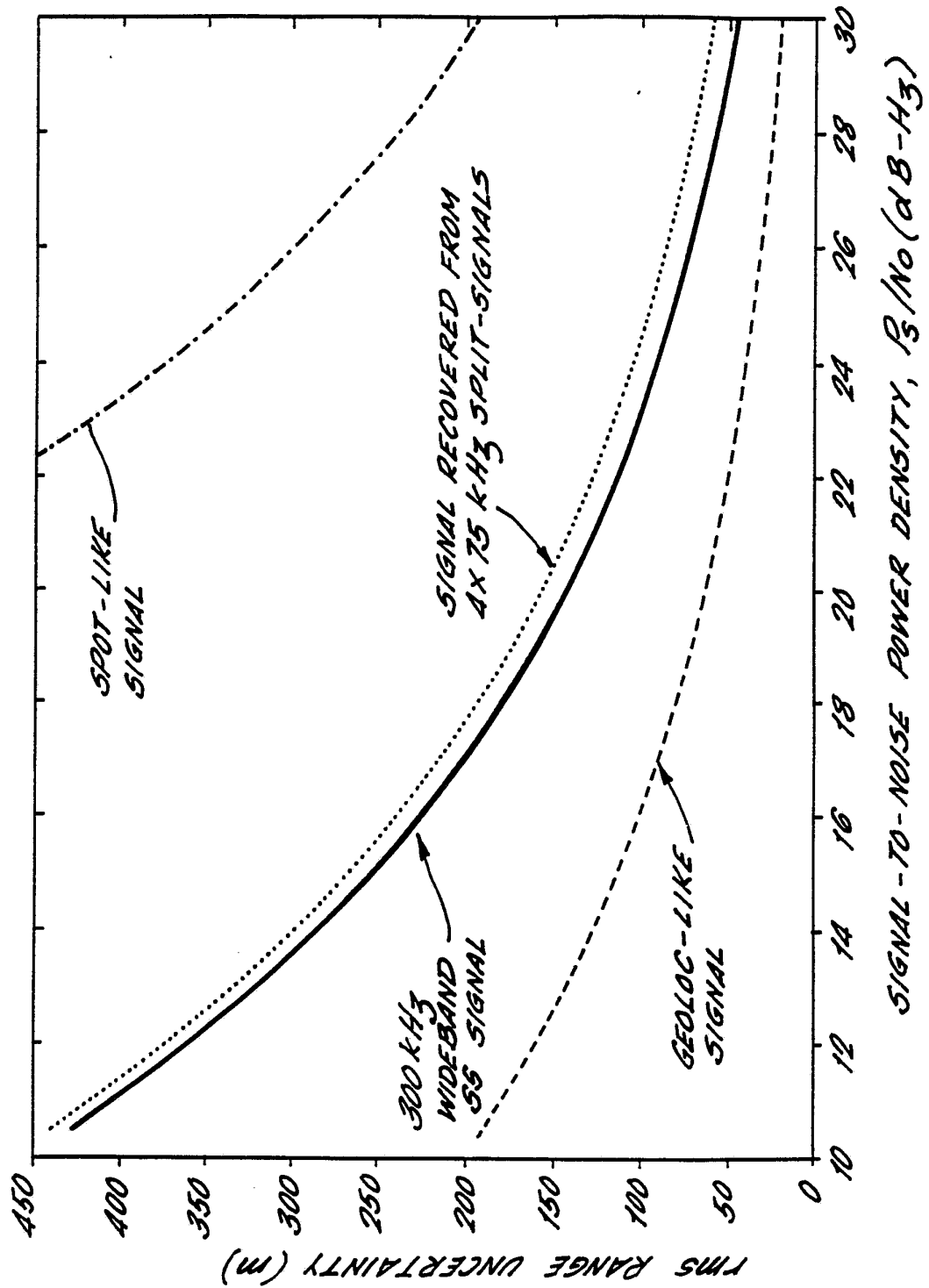
FIG. 10.

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01S11/08;   G01S5/10

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G01S

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category[o]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
A	EP,A,0 131 260 (INTERNATIONAL STANDARD ELECTRIC CORPORATION) 16 January 1985 see page 3, line 23 - page 5, line 4; figures 1-3 ---	1,11,15
A	US,A,3 755 816 (KRATZER) 28 August 1973 see the whole document ---	1,11,15
A	EP,A,0 470 272 (ASCOM RADIOCOM AG) 12 February 1992 see the whole document -----	1,8,11, 15

° Special categories of cited documents : [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
12 AUGUST 1993	2 5. 08. 93

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	HAFFNER R.D.R.

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.   12/08/93

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		JP-C-	1704204	14-10-92
		JP-B-	3062332	25-09-91
		JP-A-	60051338	22-03-85
US-A-3755816	28-08-73	US-A-	4004237	18-01-77
		US-A-	4095226	13-06-78
EP-A-0470272	12-02-92	None		