SCIENCE & TECHNOLOGY

DIGITAL SHORT-RANGE RADIO

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1. Introduction

An interim standard for Digital Short Range Radio (DSRR) has been approved recently by the European Telecommunications Standards Institute (ETSI). The institute was established by the European Community to assist with the harmonization of equipment specification and frequency allocations in member countries. The DSRR interim standard is one of its first radio specifications. It will go forward for public enquiry and, in due course, become a standard applicable in every community state. There could be modifications, but the interim standard will probably remain the basis of the final specification. After the standard has been finalized, no modifications can be introduced by individual states. In time, DSRR should become a true European radiocommunications system.

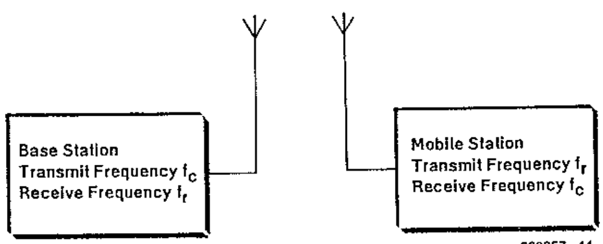
DSRR is a major advancement in business radio and should reduce many of the present problems. There are explained further in Section 2. The interim standard has a number of requirements in regard to control signalling and protocols which, at present, are not in general use. Because of developments in digital signal processing, these should not create major problems for manufacturers in the various countries. However, it also proposes the use of two frequency bands of 888–890 MHz and 933–935 MHz, known as the Low Band (LB) and the High Band (HB) respectively. The significance of two separate bands is explained in Section 3. This could result in difficulties, because EC countries are still far away from true frequency harmonization. Since the EC is committed to harmonization and the removal of trade barriers, it is considering a directive to all member states that, in order to reduce any problems in the introduction of DSRR, priority should be given to DSRR over other services in the proposed bands. At present, DSRR appears to be on target for wide use within a few years.

2. PMR channels

The channels are usually assigned for dual frequency operation, which means that a unit transmits and receives on different frequencies as in Fig. 1. If a base station has f_c and f_r as its transmit and receive frequencies, a mobile station operating to the base station must have f_r and f_c as its transmit and receive frequencies respectively. In the United Kingdom, equipment for this service must conform to the Performance Specification MPT1326. This is a fundamental specification and DSRR units must meet a similar specification—see Appendix 5. The difference is the method of operation and the use of the channels.

In the PMR (Private Mobile Radio) service, the main barrier to further development is the method of using the radio frequency spectrum. In assigning channels to users, there is insufficient spectrum for every user to have his own channel. That means that a number of users must share the same channel. This, in turn, causes a nuisance effect and loss of confidentiality since every message on a channel is detected by every receiver irrespective of the intended destination. Tone control, like EEA or ZVEI, can be used to minimize this effect. At the start of a message a transmitter sends a specific sequence of tones. Only the intended receiver can identify the sequence and is activated from the point of the operator. If an incorrect sequence, that is, a sequence for a different receiver, is detected, the receiver remains deactivated. Unfortunately this process does not solve the problem of channel sharing. A common occurrence is that two users wish to use the channel at the same time. Therefore each user must monitor the channel to ascertain that it is free before he can commence operation. Queues often occur despite the fact that many channels are regularly idle. DSRR should reduce this problem by making more efficient use of the spectrum. It should also improve user confidentiality without the need of secrecy operations, that is, encryption procedures.

1



3. DSRR frequency bands

There are two bands of 2 MHz in which channels are assigned with 25 kHz channel spacing as follows.

Channel	High band	Low band
01	933 025 MHz	888 025 MHz
02	933 050 MHz	888 050 MHz
03	933 075 Mhz	888 075 MHz
..	...	...
77	934 925 MHz	889 925 MHz
78	934 950 MHz	889 950 MHz
79	934 975 MHz	889 975 MHz

Channels 01 and 79 are used as control channels for selective signalling (SSC) and cannot be used to transmit or receive voice or data. The traffic channels are 02 to 78 inclusive: the usual type of operation illustrated in Fig. 2. Two units, A and B, operate to each other through a repeater or master unit. This is dual-frequency operation with repeaters and master units transmitting in the High Band and receiving in the Low Band. Units (mobiles) transmit in the Low Band and receive in the High Band. If A and B want to operate directly to each other, single frequency operation would be used. In this method, the units transmit and receive on the same channel in the same band: High Band.

In operation, a unit will scan and identify a free traffic channel which is subsequently used for voice or data. The number of the

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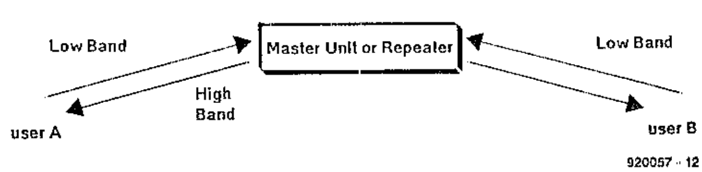

particular traffic channel plus certain control signals are transmitted to the intended receiver on the control channels. In order to avoid congestion, where a number of units would be considering the same traffic channel, there is a specific algorithm for channel spacing:

$$N_j = (N_{j-1} + 1) \bmod 77 + 2 \qquad \text{[Eq 1]}$$

for j>0 where N_0 is the seed. Thus, the mathematical operation is an additive congruence generator where N_j will only take values between 2 and 78 inclusive. The two control channels, 01 and 79, will be excluded automatically. If a different seed is used by different units, the chances of two or more units identifying and choosing the same channel would be greatly reduced. On switch-on, the seed is the least significant 7 bits of the call code (refer SSC). For successive seeds, the least significant 7 bits of the 16 check bits of the previous SSC is used. This is discussed in more detail in Section 5.

4. DSRR modes of operation

There are three main modes of operation.

a) In the *standby mode* a unit monitors 2 control channels for the appropriate control signals. It does not transmit or receive voice or data.

b) In *call set-up mode* a unit transmits and receives control signals (no voice or data).

c) In *communication mode* a unit is in full operation, that is, transmitting and receiving voice or data. Control signals are also transmitted and received in this mode.

Consider an example where user A wishes to contact user B in single-frequency operation. The main steps can be summarized by the following procedure, in which it has been assumed that *A* has just been switched on and is in the standby mode.

i) *A* enters call set-up mode. The traffic channels are scanned to find a free channel. If no channel is available, the unit will return to standby mode.

ii) *A* transmits an *SSC* on the control channel to *B*. This code includes identifiers for *A* and *B*, number of proposed traffic channel, and so on. The format of the code words is discussed in Section 5. *A* switches to receive mode on the control channel.

iii) *B* transmits an *ACK* to *A* on the control channel and switches to receive mode on the traffic channels specified in the *SSC* from *A*. On receipt of the *ACK* from *B*, *A* switches to the traffic channel. If no *ACK* or another *SSC* different from ii) is received by *A*, a set of retry procedures is implemented.

iv) *A* transmits the call set-up *SSC* as in ii) on the traffic channel to *B*. *B* sends an *ACK* and both units enter communication mode. If no voice or data is transmitted after 10 seconds, or if the traffic channel has become busy between ii) and iv), or the *SSC* or *ACK* is not received, both units revert to standby mode.

v) In communication mode, all transmissions are preceded by a full *SSC*. There is a limit of three minutes to the time in communication mode in order to avoid congestion. In addition, if no valid voice or data is received after a certain period (5 seconds, or 10 if the unit has just entered the mode), both units return to the standby mode.

This is a simplified description and the reader should consult the official standard for a proper explanation. For operation through repeaters or master units, the procedure must be varied. However, the entire operation is a major change from the present method for PMR. The digital signal processing as in the SSC and ACK control signals is central to the system.

5. Selective signalling code

The selective signalling code (SSC) is a block of 568 bits which is fundamental to DSRR operation in all mode. It is sub-divided into the following blocks:

a) Preamble of 256 bits of 1010 ...,etc. (bit reversal) for bit synchronization of the decoder in the receiver.

b) Frame synchronization of 16 bits to establish code word framing in the decoder of the receiver.

c) Code word of 88 bits.

b) and c) are transmitted three times as in Fig. 3.

3

Preamble 256	Frame Synchronization 1 16	Code Word 88	Frame Synchronization 2 16	Code Word 88	Frame Synchronization 3 16	Code Word 88

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The code word in c) is sub-divided further as follows:

SSC number	1	
Traffic channel code	7	
First call code	24	
Command code	4	
Reserved	2	
Code word counter	2	
Manufacturer's code	8	
Second call code	24	72 bits
Cyclic redundancy check	16	

The 16 check bits are generated from the 72 other bits by a (88,72) cyclic code which has as its generator polynomial

$$x^{16}+x^{14}+x^{12}+x^{11}+x^{9}+x^{8}+x^{7}+x^{4}+x+1.$$

This should be a factor of $(x^{88}+1)$ as per the mathematical conditions for cyclic codes. Refer to Appendix 1 for the various factors and other information. The code is supposed to have a *Minimum Distance* of 6 which will permit detection of up to five errors per word. This is the minimum number if differences in any two code words of 88 bits and is explained further in Appendix 2. The encoding operation can be summarized in the following steps:

1) Code word ($d_{72}\, d_{71}\, d_{70} \ldots d_3\, d_2\, d_1$) before the check bits are generated.

2) Code word

88 87 86 ... 19 18 17	16 15 14 ... 3 2 1
$d_{72}\, d_{71}\, d_{70} \ldots d_3\;\; d_2\;\; d_1$	* * * ... * * *
Data bits	Check bits

3) Code word can be written as a polynomial over GF(2) as follows:
$d_{72}\, x^{87} + d_{71}x^{86} + \ldots d_3x^{18} + d_2x^{17} + d_1x^{16}$
with the check bits taken to be zero in each of the terms from x^{15} to x^0.

4) Polynomial in 3) is divided by the generator polynomial and the remainder, which is a polynomial of degree 15 with terms from x^{15} down to x^0, is added back to the original polynomial in 3) to produce the new revised polynomial of the final code word. The * in each location from 1 to 16 has now been replaced by a '1' or '0' as appropriate.

5) The final check bit corresponding to the coefficient of x^0 is inverted in order to give protection against misframing in the decoding operation.

The format for the ACK signal is exactly the same as for the SSC, but there are some variations. For example, the First Call Code for the SSC becomes the Second Call Code for the corresponding ACK signal.

6. Speech codec

Each speech frame of 20 ms is encoded into 76 speech parameters and this in turn is processed as a block of 260 bits. It should be noted that these bits are not of equal value. However, there is no need to examine this point. The codec is similar to that for the GSM

(Groupe Special Mobile formed by CEPT in 1982 to write a Pan European Digital Cellular Telephone Standard).

The 34 significant bits, known as Class 1 bits, from the 260 bit block are expanded to 39 by the addition of five parity bits. A cyclic code with generator polynomial $(x^5 + x^2 + 1)$ produces the additional bits. The procedure is exactly the same as in Section 5 with the exception that the block size is 39. The generator polynomial should be a factor of $(x^{39} + 1)$ as per the mathematical requirements. Refer to Appendix 1 for the various factors and additional information. The check bits represent the lower powers of the new polynomial for x^4 down to x^0.

4

Location 43 Tail Bits (4)	Location 39 Data Bits (34)	Location 5 Check Bits (5)	LSB

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The 39 bit block is again expanded to 43 by four tail bits that are set to '0'. The positions are shown in Fig. 4. This new 43-bit block is re-ordered by a permutation operation as follows:

position $(n) \Rightarrow$ position $(17+n)$ for $n = 1$ to 5;
position $(n) \Rightarrow$ position $(n/2-2)$ for $n = 6, 8, 10, 12 \ldots 38$;
position $(n) \Rightarrow$ position $[42-(n-1)/2]$ for $n = 7, 9, 11 \ldots 39$

The positions in the actual standard are numbered from 0 to 42 and 0 represents the least significant location. The data bits are given as d(0) to d(33) with d(33) corresponding to the term x^{38} of the polynomial. Refer to Appendix 3 for the complete table.

The 43-bit block is expanded to 86 with a convolutional code as follows:

43-bit block $(d_{43}\ d_{42}\ d_{41} \ldots d_3\ d_2\ d_1)$

86-bit block $(b_{86}\ b_{85}\ b_{84} \ldots b_3\ b_2\ b_1)$

$$b_{2n} = (d_n + d_{n-3} + d_{n-4}) \bmod 2$$
$$b_{2n+1} = (d_n + d_{n-1} + d_{n-3} + d_{n-4}) \bmod 2$$

for $n = 1$ to 43 and $d_m = 0$ for $m \leq 0$

5

Location 312 Class 2 Bits (226)	Location 86 Convoluted Block	LSB

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A new 312-bit block is formed by the 86 bits and the unused 226 bits, known as Class 2 bits, from the original block as in Fig. 5.

6

Location 320 319 318 317 316 315 314 313 1 0 0 1 0 1 1 1 Synchronization Bits (8)	Location 312 Class 2 Bits (226)	Location 86	LSB

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A new block of 320 bits is generated as in Fig. 6 by the addition of eight synchronization bits. The bits are re-ordered according to the equation

position $n \Rightarrow$ position $[16\,(k \bmod 20) + \text{INTEGER}\,/(20 + 1)]$

for $k = 0$ to 319. n refers to the position in the new block. The first bit $(n = 1)$ is transmitted first.

7. Summary

The overall situation can be summarized in the following points

(1) DSRR is more efficient in the use of spectrum since High Band and Low Band require a total of 4 MHz.

(2) DSRR provides a higher level of confidentiality and protection for the average user. In business radio, each user is licensed for a specific channel that must be shared with other users. A channel could be unintentionally or deliberately blocked by an unmodulated carried. Te Co-channel Rejection Test in MPT 1326 (which was not in the previous specification MPT 1301) does reduce but not eliminate, this problem. In addition, users can obtain low-cost scanning equipment to monitor messages to and from competitors. However, in DSRR, a user does not actually know the traffic channel that is chosen automatically by a scanning algorithm.

(3) The DSRR Standard has no requirement for an encryption facility as in the GSM. The method of encryption for the GSM has not been made public, but is believed to be a stream cryptosystem. A pseudo-random binary sequence is generated by an arrangement of shift registers and applied to the sequence of data bits in an addition modulo 2 operation. For the DSRR, there is no reason that an encryption device, such as a scrambler, cannot be added, but this is not required to meet the standard.

(4) DSRR has scope for further development and expansion. In business radio, a reduction in the channel spacing to $6^1/_4$ kHz would provide more channels, but would not be considered an improvement.

(5) The encoding operation for data other than voice transmission is left to the manufacturer. The decoding operation for control signals, voice and data is also left to the manufacturers.

Appendix 1

The following factors were obtained using MATHEMATICA by Stephen Wolfram

$$(x^{88} + 1) = (x + 1)^8 (x^{10} + x^9 + x^8 + x^7 + x^6 + x^5 + x^4 + x^3 + x^2 + x + 1)^8$$

$$(x^{16} + x^{14} + x^{12} + x^{11} + x^9 + x^8 + x^7 + x^4 + x + 1) = (x + 1)^2 (x^7 + x^6 + x^3 + x + 1)(x^7 + x^6 + x^5 + x^4 + x^3 + x^2 + 1)$$

$$(x^{39} + 1) = (x + 1)(x^2 + x + 1)(x^{12} + x^{10} + x^9 + x^8 + x^7 + x^3 + x^2 + x + 1)(x^{12} + x^{11} + x^{10} + x^9 + x^5 + x^4 + x^3 + x^2 + 1)(x^{12} + x^{11} + x^{10} + x^9 + x^8 + x^7 + x^6 + x^5 + x^4 + x^3 + x^2 + x + 1).$$

$(x^5 + x^2 + 1)$ has no real factors

The interim standard does not include an analysis of the generator polynomials and, consequently, the choice of the factors in each of the two cases is not known.

Appendix 2.

Consider a simple 3-bit word that has an additional bit for even parity. Any two code words differ in at least one position in order to have distinct code word. When the parity bit on the right in the table is included, the minimum variation becomes 2. To correct a single error per word, the minimum variation would have to be 3. This is know as the *Minimum Distance*. A typical example is the (7, 4) Hamming Code, which has four data and three check bits. A code of Minimum Distance 5 would be able to detect up to four errors per word or be capable of correcting up to two errors per word.

0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

Appendix 3.

Permutation 1

…ition	New position	Notation in DSRR Standard		
1	18	0	p(0)	17
2	19	1	p(1)	18
3	20	2	p(2)	19
4	21	3	p(3)	20
5	22	4	p(4)	21
6	1	5	d(0)	0
7	39	6	d(1)	38
8	2	7	d(2)	1
9	38	8	d(3)	37
10	3	9	d(4)	2
11	37	10	d(5)	36
12	4	11	d(6)	3
13	36	12	d(7)	35
14	5	13	d(8)	4
15	35	14	d(9)	34
16	6	15	d(10)	5
17	34	16	d(11)	33
18	7	17	d(12)	6
19	33	18	d(13)	32
20	8	19	d(14)	7
21	32	20	d(15)	31
22	9	21	d(16)	8
23	31	22	d(17)	30
24	10	23	d(18)	9
25	30	24	d(19)	29
26	11	25	d(20)	10
27	29	26	d(21)	28
28	12	27	d(22)	11
29	28	28	d(23)	27
30	13	29	d(24)	12
31	27	30	d(25)	26
32	14	31	d(26)	13
33	26	32	d(27)	25
34	15	33	d(28)	14
35	25	34	d(29)	24
36	16	35	d(30)	15
37	24	36	d(31)	23
38	17	37	d(32)	16
39	23	38	d(33)	22
40	40	39)		
41	41	40)	tail bits set to '0'	
42	42	41)		
43	43	42)		

Appendix 4.

Permutation 2

Position	k	16(k mod 20)	Integer (k/20)	New position (n)
1	0	0	0	1
2	1	16	0	17
3	2	32	0	33
…	…	…	…	…
20	19	304	0	305
21	20	0	1	2
22	21	16	1	18
…	…	…	…	…
40	39	304	1	306
41	40	0	2	3
42	41	16	2	19
…	…	…	…	…
319	318	288	15	304
320	319	304	15	320

Appendix 5.

Radio frequency characteristics

Transmitter	
Frequency error	±2.5 kHz (maximum)
Carrier power	4 watts (maximum)
Adjacent channel power	≥70 dB below carrier power or 0.2 µW (maximum)
Spurious emissions	0.25 µW (maximum) 2 nW (maximum) in standby mode
Intermodulation attenuation	≥40 dB for any component
Receiver	
Sensitivity	6 dB µV e.m.f. (maximum) for a bit error rate of 10^{-2}
Co-channel rejection	−18 dB (minimum)
Adjacent channel selectivity	50 dB (minimum)
Intermodulation response	55 dB (minimum)
Spurious response rejection	60 dB (minimum)
Blocking	84 dB (minimum)
Spurious radiations	2 nW (maximum)

For the actual methods of measurement, the reader should consult the standard.