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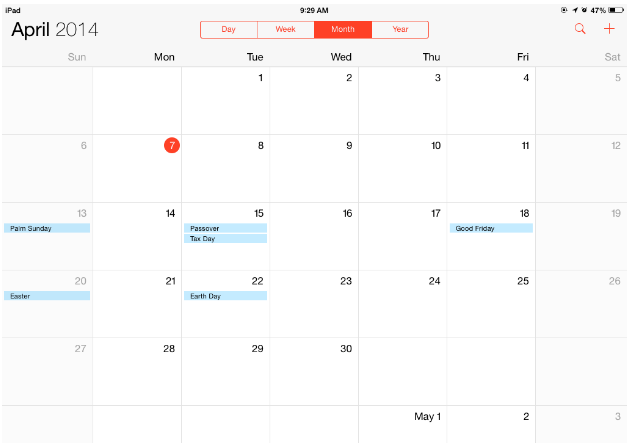
| **Subject:**<br>Modification of LORTM for Band-1 Operation, ALMA Project | **Date:**<br>2014 April 14<br>Memo_DK002_2014 | **From:**<br>D. Kubo,<br>R. Srinivasan |
| **To:**<br>Ted Huang | **cc:**<br>Ming-Tang Chen | **Location/Phone:**<br>Hilo Office/<br>808-961-2926 |

Filename: Memo_DK002_2014_revNC.doc
References: MZM-LORTM Users Manual
https://dl.dropboxusercontent.com/u/51016221/Memo_RS_2012_MZM_LORTM_Op_Manual_Revision_E.pdf

## I. Summary

Work dates: April 2 – April 16, 2014. The original MZM-LORTM was designed to operate from 65.5 – 122 GHz and precluded bands 1 and 5 due to the architecture. We have successfully implemented the Band-1 modifications to provide support over the frequency range of 20 - 60 GHz, and in addition, have maintained the original normal function of 65.5 – 122 GHz. A brief description of the modifications and test results are contained in this memo. We were successful in locking the WCA to the MZM-LORTM. Minor additional work is required to repair a damaged connector and to add delay compensation fiber.




## II. Initial Checkout of MZM-LORTM (April 2, 3)

We inspected the LORTM and configured test hardware as shown in *Fig. 1*. This is our first use the Yokogawa AQ6370C OSA instrument which provides much finer spectral resolution than our Agilent unit and allows us to resolve the two closely spaced optical tones in the LSB (just visible in OSA in photo below). *Fig. 2* below shows the optical and RF outputs for 100/106 GHz. We used a W-band NTT photomixer to detect the RF signal.

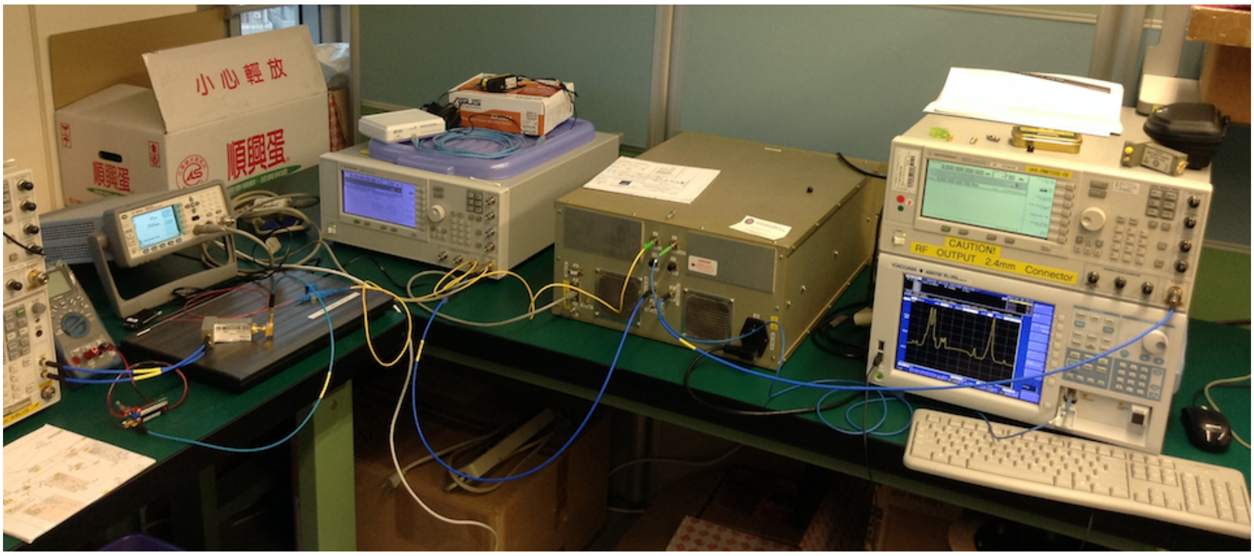



*Fig. 1 LORTM Test Setup. Rear panel view of LORTM (center). OSA on right shows optical spectra for 100/106 GHz. Ref. 1 = 25.75 GHz, Ref. 2 = 3.00 GHz.*

An Agilent E4448A RF spectrum analyzer was used to capture the spectrum and integrated phase noise, which was measured to be 2.5 degrees RMS (3 kHz to 3 MHz). Previous measurements at 100 GHz produced ~1.7 degrees RMS using an Agilent 8563E spectrum analyzer over the same integration bandwidth. The Agilent 8563E instrument performed continuous phase noise measurements that required several minutes to complete, however, the E4448A appears to be performing the measurements using captured digitized data that take only a few seconds to complete. This leads us to believe that the phase noise measurement values produced by the E4448A are less accurate and may explain the higher value of 2.5 degrees relative to the previous 1.7 degrees measures with the older instrument. We will attempt to repeat this measurement using a 8563E at a later date after the phase noise utility module has been installed.

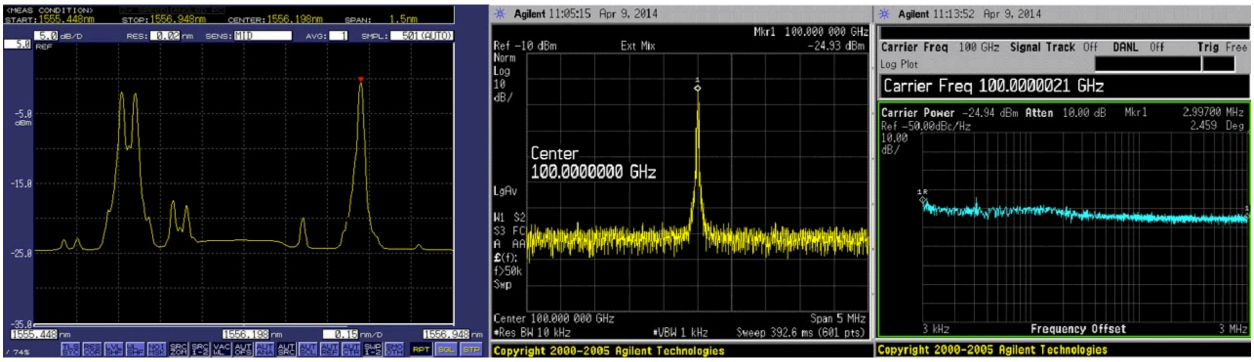



*Fig. 2 100/106 GHz output from LORTM. Left – optical spectral output captured by OSA; center – RF spectral plot from NTT photomixer output captured by E4448A; right – L(f) phase noise plot.*

We spent approximately a day collecting data using the new OSA for an upcoming IEEE paper we plan to submit on the MZM-LORTM. We noticed the J6 3.5 mm connector that serves as the Ref. 2 IF input (0.222 – 3.500 GHz) was damaged but the unit was still operational (refer to *Fig. 3*). We have spares of this 3.5 mm connector in our Hilo office and I will perform the replacement in May during my visit here for the GLT F2F in May. Based on a limited sample of tests, we are fairly certain that the MZM-LORTM unit is functional and is operating as we had left it in Taichung in 2011.

<u>Test Equipment List:</u>
Ref. 1 – Agilent E8257D, S/N MY50423019
Ref. 2 – Agilent E8257D, S/N US47491402
Optical Spectrum Analyzer – Yokogawa AQ6370C
W-Band Photomixer – NTT 10D-PMW-09001-0, S/N 2190901
DC Bias Source for above – Custom battery with potentiometer
W-Band Harmonic Mixer – Agilent 11970W
RF Spectrum Analyzer – Agilent E4448A, S/N MY45300144
50 GHz Photomixer – U2T XPDV1020R, S/N 27.R32.520/B3.118
DC Bias Source for above – U2T PPS-03, S/N BO1.0025
Optical Power Meter – Oz Optics POM-300-IR, S/N 127767-3

Items brought from Hilo

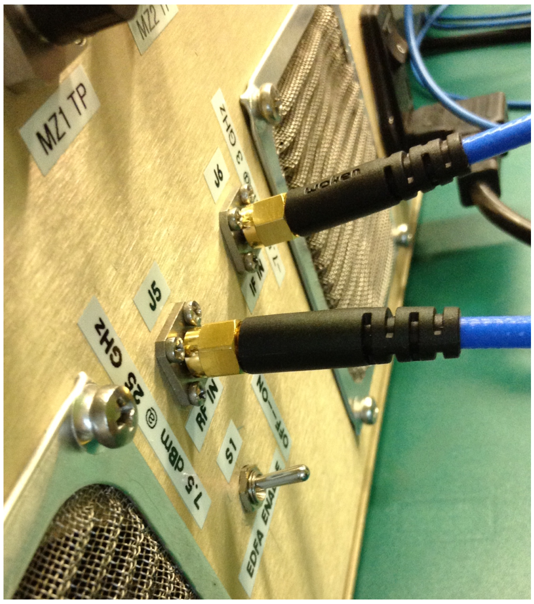



*Fig. 3 Damaged J6 connector. This 3.5mm connector is visibly bent upward but is still functional.*

## III. Modification for Band-1 (April 5-7)

The basic concept of this modification is to remove the upper side band (USB) optical tone by turning off the RF power amplifier for MZ1, and to re-inject the laser carrier with the MZ2 signal at the appropriate level. Since this LORTM unit will be used to support bands 6 and 7 for the GLT project, our goal is to provide two modes, a normal mode to support the existing bands, and a Band-1 mode to support bands 1 and 5. The modification of the MZM-LORTM consists of the addition of the following components (refer to *Fig. 4* and *Fig. 5*):

a) General Photonics 90/10 pigtail optical coupler to pick-off a sample of the laser carrier (CP4)
b) Oz Optics variable optical attenuator to fine adjust the sampled laser carrier power (AT3)
c) Leoni SPDT optical switch to select between normal mode and Band-1 mode
d) General Photonics 90/10 NoTail optical coupler to inject the sampled laser carrier with the MZ2 signal (CP5)
e) Rear panel mounted DPDT toggle switch to simultaneously control the MZ1 RF power amplifier and Leoni optical switch

The optical path order of the added components is: CP4 (item a)), Leoni switch (item c)), AT3 (item b)), and CP5 (item d)). Not shown in the schematic are the Leoni optical switch and rear panel mounted toggle switch. The Leoni optical switch is used to either inject the laser (Band-1 mode) or not (Normal mode), and the rear panel toggle switch is used to control the Leoni switch and enable or disable the AR1 Centellax RF power amplifier. The up position of the toggle switch is Normal mode (Centellax AR1 on, laser carrier injection disabled) and the down position is Band-1 mode (Centellax AR1 off, laser carrier injection enabled).

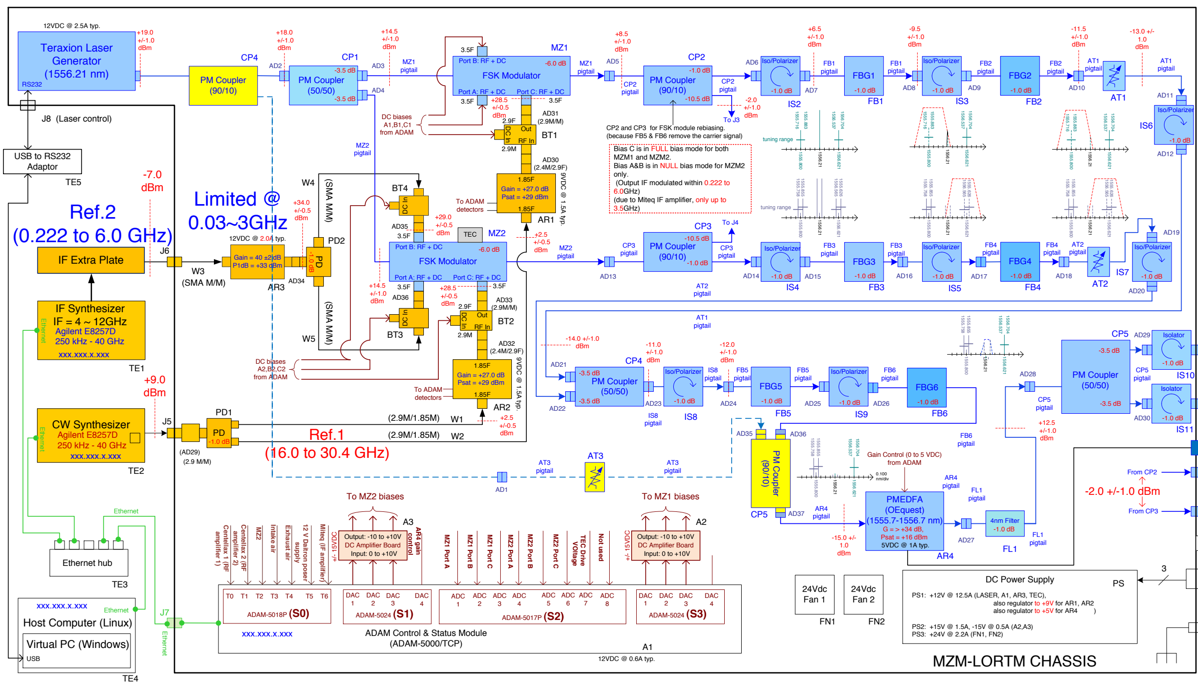



*Fig. 4 LORTM schematic with modifications. New components are shown in yellow, the SPST optical switch and DPDT toggle switch are not shown in this drawing.*

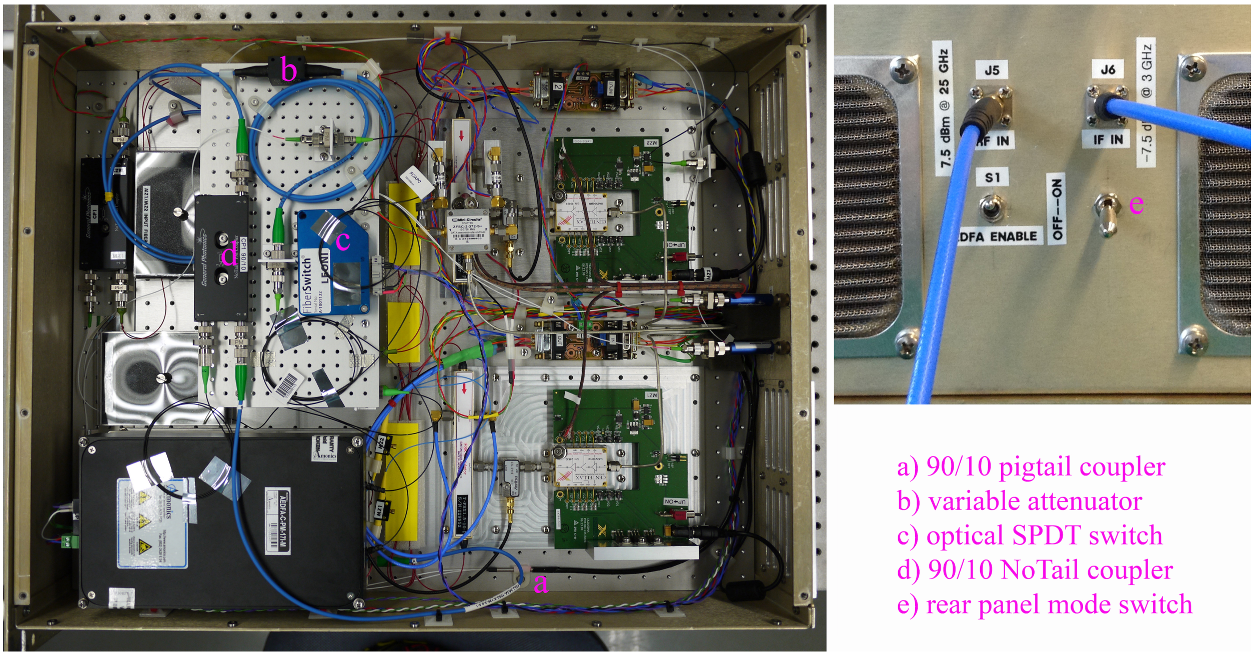



*Fig. 5 LORTM after modifications. Note that components b), c) and d) were mounted onto the combiner plate. Toggle switch e) was added to switch between normal and Band-1 modes (up is normal, down is Band-1).*

## IV. Performance Tests (April 8-10)

*Fig. 6* shows the optical outputs from J2 for both Normal (left) and Band-1 (right) modes controlled by the S2 toggle switch located on the rear panel. Note the suppression of the USB tone and the re-injection of the 1556.21 nm laser carrier for the Band-1 mode.


*Fig. 6 Optical output at J2. Ref. 1 = 25.75 GHz, Ref. 2 = 3.00 GHz. The left plot shows the LORTM in normal mode generating RF references of 100.00 and 106.00 GHz (mode switch up). The right plot shows the LORTM in Band-1 mode producing 48.50 and 54.50 GHz (mode switch down).*

The MZM-LORTM was setup for 44/50 GHz using Ref. 1 = 23.5 GHz, and Ref. 2 = 3.0 GHz. The optical and RF spectral plots are shown in *Fig. 7*. We immediately noticed the high noise pedestal surrounding the 44 GHz RF signal (center plot) with a tone to noise ratio of approximately 40 dB and integrated phase noise value of 10 degrees RMS (3 kHz to 3 MHz). In comparison, the 100 GHz signal seen in *Fig. 2* has a tone to noise ratio of approximately 55 dB and integrated phase noise of 2.5 degrees RMS. Fortunately, we had seen similar symptoms during our early LORTM development work and recognized the cause to be unequal path lengths between the modulated signal path and the injected laser paths between CP1 and CP5 of *Fig. 4*. We added various lengths of fiber to the laser injection path and determined a rough compensation length of 14.3-meters. We did not have enough fiber and adapters to find out what would happen if we went longer than this value. The right panel of

*Fig. 7* shows the RF spectrum after optical length compensation with a tone to noise ratio of slightly more than 55 dB. The integrated phase noise of this 44 GHz tone was 1.2 degrees RMS, an 8x improvement over the uncompensated condition.

Since the 14.3-meter compensation length consisted of multiple segments of jacketed fiber, we could not install it into the LORTM unit so the performance is currently as shown in the center plot of *Fig. 7*. I plan to purchase several sets of buffered fiber bracketing the 14.3-meter value (e.g., 13.5, 14.0, 14.5, 15.0, and 15.5-meters) and will either install it myself or have Johnson Han perform the work. This should bring the performance equal to or better than what is shown in the right plot of *Fig. 7*.

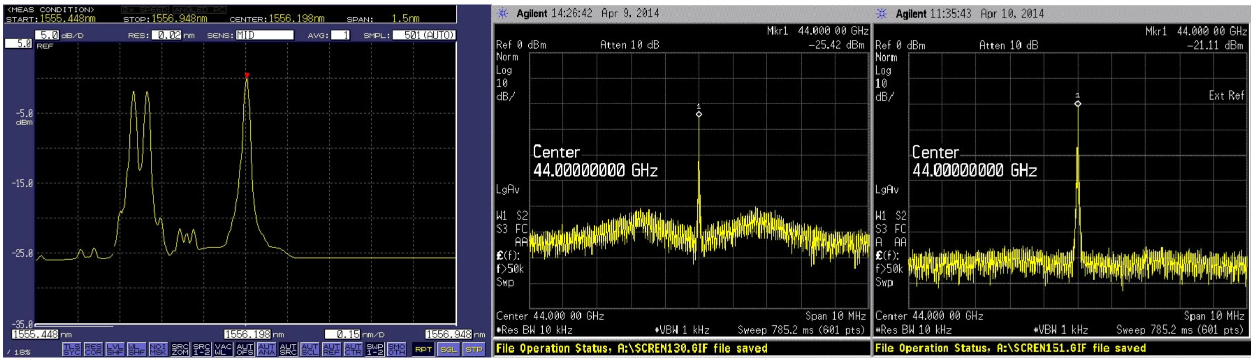



*Fig. 7 44/50 GHz output from LORTM. Left – optical spectral output captured by OSA; center – RF spectral plot from U2T photomixer output captured by E4448A without fiber length compensation; right – RF spectral plot with 14.3 meters of fiber compensation.*

## V. Software Interface (April 10, 11, 13)

The control software for the LORTM resides in the Dell laptop. The username for this laptop is "rsriniva" and the password is "Eafeic2009", both without the quotes. Ranjani has generated a simple web based software GUI interface as shown in *Fig. 8*. Under the "Set LORTM" window, the user is prompted to enter the LO and TS (test signal) frequencies in GHz, and the FLOOG (first offset LO generator) frequency in MHz. The software then automatically adjusts the Ref. 1 and Ref. 2 synthesizers (Agilent E8257D) via their Ethernet interfaces. Optional user interfaces are provided in the GUI to fine adjust the DC biases to MZ2 as well as the EDFA gain.

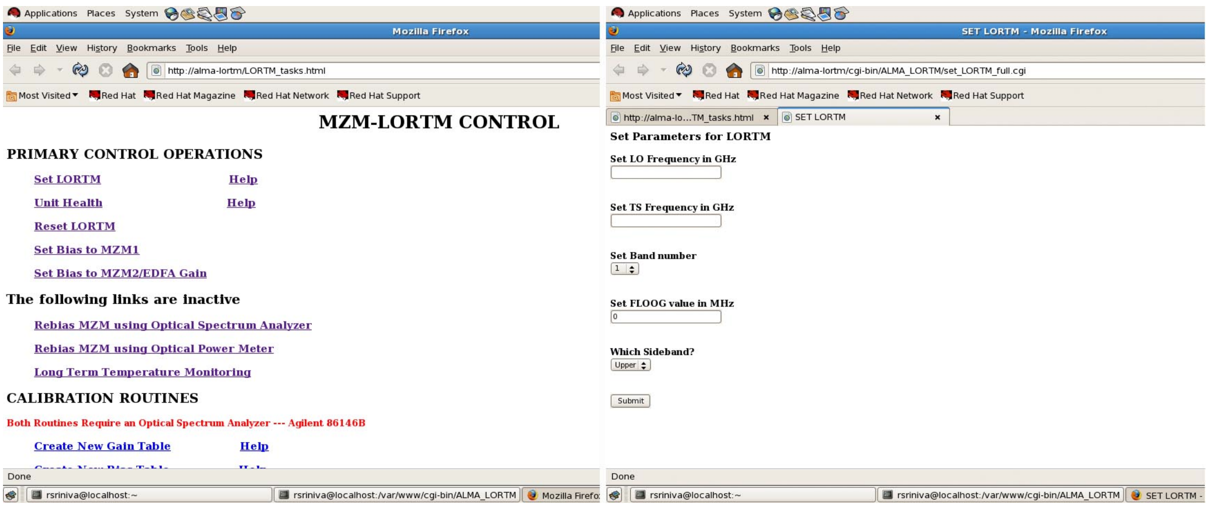



*Fig. 8 Example screens of GUI control interface. The left panel shows the default homepage of the FireFox browser after it is launched and is the main page to control the LORTM. Selecting the "Set LORTM" opens up the page shown on the right panel.*

**VI. Interfacing to the ALMA Band-1 WCA (April 11, 14)**

We relocated the MZM-LORTM and support equipment from R1031 to R1032 to be in the same lab as the ALMA Band-1 work, refer to *Fig. 9*. Using our U2T photomixer, we were successful in locking the WCA across its permissible lock range of 27.0 – 40.0 GHz, albeit with very poor phase noise (due to the fiber length imbalance described earlier).

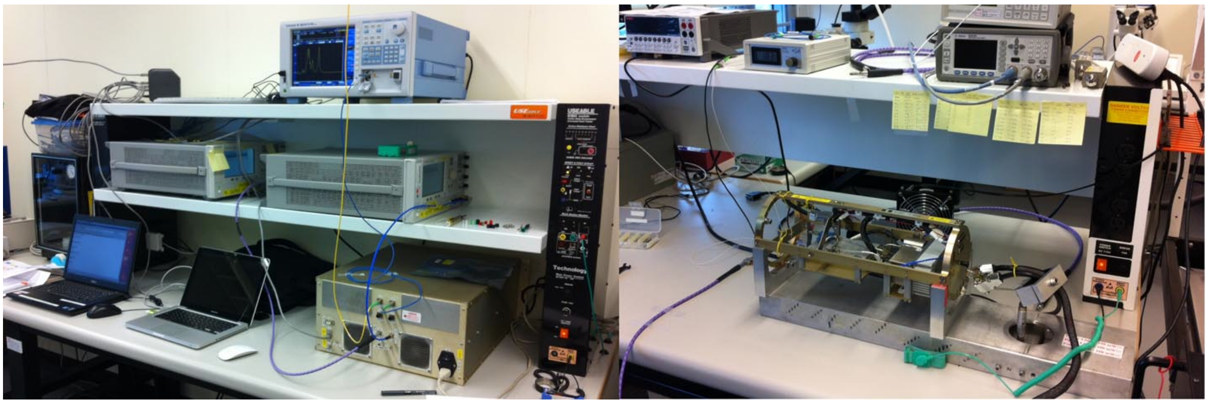


*Fig. 9 Photos of LORTM test setup in R1032 lab. Left panel – upper shelf is OSA, middle shelf are the two RF synthesizers (Ref. 1, Ref. 2), and the LORTM is on the lab bench. Note the yellow fiber carrying the optical output signal over to the U2T located near the WCA . Right panel – Band-1 WCA located on a separate workbench. The U2T photomixer is located at the end of the purple Gore cable just visible behind the WCA.*

**VII. User training session with Yue-Fang Kou (April 14, 15)**

The referenced "MZM-LORTM User's Manual" was updated by Ranjani to provide instructions for Band-1 operation. She provided one-on-one training with Yue-Fang on the power up and operation of the MZM-LORTM.