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1090 Radio Frequency Measurement Facility (RMF) Enhanced Reception Technique Implementation Software Description

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Summary
The 1090 Radio Frequency Measurement Facility (RMF) was developed as a means to analyze the 1090 RF environment. The RMF hardware consists of dual channel A/D converters that sample an incoming analog video signal at a 10 MHz rate and store the digitized data on high density digital tape recorders. The video signal is provided from a receiver external to the RMF. In Frankfurt, the receiver video signal was provided by the Link-Display Processing Unit (LDPU) for both the top and bottom antennas. RMF software was developed to analyze the recorded data to characterize the 1090 MHz RF environment, measure the extended squitter performance in high fruit rate environments, and evaluate the performance of the improved mode S processing techniques. The RMF data is processed off-line to detect extended squitter messages and other Mode S messages using the enhanced reception techniques defined in the MOPS appendix I. The details of the RMF software implementation are contained below.

1090 Radio Frequency Measurement Facility (RMF) Enhanced Reception Technique

Implementation

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Pulse Positions and Leading Edge Positions

Of fundamental importance to the message decoding process is the location of pulses and their leading edges. With the RMF software implementation, a pulse consists of 3 or more successive samples above threshold. A valid pulse position is any sample that is above threshold and is followed by 2 other samples above threshold. Since the RMF samples at a 10 MHz rate, each sample is 100 nanoseconds apart. A minimum pulse averages 300 nanoseconds in duration. The method described in appendix I is based on an 8 MHz sample rate where a minimum pulse averages 375 nanoseconds in duration.

A leading edge is a valid pulse position that is 4.8 dB or more greater than its preceding sample and less than 4.8 dB lower than its succeeding sample**.**

Threshold

The user may select either a fixed threshold at specified level in DBM or an adaptive threshold at a specified level (DBM) above noise. The adaptive threshold method uses a process to monitor and track the current noise level, the threshold will maintain a user defined level in DBM above the noise. The adaptive threshold was developed to provide a stable threshold when DC fluctuations in the signal level from the receiver are present.

Preamble Detection

All pulses above the receiver threshold are detected. The preamble detection logic advances through the digitized data one sample at a time until a pulse position or lead edge is found. The pulse position or lead edge establishes a potential preamble reference position. For a preamble to be declared, there must be at least one lead edge or pulse position located within +/- one sample period of the nominal position of each of the three remaining preamble pulses.

The pulse sample timing tolerance is limited to either one sample plus or one sample minus but not both in the same preamble. If one pulse of a preamble set is present only in the – 1 clock position and another pulse is only present in the + 1 clock position then the preamble is cancelled.

Timing offset is not necessarily limited to one direction during preamble detection. If there are 2 or more lead edges in either the +1 clock offset or –1 clock offset direction, then the reference position will be shifted in the direction that has the most lead edges. If there is a tie, both will be processed and the one that yields the most high confidence bits after the bit and confidence declaration step is selected.

It is required that there is at least 2 lead edges declared within the + or **-** 1 sample tolerance range of the four pulses.

Preamble Validation

It is required that there is a pulse position or lead edge declared within + or – one sample period of the start of the 1 chip or the start of the 0 chip for each of the first five data pulses of the message.

Reference Level Generation

The reference level generation process begins by selecting amplitude samples from each of the preamble pulses that are considered appropriate candidates, namely those that have leading edges declared in their reference positions. A one clock tolerance is allowed for lead edge inclusion but only in one direction since it is undesirable to consider both a positive and negative reference position shift within the same preamble. Lead edge selection is as follows: if the reference position was shifted minus one clock, then lead edges are included from the reference position and plus one clock. If the reference position was shifted plus one clock, then lead edges are included from the reference position and minus one clock. If there was no reference position shift, then the number of lead edges in the plus one and minus one clock positions are compared, and the lead edges from the position that has the most lead edges is used. If there is a tie the default is reference position and minus one clock.

The two amplitude samples after each valid lead edge position are entered into the reference level declaration algorithm (up to 8 samples are possible).

For each qualified sample amplitude, the amplitude is compared to all other qualified amplitude samples and the number that lies within plus or minus 2 dB is counted. If the highest count is unique, then the reference level is set to the amplitude of that sample. If there is a tie, it is resolved by removing all amplitudes from the tied set that are greater than 2 dB above the lowest amplitude in the tied set. The reference level is set to the average of all remaining samples.

Re-triggerable Preamble Detection

The decoder will only re-trigger when a signal is already being processed if the amplitude of all 5 data pulses of the new signal is at least 3 dB above the declared level of the existing signal. When in a re-trigger situation, the preamble validation step will require that there exists not only a pulse position or lead edge in the start of either the 1 chip or 0 chip, but that the amplitude resulting from the average of the two amplitude samples following the lead edge or pulse position found must exceed the amplitude of the reply in progress. This is required of all five pulses and all lead edges or pulse positions within + or – 1 clock of the start of both the one chip and the zero chip will be tested until a valid pulse amplitude is found or determined not to exist.

Enhanced Bit and Confidence Declaration

There are currently three enhanced bit and confidence declaration techniques that have been developed for the RMF: the center sample method that follows the method defined in appendix I; a multiple sample method that is a variation of the center sample method; and the 5-5 multiple amplitude method that is a variation of the 4-4 multiple amplitude approach defined in appendix I.

Center Sample Method

A high confidence one is declared when the center sample of the one chip is within + or – 3 dB of the preamble reference level and the center sample of the zero chip is not. A high confidence zero is declared when the center sample of the zero chip is within + or – 3 dB of the preamble reference level and the center sample of the one chip is not. If neither of the above conditions are met, the bit is declared low confidence and the bit value is awarded to the chip that has the highest amplitude. If the amplitudes are the same the bit value is set to zero.

Multiple Sample Method

With a 10 MHz sample rate, each bit is sampled 10 times, 5 per chip. The multiple sample method utilizes all samples by counting the number of samples in each chip that are within + or – 3 dB of the preamble reference level. The bit value is determined by which chip has the highest count. A tie defaults to a bit value of zero. High confidence is assigned if the count differs by 3 or more, otherwise low confidence is assigned.

The 5-5 Multiple Amplitude Method

Each of the 10 samples are quantized into four levels:

0: below threshold (-6 dB relative to the preamble)
1: above threshold but below the +/- dB preamble window
2: within the +/- 3 dB preamble window
3: above the +/- 3 dB preamble window

The 5-5 method forms two estimates of the bit data and confidence values, one using the odd samples (1-3-5-7-9) and the other using the even samples (2-4-6-8-10). The lookup value for the odd and even patterns are built from the five 2 bit quantized values. Therefore, there is a lookup table of size 1024 for both the odd and even patterns. The lookup tables provide one of the following values:

H1: the pattern occurred 90% or more when the bit was a ‘1’
M1: the pattern occurred 70% - 90% when the bit was a ‘1’

L1: the pattern occurred 50% - 70% when the bit was a ‘1’
L0: the pattern occurred 30% - 50% when the bit was a ‘1’
M0: the pattern occurred 10% - 30% when the bit was a ‘1’
H0: the pattern occurred 10% when the bit was a ‘1’

The odd and even values resulting from the lookup tables are used to index another table that provides the bit and confidence value. The odd / even pattern combining table is as follows:

Odd and Even Sample Combination Table

Odd (1,3,5,7,9) **Even (2,4,6,8,10)**

	H1	**M1**	**L1**	**H0**	**M0**	**L0**
H1	H1	H1	H1	L0	H1	H1
M1	H1	H1	L1	H0	L0	L1
L1	H1	L1	L1	H0	L0	L0
H0	L0	H0	H0	H0	H0	H0
M0	H1	L0	L0	H0	H0	L0
L0	H1	L1	L0	H0	L0	L0

Enhanced Error Detection and Correction Techniques

The RMF enhanced reception implementation utilizes both the conservative and the Brute Force error detection and correction techniques. The method applied follows that recommended in appendix I.

Conservative Technique

This technique is attempted only if the span of all low confidence bits in a message is no more than 24 bits. There must also be a limit of 12 low confidence bits total. Error correction is successful when a conversion of some or all of the low confidence bits results in a zero error syndrome.

Brute Force Technique

The brute force technique is applied only when the conservative technique has failed. The brute force technique is applied only if there are 5 or less low confidence bits in the message, but the low confidence bits are not limited to a 24 bit span. Error correction is successful when a conversion of some or all of the low confidence bits results in a zero error syndrome.

The RMF “Gold Standard”

The RMF 1090 environment analysis software was developed using the enhanced reception techniques to measure the Mode S fruit rate in high density fruit environments such as Los Angeles and Frankfurt Germany. When utilizing any of the methods described above, there are a high number of false triggers especially when using a low threshold. To counteract this effect, modifications to the technique and a number of filters were applied. The filter settings are selectable via a user menu and were optimized to reduce triggering to occur only on real Mode S signals with as little false trigger rate as possible. Data analysis has shown that with these modifications and additional filters in place, the extended squitter reception performance increases significantly over the strait appendix I implementation described above, and over the real time reception performance of the LDPU. The term “RMF Gold Standard” applies to this optimized reception technique. The RMF gold standard modifications and filters are described below:

The 5-5 Multiple Amplitude Method

Of the 3 methods developed for bit and confidence declaration, the 5-5 multiple amplitude method yields the best performance. Various Frankfurt data samples were processed with all three techniques and evaluated on their ability to detect and decode extended squitters and short squitter messages. The RMF gold standard utilizes the 5-5 multiple amplitude method.

The Odd-Even Sample Combination Table

It was determined that there were frequent occurrences of data bits declared wrong and with high confidence when using the 5-5 multiple amplitude method with the odd-even sample combination table as defined in the MOPS appendix I. This problem was reduced by using the modified table shown below.

Alternative Odd and Even Sample Combination Table

Odd (1,3,5,7,9) **Even (2,4,6,8,10)**

	H1	**M1**	**L1**	**H0**	**M0**	**L0**
H1	H1	H1	H1	L0	**L1**	**L1**
M1	H1	H1	L1	**L0**	L0	L1
L1	H1	L1	L1	**L0**	L0	L0
H0	L0	**L0**	**L0**	H0	H0	H0
M0	**L1**	L0	L0	H0	H0	L0
L0	**L1**	L1	L0	H0	L0	L0

Use of DMTL in Preamble Validation

Data analysis showed that there were occasions where the enhanced decoder would trigger too early on some otherwise valid mode S replies due to the location of fruit prior to a preamble pulse group and prior to the data block. With the combination of low receiver threshold and high fruit rate, it is not that difficult to find a stray pulse position to satisfy the first or second data pulses tested during preamble validation, and then have the actual mode S data block pulses satisfy the rest. Usually the fruit is at a significantly lower amplitude with respect to the actual reply. A solution to this problem is to add an amplitude requirement to the preamble validation step.

The processing order was modified to perform reference level generation prior to preamble validation. This was done so that the dynamic threshold determined by the reference level process can be applied to the preamble validation step. The preamble validation process was modified to not only test for the presence of a pulse at either the 0 or 1 chip of the first five data bit positions, but to also require that the peak amplitude of the pulses found must exceed the dynamic threshold. The dynamic threshold is set to 6 dB below the amplitude of the preamble.

Preamble Pulse Amplitude Variation

A software filter was added that eliminates preamble declaration when there is greater than a 6 dB variation in amplitude between the preamble pulses. This filter is intended to help eliminate false triggers from fruit.

NOTE: The following software filters are included in the RMF "Gold Standard" and through testing have shown to improve detection. However, it is understood that they may be impractical to apply to real-time applications.

Preamble Pulse Amplitude Variation 2

It was determined that the preamble pulse amplitude variation limit could eliminate triggering on real mode S preambles that have greater than 6 dB amplitude distortion due to overlapping ATCRBS. To limit this effect, the message is cancelled only if there is greater than a parameter number (12) of low confidence bits in the message. Thus, if a message has greater than a 6 dB variation in amplitude between preamble pulses, but 12 or less low confidence bits in the data block, the message is retained.

Low Confidence Limit Filter

A message is cancelled if it has greater than a parameter number of low confidence bits (24).

Bit Lost Limit Filter

If a parameter number of consecutive data bits (3) contain a sample pattern of all zero's (all samples are more than 6 dB below the reference level) the message is cancelled.

Pulse Position Gap Filter

If within the data block portion of a message there is greater than a parameter number of consecutive samples (13) without a pulse position declared, the message is cancelled.

DF Code Filter

The first five data bits are decoded for bit and confidence declaration. If the high confidence bits determine that the message can not be either a Df=11 or Df=17, the message is cancelled.