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(71) Applicant: ERICSSON INC. [US/US]; 7001 Development Drive, P.O. Box 13969, Research Triangle Park, NC 27709 (US).

(72) Inventor: ZANGI, Kambiz, C.; 3212 Quiet Mill Road, Raleigh, NC 27612 (US).

(74) Agents: MOORE, Stanley, R. et al.; Jenkens & Gilchrist, P.C., Suite 3200, 1445 Ross Avenue, Dallas, TX 75202 (US).

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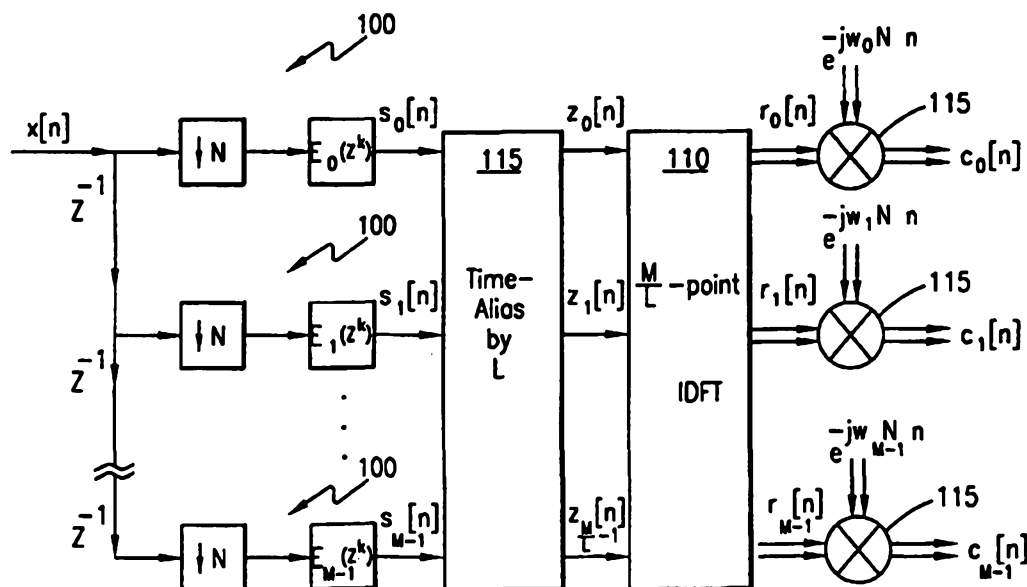
(57) **Abstract**

    A receiver and channelizer for processing a wideband signal is disclosed. The channelizer consists of a receiver for receiving a wideband signal. The received wideband signal is processed by a subsampled DFT–channelizer to extract a selected number of regularly spaced channels from a plurality of channels within the received wideband signal. These extracted regularly spaced channels are then output for further processing by a receiver.

WIDEBAND CHANNELIZATION USING

SUBSAMPLED DISCRETE FOURIER TRANSFORMS

BACKGROUND OF THE INVENTION

5   Technical Field of the Invention

The present invention relates to wideband channelization techniques, and more particularly, to a method for using subsampled discrete fourier transform filter banks to channelize wideband signals.

10

       Description of Related Art

Radio receivers requiring simultaneous reception of multiple radio channels require the extraction of a number of radio channels from a wideband signal. Such receivers

15 may include macro base stations, micro base stations, pico base stations and others. These types of receivers typically operate according to a frequency reuse plan that effectively restricts each base station to a regularly spaced subset of all available channels.

20   In one prior art implementation, individual radio channels are extracted from a wideband signal utilizing a DFT (discrete fourier transform) filter bank. One example of an existing approach which extracts each available channel from the wideband signal utilizing a

25 DFT-channelizer is described in U.S. Patent No. 5,606,575 to Williams. Another approach described in Kovacevic J et al, "Perfect Reconstruction Filter Banks with Rational Sampling Factors", IEEE Transactions on Signal Processing, vol. 41, no. 6, pages 2047-2066 extends the approach of

30 extracting uniformly spaced frequency bands to allow for nonuniform division of the wideband spectrum. The problem with these existing DFT-channelizers is that they extract every channel from the wideband radio signal. This requires a great deal of arithmetic operations by the channelizer and increases the cost/complexity of the
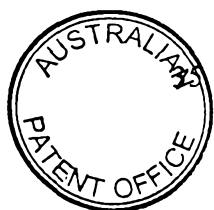
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receiver, especially since each base station is only utilizing a regularly spaced subset of all available channels. Accordingly, a more efficient, less complex method for extracting radio channels from a wideband

5   signal is desired.

-2-

SUMMARY OF THE INVENTION

The present invention overcomes the foregoing and other problems with a channelizer for use in processing a wideband signal within a receiver. A wideband signal is initially processed by a subsampled filter bank to extract a selected number of regularly spaced channels from the plurality of channels within the received wideband signal. The subsampled DFT-channelizer consists of a bank of polyphase filters for extracting all of the potential channels from the wideband signal (M channels in all). The outputs of the polyphase filters are then time aliased to generate a second sequence of signals equal in number to the selected number of regularly spaced channels $\frac{M}{L}$ desired channels).

This second sequence of signals are processed by an $\frac{M}{L}$-point inverse discrete fourier transform resulting in $\frac{M}{L}$ bandpass signals. The inverse discrete fourier transform coefficients are then mixed with a sequence of carrier signals to shift these bandpass signals to baseband, resulting in extraction of $\frac{M}{L}$ regularly spaced channels from the wideband signal. This system significantly decreases the amount of required processing power. In the system in accordance with the present invention, the number of arithmetic operations necessary to produce the desired channels are significantly less than the number of arithmetic operations presently required to extract every channel.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, reference is made to the following detailed description taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a block diagram of a generic wideband receiver;

FIGURE 2 is a functional diagram of a single branch of a DFT-channelizer;

-3-

FIGURE 3 is a diagram of a DFT-channelizer; and

FIGURE 4 is a block diagram of a subsampled DFT-channelizer.

5   DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, and more particularly to FIGURE 1, there is illustrated a block diagram of a generic wideband receiver. A transmitted wideband signal is received at an antenna 5. Through several stages of

10   mixing and filtering (shown generally at 10), the signal is processed to a desired frequency band, and is then mixed down by a mixer 15 to a baseband signal x(t) with relatively wide bandwidth for input to a wideband analog-to-digital converter 20. The analog-to-digital converter

15   20 converts the analog wideband signal x(t) to a digital wideband signal x(n) which is then processed by a digital channelizer 25 to extract the various radio channels 30. The prior art DFT-channelizer 25 (as shown in FIGURE 3) provides a computationally efficient manner for extracting

20   every channel within the wideband signal x(n).

Referring now to FIGURE 2, there is illustrated a functional diagram of one branch of a DFT-channelizer $H_o(w)$ represents a real, lowpass FIR filter. Every other filter within the filter bank is a modulated version

25   of this lowpass prototype. Thus, $H_i(w) = H_i(w - \frac{2\pi}{M}i)$; $0 \leq i \leq M-1$, M equals the number of channels. Note that $H_i(w)$ represents a bandpass complex-valued filter centered on the discrete time frequency $\frac{2\pi}{M}i$, or equivalently centered around the continuous time frequency

30   $\frac{F_s}{M}i$ (F_s is the sampling frequency of the A/D converter), M equals the total number of channels between $\{-F_s/2, + F_s/2\}$. In other words there are exactly M equal bandwidth filters in the filter bank, spaced apart by $f_{cs} = \frac{F_s}{M}$. The DFT-channelizer of FIGURE 3 is valid only when

35   M is an integer multiple of the downsampling factor N (i.e., M = N x K; where K is some positive integer). The DFT-channelizer can be efficiently implemented using an

-4-

inverse discrete fourier transform (IDFT) and the
polyphase decomposition of the lowpass prototype filter
$H_o(n)$. This implementation is typically referred to as a
DFT-channelizer and is illustrated in FIGURE 3.

$$r_k[n] = \sum_{i=o}^{M-1} S_i[n]e^{j\frac{2\pi}{M}ki} \; ; \; 0 \leq K \leq M-1$$

5

Referring now to FIGURE 3, there is illustrated a
block diagram of a DFT-channelizer. In FIGURE 3, the
$E_i(z)$s represent the polyphase components of $H_o(z)$. Thus,

$$H_i(z) = \sum_{i=o}^{m-i} z^{-i} E_i(z^m)$$
$$where: \quad e_i(n) = h_i[nM+i] \quad o \leq i \leq M-1$$

The main limitation of a prior art DFT-channelizer
is that it channelizes every channel in the frequency
range $\left\{-\dfrac{F_s}{2}, \dfrac{F_s}{2}\right\}$; even though only a subset of these
channels might actually be needed. For example, in most
cellular systems using a 7/21 frequency reuse plan, each
base station only uses one out of every seven radio
channels. Thus, a receiver would only need to channelize
every 7th channel.

Referring now to FIGURE 4, there is illustrated a
block diagram of a subsampled DFT-channelizer of the
present invention. For the subsampled DFT-channelizer,
it is assumed that only every L-th output channel must be
computed and that the total number of channels M is an
integer multiple of L, thus

$$M = L \; x \; r$$
$$where \; r \; is \; some \; positive \; integer$$

From the discrete wideband signal x(n), the
subsampled DFT-channelizer computes only the desired
channels $\left\{c_o[n], c_L[n], c_{2L}[n], \cdots, c_{M-L}[n]\right\}$.

Comparing FIGURE 4 to FIGURE 3, we see that the subsampled DFT-channelizer replaces the M-point DFT in the DFT-channelizer with a time-aliasing block and an $\frac{M}{L}$-*point* IDFT. The combined complexity of the time-aliasing block and the $\frac{M}{L}$-*point* IDFT is much smaller than the complexity of the M-point IDFT.

The outputs of the time-aliasing block are formed from the output of the polyphase filters according to

$$z_i[n] = \sum_{r=o}^{L-l} s_{i-Qr}[n] \quad 0 \le i \le Q-1,$$

$$where \ Q = \frac{M}{L}; \ and$$

$$r_{KL} = \sum_{i=o}^{M-1} Z_i[n] e^{j\frac{2\pi}{Q}Ki}; \quad 0 \le K \le Q-1$$

The Q outputs of the $\frac{M}{L}$-*point* IDFT in the subsampled DFT channelizer of FIGURE 4 are $\{r_o[n], r_L[n], r_{2L}[n], \cdots, r_{m-L}[n]\}$, (i.e., every L-th output of IDFT block in FIGURE 3).

Similarly, the final outputs of the subsampled DFT-channelizer in FIGURE 4 are $\{c_o[n], c_L[n], c_{2L}[n], \cdots, c_{m-L}[n]\}$, (i.e., every L-th final output of the DFT-channelizer in FIGURE 3).

For example, let us consider an analog signal x(n) of approximately 10 MHz of bandwidth, and let us assume that each radio channel conforms to the D-AMPS standard. Specifically, the channel spacing is f_{cs} = 30 KHz. Furthermore, let us assume that a 7/21 frequency reuse pattern is used. Hence, only every 7th channel needs to be extracted from x(n), i.e. L=7.

The full DFT-channelizer of FIGURE 3 can be used to extract every 30 KHz band in x(n) if the sampling frequency of A/D converter is set at F_s = 34.02 MHz. In this case the total number of channels is $M = \frac{34.02 \ MHZ}{30 \ KHZ} = 1134$. An IDFT of size 1134 needs to be implemented by the DFT-channelizer every $\frac{r}{N}$ seconds. Since 1134 is a highly composite number, a Dooley-Tukey

-6-

FFT algorithm can be used to compute this IDFT efficiently.

Alternatively, the subsampled DFT -channelizer of FIGURE 4 can be used to extract only every 7th channel from x(n) (i.e., L=7 if the sampling frequency of the A/D converter is set at F_s = 34.02 MHz. In this case, a 162-point IDFT needs to be implemented by the subsampled DFT-channelizer every $\frac{F_s}{N}$ (since $\frac{M}{L} = \frac{1134}{7} = 162$). The complexity of a 1134-point IDFT is about 7 times the complexity of a 162 point IDFT.

Referring now back to FIGURE 4, the discrete wideband signal $x[n]$ is sampled and filtered by the bank of polyphase filters 100 to generate the sequence $s_i[n]$. Each branch of the $s_i[n]$ signal is time aliased by L at 105 to generate a new sequence $z_i[n]$. An $\frac{M}{L}$-point IDFT 110 is taken of the sequence $z_i[n]$ to yield the sequence $r_i[n]$. This sequence is mixed with carrier signal sequence $e^{jW_r N n}$; where $W_r = \frac{2\pi}{Q} \times r$ at mixer 115 to yield the selected channels from the wideband signal.

The $\frac{M}{L}$-point IDFT in the subsampled DFT-channelizer can be computed using any known fast algorithm for computing DFT/IDFT. These algorithms include the radix-2 FFT algorithm, the Cooley-Tukey FFT algorithm, the Wionogard prime-length FFT algorithm, and the prime-factor FFT algorithm. Depending on the exact value of $\frac{M}{L}$, a particular algorithm for computation of the IDFT might be more efficient. Hence, the free parameters of the subsampled DFT-channelizer (e.g., F_s and M) can be chosen such that the resulting IDFT can be computed more efficiently using a particular FFT/IFFT algorithm. In other words, these parameters can be chosen to get an IDFT size that can be computed efficiently.

For example, if $\frac{M}{L}$ is a highly composite number, the Cooley-Tukey FFT algorithm can be used to efficiently compute the resulting IDFT. On the other hand, if $\frac{M}{L}$ is a prime number, the Winograd prime-length FFT algorithm can be used to efficiently compute the resulting IDFT.

Finally, if $\frac{M}{L}$ is a power of four, the radix-4 FFT algorithm can be used to efficiently compute the resulting IDFT.

Although a preferred embodiment of the method and apparatus of the present invention has been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it is understood that the invention is not limited to the embodiment disclosed, but is capable of numerous rearrangements, modifications, and substitutions without departing from the scope of the invention as set forth and defined by the following claims.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1.   A receiver, including:

first circuitry for converting a received signal to an analog baseband signal;

an analog to digital converter for converting the analog baseband signal to a digital baseband signal; and

a subsampled DFT-channelizer for extracting a plurality of selected, regularly spaced channels from the digital baseband signal, including:

a plurality of polyphase filters for extracting a first sequence of signals;

second circuitry for time aliasing the first sequence of signals to generate a second sequence of signals;

an $\frac{M}{L}$-point inverse discrete fourier transform for calculating IDFT coefficients for the plurality of selected, regularly spaced channels from the second sequence of signals; and

a combiner for combining the IDFT coefficients with a carrier signal sequence to provide the plurality of selected, regularly spaced channels.

2.   The receiver of claim 1 wherein the first sequence of signals includes each channel within the digital baseband signal.

3.   The receiver of claim 1 wherein the second sequence of signals includes only a number of signals equal to the plurality of selected, regularly spaced channels.

4.   The receiver of claim 1 wherein the subsampled DFT-channelizer can extract any first channel from the digital baseband signal as one of the plurality of selected, regularly spaced channels.

5.   A channelizer for processing a wideband signal including:

an input for receiving the wideband signal;

a subsampled DFT-channelizer for extracting a number of selected, regularly spaced channels from a plurality of channels within the received wideband signal, including:

a plurality of polyphase filters for extracting a first sequence of signals;

a circuitry for time aliasing the first sequence of signals to generate a second sequence of signals;

an $\frac{M}{L}$-point inverse discrete fourier transform for calculating IDFT coefficients for the plurality of selected, regularly spaced channels from the second sequence of signals;

a combiner for combining the IDFT coefficients with a carrier signal sequence to provide the plurality of selected, regularly spaced channels; and

an output for outputting the selected, regularly spaced channels.

6.   The channelizer of claim 5 wherein the first sequence of signals includes each channel within the wideband signal.

7.   The channelizer of claim 5 wherein the second sequence of signals includes only a number of signals equal to the plurality of selected, regularly spaced channels.

8.   The channelizer of claim 5 wherein the subsampled DFT-channelizer can extract any first channel from the wideband signal as one of the plurality of selected, regularly spaced channels
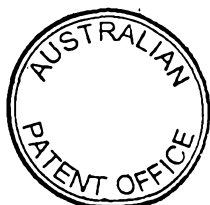

9.   A method for processing a wideband signal including a plurality of regularly spaced channels, including the steps of:

receiving the wideband signal including the plurality of channels;

filtering the wideband signal to extract a first sequence of signals within the wideband signal;

time aliasing the first sequence of signals to obtain a second sequence of signals;

processing the second sequence of signals according to an $\frac{M}{L}$-point inverse discrete fourier transform to obtain IDFT coefficients of the plurality of regularly spaced channels; and

mixing the IDFT coefficients with a carrier signal sequence to obtain a selected number of regularly spaced channels;

outputting the selected number of regularly spaced channels.

10. A method for processing a wideband signal including a plurality of regularly spaced channels, including the steps of:

receiving the wideband signal including the plurality of channels;

filtering the wideband signal to extract each of the plurality of regularly spaced channels;

determining IDFT coefficients for a selected number of regularly spaced channels from the extracted plurality of channels;

mixing the IDFT coefficients with a carrier signal sequence to obtain the selected number of regularly spaced channels; and

outputting the selected number of regularly spaced channels.

11. A receiver, channelizer or method substantially as herein described with reference to any one of the embodiments of the invention illustrated in the accompanying drawings.

DATED this 21st day of August 2002

ERICSSON INC.

WATERMARK PATENT & TRADE MARK ATTORNEYS
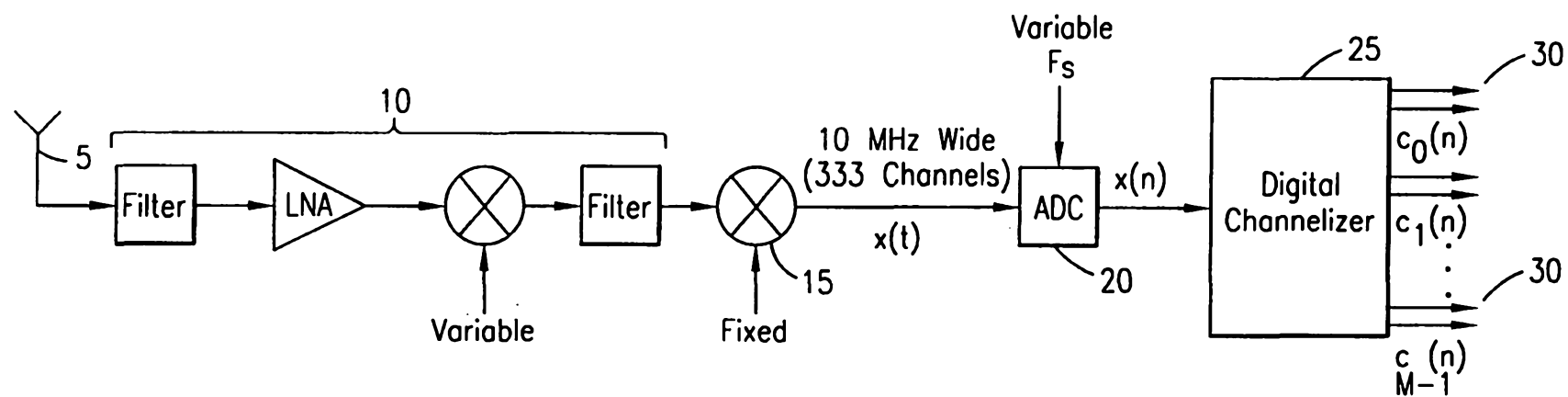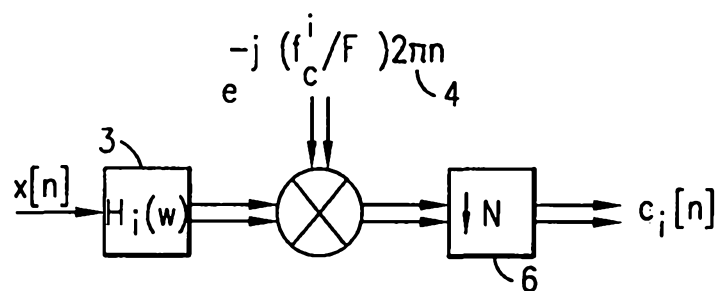290 BURWOOD ROAD
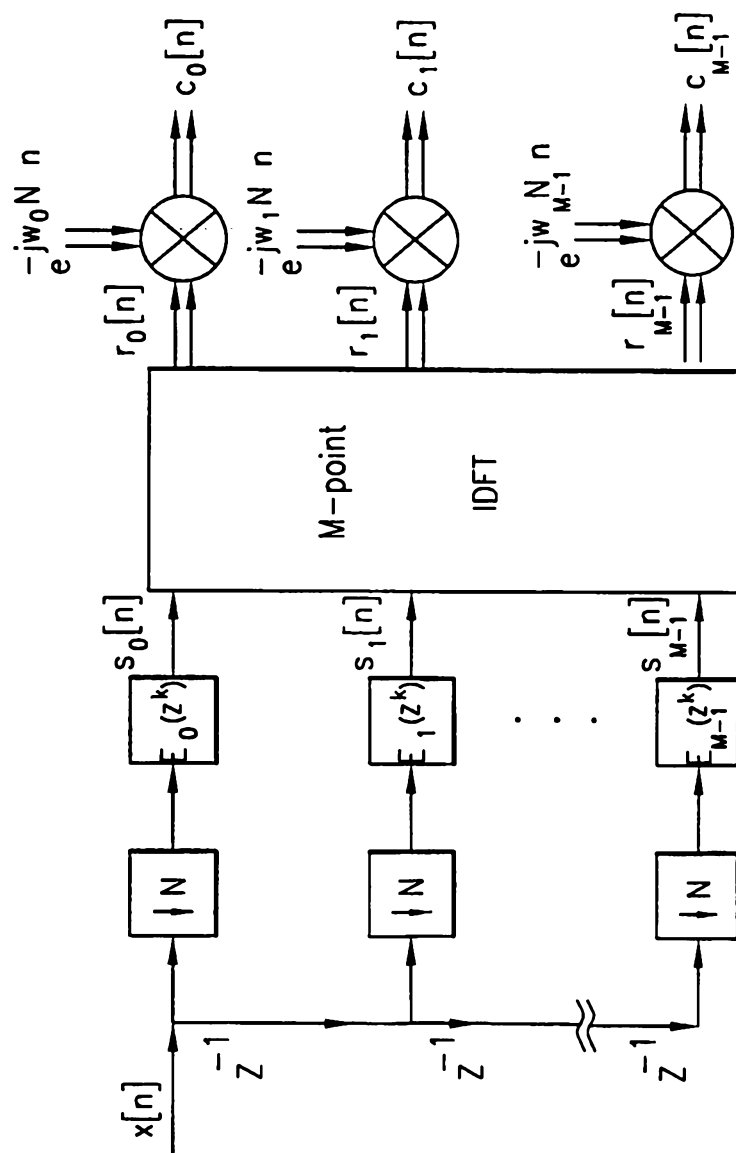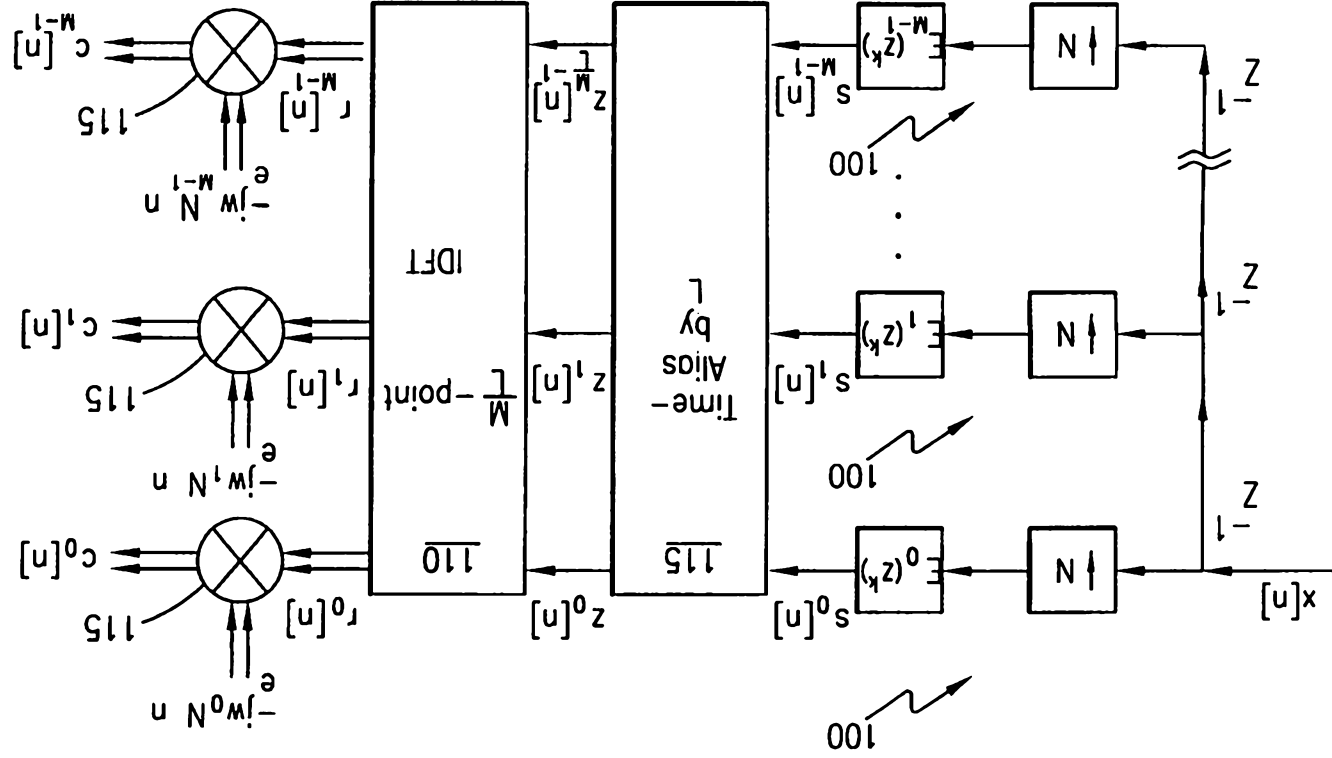HAWTHORN VICTORIA 3122
AUSTRALIA

PNF/AAL/CMM

FIG. 1

FIG. 2

FIG. 3

FIG. 4

$x[n]$

$\uparrow N$ $E_0(z^k)$ $s_0[n]$ 100

$\uparrow N$ $E_1(z^k)$ $s_1[n]$ 100

$\uparrow N$ $E_{M-1}(z^k)$ $s_{M-1}[n]$ 100

z^{-1} z^{-1} z^{-1}

Time-Alias by L   115

$z_0[n]$ $z_1[n]$ $z_{M-1}[n]$

$\frac{1}{M}$-point IDFT   110

$r_0[n]$ $r_1[n]$ $r_{M-1}[n]$

$-jw_0 \frac{N}{e} n$ $-jw_1 \frac{N}{e} n$ $-jw_{M-1} \frac{N}{e} n$

115   115   115

$c_0[n]$ $c_1[n]$ $c_{M-1}[n]$