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De-Collision Algorithm for AIS for Multi-User on Single Satellite Antenna

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Abstract*: *The Automatic Identification System (AIS), acquired popularity and preferences to be deployed in navigational systems for collision avoidance due to wider coverage. The recently developed satellite AIS provides better precision than the earlier employed Terrestrial AIS. Satellite AIS technology utilizes Gaussian Mean Shift Keying (GMSK) to modulate the message. The modulated AIS message is then transmitted and received between ships and satellite AIS over SOTDMA channel. The conventional single axis satellite AIS transceiver failed to decode the message accurately due to message overlap. In earlier work 3-AIS trans-receiver was developed to reduce the chance of message collision; however, system became bulky and complex. In this paper, collision mitigation algorithm is developed and the single axis transceiver is retained. Thus the complexity is reduced greatly and collision is eliminated as well. Hard Viterbi Algorithm developed in this work corrects the overlapped AIS message for proper decoding of the received messages. The transmitter, receiver and Viterbi algorithm are designed in VHDL Language and simulation of all blocks is performed in Eldo Simulator.

Index Terms*: *Automatic Identification System, Terrestrial AIS, Satellite AIS, GMSK, SOTDMA, Viterbi Algorithm, VHDL.

I. INTRODUCTION

The identification of navigating ships in ocean has been a challenge over a decade. Recently, AIS was designed and deployed in navigating vessels to determine the location and identity of the on-coming Ships. Initially, the primary purpose to deploy such AIS system was to avoid collisions between navigating ships; however, for military applications identifying potentially hazardous intruders in the sea limit became popular. Terrestrial AIS over the years have been proven to be a better identification system; however, as it can only detect the ships near the coastal area it poses coverage limitations [1], [2] & [5]. Identification of ships navigating in Deep Ocean is beyond the limit of terrestrial AIS. Satellite AIS developed exploiting the space technology overcomes the coverage limitation posed by terrestrial AIS. Further, satellite AIS proved to be more precise in vessel identification in Deep Ocean than the terrestrial AIS due to its large FOV (Field of View). All ships that are in vicinity of its FOV are effectively been identified. AIS is the new technology of communication engineering used by the navigating vessels in the ocean to avoid the collision by other navigating vessels. The major problem associated with AIS is message collision [5]. To avoid message collision the SOTDMA (Self-Organized Time Division Multiple Access) is used. SOTDMA proved robust between ship and ship to ground station communication. However, this approach is not effective for satellite AIS because of its large FOV. The SOTDMA cell is around 80km in diameter [2] and many such SOTDMA cell is lies under FOV of satellite resulting is message collision at the satellite receiver. The FOV of the satellite is depends upon conical/opening angle of the satellite and the orbit of satellite, if altitude of satellite is 700km and antenna conical angle is 60O then approximately is FOV 824km which is more than the 10 times of SOTDMA cell radius. For satellite having altitude 700km and opening angle of antenna is 38O then its FOV is around 485km [2].

To deal with message collision many techniques and algorithm has been developed and each is proven robust to identify the correct the errors in received sequence due to message overlapping. Viterbi Algorithm is most widely used method to correct the error bits [10], other approaches to correct the message sequence is Maximum likelihood sequence estimation, Joint Shape Based Demodulator (JShBD) [2], CRC Based Detection [12] etc.

The content of the text is arranged as: Section II keyed the background of the research. This part focuses mainly on the technical characteristics of AIS, standards for, or related to AIS, Message types and their characteristics AIS packet structure, channel type, Modulation scheme for AIS etc. Section III succinctly explains design and implementation of AIS Transmitter and Receiver, Viterbi development for AIS. Section IV consists of simulation result of AIS transmitter and receiver, soft Viterbi decoding used for AIS (all design modules are implemented using VHDL and simulated in Mentor Graphics ModelSimSE Simulator), and in last section the research is concluded followed by the references.

II. BACKGROUND

A. *Technical Characteristics of AIS*

The AIS uses two different bandwidths for the communication. These radio frequency bandwidths called channel. These channels are: -

- 161.975MHz or Channel 87B/Channel A/AIS 1
- 162.025MHz or Channel 88B/Channel B/AIS 2

The above mention frequency is reserved for AIS communication.

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The AIS message is modulated with GMSK (Gaussian Minimum Shift Keying) technique on radio frequency [9]. The advantage of GMSK is that it is constant envelope and continuous phase modulation. The transmission power for AIS is 12.5W and 2W [7]. The reserved baud rate for AIS message is 9600 bits per second.

Each AIS frame is 1 minute long and divide into 2250 time slots. Each time slots have 256 bits and time period of each slot is 26.67ms. Two channels, one for frequency 161.975 MHz and another for 162.025MHz frequency [4]. Thus, a total time slot is 4500. [7].

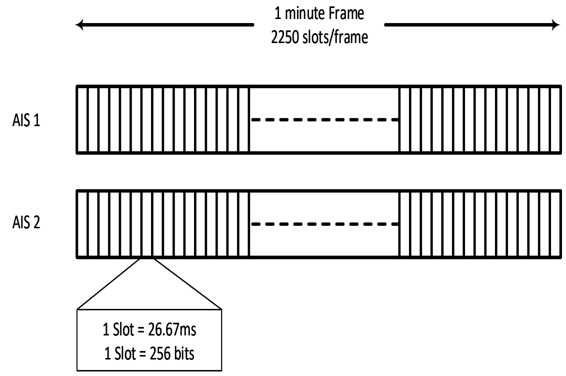

Fig. 1: AIS Time Frame

B. AIS Packet Structure

AIS packet contains 7 fields, and each field has its own significance. The AIS packet is 256 bits long which is further divided into different fields [2], [3], [7], [11].

- Ramp Up: Ramp is 8 bits long and use for turn in the AIS trans-receiver.
- Training Sequence is 24 bits long and responsible for synchronization between transmitter and receiver.
- Start Flag is 8 bits long and contains the ‘01111110’ bits in binary or 7E in hex. It is similar to HDLC flag. Its significance is to identify the start of AIS data which is 168 bits long.
- AIS Data field is 168 bits long and contains the information about ships position, longitude, latitude, speed of the ships etc.[11]. This is the core of 256 bit AIS message which contains the other important information about the ships apart from its position and speed etc.
- Frame Check Sequence (FCS) is 16 bits long and identifies the error bits in the received 168 bits AIS data. FCS is the 16CCITT polynomial CRC [7].
- End Flag is 8 bit long and identify the end of 168 bits AIS data. This is also in accordance with the HDLC packet. Basically, this is same as start flag.
- Buffer is 24 bits long and responsible for bit-stuffing, delays in distance and repeater or jitter.

AIS Packet 256 bits						
Ramp Up 8 bits	Training Sequence 24 bits	Start Flag 8 bits	AIS Data Message 168 bits	FCS 16 bits	End Flag 8 bits	Buffer 24 bits

Fig 2: AIS Packet

C. *AIS Message Format*

The AIS message structure is defined in NMEA (National Maritime Electronics Association). The AIS message must in accordance with NMEA, consider an example:

!AIVDM,1,1,,A,19NSfSpt2Wo%r4TKUR7@mUM84<L=,0*D7

“!AIVDM” – identify the sentence for AIS messages,
“1” – no of sentence to transfer the message,
“1” –number of current sentence,
empty – message identifier,
“A” – AIS Channel identifier, in this case Channel A
“19NSfSpt2Wo%r4TKUR7@mUM84<L=” –AIS data message, in this example the received AIS position of type 1,
“0” – number of fill bits for last character,
“D7” – the CRC8 checksum, calculated over the whole AIDM message between symbols “!” and “*”.

There is another sentence identifier! AIVDO which identify the received sequence of its own transmitted message.

D. Classification of AIS Class

The AIS is broadly divided into two categories depending upon the type of voyages, these are: -

- Class A: Large ships and voyages are categories in this class. Large ships or cargos must be equipped with Class A type AIS. [7] Class A type AIS can send and receive the detail information [1].
- Class B: Small ships, leisure boat etc. are categories in this class. Such ships must be equipped with Class B type AIS [7]. Class B AIS only able to send and receive the few information [1].
- Another category is Class C for fishing boat or small boats which only can receive the AIS message but not able to transmit the messages [11].

E. AIS Message Types and Access Scheme

The 27 types of different AIS messages is defined in ITUR (International Telecommunication Union-Radio Comm. Each message represents different information and some message are reserved for particular information like, message type 1, message type 2 and message type 3 are almost similar and they are used to report the position of the ships. The access scheme used by message type 1 is Self-Organized Time Division Multiple Access - SOTDMA, Random Access Time Division Multiple Access – RATDMA, or Incremental Time Division Multiple Access – ITDMA, message type use SOTDMA access scheme, message type 3 uses ITDMA and so on. Different message use either SOTDMA, RATDMA,ITDMA or FATDMA or group of access schemes. [7]. A new message type 27 is included in ITUR for long range message. The packet structure for message type 27 is different from the other messages. AIS transmitter is modelled the 256 bits AIS packet and modulated the AIS message with carrier frequency reserved for AIS channel. Before transmission the AIS packet conditioned with series of steps shown in block diagram Fig 3. First the AIS message is store in memory cell for further processing. The first 40 bits of AIS message called header are known, the modulation of this known header is not required. After this the AIS data field is started which is subjected to bit stuffing. Bit stuffing induce a binary ‘0’ after 5 consecutive ‘1’ present in series followed by 6th consecutive binary ‘1’.

The bit stuffing deals with continuous ‘1’ in sequence, similarly NRZI (Non-Return to Zero Invert) deals with binary ‘0’, whenever there is binary ‘0’ in input bit sequence then NRZI encoder toggle the previous bits from binary ‘0’ to binary ‘1’ or vice-versa, in case of binary ‘1’ as input then it simply follows the previous bits without any modification.

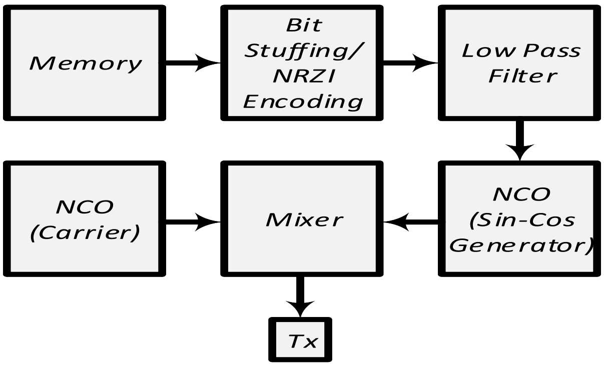

Fig 3: AIS Transmitter

The high frequency signal must be eliminated before the modulation of AIS packet. For AIS message transmitter the baud rate is 9600bps and BT = 0.4 (Bandwidth Time Product). BT value determines the wave-shaping of modulated waveform. Large value of BT smeared the Gaussian curve [8]. The received bits are transforming into antipodal stead of binary bits. The GMSK modulation gives In-phase (I) or Quadrature (Q) signals as shown in Fig 4. The integrator generates the sin and cos waveform of 25 kHz. Another NCO (Numerically Controlled Oscillator) generates the carrier frequency of 100 kHz which is added with conditioned AIS packet for transmission.

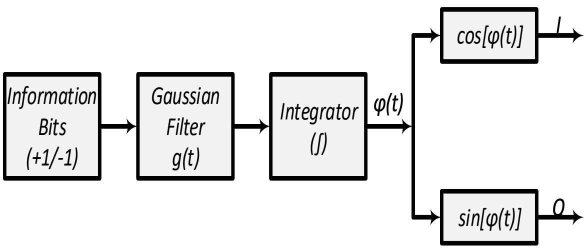

Fig 4: GMSK Modulation

III. AIS RECEIVER

The transmitted sequence is received by the receiver at the satellite. The received sequence may be overlapped due to the transmission by other ships in same time slots. The decoding of the overlapped message and the error correction of received sequence is discussed in next section.

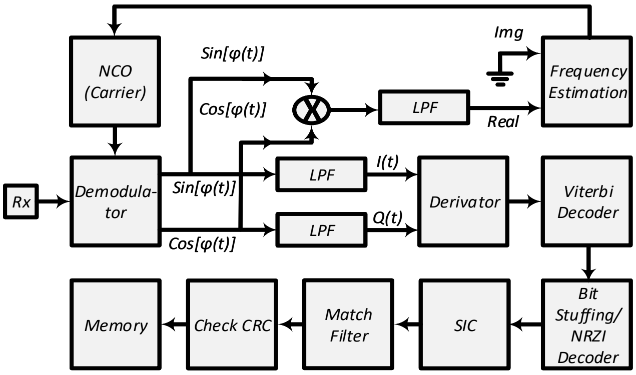

Fig 5: AIS Receiver

The received AIS message is demodulated by multiplying with carrier frequency. High frequency signal is removed by the low pass filter at 25 kHz from the received GMSK signal. The In-phase and Quadrature signal gives the angle between them. The output angle is used for identify the error and correcting the received sequence which may be corrupted due to overlapping. The 4-threshold value is defined for angle output and then all the angle is mapped into the states +4, +2, -2, -4 or 11, 10, 01, 00 for Viterbi decoding. Viterbi decoder is used for correcting the error bits due to the message overlapping [6]. Corrected sequence further process to removal of stuffed bits and NRZI encoded bits to get the actual AIS message without any modifications. The received AIS message may be overlapped which is decode by the SIC (Successive Interference Cancellation). In SIC, if the received sequence contains more than one AIS message in a time slots then receiver first demodulate the strongest user among all. After decoding of strong user, the SIC removes the strong user from the overlapped messages to decode the other overlapped sequence, this process continuous in loop till all the user not decoded. After decoding all the user checksum is calculated to further identify the error bits in decoding, if error is there then again, the whole process repeats to remove the error.The frequency of received message is affected by the Doppler shift. Before demodulating the AIS messages the original frequency of received message must be achieved to decode the signal properly. As shown in Fig 5, the doppler is slowly removed by the frequency locked loop.

IV. SIMULATION RESULTS AND DISCUSSION

A. AIS Transmitter: Bit Stuffing and NRZI Encoder

sAs Shown in Fig 6, the AIS data is stored in memory, for first 40 bits no modifications perform on AIS data because these bits are already known, when 40 bits is passed then Bit Stuffing and NRZI encoding is performed on AIS Data. The stuffed bits shown in fig 6, in bit stuff divider, between two cursors, 3 bits are stuffed (data_out) for consecutive ‘1’ in input stream (data_in). Similarly, in NRZI divider the last bits (data_out) are shown encoded with NRZI for continuous ‘0’s (data_in)..

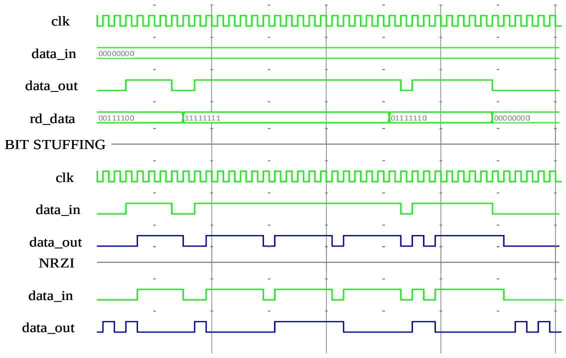

Fig 6: Simulation Result of Stuffed Bits and NRZI Encoder

B. AIS Transmitter: GMSK Modulation for AIS

The data bits are converted into antipodal (data_out) form before passing through the GMSK filter shown in fig. All '0' bits are converted into -1. This antipodal output determines the wave-shape along with BT product. The output of LPF filter further added integrator to generate the In-Phase and Quadrature Signal as shown in fig 7.

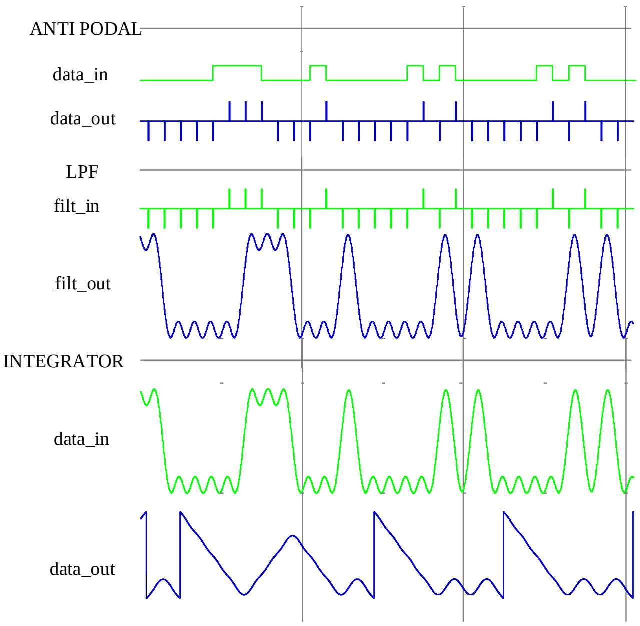

Fig 7: Output Result of GMSK Modulation

C. *AIS Transmitter: NCO Output for GMSK Modulation*

The integrator output is thus passing through the NCO which generate sin cos waveform at 9.6 kHz for Inphase and Quadrature signal. As shown in fig: addr_in is the input to the NCO and output is in the form of sin wave (sin_out) and cos wave (cos_out).

D. *AIS Transmitter: NCO Output for GMSK Modulation*

The carrier NCO generates the carrier wave at 975 kHz for modulation. This carrier wave (cos_out, sin_out) from carrier NCO is add in the mixer with the SIN-COS NCO output (sin_out) and (cos_out) from GMSK filter, for modulation of AIS packet. The Modulated wave (tx) is transmitted by the transmitter.

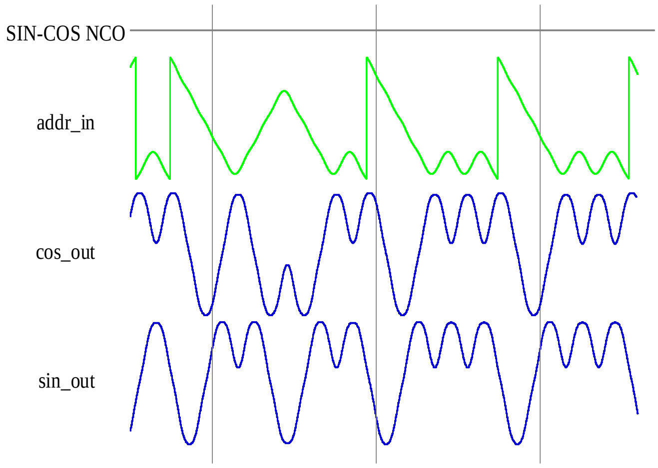

Fig 8: Simulation Result of NCO for GMSK

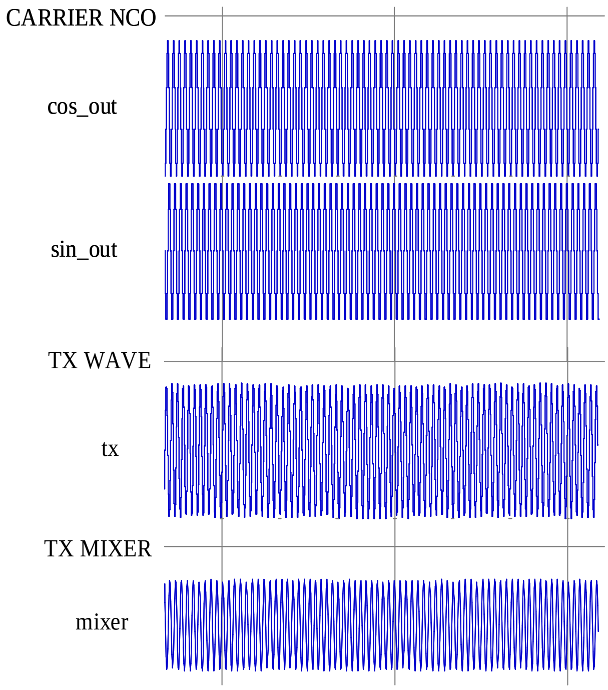

Fig 9: Simulation Result of Modulated Transmitter

E. *AIS Receiver: Demodulator and Mixer*

The received AIS message is passing through the receiver for decoding. The received AIS message is contains the high frequency carrier which is demodulated by multiplying the carrier wave with carrier frequency, this generated the high frequency signal which then pass through the filter to remove the high frequency carrier and only AIS message is leftover. Fig 10 shows the multiplied output of the received signal with carrier signal. Carrier NCO generates the cos & sin signal which is then multiplied by received signal resulting high frequency cos_mult and sin_mult signal as shown

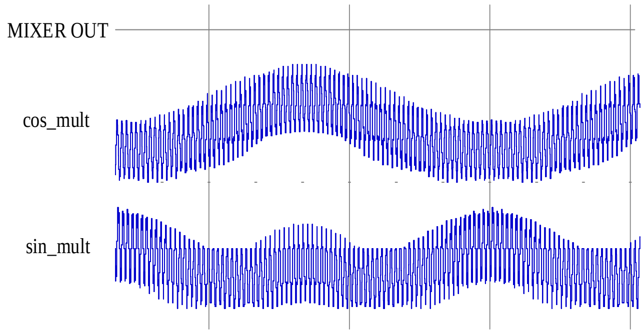

Fig 10: Simulation Result of Demodulator and Mixer

F. *AIS Receiver: Low Pass Filter*

The low pass filter removes the high frequency signal from the mixer output and only pure AIS message is remains. LPF removes all the carriers from modulated signals. As shown in fig 11, cos_mult and sin_mult is the input to the filter. Filter removes high frequency carrier from the received signal resulting low frequency filt_out for I (In-phase) and filt_out for Q (Quadrature) signal.

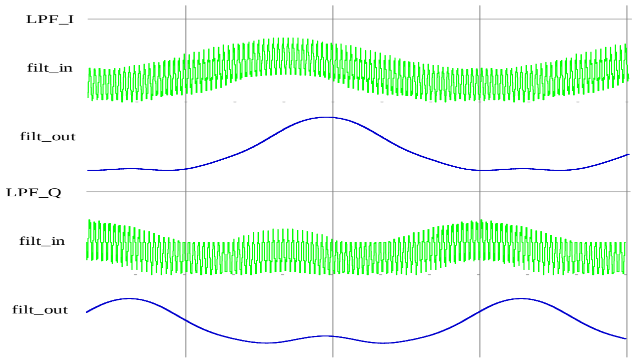

Fig 11: Simulation Result of Low Pass Filter

G. *AIS Receiver: Derivator*

The derivator identifies the angle between in In-phase and Quadrature signal which is used to correct the error bits in received sequence through Viterbi decoder. The derivator calculated the angle on the basis of the quadrant and the value of sin & cos. As shown in fig 12, if quadrant (quad) value is binary “00” means the sin and cos lies in first quadrant, similarly binary “10”, “11” and “01” represents that angle lies in II, III and IV quadrants. Then shortest angle is calculated between previous angle and the present angle. The output of derivator in tan-1 form. The calculated angle is in radians which are then converted into degrees as shown in Fig 12 by angle_out_deg.

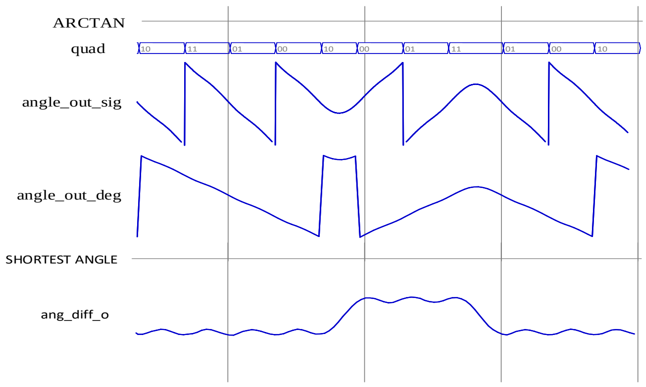

Fig 12: Simulation Result of Derivator /ArcTan

V. CONCLUSIONS

From the output waveform, the AIS packet is modulated conforming the standards define for AIS Message modulation. The transmitted carrier is received & decoded to obtain the AIS packet, for decoding the AIS message the complex set of Viterbi algorithm is required. Viterbi Algorithm reports the error bits on the basis of trellis calculation and corrects the error by Add-Compare-Select unit or through trackback trellis. Soft Viterbi is implemented for this project. The implemented architecture is only able to decode the overlapped sequence if there is difference between power levels of received sequence, phase or in frequency, if two or more overlapped AIS message having same frequency, phase and amplitude then it is difficult to decode with this architecture. The architecture need to complex improvement or modification to decode all the overlapped sequence irrespective of their phase, frequency, amplitude and doppler shift.

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