Improving Test Efficiency on a Limited Budget – A Measurement Timing Case Study

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Abstract— **Antenna test facilities are large investments that are expected to be used for decades. Some facilities are well-maintained with periodic upgrades to the latest equipment, while others attempt to minimize changes to the existing system due to the difficulty of recertifying test procedures or lack of sufficient budget. Meanwhile, antenna designs and test processes continue to evolve and require more extensive antenna performance data packages than ever imagined when the test facility was initially installed. As a result, total test times may grow exponentially, thus limiting range throughput. The size of collected data files can also become extremely large, even exceeding the capacity of some common commercial databases.**

This case study illustrates that periodic evaluation and optimization of system test processes and measurement timing can sometimes pay large immediate dividends in range throughput and productivity. In addition, by creating an accurate system measurement timing model, sensitivity studies can easily be conducted to provide guidance in selecting the most effective alternative test plans or incremental investments in new equipment.

I. Introduction

Test time, productivity, and throughput are important issues that have been a topic of discussion for many years [1][2][3]. Industry has responded by developing faster instrumentation [4][5][6][7][8][9][10][11] and implementing various creative techniques [12][13][14] for speeding up the measurement process. This case study shows that it can be advantageous from time to time to re-examine how these instruments are configured and used in a system as test requirements change.

An existing spherical near-field test facility that was used productively and effectively for many years had become a bottleneck. Changes in antenna designs and test processes drove test times to an extreme, approaching 300 hours of data acquisition for a single antenna and 160 hours for additional processing. Schedule pressures drove facility managers to investigate options to shorten this process without reducing the amount of data being collected.

A system measurement timing assessment was conducted for this test facility to determine the most effective means of reducing the data acquisition time. The assessment was conducted as a series of steps:

- Establish a baseline of the acquisition timing before making any changes
- Create an accurate system timing model for this test facility and its specific characteristics
- Optimize the system timing for the current system without any new equipment
- Simulate potential improvements that could be accomplished with new or additional equipment
- Summarize the test time benefits of various options

II. System Description

A general overview of a typical measurement sequence for antenna measurement systems is described in [1]. The block diagram in Figure 5 illustrates the primary interconnections and signals that are related to the instrument timing for this particular system. A Position Trigger generated by the MI-4193 Position Control Unit initiates a measurement sequence at each point in space. The MI-788 Networked Acquisition Controller (NAC) manages the process of making multi-channel, multi-frequency measurements.

The MI-750-H1 Receiver measures the RF signal on receipt of a Receiver Trigger and indicates when the measurement is complete on the Measurement Done signal. The receiver also accepts a Frequency Trigger to change its internal frequency and passes this signal on to the two MI-3111 Signal Sources that are used to generate the Transmit and LO RF signals. The receiver then monitors the Source Lock status and reports the completion of a frequency step on the Frequency Done signal to the NAC. This process is repeated at all desired measurement positions.

The complete data acquisition process is under the control of MI-3000 Arena™ software operating on a workstation. The measured data is periodically transferred to the workstation and stored in a database.

III. Acquisition Timing Baseline

An important goal of the assessment was to gather detailed information on the system timing which could be used to create a precise timing model. The timing model was used to optimize current system timing, to accurately predict system test times for various test requirements, and to make recommendations for additional modifications that will reduce overall test time. The model was based on many factors that affect system timing as described in several previous papers [1][15][16].

A. Baseline Measurements

A baseline of the current system timing was developed. The timing-related settings for each instrument was reviewed and documented. An oscilloscope was used to observe the trigger and status signals between equipment to gain further insight. The critical timing parameters that were measured included:

- Frequency Trigger and Lock timing between the receiver and signal sources
- Frequency Trigger and Frequency Done timing between the Networked Acquisition Controller (NAC) and receiver
- Measurement Trigger and Measurement Done timing between the NAC and receiver using several different receiver sample rates
- Position Trigger Timing Jitter (variation of time between position triggers)
- Impact of Multiplexer timing when controlled by the receiver or the NAC

A stopwatch was used to measure longer time intervals that impact the overall test time, such as the time required for the step axis to move and settle and the time required to initialize the next scan.

B. Baseline Timing Model

All of the timing information gathered was then used to create the system timing model. The timing model was used to predict scan speed as a percentage of maximum positioner speed, and these predictions were verified by running several scans with different sample rates, number of frequencies, and multiplexer configurations.

It had been observed that one particular test scenario was requiring approximately 72 hours of acquisition time for 1 of 4 antenna ports to be measured. The updated timing model predicted 73.4 hours. This test scenario required 0.45 degree position trigger spacing, 485 frequencies, 10 kHz sample rate, no multiplexers, 0 to 180 degrees on the step axis, and 2 polarizations. With an error of less than 2% between predicted and measured acquisition time, the updated timing model was considered to be sufficiently accurate.

IV. System Timing Optimizations

While measuring the baseline timing, several observations were made regarding the frequency switching timing and these areas were explored for possible optimization.

A. Signal Source Trigger/Lock Timing

The standard approach for many types of signal sources is to use active low trigger signals. The default frequency trigger pulse width in this system is 15 µs. This works well under a wide variety of applications, however it is not optimum in this case. This particular signal source steps to its next frequency on the rising edge of the trigger signal. So the standard configuration results in a 15 µs delay before the signal source begins to change frequency. This delay is not significant for a small number of frequencies, but begins to have an impact for a large number of frequencies.

Therefore, the default receiver Frequency Trigger output was modified to provide an active high trigger signal to both signal sources to eliminate the 15 µs delay.

B. Frequency Done Timing

The Networked Acquisition Controller (NAC) provides a Frequency Trigger to the receiver, which the receiver subsequently relays to the signal sources while also setting its Frequency Done signal false. Once the receiver senses that the signal sources are Locked, the receiver applies a programmable Source Settling Delay then sets the Frequency Done signal back to true. These transitions are sensed by the NAC and the next action can begin.

For the baseline test setup, this complete process was measured to be approximately 625 µs, which seemed much longer than required. The elements of this were:

- Inverted Trigger = 15 µs
- Source Settling Delay = 500 µs
- Source Lock synchronization signal = 105 µs
- Overhead = 5 µs

The signal source frequency switching timing was then examined in more detail. It was noted that the MI-3111 Signal Source Lock output signal is not a true indication of lock. It is a synchronization signal that always transitions low when triggered and then transitions high in 105 µs +/- a few µs. Historical measurements of these sources indicate that it actually switches frequencies in approximately 120-180 µs, well within its specification of 200 µs maximum. Therefore, if other timing delay settings are used to ensure that 200 µs is allowed for the source to switch frequencies, it is not essential to use the Lock signal from the sources.

So the signal source Lock lines were disconnected and the receiver settings were changed to ignore them. Delay settings were changed in the receiver to achieve a total delay of 210 µs between triggering the sources and reporting Frequency Done to the NAC. This was achieved by changing the Source Settling Delay to 100 µs and using another receiver parameter to set the Frequency Trigger to Lock sense delay to 110 µs. This combination provides 10 µs for RF propagation and settling time beyond the source switching speed maximum specification. This timing was subsequently verified by using an oscilloscope to measure approximately 212 µs.

C. Validation of Optimized Timing

The new timing for frequency switching was also tested at the system level to ensure that the RF data was valid. A test technique was devised to make several measurements in rapid succession throughout the frequency switching process. A relatively strong RF signal was applied to the mixer associated with the signal channel of the receiver. The measurements were initiated during a time where the frequency transition was known to be incomplete and measured results would be near the noise floor. Later measurements would occur after frequency transitions were complete and should produce a constant strong signal level.

This technique was implemented by configuring the receiver as if it had an 8-port multiplexer attached, although in reality no multiplexer was present. The receiver then made 8 sequential measurements in time corresponding with each port of the multiplexer. All measurements should be nearly identical except for the effect of frequency switching. The total of the delay settings was reduced to 100 µs to ensure that the first few receiver measurements would occur before the frequency transition had been completed. The receiver sample rate was set to 46.4 kHz for a sample time of approximately 25 µs for each multiplexer state.

The 8 readings were compared using the plot function of the system software. The plots showed the transition from low level signals to a stable signal level, and the frequency switching time was estimated based on the receiver timing. The results confirmed that the sources do switch frequency in approximately 180 µs as expected, and that a lengthy settling delay beyond 200 µs is not required for this system. Several actual measurement scans were also performed and the measured data examined as further confirmation of the optimized timing.

D. *Impact of Optimizations*

The reduction in frequency switching timing from 625 µs to 212 µs had a major impact on test scenarios that require a large number of frequencies. The baseline test scenario that required 73.4 hours can now be performed in 37.7 hours. For all 4 antenna ports, the total baseline acquisition time was 294 hours. This complete acquisition can now be done in 151 hours for a savings of 143 hours. Other similar test scenarios using a large number of frequencies will also benefit from improved test times.

Note that the original Source Settling Delay of 500 µs had been selected during system installation when few frequencies were being measured and much less data was being acquired. In many simple data acquisitions, a system can run at maximum positioner speed with timing margin to spare. Reducing timing delays offers little advantage in these cases. A relatively long source settling delay would have been a conservative and justifiable choice at that time.

V. Potential for Additional Performance Improvements

The timing model was subsequently used to predict the effects of additional changes that could be made to further reduce acquisition time. Ideas included adjustments to receiver sample rate, position trigger jitter reduction, use of multiplexers, signal sources with faster frequency switching times, and a simultaneous 4-channel receiver. A sensitivity study was conducted to separately evaluate the impact of each proposed change and to determine which ones would provide the greatest benefit. The baseline test case with the optimized timing of 151 hours was used for comparison. The predicted effects were then validated by configuring the existing system hardware to simulate installation of the new equipment and measuring the results.

A. *Receiver Sample Rate Tradeoffs*

For the baseline system, the receiver sample rate had been set to 10 kHz. This provides a receiver sensitivity of -110 dBm when using the simple averaging choice of digital filter and its standard mixer. This system uses a mixer with extended frequency range of 2-40 GHz, which results in a 4 dB degradation of sensitivity to -106 dBm at 10 kHz.

The receiver used in this system can operate with sample rates from 1 Hz to 4 MHz with a corresponding impact on sensitivity and overall test time. The chart in Figure 1 shows the relationship between sample rate, sensitivity, and acquisition time for a few incrementally faster sample rates. For example, a 31.6 kHz sample rate could be used instead of 10 kHz to reduce acquisition time from 151 to 122 hours. The downside is that measurement uncertainty is degraded some by the noise floor being at -100 dBm instead of -106 dBm. The system measurement uncertainty budget would need to be examined to determine whether this is an acceptable tradeoff.

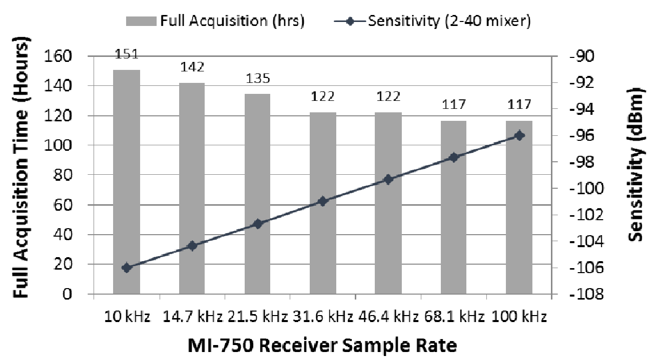

Figure 1. Receiver Sample Rate Tradeoffs

B. *Position Trigger Jitter Reduction*

The desired measurement spacing in a spherical near-field system is generally dictated by the antenna under test size and operating frequency. This spacing defines the location at which position triggers should occur along the scan axis. In the ideal situation, the scan axis moves at a constant speed and the time between position triggers is constant. However, there is usually some variation in the position trigger timing due to imperfect speed regulation in the control of the scan axis.

The time required to make the measurements at each position trigger is driven by several parameters, such as the number of frequencies, number of beams, and receiver sample rate. For a defined acquisition, the time required is nearly constant, and this amount of time must be allowed between each position trigger. If the variation in the position trigger timing sometimes results in too little time to finish the measurements before the next trigger is generated, an overspeed condition occurs. So the positioner speed must be slowed slightly to allot sufficient time between position triggers in the worst case condition.

The position trigger timing variation on the azimuth axis in this facility was measured. The measurement methodology was not extremely precise nor was it performed over a very long period of time, so the results are best interpreted as an approximation. Position trigger timing was observed by monitoring the Position Trigger signal on an oscilloscope. The positioner was moved through 3 scans of 1 revolution each at 4 different speeds: 30%, 15%, 8%, and 6%. The results are shown in Table I .

TABLE I. POSITION TRIGGER TIMING VARIATION

Speed	Minimum time	Maximum time	Variation
30%	76.1 ms	88.2 ms	12.1 ms
15%	154.4 ms	175.5 ms	21.1 ms
8%	305.2 ms	322.4 ms	17.2 ms
6%	406 ms	425 ms	19 ms

At some speeds, more scans were observed for a longer period of time. More variation can be seen by watching for a longer period of time. So the numbers in the table are an indication of timing variation, but not necessarily the worst case. Also note that the variation is not proportional to speed. For the final timing model, a parameter was added that can be adjusted manually for estimating the timing margin needed to minimize overspeeds.

There is some potential for improvement of the position trigger timing variation. The improvement in overall test time would be small for the baseline test case that was examined (~10%), but it might be significant in some other test scenarios. Further investigation might be conducted using other available hardware to determine whether improvements could be gained by:

- Modifying the positioner to reduce the maximum speed of the scan axis
- Explore whether the control loop tuning can be improved using the existing controller
- Replacing the controller with a more advanced one, such as the MI-710C Position Controller

C. *Multiplexer Considerations*

Sometimes adding a multiplexer to measure multiple ports in a single acquisition can provide a productivity boost, especially if the positioning system is running at maximum speed. But if the system is already running at less than full speed, the degree of improvement depends on several factors, and having a valid timing model becomes an important tool in predicting system test times.

Detailed measurements were made of multiplexer timing, both when controlled by the receiver and when controlled via the beam port on the NAC. The results were included in the timing model. The NAC has a slightly longer timing overhead than the receiver which becomes apparent when comparing test times.

The chart in Figure 2 shows a comparison between the baseline test case with no multiplexers and 3 other configurations using 1 or 2 multiplexers. The comparison includes:

- No multiplexer
- A 2-port multiplexer on the transmit side with a dual-port probe (Tx)
- A 4-port multiplexer on the antenna under test (Rx)
- Both a 2 port Tx mux and a 4 port Rx mux

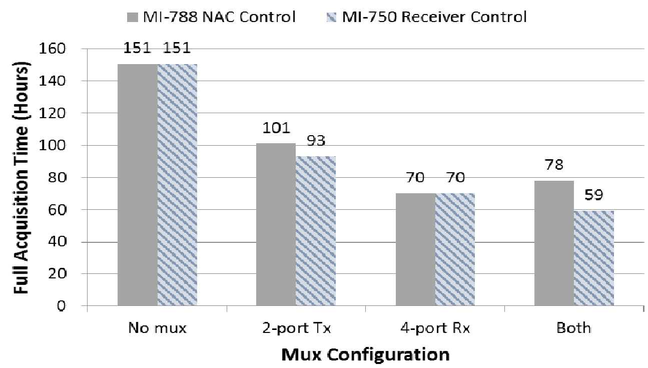

Figure 2. Comparison of Multiplexer Configurations

The chart shows that test time can be shortened by using multiplexers. One surprise is that the test time is not further reduced when both multiplexers are used and controlled by the NAC. The issue is that this combination must run very slowly, and the position controller has limited resolution at very low speeds. For this test case, the positioner speed was set to 2% which provided much longer timing margin between position triggers than was necessary. The timing margin could be reduced by increasing the positioner speed. But the next higher setting is too fast under these conditions. So the total acquisition time is skewed from what might be expected.

D. *Faster Switching Signal Sources*

The existing signal sources are specified to switch frequency in less than 200 µs. The possibility of incorporating either of two types of faster switching signal sources was explored. The timing model tool has been used to estimate the improvement to the total test time using a switching speed of 50 µs for new source 1 and 1 µs for new source 2. The result is shown in Figure 3, with the total test time shown on the vertical bars and the switching speed shown on the dashed line. As might be expected for a test requiring a large number of frequencies, a significantly faster signal source would be extremely beneficial.

Note that 10 µs of settling time was added to the switching times to allow for propagation delays through the system, so the improvements with a 1 µs switching speed are not as great as might be expected. Note that the settling time might be reduced with further study of the RF paths.

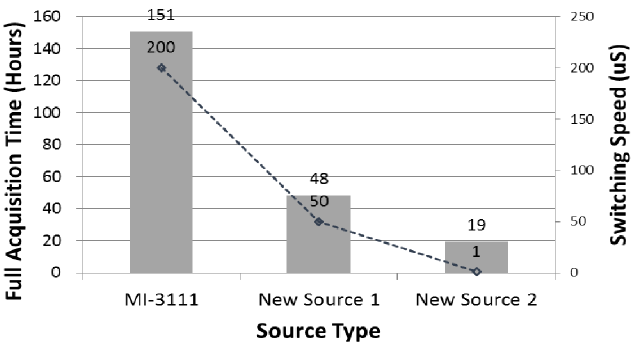

Figure 3. Effect of Signal Source Switching Speed

E. Simultaneous Multi-channel Receiver

As a final potential improvement, the use of a simultaneous multi-channel receiver was explored. The impact of using this receiver as compared to the baseline test case is significant. Since the baseline test case measures each of the 4 AUT ports with a completely separate acquisition and the multi-channel receiver would collect data for all 4 AUT ports simultaneously without slowing down the scan axis speed, the acquisition time would be reduced by a factor of 4. The resulting acquisition time would drop from 151 hours to 38 hours.

F. Combinations of Improvements

Additional performance improvements were analyzed by combining several improvements described in the previous sections. Refer to Table II for a summary of the configurations that were evaluated with the resulting test times shown in Figure 4. The timing model spreadsheet previously developed and verified was used for this analysis.

For all combinations, the receiver sample rate is increased to 68.1 kHz with a corresponding increase in the noise floor of 8 dB. It is assumed that this yields adequate signal to noise ratio for the measurement or that other steps have been taken to increase the maximum signal level (such as adding an amplifier) to result in an acceptable signal to noise ratio.

The first three examples use multiplexers and do not use the simultaneous multichannel receiver. The second three examples start with the simultaneous multichannel receiver, then only adds a 2 port multiplexer with dual ported probe.

It is also assumed that New Source 1 with 50 µs switching speed has been implemented in the system in configurations 1 through 5, and New Source 2 with 1 µs switching speed was used in configuration 6.

For configurations that use the 4 port multiplexer, it is assumed that the multiplexer is controlled by the NAC, enabling a feature that records position in every multiplexer state. For the 2 port multiplexer configuration on the transmit side, an appropriate dual polarized probe is also required. It is assumed that the 2 port multiplexer is controlled by the receiver, and that separate position information is not required because the measurements are made very closely in time. The 4-channel simultaneous receiver obviates the need for a 4-port multiplexer at the AUT.

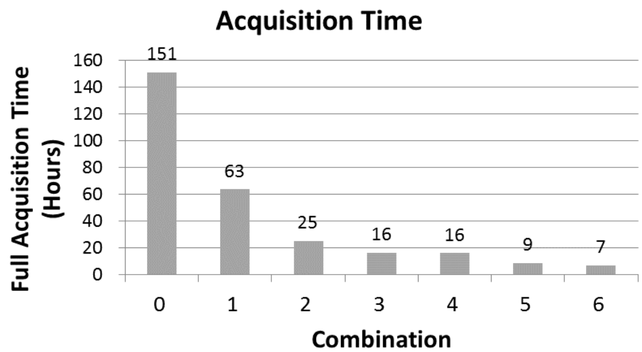

Figure 4. Acquisition Time for Various Potential Configurations (see Table II)

The result of this examination shows that by using a combination of several of these improvements along with a modest investment in new equipment, total acquisition time could be further reduced to 7 hours, achieving a 95% reduction in acquisition time as compared to the optimized baseline.

VI. Post-processing Improvement

Post-acquisition processing time was also addressed separately from the timing study. Some of the extensive processing time was caused by a data file size limitation. The data files for these acquisitions exceeded the 2 GB limit imposed by the commercial database software used to store acquisition files in this system. The full hemispherical scan had previously been divided into segments that included a subset of the complete acquisition to keep each individual acquisition file below the limit. Part of the post-acquisition processing included combining and restructuring these files. By implementing an alternate file structure to support data acquisitions greater than 2GB, approximately 25% of the total post-processing time was eliminated.

VII. Conclusion

Increased demands on antenna test facilities warrant a review of system performance, especially when overall test times become excessive. Timing adjustments in instruments can be used to optimize measurement times and improve throughput. Reducing or eliminating small extra delays can make an enormous improvement in range productivity and throughput.

In this case, excellent immediate improvements were made, and potential changes for additional dramatic reduction in test times have been identified with high assurance of success.

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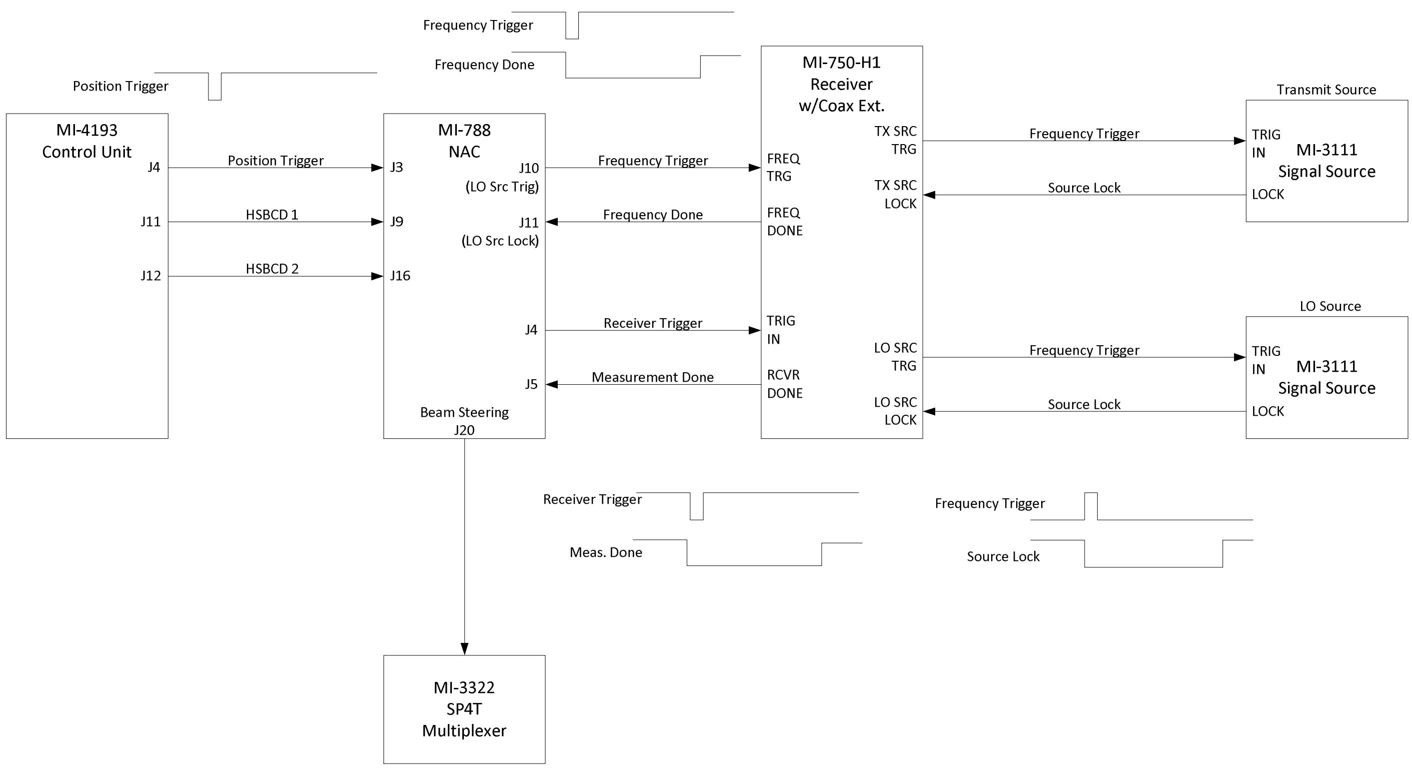

Figure 5. Block Diagram of Instrument Timing Interconnections

TABLE II. POTENTIAL CONFIGURATIONS FOR FURTHER IMPROVEMENT

Combination	Sample Rate	Source	4 port Mux	2 port Mux	Simultaneous 4 Channel Receiver
0	10 kHz	Existing	No	No	No
1	68 kHz	New 50 µs	Yes	No	No
2	68 kHz	New 50 µs	Yes	No	No
3	68 kHz	New 50 µs	No	Yes	No
4	68 kHz	New 50 µs	No	No	Yes
5	68 kHz	New 50 µs	No	Yes	Yes
6	68 kHz	New 1 µs	No	Yes	Yes