How to Place in the Results of the April 8th, 2015, Frequency Measuring Test

Prepared for the monthly meeting of the
Harris-Intersil Amateur Radio Club
March 12, 2015

Goal: Achieve Frequency Measurement Off-air Results With < 10 Hz Error

- Approach
  - Review history of FMT in context of other requirements for frequency measurements.
  - Look at some frequency sources that have been used for local and external references.
  - Consider some techniques.
  - Demonstrate one almost foolproof way for you to qualify with an error of less than 10 Hz.

Fundamental Truths:

- Frequency is the inverse of the time of the period, and the converse is true.
- F = 1/T, and T = 1/F
- Everything else follows from these truths.

- Much of the information in these slides comes from NIST, wikipedia, and various manufacturers. It’s readily available, but the significance is not apparent to all readers.

The Need for Periodic Frequency Measurement (including emissions measurement)

- Oscillator (or Transmitter) Tuning Errors
- Malfunctioning Equipment
- Transmitter Oscillator Frequency Drift

Generally, the concern is frequency drift since the other possibilities are uncommon.

The Evolution of the FMT

- The ARRL Frequency Measuring Test started about 1931 as part of the ARRL (self-policing) Official Observer qualification program. The intent was to give some degree of assurance that the notices were based on technical competence.
- The top-rated OO certification was available to only those whose FMT measurements were qualifying. Only those OOs could send frequency-related notices to other amateur stations.

Tighter Frequency Requirements Have Paralleled Communications Equipment Development

Amateur

- Official Observer

Year	Qualifying
1976	Class I <100 Hz
	Class II ~400 Hz

Commercial

- Land Mobile Two-Way

Year	General Summaries
1950	0.005% >50MHz
	0.01% <=50MHz
2009	1.0 ppm [generalization; see (FCC) 47 CFR (Part 90) §90.13 Frequency Stability]

Frequency Sources

- This category addresses local frequency sources that one might have available without conveyance by some communications link or broadcast.

Frequency Sources -- Crystal

- Use as a standard began in 1920 when potential of quartz crystals was recognized by National Bureau of Standards and General Radio.
- WWV attained 1 * 10 E -5 in 1929.
- WWV attained 1 * 10 E -8 in 1952.
- Quartz crystals were used as WWV (monitored) reference until 1959.
- Drift was corrected through US Naval Observatory comparisons.

Frequency Sources – Atomic Standards

- There are several varieties of these.
- Most depend on exciting gas atoms near a specific frequency, and measuring the exact frequency-dependent maximum attenuation frequency from a sweeping frequency synthesizer source whose 5 or 10 MHz source is disciplined with feedback from the effect of the sweeps.

Frequency Sources – Ammonia Atomic Standard

- There were only two built by NIST.
- Operating frequency was 23,870.1 MHz.
- First one in 1948 attained 1 * 10 E -7.
- Second one in 1949 attained 2 * 10 E -8.
- These proved the atomic standard concept, which laid the path to use of other materials.

Frequency Sources -- Cs

- In 1952, a cesium atomic frequency was measured at 9,192.632 ± 0.002 MHz.
- In 1955, a cesium atomic frequency was measured at 9,192,631,770 ± 20 Hz.
- NBS (NIST's predecessor) faltered, and the first operational unit was developed overseas.
- Several companies produced Cs-based primary frequency standards.
- Perhaps the best known was the HP 5061 "flying clock" in 1960s. (HP 5062A ~$17K in 1976)

Frequency Sources -- Rb

- The rubidium secondary standard is quite compact, more reliable, and far less expensive than the Cs standard.
- Because of the atomic structure, its atoms do not define a frequency, but it is useful in that it can be adjusted against a primary standard and retain that setting for a long time.
- Long term stability is better than that of quartz oscillators (e.g., drift).
- The atomic frequency used is 6,834,682,608 Hz.

Frequency Sources -- H

- This atomic standard is complex and far more cumbersome than the Cs.
- There is little material in the literature on this, so there presumably are reasons for its lack of popularity. (Reportedly it is the most complex and most expensive frequency standard.)
- The atomic excitation frequency is 1,420,405,752 Hz.

Frequency Sources – Cesium Fountain

- This is the most recently developed technique, but the concept dates to 1954.
- The first demonstration was in 1989 at Stanford. The first operational unit was developed in France by the Paris Lab of Time and Frequency.
- NIST developed one in 1997 and attained 1.7x10 E -15; it expects to achieve ≤ 5 x 10 E -16.

External References

- This category represents frequency-controlled sources whose output is (or was) typically available to the general public.

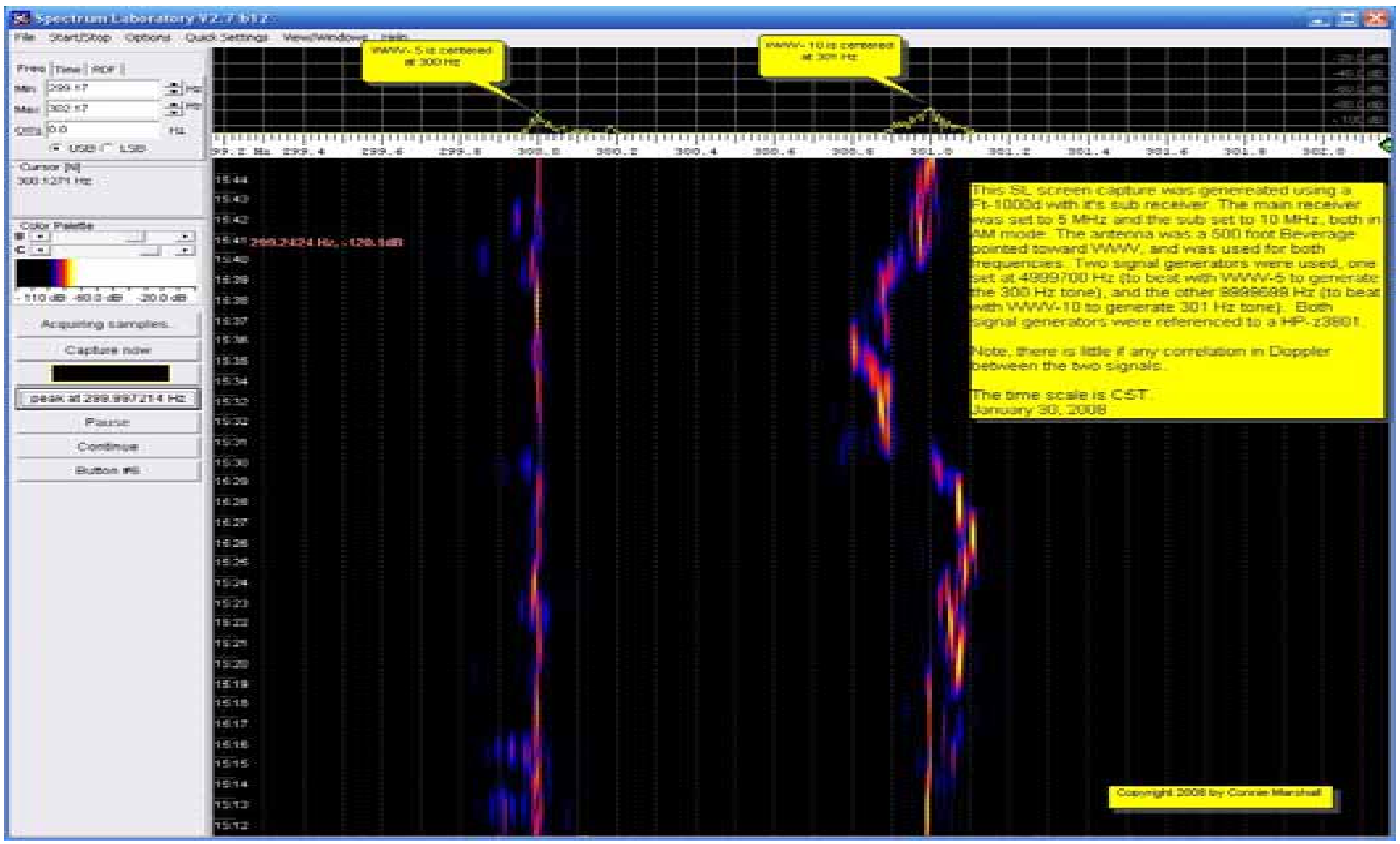
External References -- WWV

- This is an official time and frequency standard in the USA.
- An outgoing frequency is accurate to 1 x 10 E -13, but this is not preserved on the trip through the ionospheric variations.
- 1958 accuracy 2x 10 E -10
- 1966 accuracy 2x 10 E -11
- 2015 accuracy 1x 10 E -13

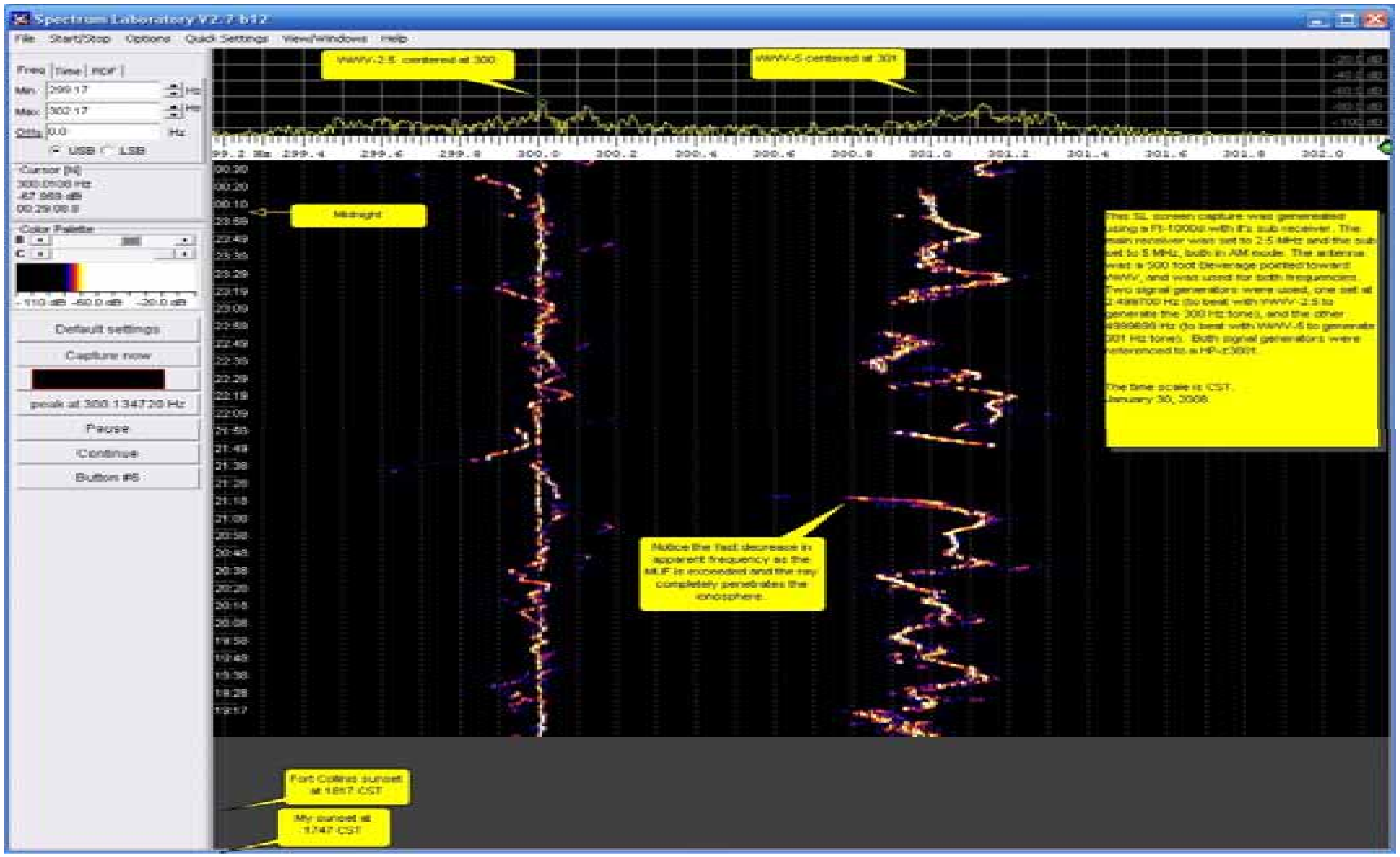
Frequency (MHz)	KW
2.5	2.5
5	10
10	10
15	10
20	2.5
25	1

All antennas are $\lambda/2$ vertical monopoles except the 25 MHz test installation.

External References – WWV and Doppler Shift (1 of 2) (5 & 10 MHz; 3 PM, © K5CM.com, in OK)



External References – WWV and Doppler Shift (2 of 2) (2.5 & 5 MHz; 7 - 12 PM, © K5CM.com, in OK)



External References -- NBA

- This operation was short-lived, and preceded WWVL on 20 KHz (which started in August, 1963).
- 18 KHz

External References -- WWVL

- Service started in August, 1963.
- Service was discontinued in 1972.
- The WWVL antenna was added to the WWVB antenna system on 60 KHz after WWVL operation ceased.

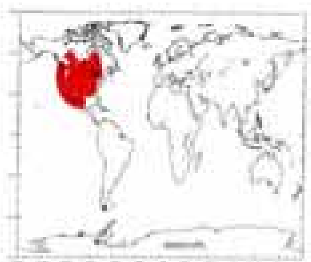
- 20 KHz

External References -- WWVB

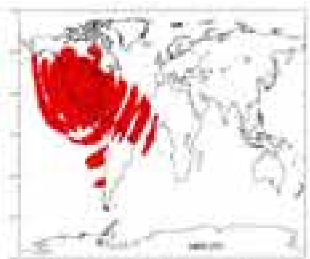
- Started in 1963 at 5 KW, and then 7 KW.
- Phase advance of 45° (~2 µs) at 10 minutes after the hour for five minutes for identification.
- Modulation format changed in October, 2012, from AM/PWM to AM/PWM/PM; this obsoleted some devices depending on this service.
- 60.000… KHz
- 70 KW (ERP)
- Two 54 KW XMTRs into 50.6 % and 57.5% efficient antennas
- This is the source signal for the 50 million plus popular “atomic clocks”.

External References – WWVB (NIST Coverage Maps)

0000Z

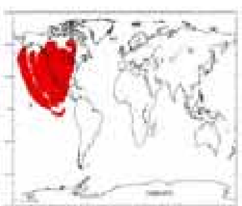


0400Z

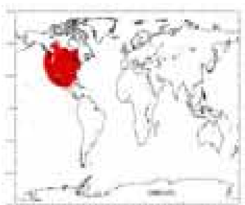


0800Z

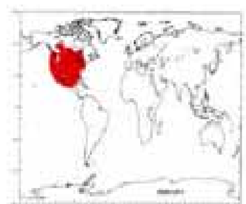
1200Z



1600Z



2000Z



Red shows areas where signal levels of >= 100 microvolts/meter are present for the time shown.

External References -- Omega

- This was a cesium referenced hyperbolic navigation system.
- Project was approved in 1968. Operation started in 1971.
- Eight stations were around the world; the only one in North America was in North Dakota.
- Eight time slots in ten seconds; each station had a different frequency in most slots (pseudo TDM).
- Shared frequencies were 10.2, 11.05, 11.33, 11.8, 12.0, 12.3, 12.9, and 13.0 KHz.
- System closed 9/1997.

External References -- LORAN C

- LORAN A was the 160 meter WW II predecessor.
- LORAN C was on 100 KHz with an atomic standard.
- US LORAN C operated as hyperbolic navigation system under Coast Guard Navigation responsibility.
- Closed on Feb. 8, 2010, despite calls for retention as back-up to GPS.
- Power typ. 100s of KW due to low antenna efficiencies (λ=9,840 ft).
- Little site commonality except tall antennas and very high power.
- Master and up to five slaves had coded pulse phase inversion patterns in similar pulse strings.
- Still used outside USA.

External References – Colorburst

- Provided continental frequency reference.
- Each major TV network had its own Cs standard.
- System operated with NTSC from 1960s or 1970s until HDTV replaced NTSC as the US TV broadcast standard.

- Colorburst frequency 3.579545… MHz = (63/88) x 5.000… MHz standard. (Process was reversible.)
- TV networks provided the 3.579545… MHz signal to with offset of ~-3.2 E -8 (~-0.11 Hz)
- Technique was also displaced by NTSC station retiming equipment added prior to the advent of HDTV.

External References -- GPS

- There are two approaches.
- -There are clockable signals appearing in the receiver IF at 1.023 and 10.23 Mb/s good to

  1x 10 E-12 or better.
- -Most modules can produce a 1 pulse/sec output for measuring local clock transitions/sec.

- There are a number of surplus clock units available on e-Bay in the range of a couple hundred $ with readily available instructions whose earlier life was associated with providing timing for cell phone sites and the like.

External References -- CHU

- This is a time and frequency standard in Ontario, Canada.
- The outgoing signal is accurate to 5x10E-12, but this is not preserved on the trip through the ionospheric variations.

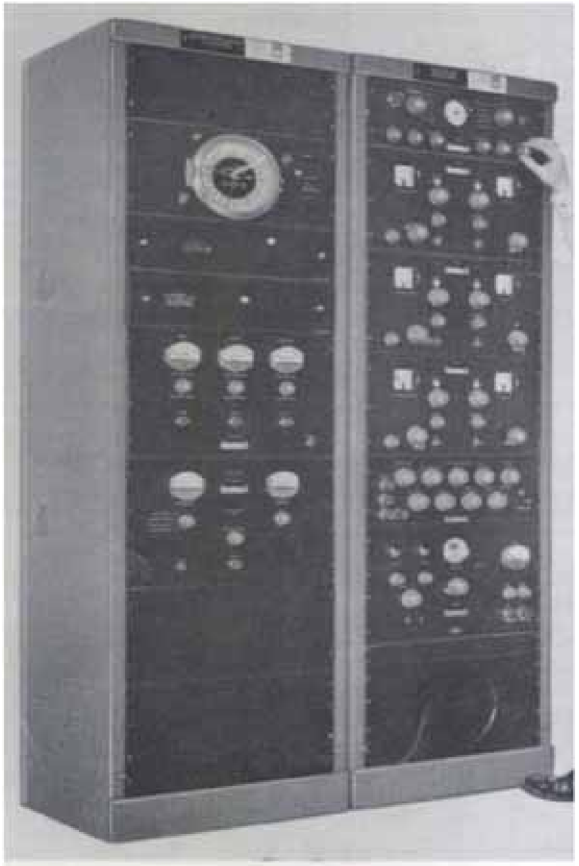
Frequency (MHz)	KW
3.33	3
7.85	5
14.670	3

All antennas are vertically polarized.

(Western Canada partially relies on WWV in Colorado.)

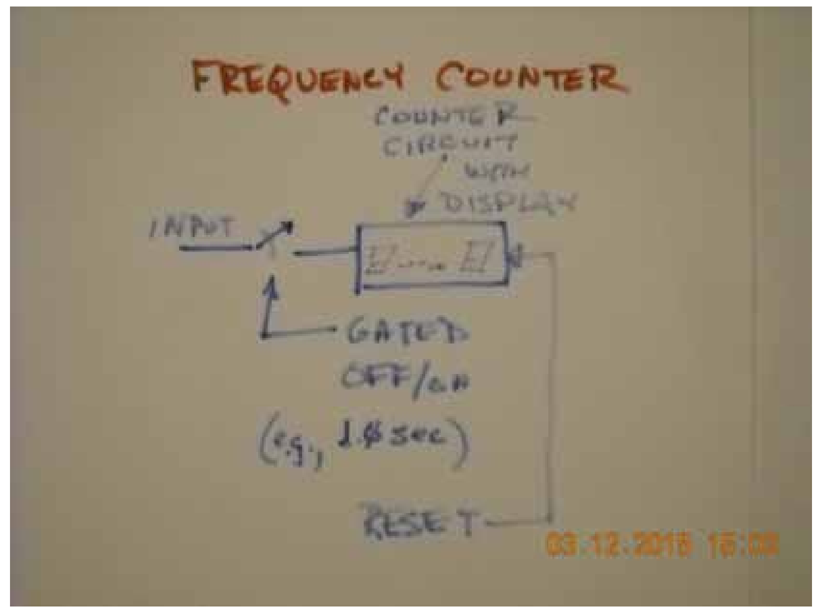
FMT Measurement Techniques

- The General Radio equipment to the right was good to about 1 x 10 E -8 in 1960, and cost around $50,000 in today's money.
- Hams can do it for less, as shown in the following slides.



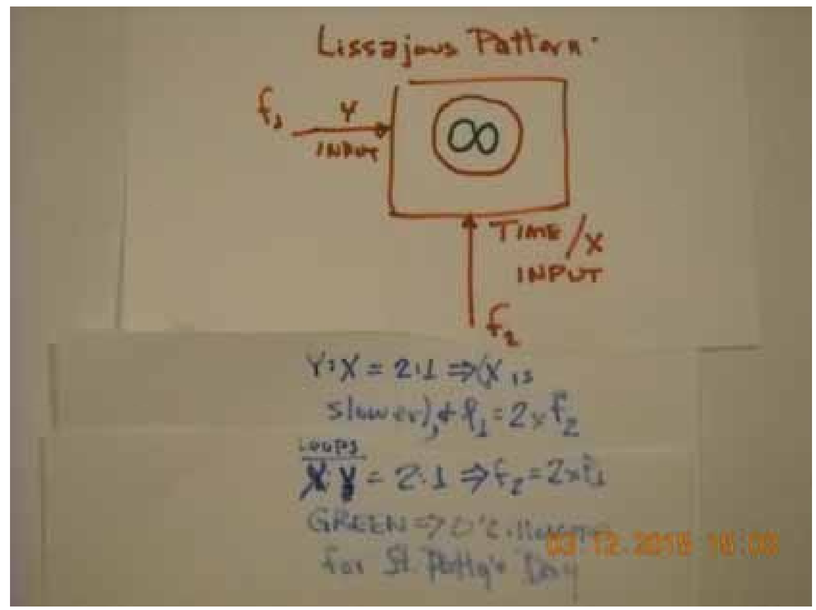
FMT Techniques -- Counter

- Used counters can now be purchased for \$15 to \$20 if you are patient.
- The input can be an output of a zero-beating oscillator, or the composite of all signals in a receiver, or a beat note, or ???



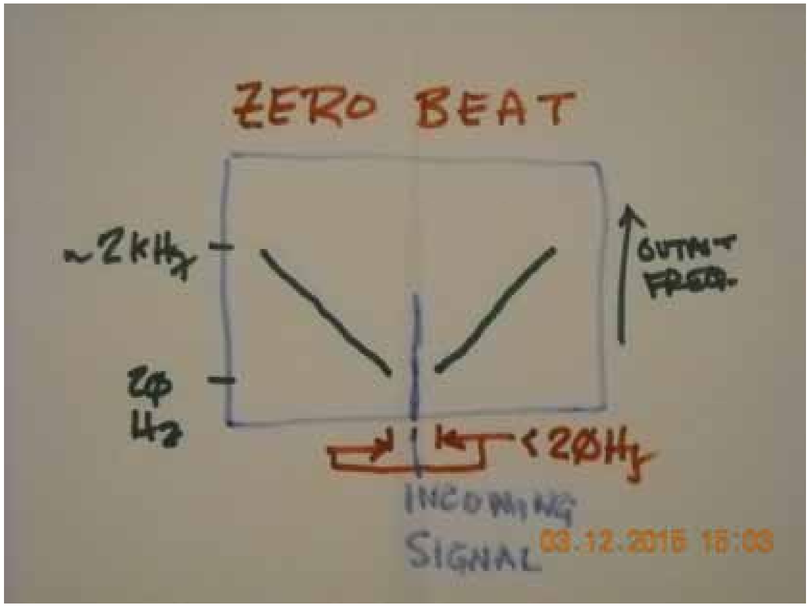
FMT Techniques -- Oscilloscope

- An oscilloscope can be used to make a Lissajous comparison with a calibrated, local audio oscillator to match a local audio tone from a receiver.



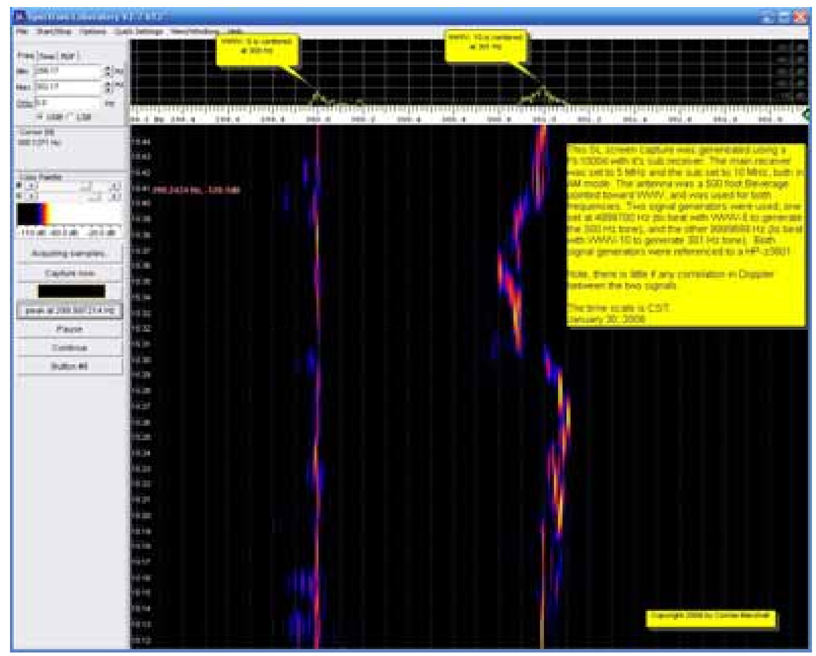
FMT Techniques – Aural Zero Beat

- This is very old school, but any CW operator who has used a separate transmitter and receiver knows this--turn off the BFO, and vary the generator tuning (VFO frequency) until the beat note descends in frequency and disappears.



FMT Techniques – Computer Audio Analysis

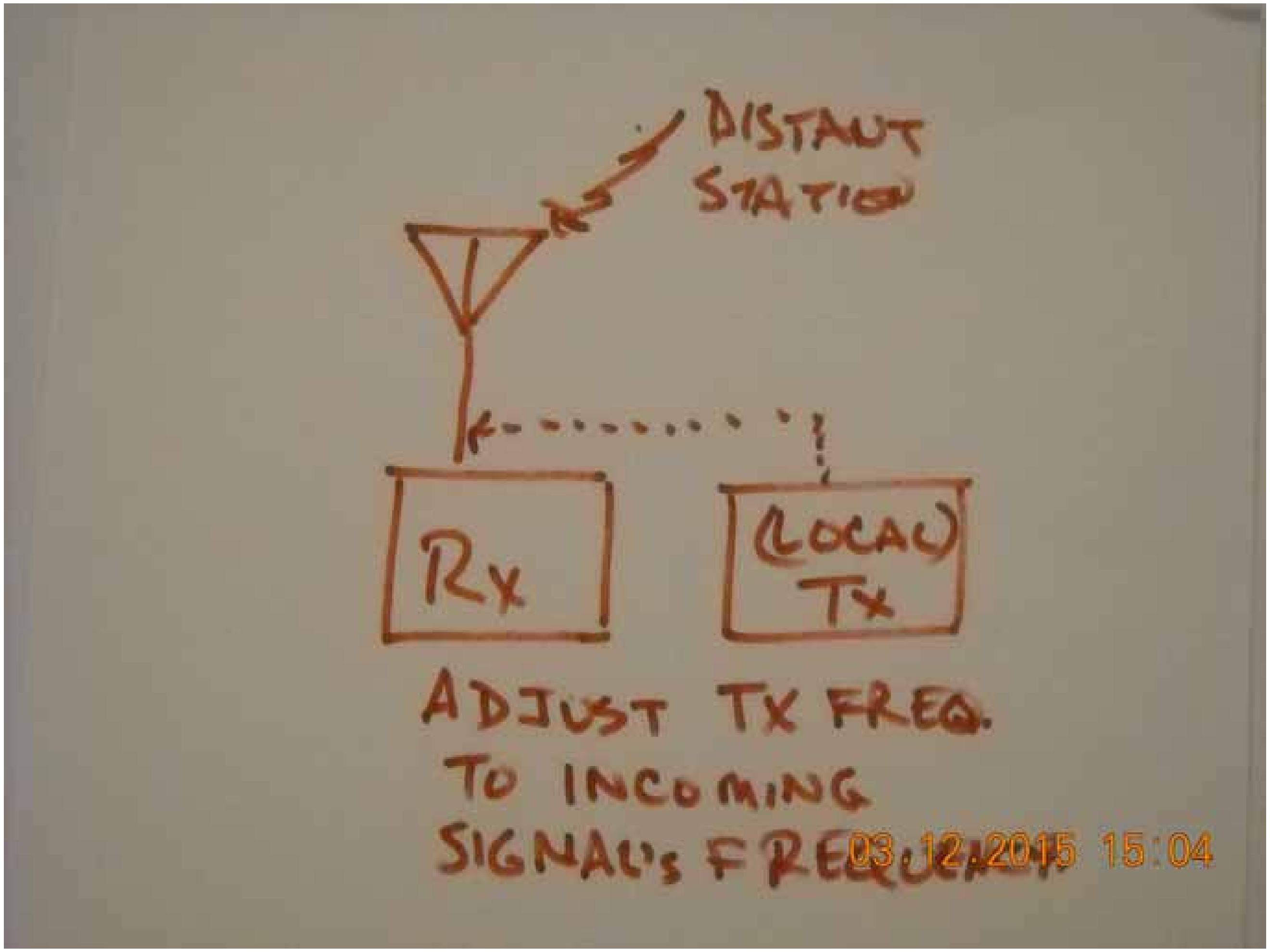
- This is very new school: Find the signal, insert some known frequencies in the passband, and let the software identify each audio frequency, to which you note the difference between the RF reference and the unknown frequency.
- See April, 2015, *QST*, page 37 for more information.



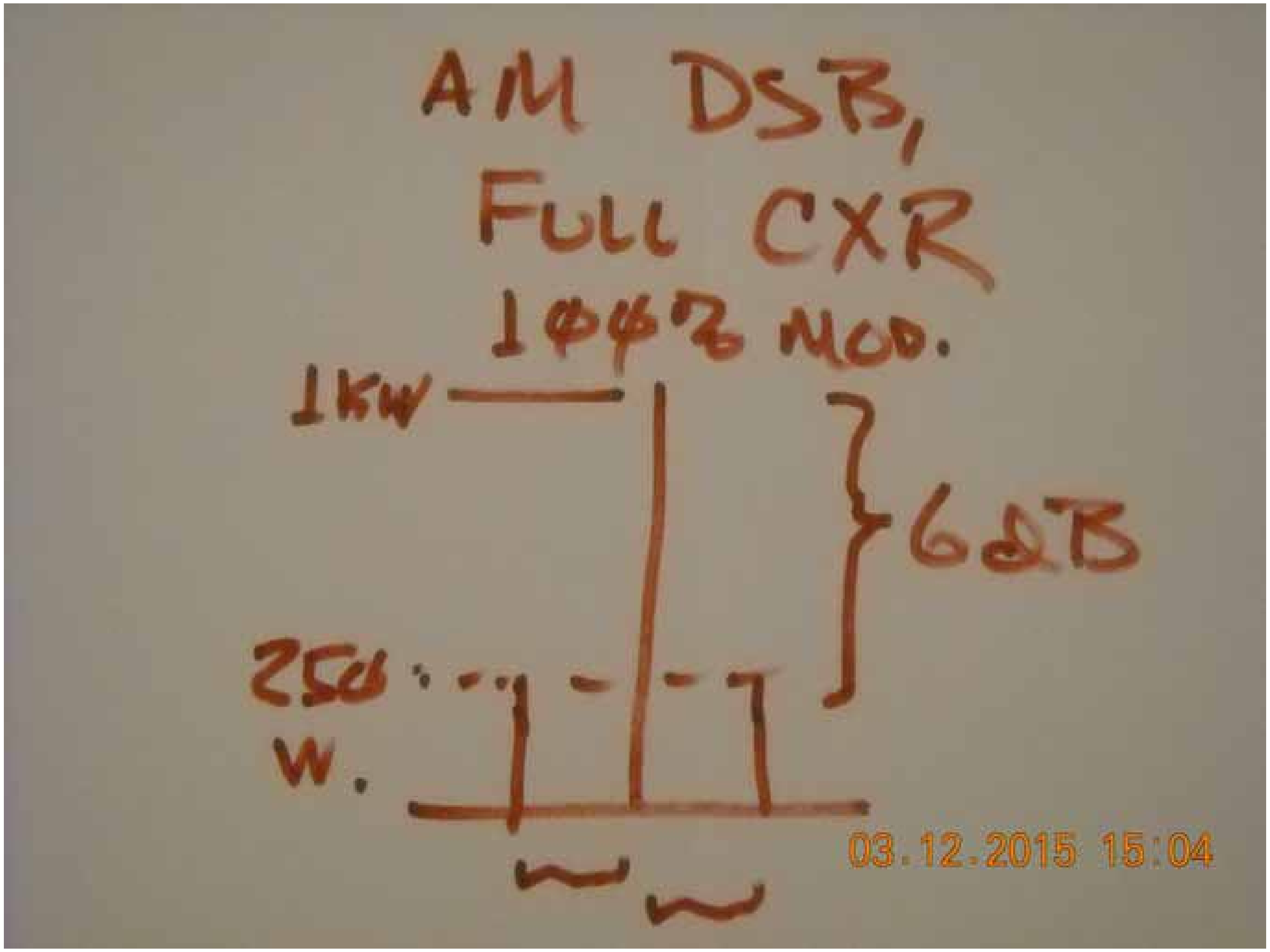
© K5CM.com (substitution)

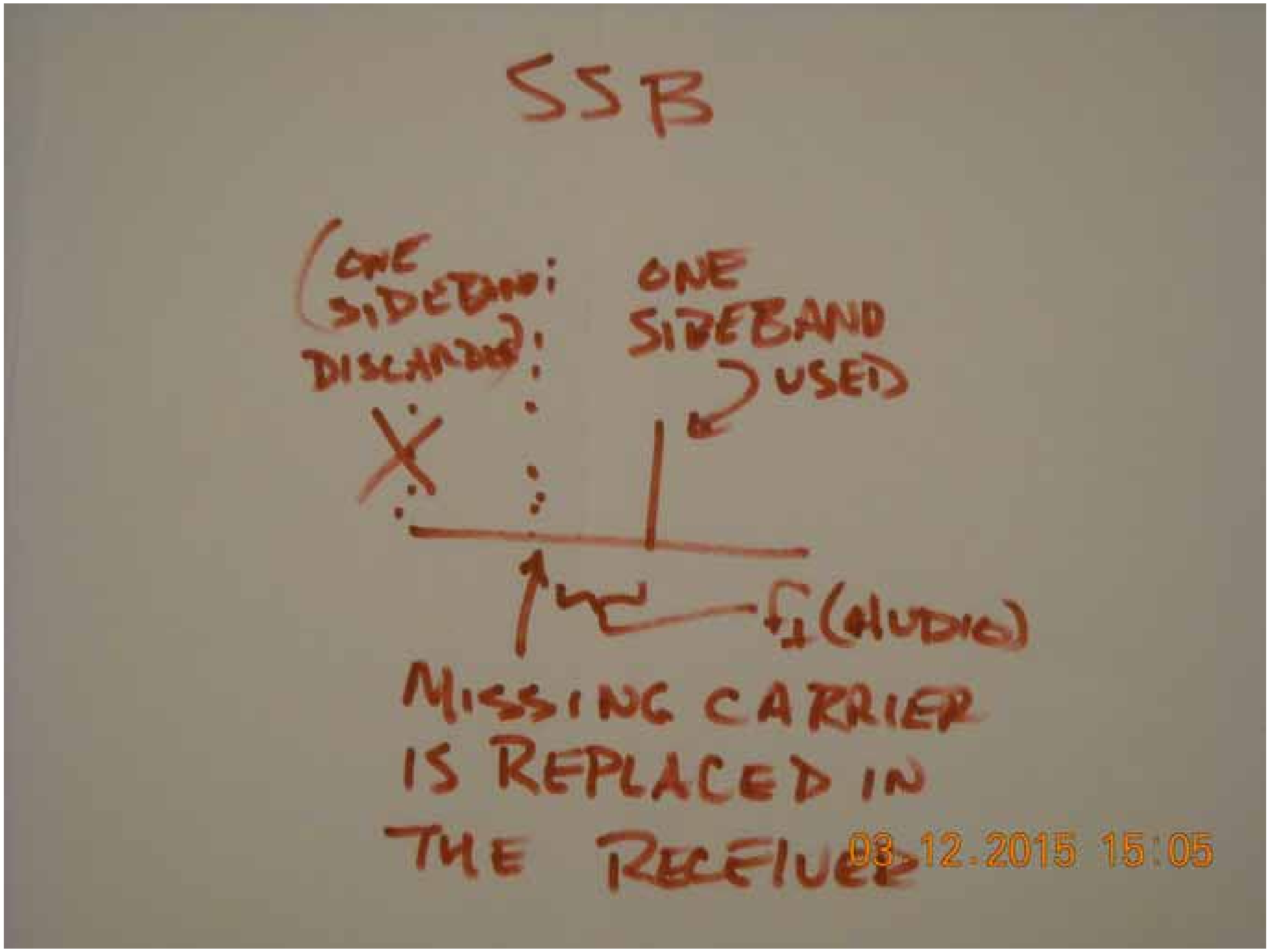
FMT Techniques – Double Carrier Heterodyne (DCHT)

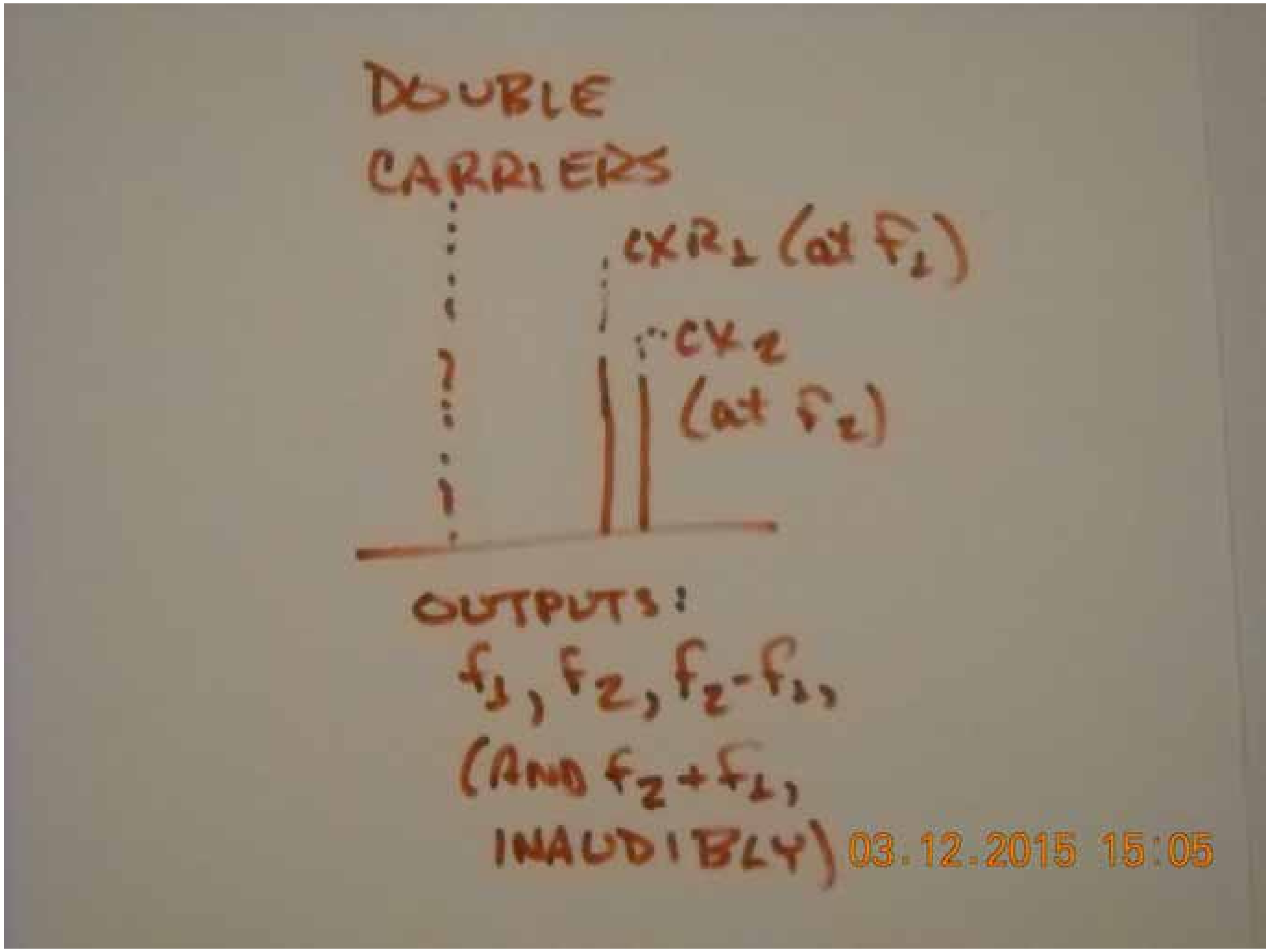
- Enhances detection of zero-beat frequency.
- Based on modulation theory for amplitude-modulated, double-sideband modulation, with full carrier.
- There are several variations for implemenation, but a frequency source with a high resolution readout (isolated from the antenna) and an SSB receiver are the straightforward components.


DISTANT
STATION
Rx
(LOCAL)
Tx
ADJUST TX FREQ.
TO INCOMING
SIGNAL'S
03.12.2015 15:04

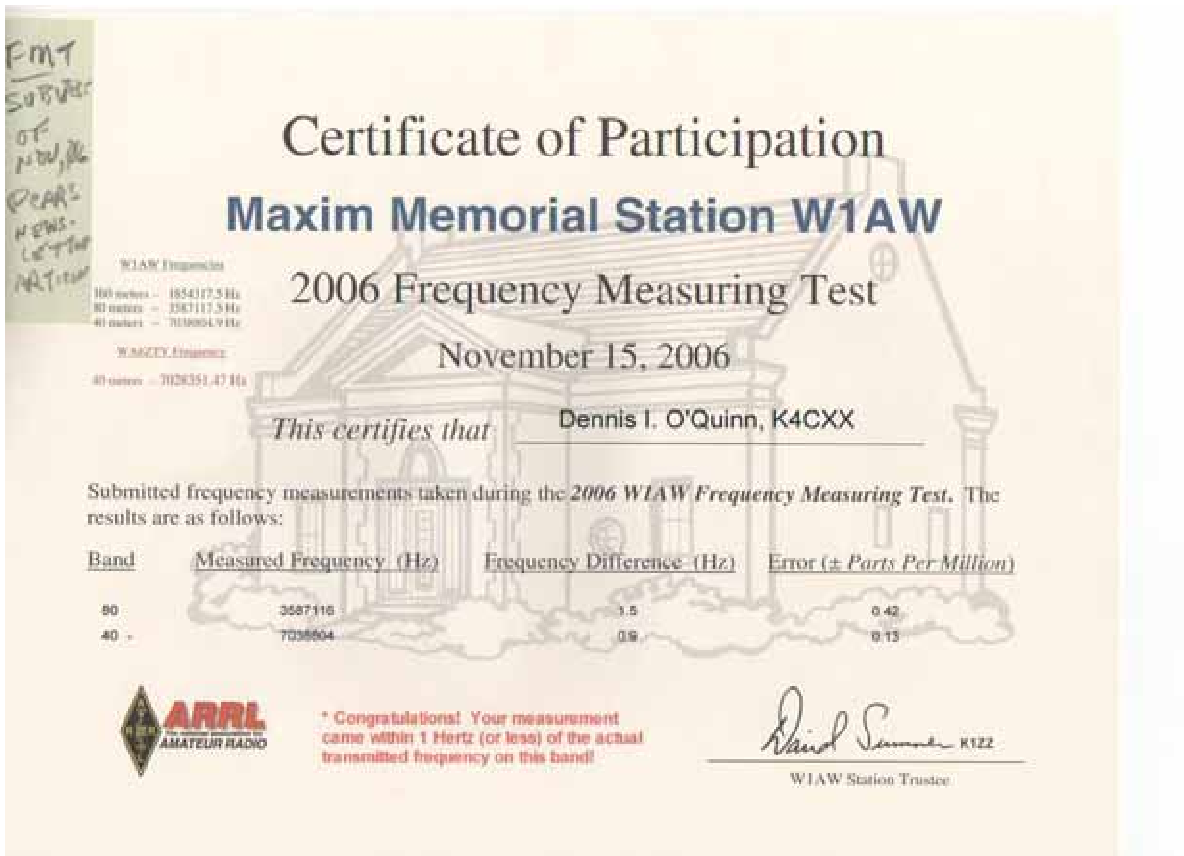

ZERO BEAT
AUDIBLE
AUDIO
DIFFERENCE
FREQUENCY
DISTANT
STATION
03.12.2015 15:04


AM DSB,
FULL CXR
100% MOD.
1KW
6dB
250
W.
03.12.2015 15:04


SSB
ONE SIDEBAND DISCARDED
ONE SIDEBAND USED
MISSING CARRIER IS REPLACED IN THE RECEIVER
03.12.2015 15:05


DOUBLE
CARRIERS
CXR1 (at f1)
CXR2
(at f2)
OUTPUTS:
f1, f2, f2-f1,
(AND f2+f1,
INAUDIBLY)
03.12.2015 15:05

2006 Results with DCHT, Counter, & Modified Lampkin MFM Oscillator



Certificate of Participation

Maxim Memorial Station W1AW

2006 Frequency Measuring Test

November 15, 2006

W1AW Frequencies

160 meters - 1854317.5 Hz
80 meters - 3587117.5 Hz
40 meters - 7038804.9 Hz

This certifies that Dennis I. O'Quinn, K4CXX

Submitted frequency measurements taken during the ***2006 W1AW Frequency Measuring Test.*** The results are as follows:

Band	Measured Frequency (Hz)	Frequency Difference (Hz)	Error (± *Parts Per Million*)
80	3587116	1.5	0.42
40 *	7038804	0.9	0.13

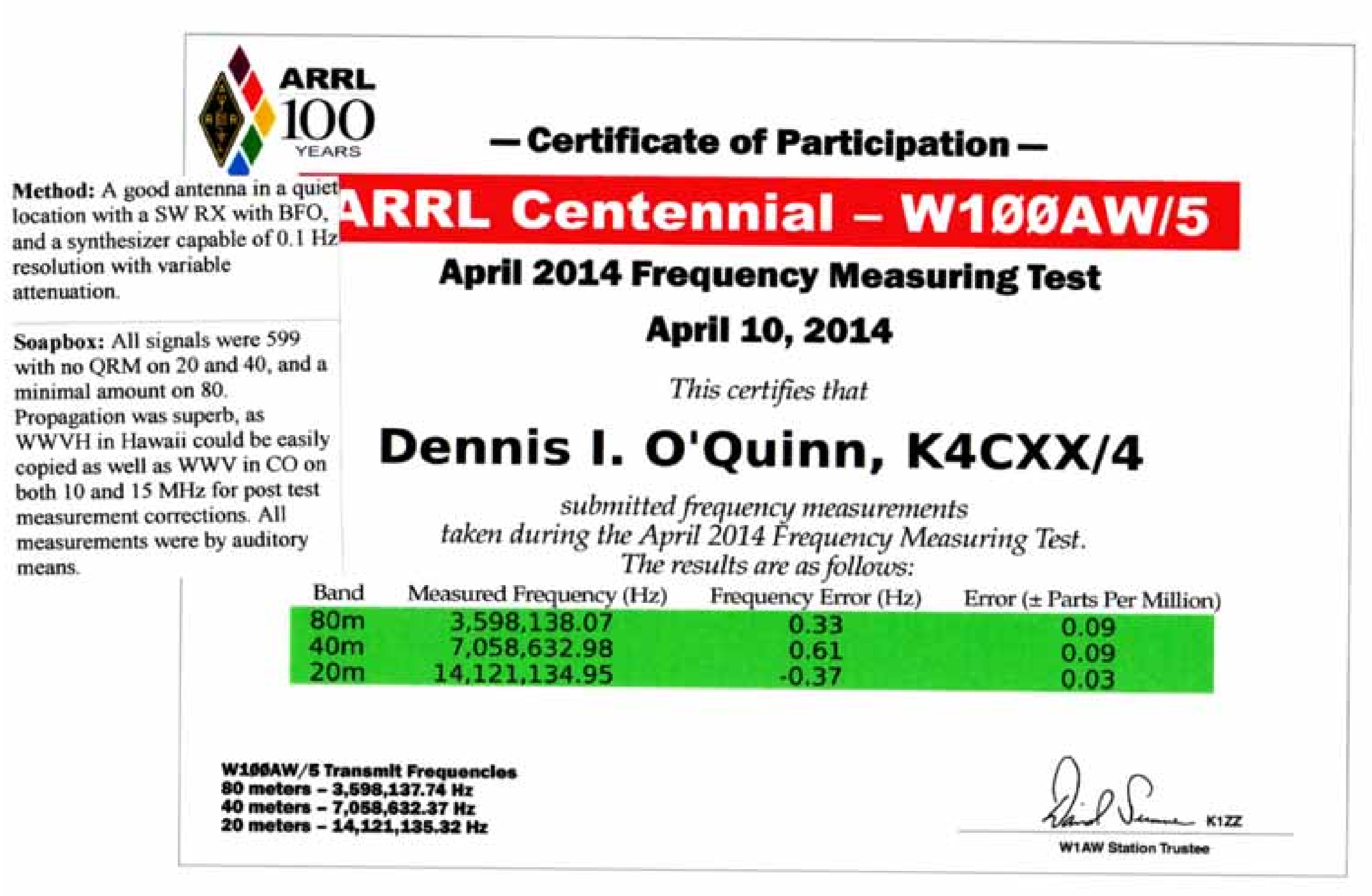
ARRL AMATEUR RADIO

* Congratulations! Your measurement came within 1 Hertz (or less) of the actual transmitted frequency on this band!

K1ZZ

W1AW Station Trustee

Results with DCH Technique and a 0.1 Hz Resolution Synthesizer



ARRL 100 YEARS

— Certificate of Participation —

Method: A good antenna in a quiet location with a SW RX with BFO, and a synthesizer capable of 0.1 Hz resolution with variable attenuation.

Soapbox: All signals were 599 with no QRM on 20 and 40, and a minimal amount on 80. Propagation was superb, as WWVH in Hawaii could be easily copied as well as WWV in CO on both 10 and 15 MHz for post test measurement corrections. All measurements were by auditory means.

ARRL Centennial – W1ØØAW/5

April 2014 Frequency Measuring Test

April 10, 2014

This certifies that

Dennis I. O'Quinn, K4CXX/4

submitted frequency measurements
taken during the April 2014 Frequency Measuring Test.
The results are as follows:

Band	Measured Frequency (Hz)	Frequency Error (Hz)	Error (± Parts Per Million)
80m	3,598,138.07	0.33	0.09
40m	7,058,632.98	0.61	0.09
20m	14,121,134.95	-0.37	0.03

W1ØØAW/5 Transmit Frequencies
80 meters – 3,598,137.74 Hz
40 meters – 7,058,632.37 Hz
20 meters – 14,121,135.32 Hz

K1ZZ
W1AW Station Trustee

Demonstration of DCH Technique

Approximate major equipment list:

- Receiving antenna with good reception [i.e., low noise, good height, no EMI (=> coax runs), etc.]
- One isolation device (amplifier, or directional coupler, or reactive power divider, or isolator) to keep synthesizer's signal off antenna
- One (preferably SSB) receiver with a BFO
- One HF frequency synthesizer (or stable signal generator with single-digit or less Hz readout).
- (Recommended) UPS for power interruptions.
- (Recommended) RF attenuator for signal source

(Performance of Demonstration

Of Double Carrier Heterodyne Technique

In Measuring Simulated Off-the-Air Signal)

Finally,

- Don't forget to "read" WWV on its highest, good frequency afterwards, and apply a correction factor to all of your readings.
- Example: I read W1AW on 3,697,456.5 Hz. I read WWV at 15,000,004.3 Hz. I corrected the W1AW reading to [(3,697,456.5 Hz) x

  (15,000,000 Hz/15,000,004.3Hz) =>

  3,697,455.44 Hz and submitted it within the next 24 hours.

Thank you for your interest.

Good luck on your FMT entries.

… de k4cxx@arrl.net