

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 companded 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	$\times 1.5$ to $\times 2$	None, interoperable with existing equipment	Interleaving	Used in land mobile radio service
5 kHz or 6.25 kHz linear modulation	$\times 2.5$ to $\times 5$	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	$< \times 4$	Extra or dual mode equipment required	Interleaving (with careful planning)	No commercial equipment available
Reallocation of duplex channels to simplex	$\times 1.3$	None	"Over night" changeover but simple	Minor changes to current equipment
25 kHz 4-TDMA approach	$\times 4$	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

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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).

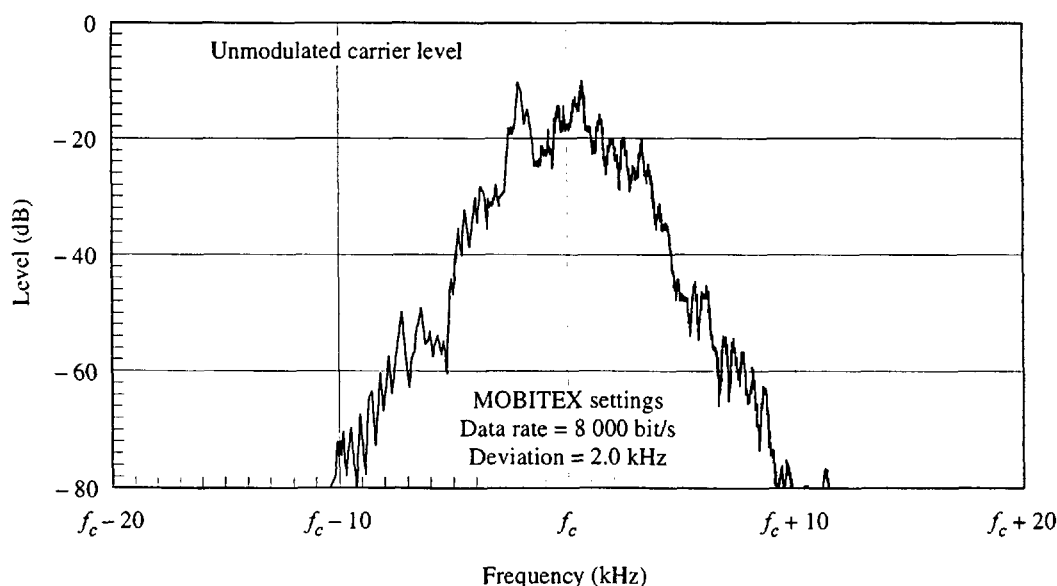
3.3.1 Two-tone FSK, the DSC standard method

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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