NICAM 3 : A COMPANDED PCM SYSTEM FOR THE TRANSMISSION OF HIGH QUALITY SOUND-PROGRAMMES

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INTRODUCTION

The BBC has chosen to develop a new digital sound-programme transmission system, for use, in particular on 2048 kbit/s digital bitstreams. The system, known as NICAM 3 (Near-Instantaneously Companded Audio Multiplex, Mark 3) was outlined in a contribution (1) to the International Broadcasting Convention in 1978. The main reasons for the development are that it offers a better audio quality than any other companded system so far examined, and it is possible to obtain six sound-programme channels on a 2048 kbit/s bit-stream. Samples are initially coded to 14-bit accuracy, and reduced to 10 bits for transmission.

This contribution gives details of the system, including the architecture and bitstream format, and some applications are described.

CHOICE OF BITSTREAM FORMAT

Constraints

The following factors were considered:

i) Dedicated use of 2048 kbit/s digital circuits.

ii) Partial access to 2048 kbit/s digital circuits.

iii) Most efficient use, particularly of dedicated circuits.

iv) Conformity with international proposals (2)

Since partial access to 2048 kbit/s digital circuits was one of the initial constraints, it was decided to work out the bitstream requirements firstly on an individual channel basis. Assuming that for dedicated 2048 kbit/s use six sound-programme channels are required, the maximum possible number of kbit/s per channel would be $341\frac{1}{3}$. To allow a reasonable margin for overall framing and other housekeeping purposes 338 kbit/s have been allocated to each channel, divided as shown below.

Single Channel Characteristics

The nominal bandwidth, pre-emphasis characteristic, overload point and sampling frequency, have all been chosen to conform to the majority of the proposals in the CCIR Report referred to above (2). These are:

Nominal bandwidth	0.04 to 15 kHz
Pre-emphasis characteristic	CCITT Rec.J.17 (6.5dB loss at 800Hz)
Overload-point at input to ADC	+12dBm0s *
Sampling frequency	32kHz ± 50 parts per million.

* The abbreviation dBm0s stands for a measurement made on a sound-programme circuit, in decibels relative to one milli-watt, referred to a zero-level point.

Bit Allocation

Three blocks of 32 samples plus various housekeeping bits form a single channel frame in a total time of 3ms. The number of bits per frame is thus 3 x 338 = 1014 bits, which are allocated as shown below. (illustrated in Figure 1).

	Bits/frame	Bit-Rate/Channel
Sample words (10 bits each)	960 bits	320 kbit/s
Range-coding (with error protection)	11 bits	3.6 kbit/s
Sample word error protection	32 bits	10.6 kbit/s
Framing	7 bits	2.3 kbit/s
Signalling	4 bits	1.3 kbit/s
Total	1014 bits	338.0 kbit/s

In the serial output bitstream of a channel the housekeeping bits occur in groups of nine separated by 160 sample bits. They are spread out to provide protection against bursts of errors. Descriptions of the housekeeping functions follow.

Range Coding

As explained in the previous paper (1), in the NICAM companding technique, each group of 32 samples is accompanied by a range code, indicating which of the five companding ranges is in use for the group. The number of bits required for this purpose has been reduced by combining the range codes for the three blocks of 32 samples in each frame. The number of possible states for three range codes is $5^3 = 125$, and this number requires seven bits to identify it. It is important that occasional bit errors should not affect the selection of ranges, so an additional 4 bits have been allocated to provide single error correction, according to a technique described by R.W. Hamming (3).

Sample Error Protection

Thirty-two bits have been allocated for sample word error protection. The five most significant bits in each sample are protected, and it is considered that a relatively simple error concealment system will be sufficient in most cases, but if required, a more complicated system giving single error correction may be employed. A Wyner Ash (4) 16, 15 single error correcting code has been proposed. It is anticipated however that even without this, the system error-protection should be adequate up to error-rates of at least 1 in 10^5.

Framing

Seven bits per frame are used as a framing pattern.

These differ in alternate frames so that the complete pattern comprises 14 bits in a multiframe of 2028 bits. This has been chosen to minimise the probability of spurious recognition of the pattern in the sample and other housekeeping bits. A reframing time after individual channel frame loss of about 12ms is expected.

Signalling

The four bits per frame which are left have been allocated for signalling. This facility is available for a variety of purposes including local opt-out and transmitter switching.

Overall 2048 kbit/s Multiplex Bitstream

One of the factors which had to be considered was that for contribution purposes, it should be possible to insert one or two channels into a dedicated 2048 kbit/s circuit, without the need to decode to audio and re-encode at the insertion point. This led to the decision to allocate bits in the overall bitstream, which could be used for synchronisation of asynchronous contribution channel bitstreams. Such bits are known as justification bits. With this in mind the 20 kbit/s available for overall housekeeping in a dedicated 2048 kbit/s circuit has been allocated as shown below. For convenience a frame time of 1 ms has been chosen and the precise bit pattern is illustrated in Figure 2.

	Overall Bit-Rate
Individual channel bits (6 x 338 kbit/s)	2028 kbit/s
Overall framing	7 kbit/s
Overall Signalling	1 kbit/s
Justification	12 kbit/s
Total	2048 kbit/s

An overall reframing time of about 2ms is expected after frame loss.

Partial Access to 2048 kbit/s Circuits

In the international field, the CCITT have recommended (5) a particular bitstream format for 30 telephony channels in 2048 kbit/s (using 64 kbit/s per channel and 128 kbit/s for housekeeping purposes). To enable such a circuit to carry a sound-programme channel it is necessary to displace six telephony channels (384 kbit/s) and therefore for this partial access application a maximum of five sound-programme channels (1920 kbit/s programme + 128 kbit/s housekeeping) may be carried in 2048 kbit/s.

SYSTEM ARCHITECTURE

Basic Coder Pair

The instrumentation chosen by the BBC for development was determined by the need for a flexible system. It is expected that NICAM 3 will eventually replace the present 13-channel PCM distribution network, but it should also be suitable for contribution circuits involving one or two sound-programme channels. In the latter case it is considered that stereo applications will predominate, and so, as a compromise between flexibility and efficiency, the design has centred around a pair of channels, which may be used either for two independent monophonic signals, or for the left and right components of a stereophonic signal. Thus a coder-pair has been designed which has separate analogue sections for the two channels, and which employs a common digital processing arrangement. A similar philosophy applies to the decoder.

An advantage of using the coder-pair structure is that reserve facilities may be provided by adding a spare coder-pair and multiplexer, instead of having to provide a completely duplicate equipment. In the event of a channel fault developing, the reserve facilities are automatically switched in. Again the same principle applies to the decoder.

Control

The use of a microprocessor was considered, but limitations of speed and of eight bit working made it impractical and little decision taking has to be performed, the activity being mainly repetitions of a series of commands. It was decided, therefore, to employ a bus structure similar to that used by microprocessors. The commands are generated by a sequencer card in read-only memory (ROM) and communicated to other cards via the bus. Each card performs its own operation (e.g. compression, parity generation) when commanded to do so, on sample or housekeeping words on the data bus. Between operations these words are stored in random access memory (RAM).

Maintenance

Ease of maintenance is an important design consideration. The use of a bus structure should mean that any changes which may be required can be effected easily. Each card is arranged to be self checking to some extent, detected faults being indicated by light-emitting diodes (LEDs) and pulling down a "fault-bus" to permit automatic changeover to reserve equipment. The technique of "Signature Analysis" is used to assist repair, in conjunction with dummy data generators to provide pre-determined data states.

APPLICATIONS (see Figure 3)

Network Distribution

The main application of this system will be the distribution of high quality sound-programmes to studio centres and transmitters all over the United Kingdom, using dedicated 2048 kbit/s digital circuits: Initially it is likely that those places which have not been covered by the existing 13-channel PCM distribution network will be fed in this way, but eventually it is expected that NICAM 3 will replace the 13-channel network. Some areas will require more than six channels, and these will be dealt with by multiplexing up to four 2048 kbit/s to 8448 kbit/s using standard telephony equipment. The 13-channel PCM distribution system is carried on analogue monochrome television links, and such links could carry 24 NICAM 3 channels.

Contribution Circuits

NICAM 3 is also intended for use on contribution circuits. In the future, some national and regional centres may have dedicated 2048 kbit/s circuits to London, in which case up to six sound-programme contribution channels can be provided.

Outside broadcasts may be required from any location. These will probably be either monophonic or stereophonic, and a coder pair feeding a radio link, with the receiver at an insertion point on the contribution network, would be one way of dealing with the problem. Another possibility would be to hire from the Post Office a number of telephony channels in a 30-channel 2048 kbit/s circuit. Each sound-programme channel would use six telephony channels or 384 kbit/s, and a stereo pair would require 11 or 12 telephony channels, i.e. 704 or 768 kbit/s depending on the techniques used for such partial access. It would be necessary to ensure that all the telephony channels employed for such a purpose have identical delays.

Synchronisation

At insertion points it would be desirable to avoid having to decode the bitstream from an outside broadcast and re-encode the signals for onward transmission. The justification bits in the 2048 kbit/s bitstream may be used to synchronise an incoming asynchronous signal by repeating or dropping an occasional bit. However, if such a technique is used, all demultiplexers would have to be fitted with the appropriate circuitry to de-justify the signals. This is an extra expense, and given that at digital mixers all contributing bitstreams will have to be synchronous, it is considered that the whole system should be operated synchronously, even though this might cause problems at a remote outside broadcast site.

One suggestion which is being investigated is the possibility of synchronising all source clocks from the 200kHz Radio 4 carrier from Droitwich. This employs a Rubidium standard, and it, or other slave-locked transmitters, can be received anywhere in the United Kingdom. A digital buffer store may be necessary at the insertion point in order to remove any slow phase jitter caused by the sky wave.

Another possibility would be to use a very stable oscillator at the remote source. A buffer store would be necessary in this case, and would overload periodically, depending on its size and the oscillator stability. Such an event would give rise to an audible click, but one such click every two hours (say) might be acceptable. A technique has been proposed (6) which would arrange for clicks due to this cause to be muted, and this could be adopted if the problem became serious.

Acknowledgement

The development of NICAM 3 has been a team effort with members of both the Research and Designs Department of the BBC involved. Their contributions are gratefully acknowledged. The authors would also like to thank the Director of Engineering of the BBC for permission to publish this paper.

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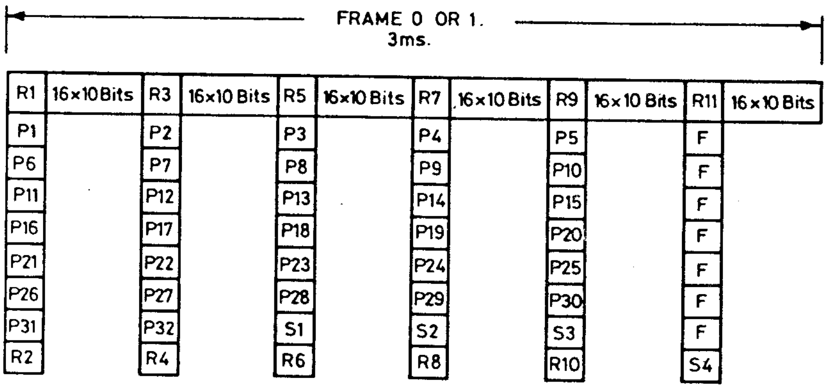
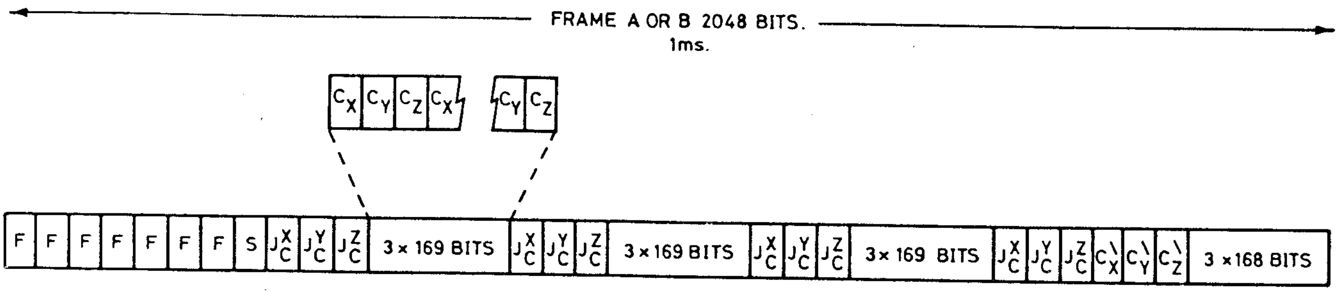


The sample bits are shown as groups of 16×10 bits.
F = Framing Bit.
P = Sample Parity Bit.
R = Range Code Bit.
S = Signalling Bit.

NOTE:
Single channel framing is contained in a multiframe - Frame 0 and 1. Framing bits are different for each frame although their positions in the bitstream sequence are identical.

Fig. 1. NICAM. 3. SINGLE CHANNEL FORMAT.



NOTE:

Six channel multiplex framing is contained in a multiframe - Frame A and B. Framing bits are different for each frame although their positions in the bitstream sequence are identical.

F = Framing Bit.

S = Signal Bit.

$J_C^{X(Y,Z)}$ = Justification Control Bit For Channel Pair X (Y,Z).

$C_{X(Y,Z)}$ = Channel Bit From Coder Pair X (Y,Z).

$J_D^{X(Y,Z)}$ = Negative Justification Service Bit For Channel Pair X (Y,Z).

$C^{\backslash}_{X(YZ)}$ = Positive Justification Service Bit For Channel Pair X (Y,Z).

Bit Rates:

3 Coder Pairs	= 3×676 =	2028 kbit/s
Framing	=	7 kbit/s
Justification	= 3× 4 =	12 kbit/s
Signalling	=	1 kbit/s
		2048 kbit/s

Fig. 2. NICAM. 3. SIX CHANNEL MULTIPLEX FORMAT.

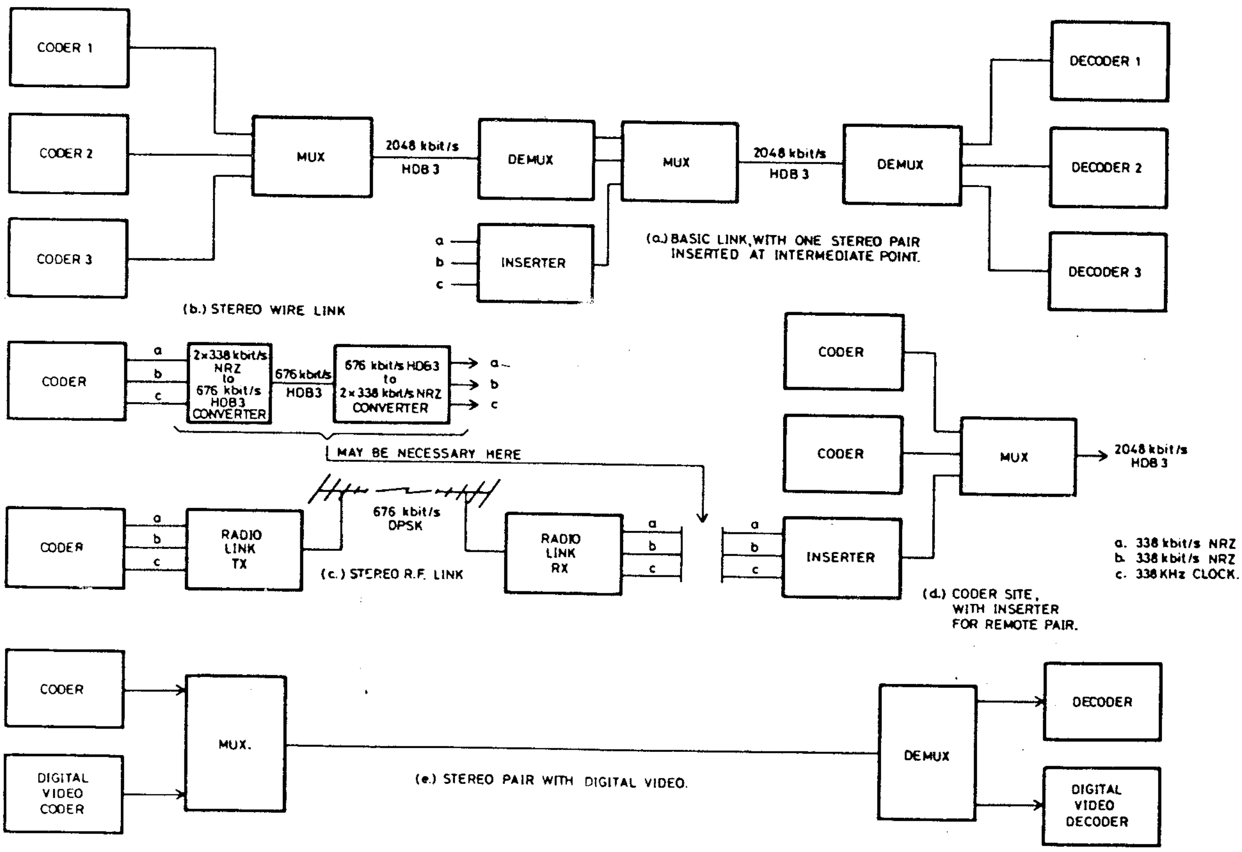


Fig. 3. NICAM 3. SOME POSSIBLE ARRANGEMENTS.