REPORT ITU-R M.2010-1

IMPROVED EFFICIENCY IN THE USE OF THE BAND 156-174 MHz BY STATIONS IN THE MARITIME MOBILE SERVICE

(Question ITU-R 96/8)

(1993-1997)

1 Introduction

1.1 Recommendation 318 (Mob-87) of the World Administrative Radio Conference for the Mobile Services (Geneva 1987) (WARC Mob-87) invites the ITU-R urgently to undertake studies to determine the most appropriate means of promoting a more efficient use of the frequency spectrum in the VHF maritime mobile band.

1.2 This Report includes a survey of spectrum conserving technologies and systems, used in or proposed for the private land mobile services, and examines various options for their suitability to the VHF maritime mobile service. A small number were selected as having the greatest potential. These have been examined in more detail to determine the likely improvement in spectrum utilization and to identify related issues, both technical and operational, and areas requiring further study.

2 Survey of technologies and systems

The maritime service must at all times provide an effective communication channel for distress and safety calls, for search and rescue operations, and for navigational information. In addition the service supports public correspondence, the broadcast of weather bulletins, port and harbour control communications and intership communications. These factors have to be considered in assessing the suitability of the alternative technologies and systems. It is particularly important that any changes to the current system:

– be implementable within the maritime VHF band as additional spectrum cannot be expected in the foreseeable future;

– provide a significant increase in spectrum capacity; the changes will have to provide enough capacity to satisfy the growth expected over the next ten or more years. However it should be noted that existing terrestrial cellular systems already cover some coastal waters and are relieving some of the pressure from public correspondence channels in the maritime VHF band;

– have minimal impact on the existing services, particularly the operation of distress and safety channels;

– take advantage of new technologies available including data transmission (see Annex 1) to provide new features, such as encryption to provide added security and privacy.

The alternative technologies and systems reviewed in this study are outlined below.

2.1 Narrow-band modulation

Replacing the current 25 kHz channels with channels of a narrower bandwidth would be a straightforward way of obtaining more channels. In principle halving the bandwidth would provide twice as many. In practice adjacent and co-channel performance is usually reduced with the result that reuse distances are increased and the full potential gain is not always realized.

The following narrow-band technologies have been considered:

– 12.5 kHz channel spacing using analogue FM. Potentially this could provide up to twice as many channels;

– 6.25 kHz channel spacing using digital speech and modulation. Potentially this could provide up to four times as many channels;

– 5 kHz channel spacing using linear modulation (a form of single-side band (SSB) modulation). Potentially this could provide up to five times as many channels.

All three approaches could provide significant capacity gains, are applicable to the VHF band, and would not entail any major changes in the way that current services operate. All are evaluated further in § 3.

2.2 25 kHz 4-time division multiple access (4-TDMA) approach

25 kHz 4-TDMA is likely to be used for land mobile applications in some parts of the world and is therefore likely to benefit from economies of scale. A 25 kHz 4-TDMA system called TETRA is the most likely candidate for future land mobile applications in Europe.

TETRA is an open European Standard and is a spectrally efficient, feature-rich system which could readily be adapted for operation in the maritime environment. In terms of spectral efficiency, TETRA compares well with the other systems under consideration and represents a raw gain in channels/kHz of 4:1 over 25 kHz FM with a high data rate capability, particularly if multiple time slots are used.

TETRA is being considered for use in the United Kingdom for maritime applications limited to national maritime applications. A description of this approach can be found in Annex 2.

2.3 Replacement of speech by data

In applications where standard messages are often used, or the message is one way, the transmission of text instead of voice can save a significant amount of channel time. For example, a 10 s voice message can be sent as text using data transmission at 1 200 bit/s in 2 s, and in less at higher bit rates. This offers a 5 to 1 improvement in channel capacity or better. However the extent to which this can be realized in practice depends on the extent to which text can replace voice.

On the optimistic assumption that half of all port operations traffic, but not public correspondence or ship-to-ship communications, can be replaced by data transmission the increase in capacity on the international frequencies would be equivalent to an additional six duplex and four simplex channels. Overall capacity would be increased by a factor of 1.2.

2.4 Automatic call set-up

The introduction of automatic call set-up systems provides a small increase in capacity, e.g. 20% assuming an existing manual call set-up time of 0.5 min for an average 2.5 min call.

3 Selected narrow-band modulation options

All the narrow-band technologies considered here are equally applicable to duplex and simplex channels.

3.1 12.5 kHz analogue FM

12.5 kHz FM modulation is already widely used in land mobile radio and could be adopted to give a halving of the channel spacing. The main advantage of this approach is that the technology is available and proven, and that the new equipment would be inter-operable with existing sets (with some reduction in performance). The major disadvantage is the limited gain in capacity relative to alternative narrow-band modulation techniques.

3.1.1 Spectrum/capacity gain

Halving the channel bandwidth would provide double the number of channels. There is, however, an increase in susceptibility to co-channel interference and therefore the minimum reuse distance would be increased. In areas where the reuse distance is anyway greater than this minimum the full gain in capacity of a factor of two would be obtained.

3.1.2 Operational issues and migration

Operationally there would need to be no changes and the new equipment would be interoperable with old equipment. Migration would be straightforward. Initially new channels could be interleaved (with suitable planning e.g. with sufficient geographical or frequency separation), and then progressively changed over to 12.5 kHz. Thus extra channels can be provided first where needed most.

3.1.3 Equipment

Equipment is available and in use for private land mobile today in the VHF bands. Costs would be expected to be about the same as for existing 25 kHz equipment.

3.2 5 kHz or 6.25 kHz linear modulation

Linear modulation based on amplitude compandored SSB (ACSSB) with transparent tone in band (TTIB) and feed forward signal regeneration (FFSR) has been shown to be suitable for land mobile radio use in 6.25 kHz [McGeehan and Bateman, 1983] and 5 kHz [Baden and Jenkins, 1990] channels. The major advantage of this technology is the large gain in spectrum capacity with little or no change to operational procedures. Its main disadvantage is the limited availability of commercial equipment at the present time, although some use is being made of 5 kHz and 6.25 kHz equipment for the land mobile service in the United States and is therefore likely to become more readily available in the future.

3.2.1 Spectrum/capacity gain

5 kHz channelling would provide five times as many channels as are presently available. As with 12.5 kHz analogue FM the susceptibility to co-channel interference, and therefore the minimum reuse distance, is increased. In areas of intense frequency reuse the overall gain in capacity will be less than a factor of 5. French [1979], suggests that a factor of 2.5 is likely, although later (unpublished) studies indicate the higher reuse factor can be expected.

3.2.2 Operational issues and migration

Operationally there need be no changes. During the changeover phase, however, extra equipment or dual mode transceivers would be required. Migration would be by interleaving (possibly with two SSB channels between each old channel). Thereafter FM channels have to be taken out and replaced by narrow-band channels.

3.2.3 Equipment

ACSSB equipment is not at present in widespread use. However equipment has been developed and is being used on a limited basis at 220 MHz in the United States of America.

3.3 6.25 kHz channels with digital modulation

A digital speech codec and digital modulation could be used to provide a single speech channel in a 6.25 kHz channel. Such a system could flexibly support both speech and data. A built-in advantage of this system is that of inherent privacy and security, thus alleviating growing problems of this nature.

3.3.1 Spectrum/capacity gain

This approach would increase the number of channels by a factor of 4. The adjacent and co-channel performance of this format is not established, however, but in areas of intense frequency reuse the gain achievable may be less.

3.3.2 Operational issues and migration

Operationally there need be no changes but extra equipment or dual mode transceivers would be required during the changeover phase. Migration to the new system would be similar to 5 kHz ACSSB.

3.3.3 Equipment

There is no known prototype equipment. Initially costs would be expected to be higher than current 25 kHz equipment but would fall with volume production.

4 Re-allocation of duplex channels to simplex

4.1 Spectrum/capacity gain

The capacity of each pair of duplex frequencies re-allocated as simplex channels is doubled. However, not all duplex channels could be re-assigned. Public correspondence channels, for example, would not be suited to simplex working. Making the assumption that all duplex channels exclusive to port operations and half those shared with public correspondence could be re-allocated as two single frequency channels the number of extra channels obtained is 16. This is equivalent to a gain in capacity of a factor of 1.3.

It should be noted that single frequency operation is normally to be avoided at radio stations required to operate on more than one channel at a time. Receiving on one antenna while transmitting on a nearby frequency on an adjacent antenna requires very high levels of filtering and considerably increases the engineering problems and cost of the installation.

4.2 Operational issues and migration

The introduction of additional simplex channels would not require any operational changes. Duplex channels could be changed over individually or in groups. New equipment would be required only where existing equipment was not re-programmable.

4.3 Equipment

There are no technical problems or risks associated with this change.

5 Summary and conclusions

Table 1 summarizes the main characteristics of the selected options.

TABLE 1

Comparison of the selected options

Option	Gain in capacity	Operational implications	Migration	Equipment
12.5 kHz analogue FM	× 1.5 to × 2	None, interoperable with existing equipment	Interleaving	Used in land mobile radio service
5 kHz or 6.25 kHz linear modulation	× 2.5 to × 5	Extra or dual mode equipment required	Interleaving (with careful planning)	In limited use in land mobile radio service
6.25 kHz channelling with digital modulation	< × 4	Extra or dual mode equipment required	Interleaving (with careful planning)	No commercial equipment available
Reallocation of duplex channels to simplex	× 1.3	None	"Over night" changeover but simple	Minor changes to current equipment
25 kHz 4-TDMA approach	× 4	New equipment required	Long transition period	Maritime versions of land mobile radio equipments

Changing to 12.5 kHz analogue FM or re-allocating duplex channels to simplex operation would be the simplest approach to improving spectrum utilization. Both would have minimal impact on current operations and a straightforward migration path. Spectrum utilization would increase by a factor of between 1.5 and 2 with 12.5 kHz analogue FM, and by a factor of 1.3 with re-allocation of duplex channels. By combining both changes, the number of duplex channels could be maintained at their present levels and the spectrum utilization gain increased to a factor of approximately 2.5.

Larger gains in spectrum utilization would be achieved with either 5 kHz linear modulation or with 6.25 kHz channels and digital voice. The former would increase utilization by a factor of between 2.5 and 5, the latter by a factor of up to 4 plus inherent security and privacy. The penalty would be the need for dual mode equipment during changeover and the increase in equipment costs. Neither technology is yet in widespread use but 5 kHz linear modulation (ACSSB) is in limited commercial use in the United States. However, it should be borne in mind that any change to the channelling arrangement of Appendix S18 to the Radio Regulations (RR) will require a decision by a future competent world radio conference which could not occur before 1997 at the earliest, by which time use of these technologies by the land mobile service is likely to have reduced the cost significantly.

The estimates of spectrum gain presented in this Report are based on studies of land mobile radio and as such provide only a guide to the performance likely in the VHF maritime band. Before firm conclusions can be drawn further work is required to verify the estimates. In particular the adjacent and co-channel performance and its implications for frequency reuse require further study.

It can be seen that 5 kHz linear modulation or 6.25 kHz channelling with digital voice or data provide the greatest potential for a significant increase in efficiency in the use of the maritime VHF band and should be the prime candidates for further study.

Annex 1 (Rationale for implementing the interim step of 12.5 kHz channel spacing) provides an example and description of a system which may be implemented within the United States for use with vessel traffic service (VTS) systems.

Annex 2 provides a description of how a 25 kHz TDMA system could be employed in the maritime VHF working environment.

REFERENCES

BADEN, C. C. E. and JENKINS, A. P. [August 1990] Linear modulation trials. Final report, University of Bradford.

FRENCH, R. C. [3 August 1979] The effect of fading and shadowing on channel reuse in mobile radio. *IEEE Trans. Vehicular Tech.*, Vol. VT-28, **3**.

McGEEHAN, J. P. and BATEMAN, A. J. [1 February 1983] Theoretical and experimental investigation of feed forward signal regeneration as a means of combating multipath propagation effects in pilot-based SSB mobile radio systems. *IEEE Trans. Vehicular Tech.*, Vol. VT-32, **1**.

ANNEX 1

Rationale for implementing the interim step of 12.5 kHz channel spacing

This Annex provides an example and description of a system which may be implemented within the United States for use with VTS systems.

1 Problem definition

The maritime mobile frequency band (156-174 MHz) supports maritime communications in coastal areas and inland waterways worldwide. RR Appendix S18 defines the channels of the maritime mobile service. These channels must support a variety of functions including: public correspondence, intership and ship-to-coast, port operations, calling and various safety purposes.

The main function of the existing VHF maritime mobile service is to provide voice and data communications among ships and coast stations for public correspondence, ship operation, intership communications, ship movement and for safety purposes. Although not used extensively, data communications are available on various channels, subject to special arrangement between interested and affected administrations. Most of the communications in the maritime mobile service is performed using analogue FM techniques for voice communications, although future requirements for digital information exchange are expected to increase.

In addition to voice communications, provisions in RR Appendix S18 also consider the use of high-speed data and facsimile transmissions as well as narrow-band direct-printing (NBDP) telegraphy and data transmission, subject to special arrangement between interested and affected administrations on various channels. Currently, the requirement states data rates of the order of 100 or 200 Bd. Articles S51 and S52 of the RR provide technical characteristics for these functions.

Congestion has become a serious problem in many areas of the world because of the rapid increase in maritime mobile usage of VHF-FM. This has resulted in degraded effectiveness of distress and safety calls on the calling channel. Since use of the maritime mobile service for voice and data is continuing to grow, this situation will worsen unless action is taken, intensifying the impact to critical services, including those used for safety and distress.

Many public correspondence providers are desirous of implementing advanced voice traffic management systems in order to increase the volume of traffic that can be accommodated. The advantageous use and implementation of these new technologies is largely dependent on the availability and efficient use of channels as would be made available by the implementation of a 12.5 kHz channel implementation scheme.

In addition, administrations implementing modern VTS, using such techniques as automatic dependent surveillance, will need internationally compatible radio channels set aside for data transmissions. For example, the United States Coast Guard envisions VTS systems in the near future moving towards automated dependent surveillance, NBDP (e.g., NAVTEX), and other digital technology which will require better spectrum management in the VHF band. By pursuing this change now, VTS will be able to take advantage of improved technology and improved spectrum management, towards developing a “voiceless” VTS.

The allocation of new additional spectrum cannot be expected in the foreseeable future. Therefore, more efficient use of the spectrum must be effectuated to provide additional channels that can be implemented in the maritime mobile service as soon as possible. Required changes must take into account other factors, such as use of low-cost transceivers interoperable with existing 25 kHz FM equipment, and the time period in which targeted improvements can be achieved. Furthermore, any new technology to reduce spectrum congestion and improve spectrum efficiency in the maritime mobile service in the short term must be able to provide for growing maritime mobile requirements while maintaining the effectiveness of distress and safety communications. Specifically, the availability of distress and safety communications for every user should not be diminished by new technology (e.g., when the new service is implemented, both new and existing transceivers should be interoperable and capable of participating in the VHF maritime distress and safety system).

2 Design requirements for future systems

Future systems should take into account several key factors related to current activities and plans for utilization of the RR Appendix S18 VHF frequency band.

2.1 GMDSS/SOLAS requirements and acceptance

Most administrations in the maritime community are currently making it mandatory to equip vessels with new VHF transceivers in compliance with the International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended in 1988, which invokes the Global Maritime Distress and Safety System (GMDSS) requirements of the International Maritime Organization (IMO) Resolution A.609 (15) (Performance Standards for Shipboard VHF Radio Installations Capable of Voice Communication and Digital Selective Calling) and Recommendation ITU-R M.493 (Digital selective-calling system for use in the maritime mobile service). Thus, any new design proposal should include these requirements without degradation in the performance of individual mobile transceivers or the overall spectrum environment.

2.2 Widespread acceptance of digital selective calling (DSC)

Major manufacturers in Europe, Asia and the United States of America have already begun to produce and sell DSC VHF marine transceivers, both mobile and base stations. DSC provides a means of performing all of the necessary and desirable features of a radio communication system including:

– trunking,

– selective calling (individual and group),

– distress calling (with emergency locating),

– radio packet data transmission,

– automatic dependent surveillance (ADS),

– vessel traffic information system (VTIS),

– automated public correspondence systems,

– automated landline interconnection,

– interoperability with current analogue infrastructure.

These features have already been detailed in several ITU-R and IMO documents and are now being included in new equipment designs.

2.3 Increased emphasis on communications interoperability

Recent catastrophic accidents resulting in loss of life, loss of property and damage to the environment have heightened public awareness to the need for worldwide interoperability of maritime communication systems and equipment. Given that analogue voice FM and DSC data protocols on 25 kHz channel spacing are currently used worldwide, any new design should provide for these modes of operation. Furthermore, any new communication frequency channels should lie in between existing channels and occupy a bandwidth not already occupied by existing channels so as not to degrade existing necessary service. In addition, any new system should not disrupt the current infrastructure by requiring that existing wide-band equipment currently operating on the RR Appendix S18 VHF frequencies (25 kHz channel spacing) be replaced with narrow-band equipment in order to avoid interfering or being interfered with by the new narrow-band system. The new frequency scheme should be compatible with the current scheme, and the new equipment should be interoperable with the current equipment in order to gain acceptance and to insure safety on the high seas and waterways.

2.4 Usage of VHF DSC for automated dependent surveillance in vessel traffic information systems (ADS/VTIS)

Some administrations have begun to use VHF DSC for ADS/VTIS. These new systems have been used to provide highly accurate and up-to-date reports on vessel locations using a differential global positioning system (DGPS) and an electronic charting system (ECS) by means of the radio packet data features of the new generation of DSC VHF transceivers. ITU-R Recommendations will be revised to document these latest features with additions and enhancements to the DSC protocol. As one example, current plans by the United States of America and Canada call for use of this system in all major ports in North America within the next several years. Already, the United States Coast Guard is operating one of these systems in Prince William Sound, Valdez, Alaska. The critical nature of these systems also poses the need for duplex frequency groupings where base frequencies are not susceptible to interference from transmissions by mobile equipment. The advent of ADS/VTIS by means of VHF DSC makes the provision of new VHF narrow-band frequency channels urgent. This urgent need was expressed in a recent paper proposed by the International Association of Lighthouse Authorities (IALA) (IALA, 19 August 1994 – Provisions for data transmissions used by vessel traffic service systems in the VHF maritime mobile band).

2.5 Emphasis on implementation cost

Most administrations are under mandate to minimize the cost of implementing any new system. The cost of new user equipment is as of much concern as the cost of the new systems. Successful implementation of any new system necessitates acceptance by the users, some of which now have inexpensive VHF transceivers and who may be tempted to convert to cellular phones if the new VHF equipment is too expensive. Any new design must be able to satisfy all performance requirements using a minimum of circuit complexity. This emphasis on cost discourages all system design approaches which cannot be simply implemented by minor enhancements to a VHF DSC analogue FM voice/data transceiver design.

2.6 Emphasis on efficient spectrum utilization

The recent proliferation of wireless systems and services has placed extreme demands on the radio spectrum. Some administrations have already exhausted the capacity of their current VHF maritime channel allocation. Thus, any new system which proposes to use interleaved interstitial (in-between) should maximize information throughput (data rate) in the available interstitial channel bandwidth.

3 Implementation methods and trade-offs

An assessment of currently available technology in view of the requirements stated above has led to the following rationale as to how to best implement this interim solution to obtaining additional VHF FM maritime frequency channels:

3.1 Optimum channel positioning and spacing

Since current RR Appendix S18 frequency channels and infrastructure should be preserved, and since new channels must come from within the current spectrum allocation, then new channels should be interstitial frequencies positioned midway between existing channels at 12.5 kHz offsets. This will facilitate a non-interfering co-existence and allow the new frequency channels to make optimum use of available bandwidth.

For ADS/VTIS, some allocation of channels could come from within a duplex frequency channel grouping which is common to all administrations worldwide such as the channel grouping (24, 84, 25, 85, 26, 86, 27, 87, 28). If this grouping was used, eight new pairs (16 new frequencies: eight new base frequencies, and eight new mobile frequencies) would be available as interstitial frequencies midway between these “public correspondence” frequencies.

3.2 Voice transmission on new channels

Since interoperability and economic considerations are prime requirements, a good alternative for transmission of voice on the new channels is narrow-band FM (NBFM) using decreased deviation. Test results have shown that reducing the maximum allowable deviation from ± 5 kHz to ± 2.5 kHz produces less than a 1 dB loss of RF threshold sensitivity at 12 dB SINAD (see Appendix 1). Transceivers capable of working both current and new channels could use a simple switch to reduce deviation on the new channels. Alternatively, new equipment could be required to constantly transmit at reduced deviation if a transition to all narrow-band channels/equipment is desired. Wide-band FM (WBFM) and NBFM equipments would be perfectly interoperable in the interim with only a minor difference in apparent “loudness”.

3.3 Data transmission on new interleaved narrow-band channels

Only three currently available modulation methods were considered to be low cost and spectrum efficient candidates for transmission and reception of data by FM transceivers on narrow-band interstitial frequencies. These methods are:

– two-tone FSK (frequency shift keying) (currently used in all DSC transceivers at 1 200 bit/s);

– GMSK (Gaussian minimum shift keying) (currently used in MOBITEX equipment at 8 000 bit/s on 12.5 kHz band channels);

– 4-level FSK (constant-envelope 4-level FM (C4FM)) with baseband filtering (in land-mobile public safety use at 9 600 bit/s on interleaved narrow-band channels on 12.5 kHz offsets).

3.3.1 Two-tone FSK, the DSC standard method

DSC currently uses this method to accomplish packet data communications for performing all of its features and functions beyond simple FM voice transmissions. The system uses two tones (1 300 Hz and 2 100 Hz) at 1 200 bit/s with a robust combination of error checking and forward error correcting (FEC) to achieve good bit error ratio (BER) performance at long radio ranges in weak signal-to-noise ratio (*S/N*) environments. Although this method does not provide the ultimate in spectrum efficiency, it does fulfil its intended purpose and has been adopted for worldwide acceptance by all administrations. Detailed IMO and ITU-R documents are in place. However, in order to fully utilize the new interstitial channels, another method should be added to new generation DSC equipment so that new systems can maximize data rate when vessels are well within radio range, such as a VTIS coverage area.

3.3.2 GMSK

The GMSK modulation method uses a two-level frequency offset (+*f*, –*f*) scheme with Gaussian-shaped bandwidth-limiting filters at baseband to accomplish the ultimate FM-compatible BER performance at moderately low *S/N* ratios (10 dB *S/N* and above). GMSK is widely used on 12.5 kHz channel spacing in land mobile applications at 8 000 bit/s. One issue with this scheme is that implementation may be encumbered with royalty considerations due to proprietary hardware and software since no public-domain use is in effect at present. Another consideration is that actual use of high data rate operation will normally be in higher *S/N* environments (12 dB *S/N* and higher), where the emphasis may shift from (*S/N* versus BER) to (data rate versus occupied bandwidth). This is especially true if FEC is used to improve BER in moderate *S*/*N* conditions. FEC is needed in order to protect radio data systems from signal fades and impulse noise interference. For these reasons, GMSK was not considered to be the best candidate for implementation in the near term. See Figs. 1, 2 and 3 for measurement results of 8 000 bit/s GMSK performance.

FIGURE 1

GMSK 8 000 bit/s modulation. Tx RF frequency spectrum resulting from a random data input

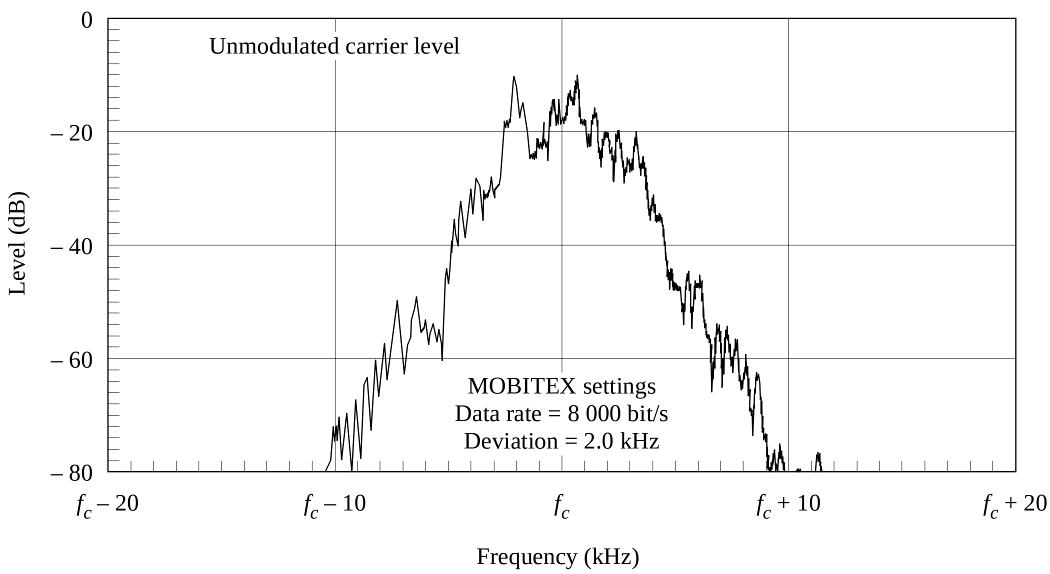

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FIGURE 2

GMSK 8 000 bit/s modulation. Typical "Tx out" frequency spectrum for a random data input

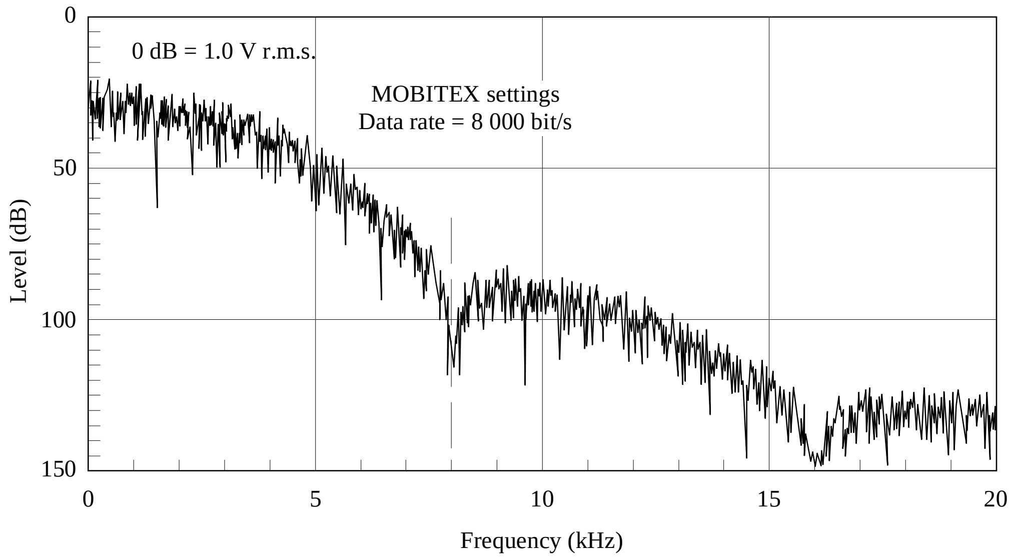

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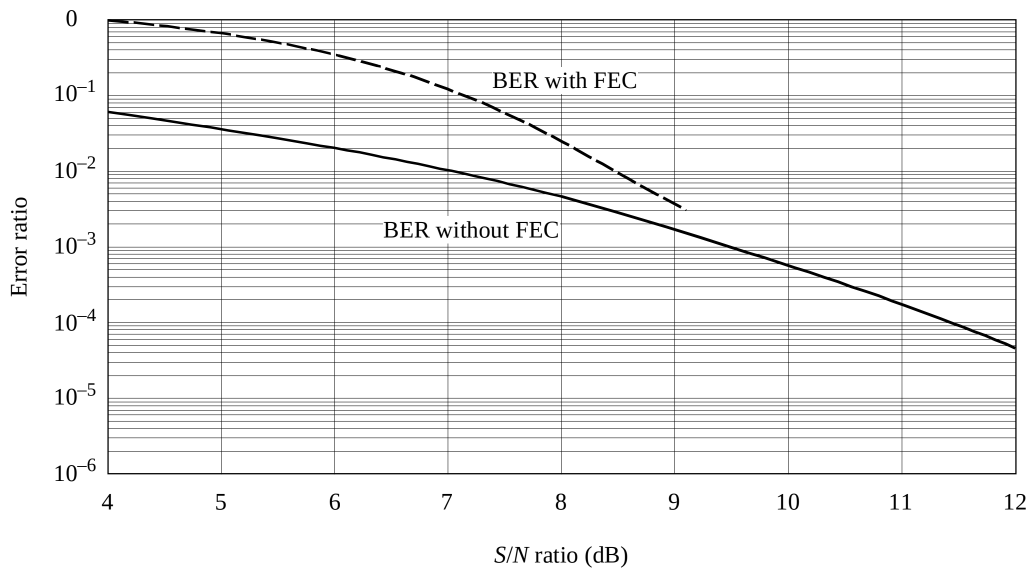
FIGURE 3

GMSK 8 000 bit/s modulation. Typical error ratios



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3.3.3 4-Level FSK (C4FM) with baseband filtering

The 4-level FSK (C4FM) method uses a four-level frequency offset (+*f*, +*f*/3, –*f*/3, –*f* for equal "eye" openings) scheme (see Fig. 4) with bandwidth-limiting filters at baseband to accomplish the ultimate FM-compatible data rate performance in a minimum occupied bandwidth at moderate *S/N* ratios (12 dB *S/N* and above). See Fig. 5 for filter response. 4-level FSK (C4FM) is used on 12.5 kHz channel spacing in land-mobile applications at 9 600 bit/s. FEC is very effective in this method to reduce BER to levels that approach GMSK performance at *S/N* ratios between 10-12 dB. Occupied bandwidth is less than GMSK, and 9 600 bit/s performance is achieved with absolutely no encroachment on 25 kHz wide-band channel occupied bandwidth. Another prime positive factor is the availability of hardware and software with usage experience in the public domain. This is due to widespread adoption in the United States of America which has been encouraged by the influence of an international group of government public safety users called “Project 25”. However, the maritime community should not adopt the land-mobile data protocol/formats for three very important reasons: non-applicability of the protocol to maritime requirements, lack of control of a protocol under separate rulemaking jurisdiction, and the worldwide acceptance of the DSC data formats and protocol which is purely under maritime rulemaking jurisdiction and has enjoyed great cooperation and progress toward the accomplishment of all applications pertinent to maritime communications. Therefore, the DSC protocol should be preserved and enhanced further as new applications arise. It is expected that some changes to the packetizing formats and FEC scheme will be needed to be documented in order to optimize performance at the higher 9 600 bit/s data rates, but the data protocol should be preserved with minimal changes. See Figs. 6, 7 and 8 for measurement results of 9 600 bit/s 4-level FSK (C4FM) performance.

FIGURE 4

4-level FSK (C4FM) 9 600 bit/s modulation

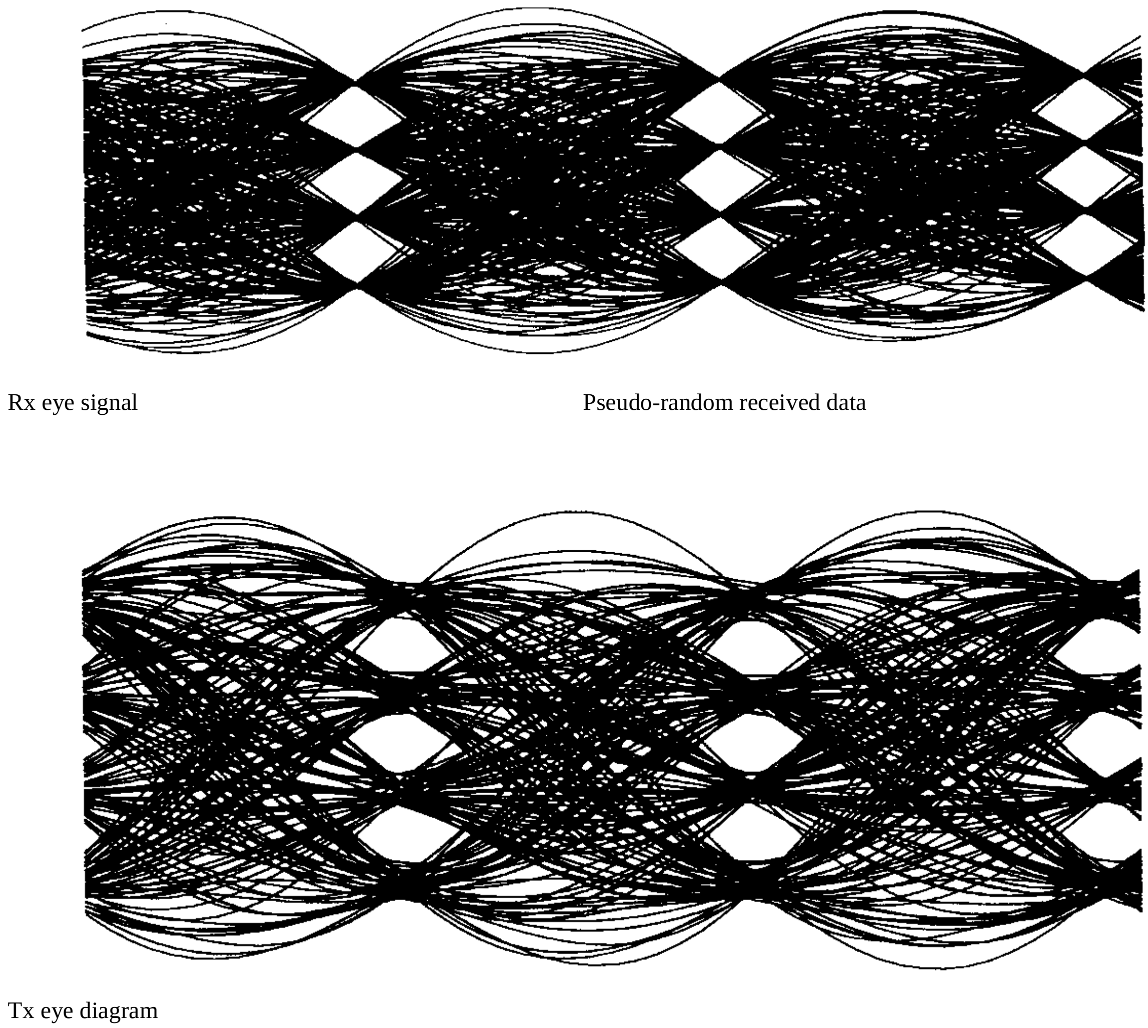

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FIGURE 5

4-level FSK (C4FM) 9 600 bit/s modulation. Filter response

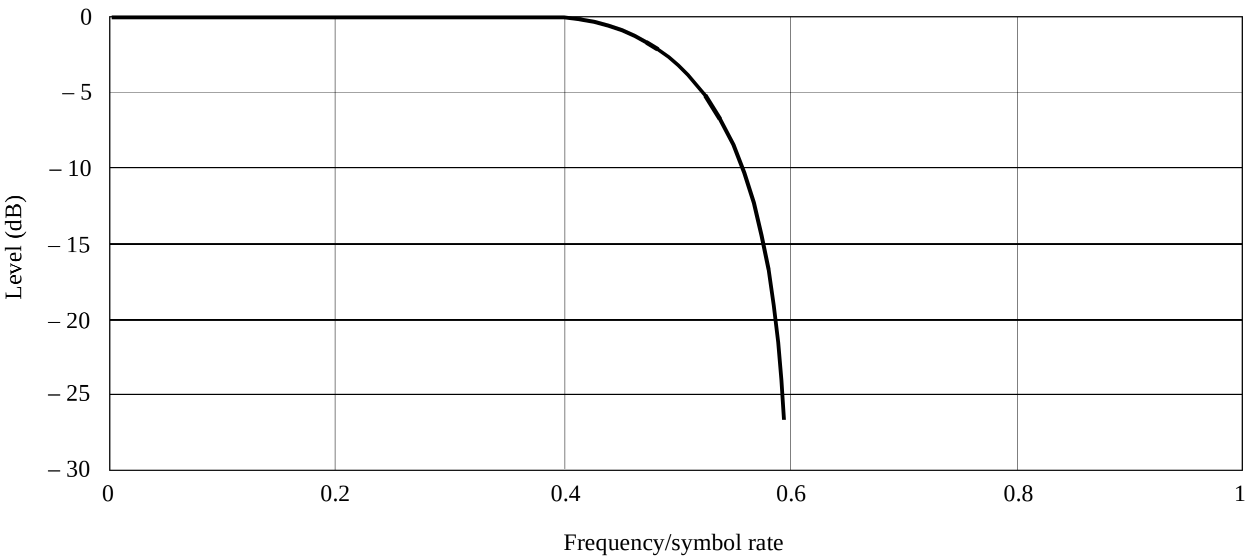

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FIGURE 6

4-level FSK (C4FM) 9 600 bit/s modulation. RF spectrum plot

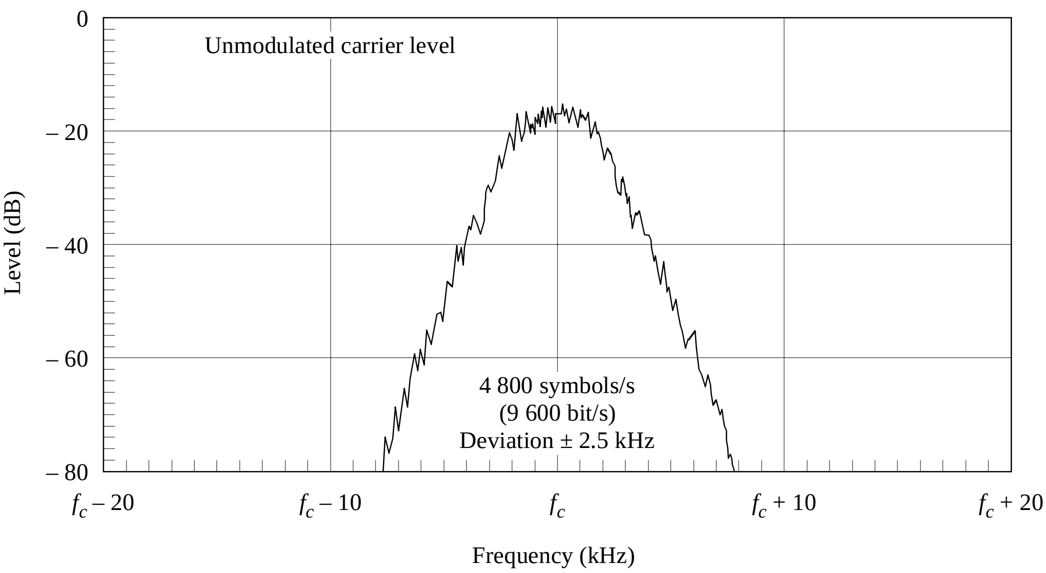

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FIGURE 7

4-level FSK (C4FM) 9 600 bit/s modulation. “Tx out” spectrum plot

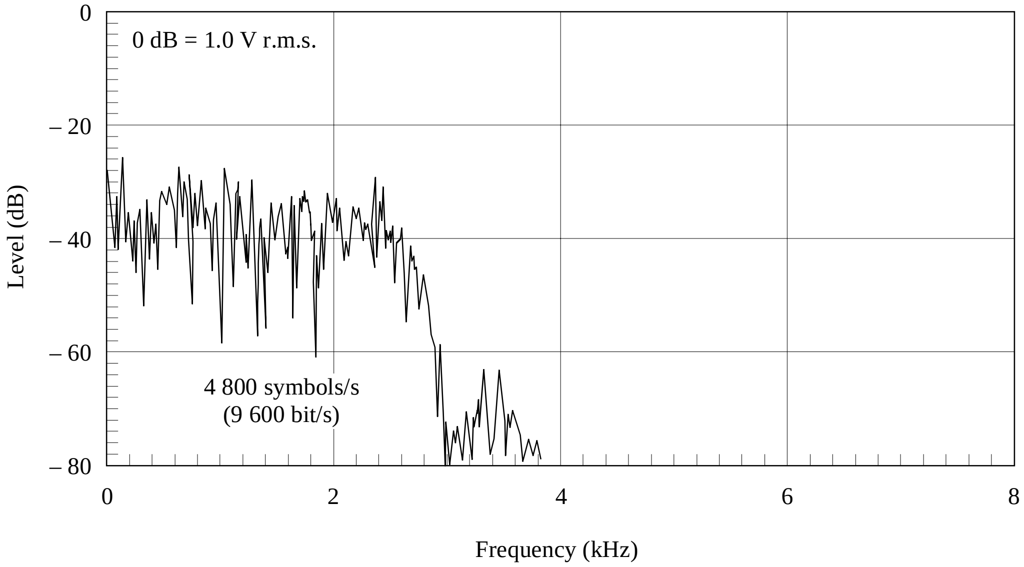

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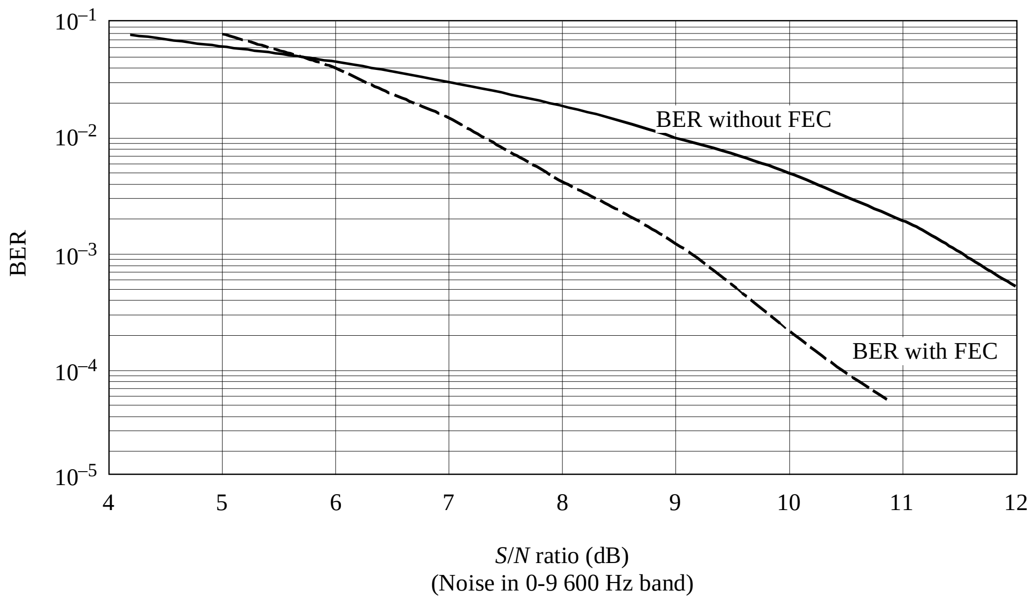
FIGURE 8

4-level FSK (C4FM) 9 600 bit/s modulation. Typical error ratios at 4 800 symbols/s



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3.3.4 Conclusions on data transmission

Because of the investments in the DSC protocol and its widespread acceptance, DSC message formats will likely be utilized for all data transmissions, both high data rate and low data rate. Two modulation methods should be used: normal DSC transmission at 1 200 bit/s, and 4-level FSK (C4FM) for high-speed DSC-formatted data transmission at 9 600 bit/s. Deviation should be limited to ± 2.5 kHz for DSC transmissions on the new interleaved narrow-band (interstitial) channels. New enhancements to the DSC protocol are presently under consideration to improve and document ADS/VTIS functionality and to address the utilization of the proposed new interstitial channels.

4 Performance standards recommendations

New performance standards are needed for new transceivers in the VHF maritime service in order to insure proper operation in a more densely crowded RF environment. Already, many users are experiencing communications interference due to inadequate receiver selectivity and dynamic range in the crowded waterways of the United States of America (for example, Mississippi River pilots have needed to order special LMR radios to work maritime frequency channels because available marine radios lacked adequate receiver performance to suppress interference due to intermodulation distortion in the receiver front end caused by nearby land mobile paging transmitters mixing with heavy marine traffic). The specifications shown in Annex 2 to Recommendation ITU-R M.1084 have been tested and verified to be achievable by a simple low-cost upgrade to a good quality commercially available marine DSC VHF transceiver. This upgrade has been detailed in Appendix 1 to Annex 1. Recent modifications such as *recommends* 4 and Annex 2 to Recommendation ITU-R M.1084 serve to document new detailed standard.

5 Feasibility of adopting 12.5 kHz channels spacing

Current technology provides many alternatives for efficient transmission of voice messages. Various modulation types have been proposed such as analogue NBFM, ACSSB, and digital variants (C4FM, CQPSK (coherent quadraphase shift keying), DPSK (differential PSK), QPSK, FSK, MSK, GMSK, etc.). The aforementioned factors of safety (SOLAS Convention, GMDSS), communications interoperability (ship-to-ship, ship-to-coast, interagency coordination, worldwide port operations), implementation cost ((upgrade versus complete retrofits), (complex multimode transceivers versus simple design enhancements)) and spectrum utilization (interstitial additions versus complete re-farming of framing of frequency channels) should all be considered before “ordering” any new system. The feasibility of adopting any of these technologies should take into account the following:

a) operational characteristics of new technologies which provide new features, such as encryption for added security and privacy, as well as voice, NBDP, FAX, DSC and data transmissions;

b) capability of implementation within the existing maritime VHF band;

c) should provide a potential to significantly increase spectrum capacity;

d) consideration of economic factors; system effectiveness, equipment availability and simplicity of operation;

e) the effectiveness and universal accessibility of VHF maritime distress and safety communications should not be diminished by the introduction of the new technology in either the short term or the long term;

f) any new technology should not interrupt the continuous availability of RR Appendix S18 maritime distress and safety communications in the VHF bands for all users;

g) any new technology should permit readily available low-cost transceivers as currently in use today.

5.1 Managing the transition (“Project 25”)

NBFM (12.5 kHz analogue FM) and the narrow-band digital C4FM/CQPSK variants appear to be the most viable and practicable candidates to reduce spectrum congestion and improve spectrum efficiency in the maritime mobile service in the near term since the new equipment should be readily available, the cost of this equipment will be comparable to existing 25 kHz analogue FM (5% to 10% increase), it is interoperable with existing 25 kHz analogue FM equipment, and is a proven technology (various administrations use both NBFM and C4FM/CQPSK for mobile applications).

Furthermore, the additional channel capacity allows for the introduction and expansion of other services such as high-speed data and facsimile. The introduction of NBFM and C4FM/CQPSK will not interrupt or negatively impact the effectiveness of distress and safety communications. Test results from the evaluation of simple NBFM/C4FM modifications to a current production FM radio unit showed complete interoperability with existing units with little degradation in performance (see Appendix 1 to Annex 1). The cost of the modification was minimal and could be performed by any certified technician in any moderately equipped radio repair station.

It should be noted that the choice of NBFM/C4FM assumes that interleaved interstitial (12.5 kHz "in-between") channels are utilized instead of "refarming" the whole spectrum on much narrower (6.25 kHz) channel spacing. If and when such "refarming" takes place, other technologies (such as linear or digital CQPSK) will provide superior performance over NBFM, since the allowable FM deviation would have to be further reduced. Thus, NBFM on interleaved 12.5 kHz channels is the overall best "next step" for voice transmission. This would not preclude some other choice in the future. C4FM provides the best low-cost data throughput, and is perfectly suitable for use on interleaved channels. Project 25 has already adopted a transition plan for migrating from 25 kHz channels to 6.25 kHz channels by implementing a scheme of NBFM and C4FM/CQPSK interleaved 12.5 kHz channels followed by full CQPSK implementation on 6.25 kHz channels.

Coast stations could be easily coordinated by simply adjusting the FM deviation on the transmitters and installing narrow-band IF filters. As an interim step, spatial separation of at least 10 km would provide enough isolation to insure compatibility and interference free operation. Already, administrations coordinating land mobile public safety systems have used this approach in adding 15 kHz channels in between their original 30 kHz channel allocations.

APPENDIX 1

TO ANNEX 1

Adding NBFM, C4FM and ADS/VTS functionality to a GMDSS DSC FM transceiver

1 The test radio unit

Several commercial off-the-shelf VHF FM transceivers are now fully GMDSS certified and compliant with Recommendation ITU-R M.493 and IMO A.609 (15). For purposes of this evaluation, the unit selected was the ROSS DSC500 because it was an all in one package (including the channel 70 receiver). It was therefore assumed to be the most practical test case to verify the criteria of this report and suggested implementation. Interestingly enough, this unit has already been utilized as part of the automatic dependent surveillance shipboard equipment (ADSSE) by two manufacturers who have supplied equipment to meet the requirements of an existing VTS in Prince William Sound. Concurrent with this report, other new suggested recommendations and updates to current recommendations are now being presented to ITU-R from the United States of America which document the current implementation of VTS 2000 along with some proposed new enhancements. All these new proposed requirements have been taken into account in the modification of this radio unit.

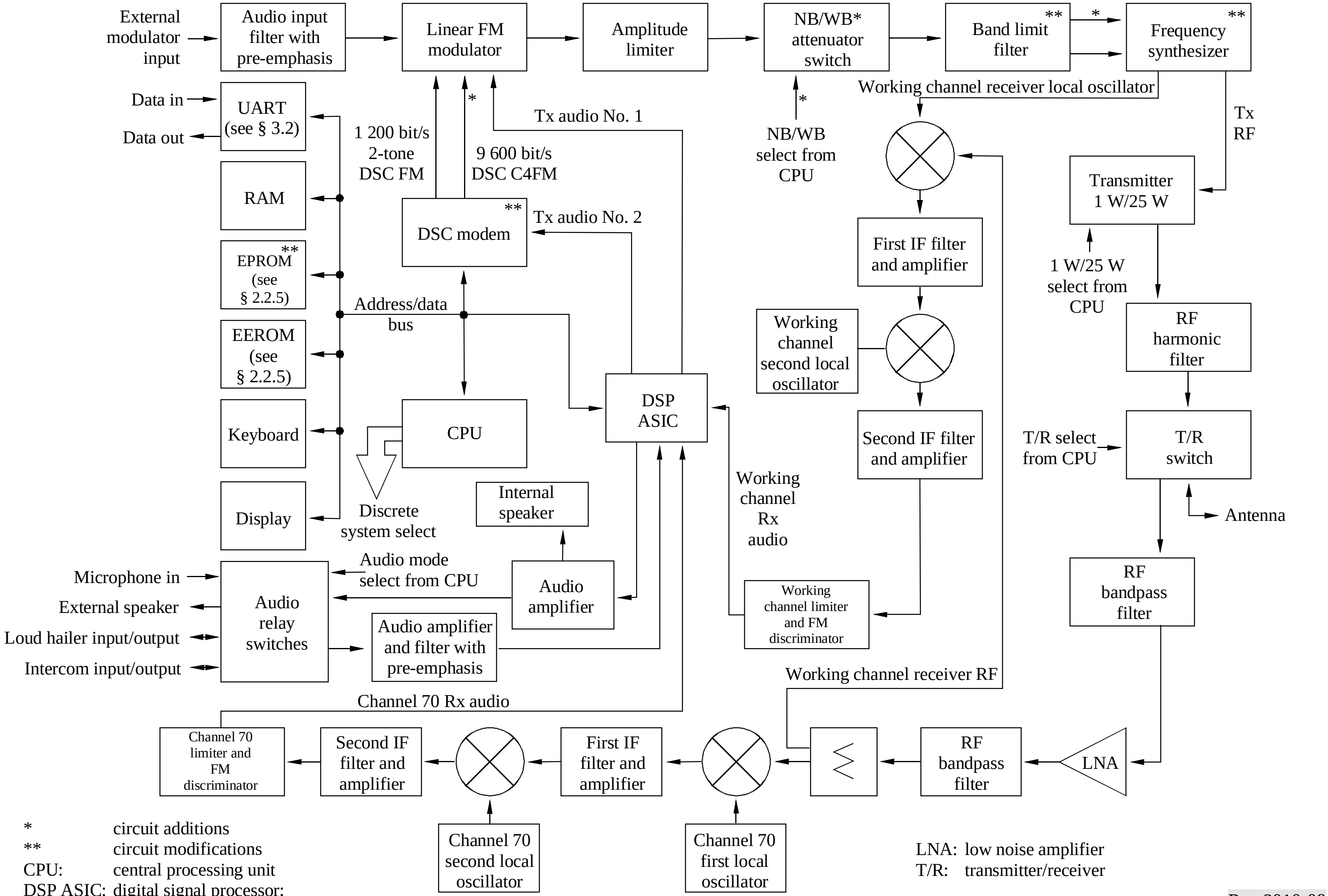
2 Modifications to the test radio unit

Figure 9 "Functional block diagram" illustrates the internal architecture of the test radio unit. Note that * denotes circuit additions and ** denotes circuit modifications.

FIGURE 9

Functional block diagram

DSC500 GMDSS DSC FM transceiver with enhancements for NBFM, C4FM, ADS/VTS



*	circuit additions
**	circuit modifications
CPU:	central processing unit
DSP ASIC:	digital signal processor; application specific integrated circuit

LNA: low noise amplifier
T/R: transmitter/receiver

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2.1 Circuit additions

2.1.1 NBFM/WBFM dual mode switch

Since this report suggests that equipment should be completely interoperable, it was thought that a mode switch would be desired instead of a “hard wired” change to the amplitude limiters to set the maximum peak deviation to 2.5 kHz. The CPU will now switch in a 2:1 attenuator in the modulation path when the user programs the radio to one of the new proposed 12.5 kHz interstitial frequency channels. This feature is not absolutely essential in a voice-only radio, as the NBFM radio could simply be adjusted to allow only the reduced deviation. In such a case, the NBFM radio would have a reduced “loudness” when its voice transmissions were received by a “normal” WBFM radio. But, if the radio must have DSC and efficient data capability as well as voice, the switched attenuator is necessary. The modification to the test radio utilized an available section of an integrated circuit switch and a previously unused discrete CPU command line.

2.1.2 Additional modulator input

The linear FM modulator must be ported to accept a DC-coupled four-level input from the DSC modem. This new input allows the “9 600 bit/s DSC C4FM” drive from the DSP ASIC (digital signal processor-application specific integrated circuit) when the radio is operating in the high-speed data transfer mode.

2.1.3 Additional frequency synthesizer modulation input

The frequency synthesizer must have a two-point modulation drive in order to perform the C4FM data transfer mode. This is because the phase-locked loop around the voltage control oscillator (VCO) resists pulling the carrier frequency at DC-coupled low rates of deviation. Thus, the reference crystal oscillator must also be modulated with the DC-coupled drive to a varactor in parallel with the crystal (parallel resonant mode).

2.2 Circuit modifications

2.2.1 Linear FM modulator

The linear FM modulator must be modified to accept an additional DC-coupled input into a “summing node” from the DSC modem. This can be implemented by a simple addition of resistors and some value changes to current parts.

2.2.2 DSC modem

The current DSC modem uses tone generators and detectors to generate and decode the 1 300 Hz and 2 100 Hz DSC tones at 1 200 bit/s. These circuits are not used in the C4FM mode. Instead of tones, the C4FM method uses four levels of carrier offset (4-FSK) to transmit a two-bit symbol with each level. The DSC protocol uses ten bits to describe a character (seven information bits and three checking bits), and thus five C4FM symbols are required per character. Since the DSP ASIC contains eight-bit A/D/A audio processing under control of the CPU, it requires only new software to coordinate the CPU, DSC modem, and DSP ASIC to accomplish the C4FM DSC modem function at 4 800 symbols/s (9 600 bit/s). Fortunately, the DSP ASIC already has a baud rate clock generator capable of handling 1 200, 2 400, 4 800 and 9 600 bit/s. This particular aspect of the radio modification to implement C4FM was an unexpected coincidence with the ROSS DSC 500 radio since the radio already had the necessary hardware facilities. Other new VHF FM radios are also likely to be using DSP circuits and techniques in the near future, since the cost of these implementations is now very low.

2.2.3 Bandlimit filter

Regulatory certification requirements have necessitated a bandlimiting audio filter on the output of the linear FM modulator on most modern radios. This filter serves as a dual purpose to not only limit the “audio passband” but also to strip off the harmonic frequency components of distortion caused by the modulation limiter’s “clipping” mechanism.

Care must be taken in "active filter" implementations not to introduce further harmonic non-linearities by "overdriving" the filter beyond its dynamic operating range limits. The test radio already had a complex active filter for this purpose. This filter must be replaced by the two filters, whose characteristics are described by § 2.9.5.2 and 2.9.5.3 of Annex 2 to Recommendation ITU-R M.1084 and the graph plot of Fig. 5 of this Report, in order to provide the needed characteristics of "flat group delay" and passband/attenuation shape factor. This filter function is best implemented with single-clip "switched capacitor" technology, along with simple R-C external components for "anti-aliasing" and high frequency noise rejection.

2.2.4 Frequency synthesizer

The frequency synthesizer must be modified to provide the proposed new channel spacing of 12.5 kHz from the current 25 kHz design. Also, some radios will need a better reference oscillator crystal in order to achieve the proposed 5×10^{-6} frequency tolerance over temperature. This crystal will need to be "paralleled" by the varactor of § 2.1.3. for low-frequency modulation boost down to the DC level. Fortunately, the test radio already had a crystal better than 5×10^{-6} and a synthesizer with two serially programmed (by the CPU) counters (both reference counter and feedback counter) with sufficient range so that 12.5 kHz programming could be accomplished with only a CPU software change. Thus, all that is needed for the test radio (besides the software) is a varactor, two component value changes in the loop filter and two additional discrete components.

2.2.5 EPROM (software changes)

The test radio has its entire program memory in a socketed EPROM (electrically programmable read-only memory). Thus, the necessary software changes to the CPU to support all of the suggested enhancements of this report which can be implemented by simply plugging in a new EPROM chip. Fortunately, there is sufficient code space, available RAM, and memory address capability because of the structure of the memory scheme. The DSC 500 test radio had recently already undergone a restructuring of its memory in order to support some new demanding ADS/VTS and data management requirements. For new functionally complex radio designs, it would seem best to keep program memory in socketed EPROM with some EEROM (electrically erasable ROM) for variants and minor alterations. The test radio had such a structure in order to provide product support to users in the field.

2.3 Cost of modifications

The total cost of materials needed to modify the test radio in order to provide all of the proposed enhancements was under twenty US dollars ($US 20). A certified radio repair depot technician could perform the modifications and check out the radio in an hour using prepared test equipment (radio test sets and personal computers with special programs).

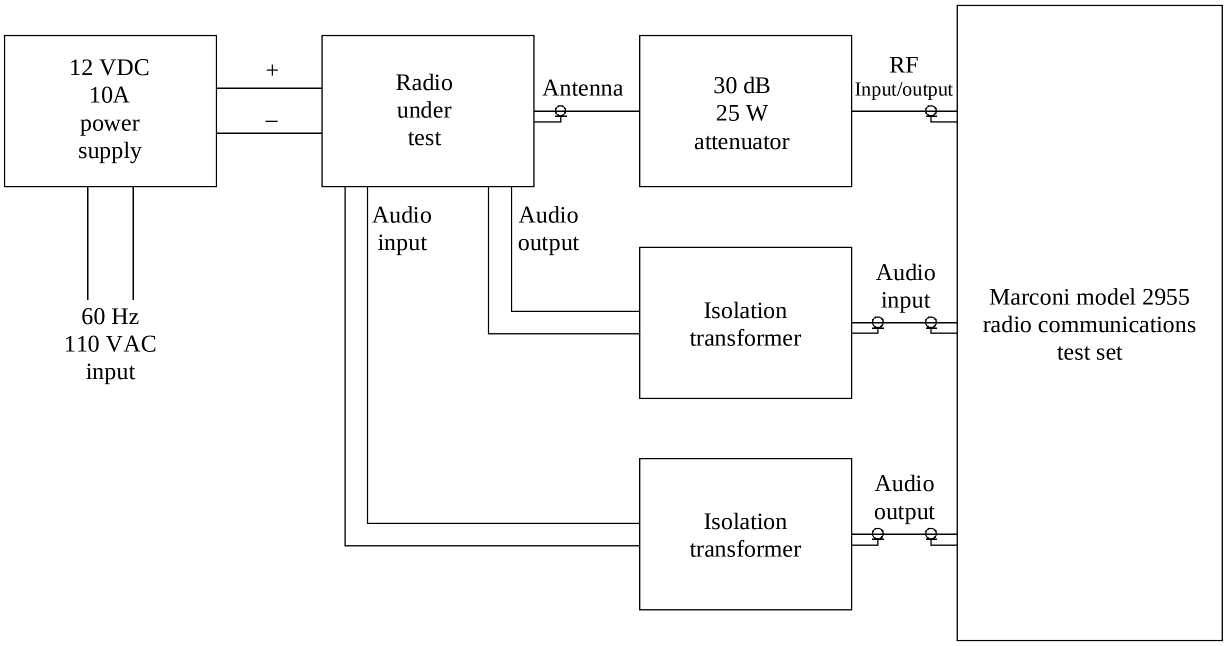
3 Test results

3.1 NBFM voice sensitivity (see Fig. 10 for test set-up)

The RF threshold sensitivity measurements were made using a Marconi Radio Communications Test Set, Model 2955. The unmodified DSC 500 radio was capable of reaching 12 dB SINAD at –122 dBm RF input with a 1 kHz test tone at 3 kHz deviation. The 3 kHz deviation is a "standard test deviation" for use on equipments designed for 5 kHz maximum deviation (limit value) on 25 kHz channel spacing. When the deviation was reduced from 3 kHz to 2 kHz (the new proposed "standard test deviation" (see § 1.1 of Annex 2 to Recommendation ITU-R M.1084) for 12.5 kHz channels with deviation limit set at 2.5 kHz peak), the RF level needed for increased to –121.5 dBm to restore 12 dB SINAD. Thus, it was determined that a RF threshold degradation of about 0.5 dB would be experienced by WBFM radios modified to NBFM criteria by reducing the modulation deviation limits from 5 kHz to 2.5 kHz.

FIGURE 10

NBFM voice sensitivity test setup



	Marconi test set	Radio under test
RF frequency Modulation	156.700 MHz 1 kHz MF sine	Channel 14 (set)
Test No. 1 FM deviation RF level	3 kHz peak –92 dBm (–30 dB)	12 dB SINAD (meas.)
Test No. 2 FM deviation RF level	2 kHz peak –91.5 dBm (–30 dB)	12 dB SINAD (meas.)

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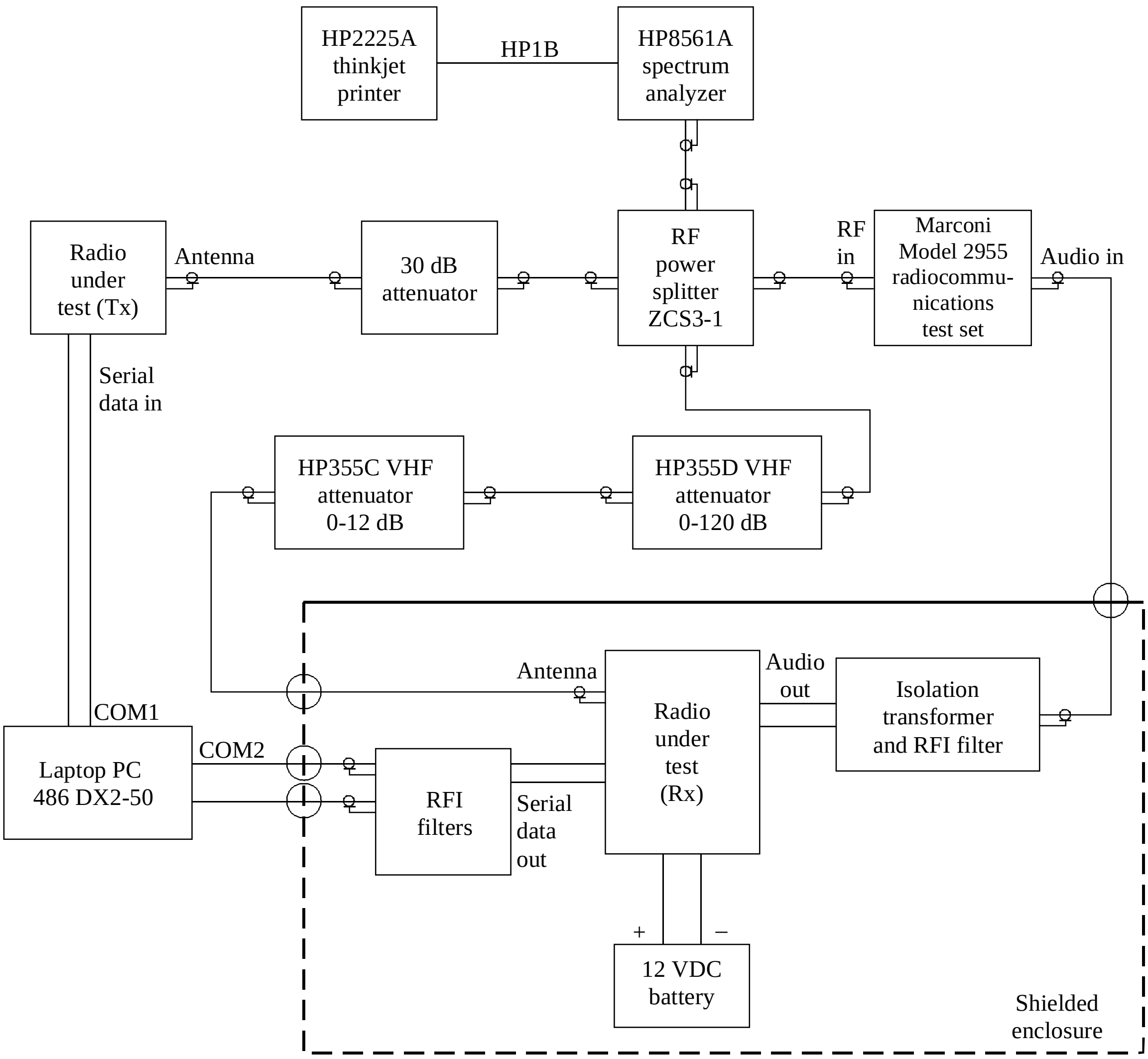
3.2 DSC data sensitivity (see Fig. 11 for test set-up)

The DSC modem in the test radio achieves a 1×10^{-3} BER at approximately 10.5 dB SINAD, which corresponds to an RF threshold of about –122.5 dBm. The 2 100 Hz tone is set for 3.5 kHz deviation and the 1 300 Hz tone is set for 2.17 kHz (pre-emphasis) deviation. With reduced deviation settings of 2.3 kHz and 1.42 kHz, respectively, the RF signal level needed to be increased to –121.5 dBm to restore a 1×10^{-3} BER. Thus, a 1 dB degradation in the RF threshold was experienced by imposing the NBFM deviation reduction. Test radios are configured to pass data through the universal asynchronous receiver-transmitter (UART) via the serial ports (Data in and Data out in Fig. 9) to personal computers on each end. The GMSK and C4FM performance curves are shown in Figs. 3 and 8, respectively, as previously discussed in § 3.3.2. and 3.3.3 of Annex 1. Note that this data was taken at 2.5 kHz deviation, the proposed new limit for 12.5 kHz channel spacing.

FIGURE 11

DSC data sensitivity test setup



RF frequency:	156.700 MHz/channel 14
Marconi test set:	Measure SINAD reference levels with no data (1 kHz FM sine)
HP spectrum analyzer and printer:	RF output spectrum measure and printout
Laptop PC:	Data text files transmit/receive and error check/measure

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ANNEX 2

Mapping of TETRA onto the functions required by maritime VHF users as proposed for the applications in the United Kingdom

1 Introduction

This Annex discusses the way in which a TDMA system such as TETRA could be employed in the maritime VHF working environment.

Maritime VHF currently operates using frequency division multiple access (FDMA) which makes for relatively straightforward spectrum planning and channel allocation. Whilst the introduction of TDMA would bring numerous user benefits, the implications of having multiple users on a single RF channel needs to be carefully considered.

In the following sections, different modes of operation of maritime VHF are considered and in each case, the way in which TETRA would be operated is discussed.

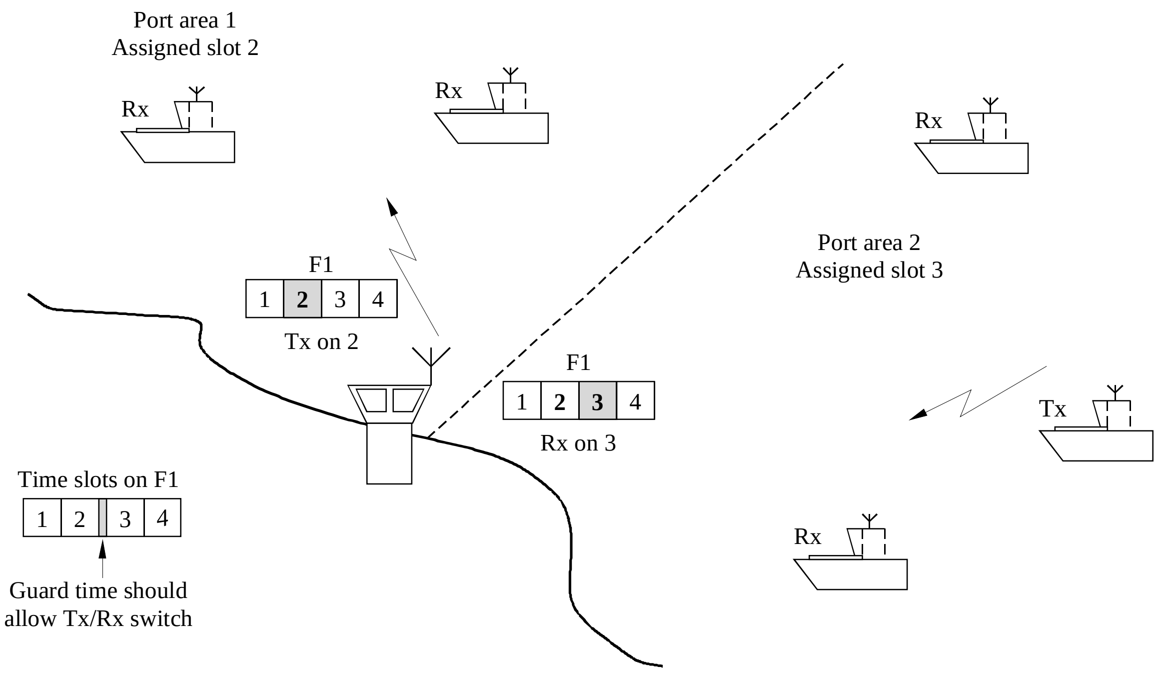
2 Mode of operation

Any new radio system must provide the functions of, and should broadly support the mode of operation of the existing system. Extra features or modes of operation will be welcome but, unless the system as a whole gains acceptance, it will not be used. For the maritime industry the preferred mode of operation is broadcast simplex. It is felt that any system that only allows point-to-point duplex or half-duplex working will not be accepted.

Figure 12 illustrates the principle of single channel simplex working with TETRA.

FIGURE 12

Efficient broadcast simplex using TETRA



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A typical vessel traffic control situation is pictured, currently two 25 kHz channels would be operated by traffic control for the two designated areas. This could be changed to two TETRA time slots operating in a single 25 kHz channel. Broadcast simplex could be retained with all ships in the area receiving all calls. Up to four simultaneous calls may be possible.

Whilst there is nothing in the TETRA specifications that should prevent single channel simplex working, it is not clear whether this is being supported by any manufacturers in their first round of product offerings. Simplex calls are associated with direct mode (mobile-to-mobile calls in the current TETRA specifications and broadcast calls to a base station would be normally handled in a talk through mode). Talking through the base station has the advantage of retransmission using the higher power of the base but is less spectrally efficient. This area of the specification is still under development however.

3 Synchronized and non-synchronized mobiles

The key difference between TDMA and analogue FDMA systems is that no communication is possible on a TDMA system until time synchronization is achieved between caller and listener. Typically with a TDMA system this does not limit communication because synchronization can be achieved long before intelligible voice communication is possible. A system would be designed with the fixed (coast) station as the timing master. TETRA does not require timing advance as the bit rate and guardbands are long (compared to say, GSM).

A mobile approaching a coast station may well be able to synchronize to other mobiles before synchronizing with the timing master. Although able to receive communication from other mobiles he should be discouraged from transmitting on the coast station channel until synchronized to the timing master. It is envisaged that mobile-to-mobile channels will be available for transmitting in this circumstance (see § 7 of this Annex). On arriving in and synchronizing to a system such as that in Fig. 12 a mobile would decide the appropriate time slot by prior knowledge, direction (automatic possibly) or monitoring transmissions. It should be noted that the base station will be transmitting control information which can be used for synchronization even if no calls are in progress.

4 Multiple systems in a single location

Currently a multitude of different "communications systems" will be operating in the maritime VHF band in a single location separated by frequency. This situation will be directly transferable to TETRA as shown in Fig. 13. Some of the systems such as the vessel traffic control and the marina shown will be public access, some may be private and only accessible to specially programmed mobiles.

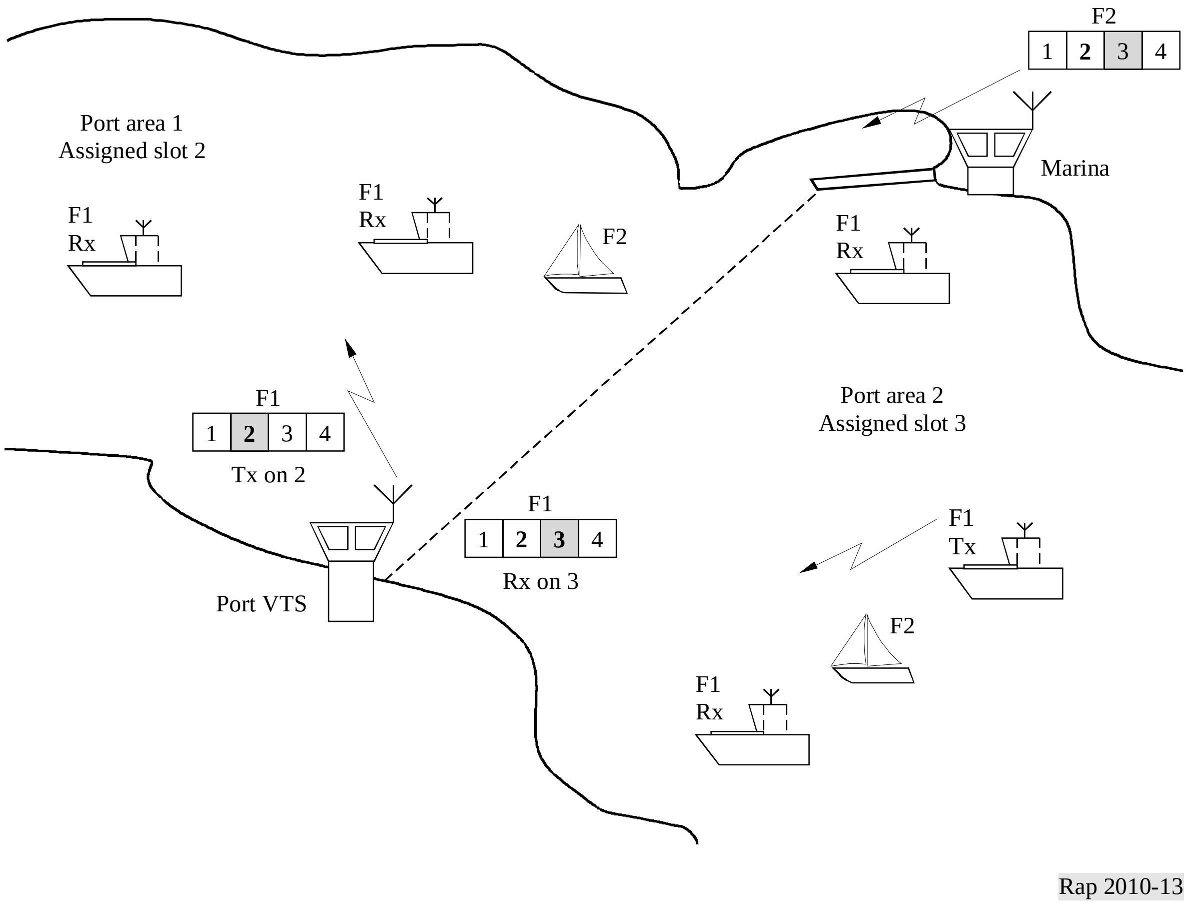
The systems need not be time synchronized to each other. Mobiles would be synchronized to a "home system" but could switch to another system and synchronize to that if necessary. It is also possible to envisage a situation such as that in Fig. 14 where two stations, remote from each other are operating synchronized systems on the same frequency. One of the systems could be nominated as timing master or they could take timing from a common source (e.g. Droitwitch or GPS). The transmission time between the two fixed stations does not make this infinitely extendable, but it could improve spectral efficiency and reduce congestion in an area where (say) several marinas are operating.

5 Adjacent and overlapping systems

Again for adjacent systems, the mapping from current practice to TETRA should be straightforward. As shown in Fig. 15, a mobile transiting between adjacent systems can communicate with either if there is an overlap or neither if there is not. The adjacent systems should be on different frequencies if they cannot synchronize, otherwise interference will result.

FIGURE 13

Multiple system operation



6 Dual watch capability and distress channel operation

In the current system, the main calling channel and the distress channel are the same. This has the advantage that simple radios can listen for distress calls whilst not in use, but the big drawback is that the distress system is very fragile and can be rendered ineffective by misuse of the calling channel. Commercial operators and fixed stations would use dual watch radios and monitor the distress channel and their operating channel simultaneously.

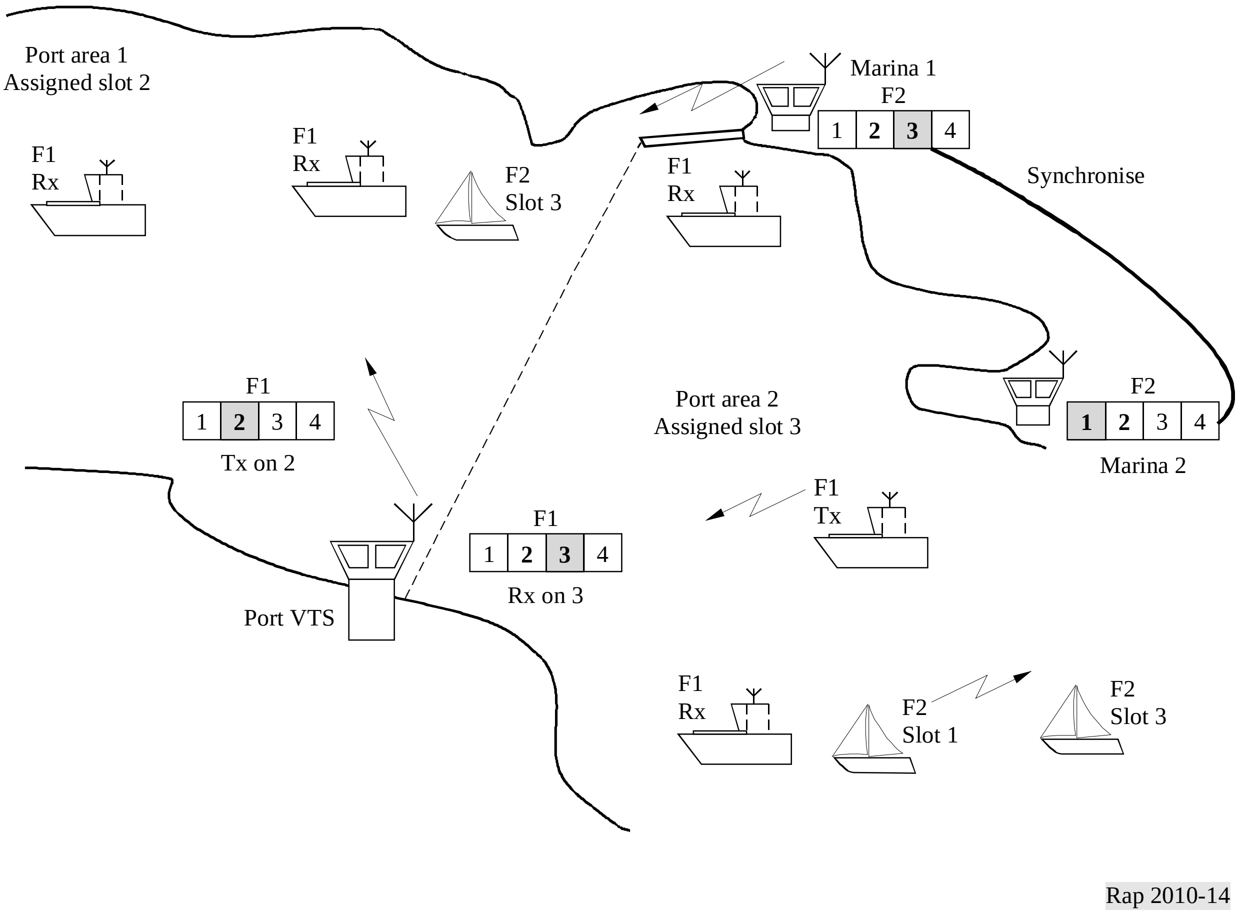
With the advent of DSC the situation will improve, with less likelihood of channel 70 (the new distress and calling channel) being abused. However there is already some doubt about the loading of channel 70 with automatic vessel tracking systems (AVTSs) coming into service.

The situation could be improved still further with TETRA with even simple sets being able to monitor their home system frequency and the frequency for distress (FD). For fixed stations that are likely to be heavily loaded a dual receiver would still be necessary to effectively monitor the FD. The situation is illustrated in Fig. 16.

Note that the simple set is monitoring on the time slot $T + 2$ modulo 4 from that on its home system. The FD channel would not normally be synchronized. However the distress transmission can be so organized that it will always be heard within four frames (approximately 200 ms). The pick-up rate and subsequent data transfer rate should be significantly better than with DSC. Once the distress signal has been detected the monitor on the home system can be dropped and a direct call to the distressed vessel can be set up. A fixed station with a dual receiver could monitor all time slots on the FD channel, and could pick up the distress call within one frame.

FIGURE 14

Multiple systems, remote fixed stations on a single frequency



It might be that the coastguard would consider the distress channel as their home system, this would give vessels in distress within range the option of synchronizing to a fixed station to make a distress call. Search and rescue operations could still be given a working channel distinct from the distress channel and this may also be a candidate for coastguard home system channel.

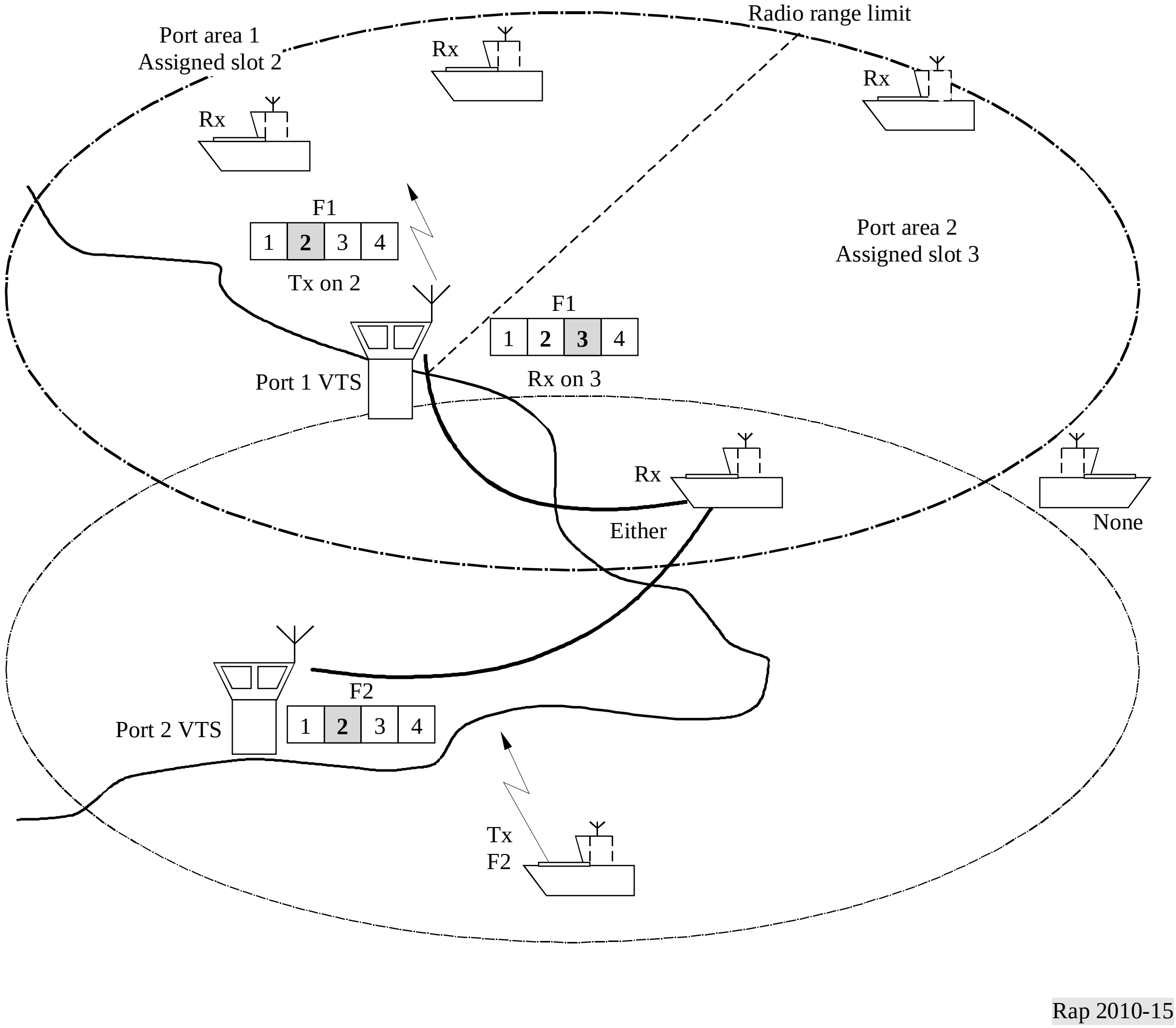
It should be noted that TETRA offers other possibilities including manual or automatic repeater mode whereby the distress call could be directly routed through a vessel to a shore station that would otherwise be out of range.

7 Duplex operation

The normal mode of duplex in TETRA systems is frequency division duplex (FDD) with shifted time slots. This mode could be used for maritime communications where desired, particularly in public correspondence and similar services. In FDD calls, a simple mobile transmits on one time slot and receives on the time slot $T + 2$ modulo 4 as shown in Fig. 17. This means that a simple mobile without a dual receiver cannot monitor a distress frequency in the manner described in § 5 of this Annex whilst holding a duplex conversation.

FIGURE 15

Adjacent TETRA systems



8 Ship-to-ship calls

The TETRA system supports “direct mode” (mobile-to-mobile) calls which could be maintained on the current ship-to-ship frequencies. When out of range of a coast station a mobile may well wish to monitor the ship-to-ship channel or a designated general calling channel as well as the distress channel in the manner described in § 5 of this Annex. A ship-to-ship call would then be set up in the same way as a distress call.

It would also be possible for mobiles to monitor more than one frequency channel other than the “home system” channel. This would allow situations such as that in Fig. 18, where a ship-to-ship call from a ship out of range of a coast station is picked up by a vessel monitoring a coast station and the distress channel. The penalty for monitoring more channels is that the maximum time to detect a call will increase (to ≈400 ms in this case). This is not currently part of the TETRA specification but would not be problematic.

FIGURE 16

Distress channel monitoring on TETRA

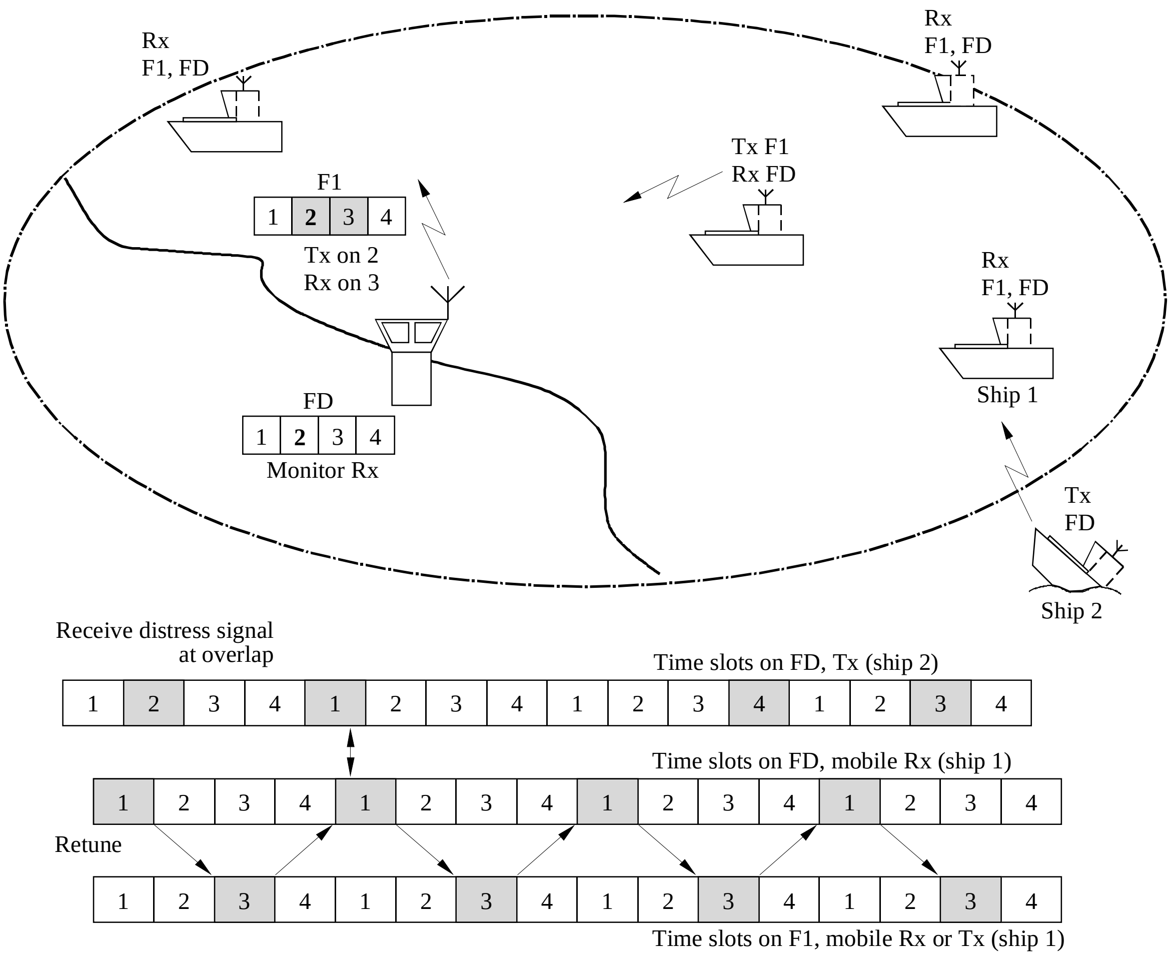


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FIGURE 17

Mobile time slot use in duplex call

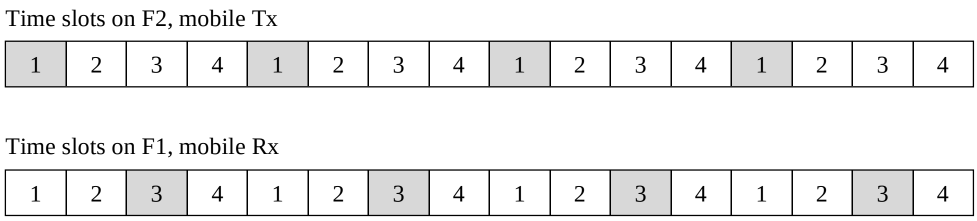

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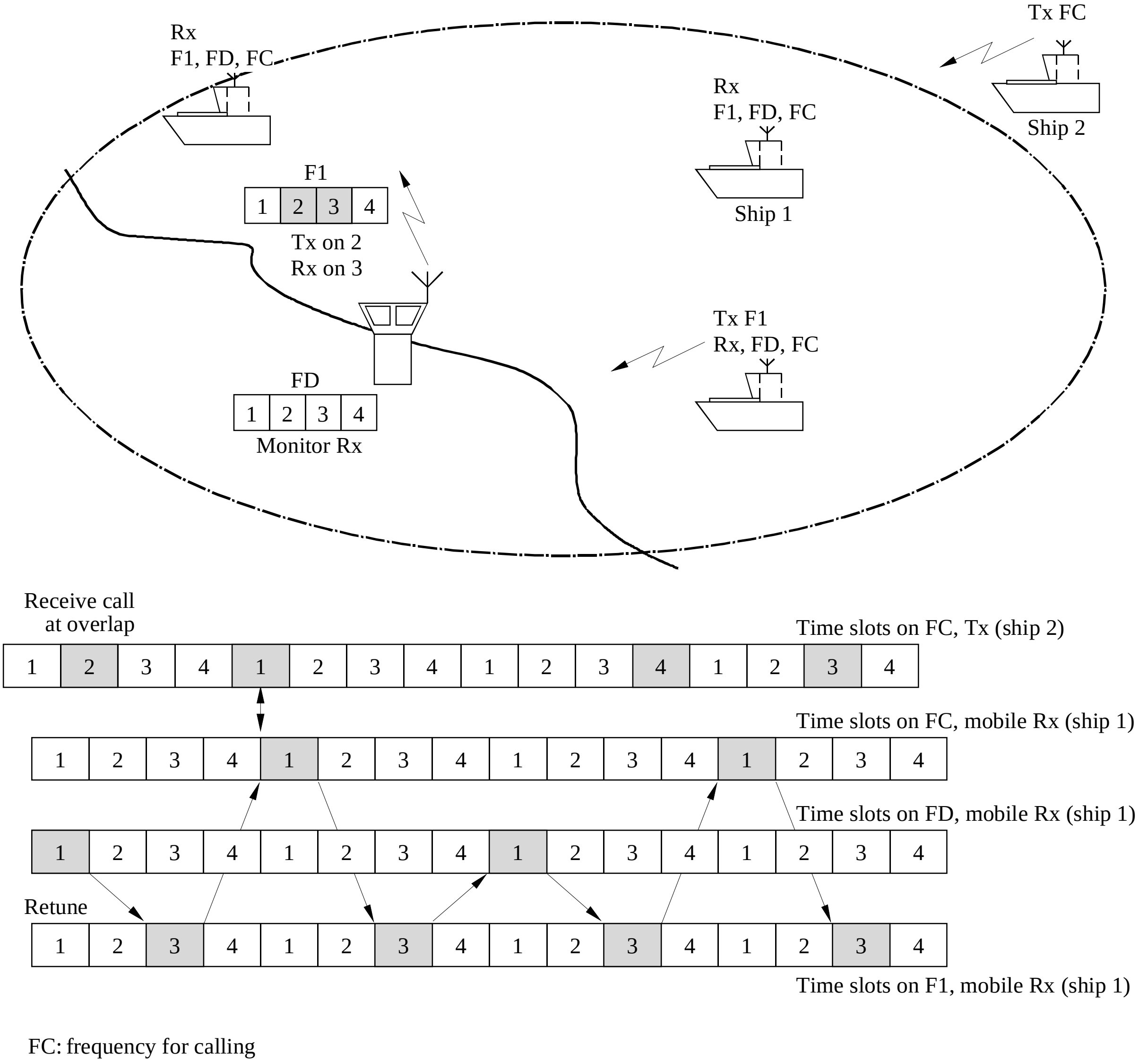
FIGURE 18

Multiple channel monitoring



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