A Fully Automated Filter Tuning Robot for Wireless Base Station Diplexers

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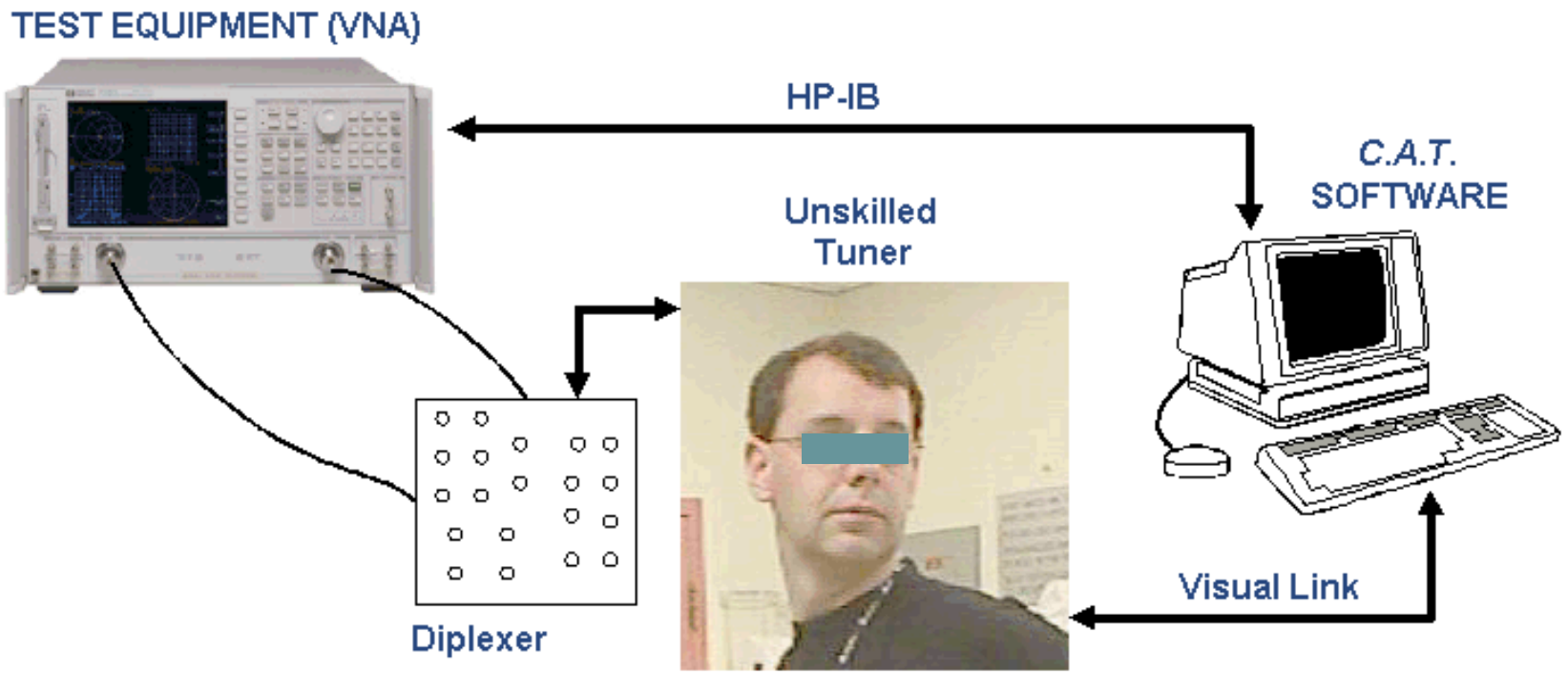
Computer Aided Tuning (CAT)

Use of computer simulation algorithm to aid a human operator adjusting the filter tuning process to gave a prescribed performance

How CAT work

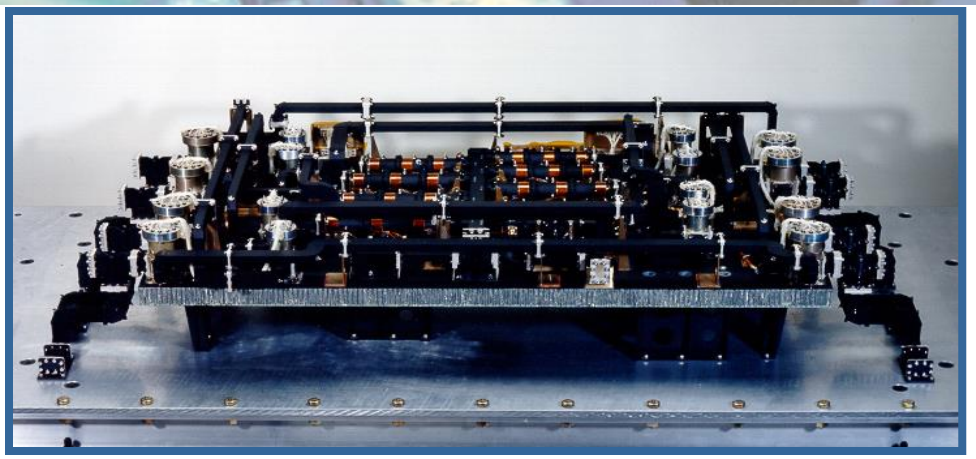
- Measure Diplexer response
- Compute device parameters by various algorithms
  - Extract Coupling matrix
  - Time Domain cloning
  - Phase cloning
  - Or combinations of the above
- Compare measured actual with ideal references
  - A golden reference
  - Ideal mathematical model
  - Or combinations
- Deduce tuning instruction

Computer Aided Tuning (CAT)

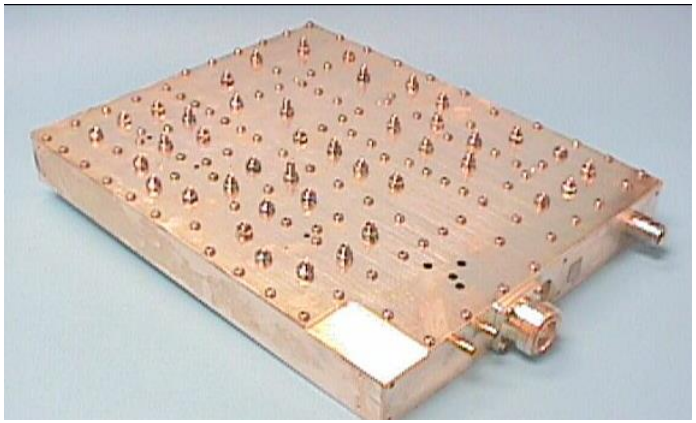


Where CAT were used at Com Dev

- Space application
  - O/P Multiplexers
  - Input Multiplexers



- Wireless applications
  - Combline filters/diplexers
  - DR Filters (TE01/HE)

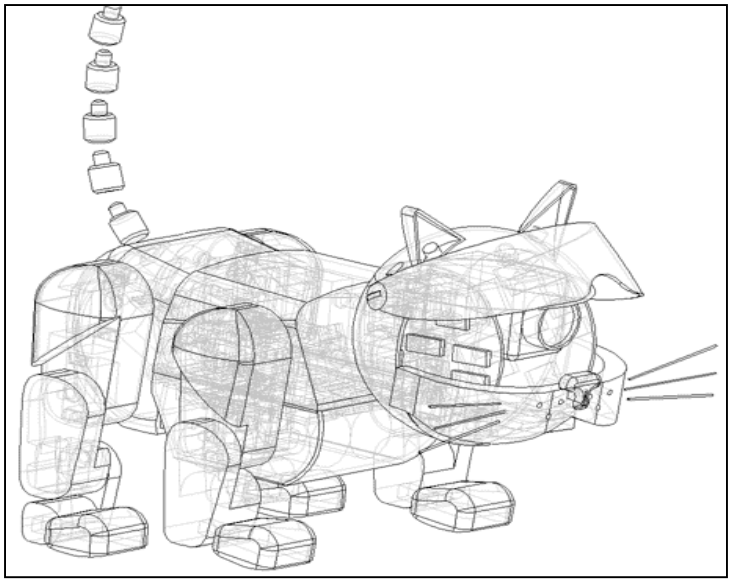


A Fully automated CAT

From

CAT

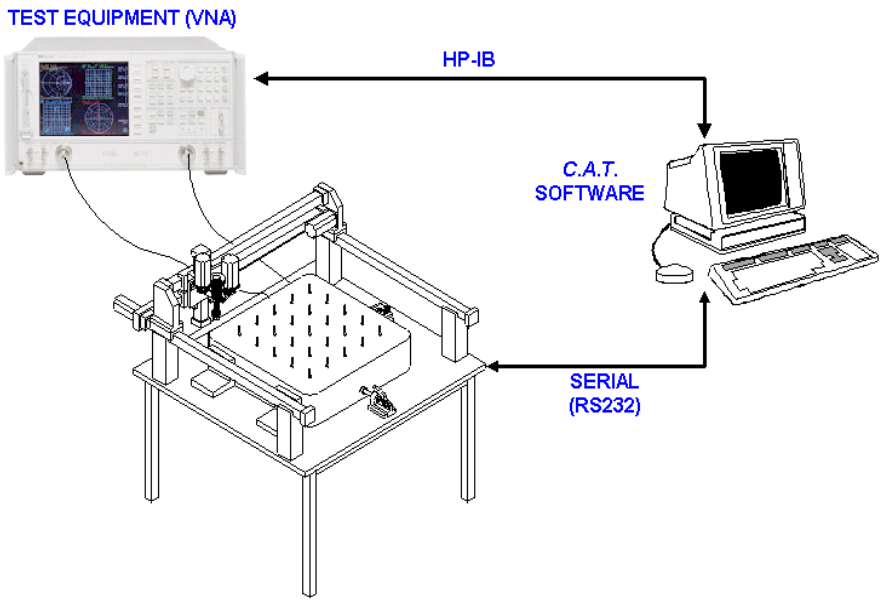
To



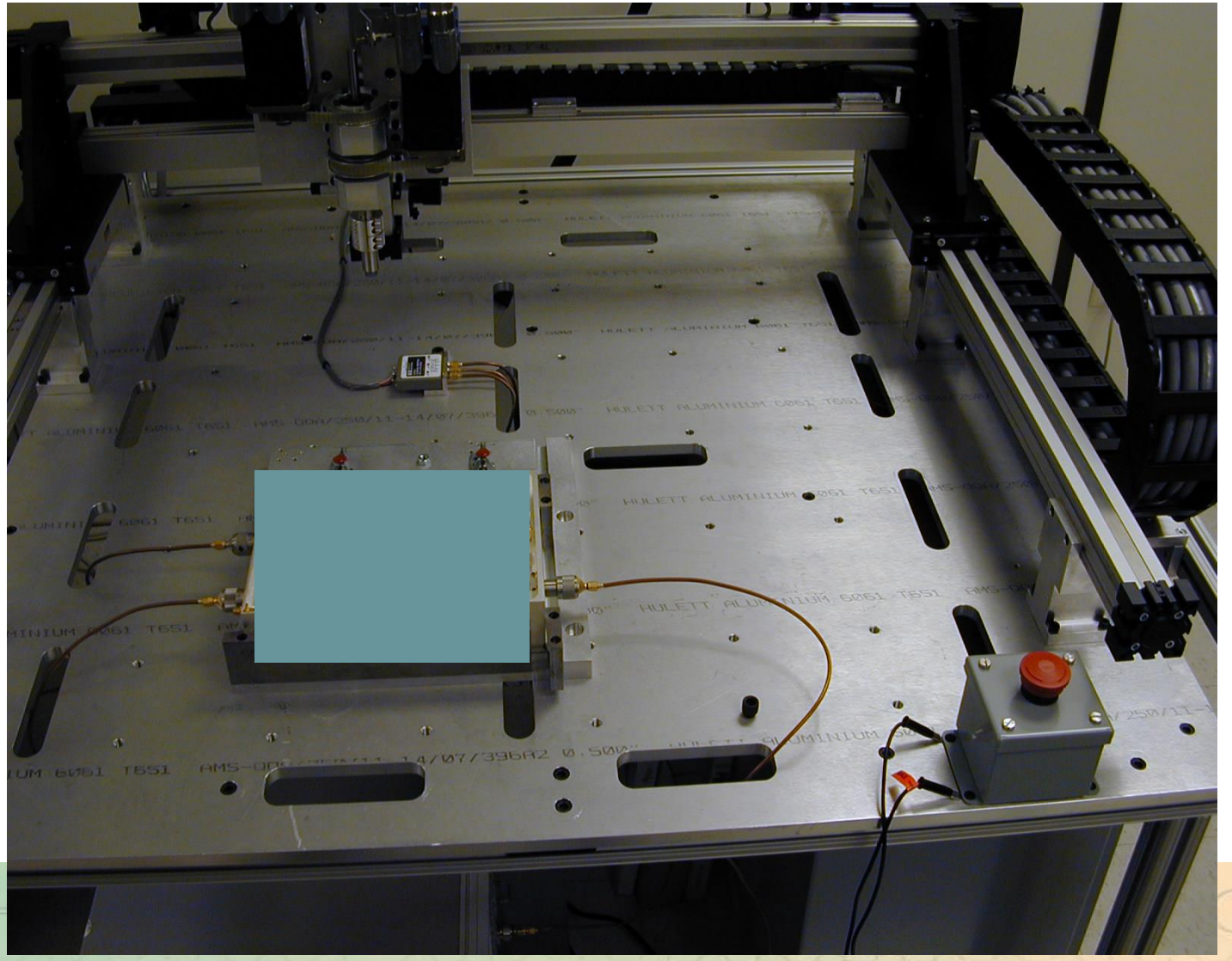
RoboCat

Design Goal of RoboCAT

- Operational
  - Able to replace the operator
  - Fully automated tuning of complex microwave filters and diplexers
  - Tuning speed 50% better then the average human tuner
  - Support 24/7 operation



Real System



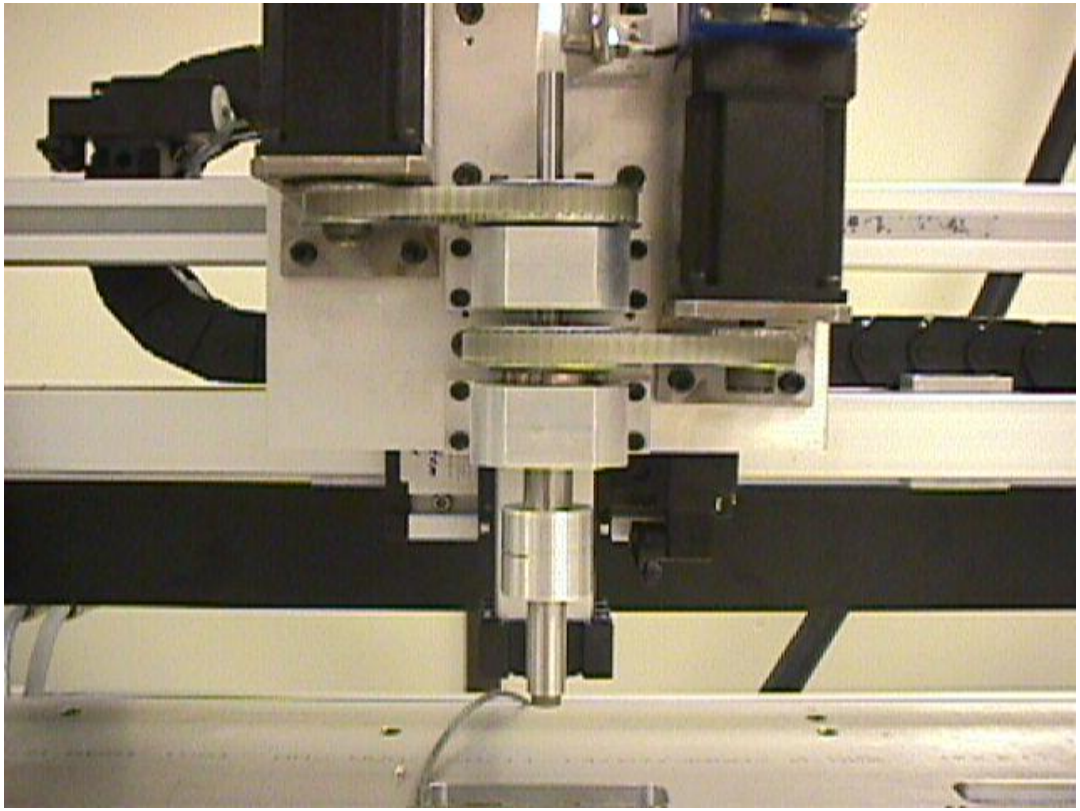
Design Goal of RoboCAT

- Implementation
  - COTS parts, no custom parts if all possible
  - Clone
    - Compute deviation (Diagnostic) for best possible solution
      - Retune based on new solution
  - Adaptive design approach, Rapid re-configuring for different forms and fits
  - Minimize location tolerance of interfaces
  - Tune through LNA and other devices

Major upfront decision

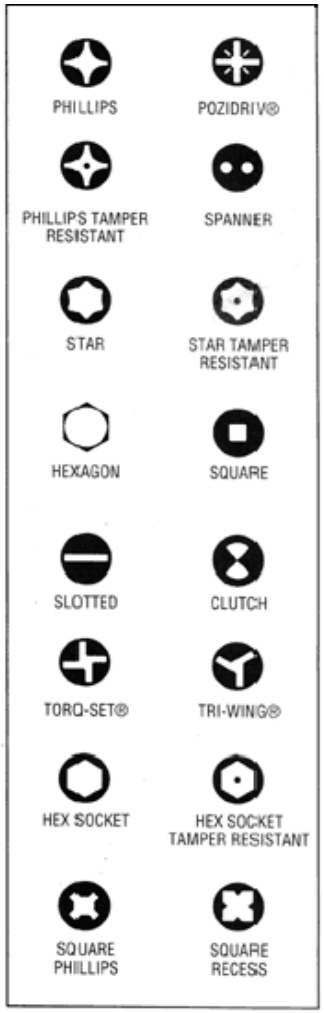
- Lock nuts or no Lock nuts, that is the question
  - Self lock screw?
  - PIM performance
  - Flexibility in adapting to different tuning screw interfaces
  - Ease of screw driver implementation

Adaptive Design Approach



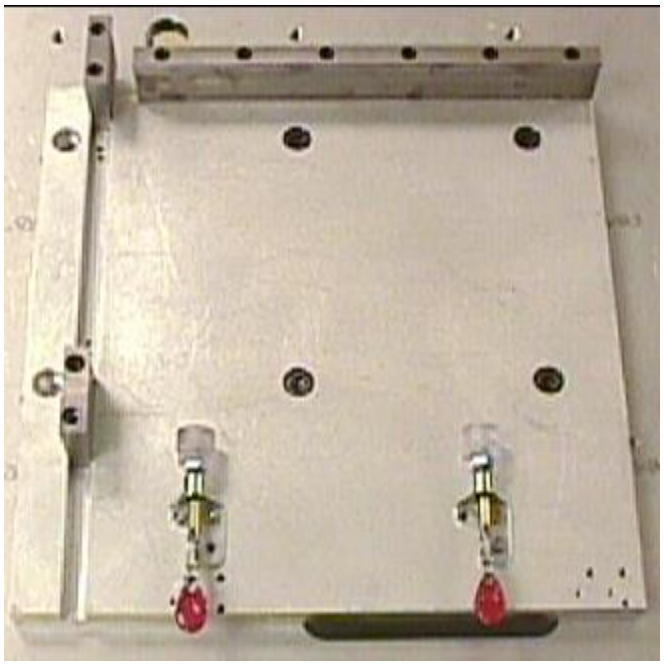
- Co-Axial tuning element (proprietary) with servo control that can be adapted to fit any combination of screw and nut design

Adaptive Design Approach



- Use of driver head that accepts standard commercial inter-changeable ¼" power driver bits
- To date we have tested Torx(T8/M5), Hexagonal(M2, 2-56) and slot (1/4")

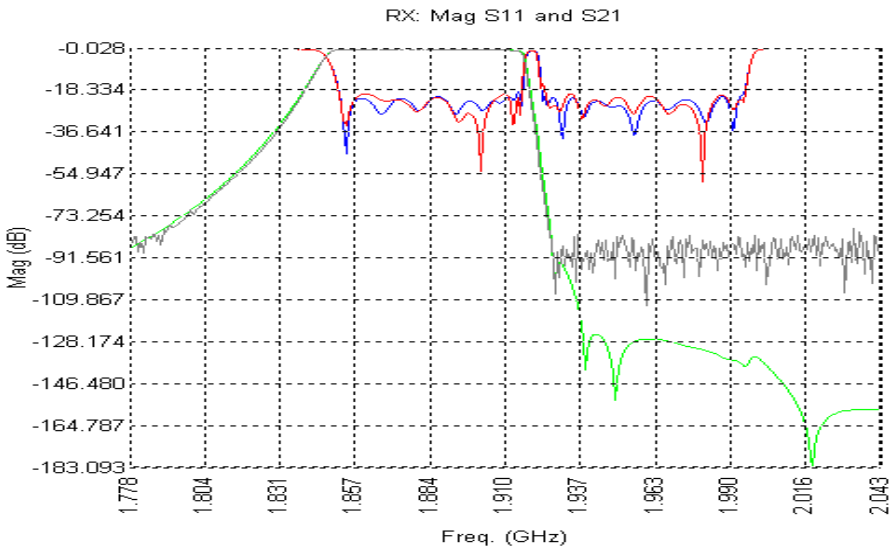
Adaptive Design Approach

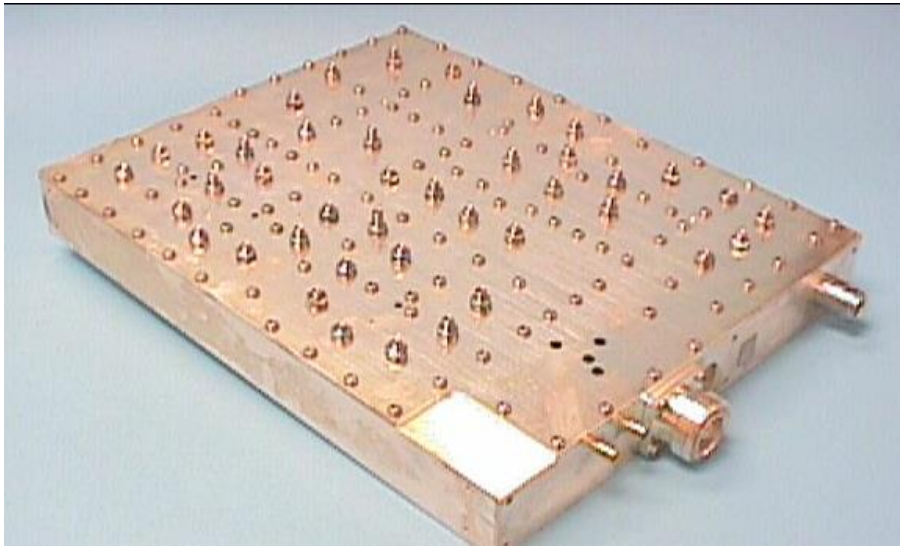


- Quick mount and dismount system
- Jig that configured to handle various size diplexers and filters

Alpha Trial #1

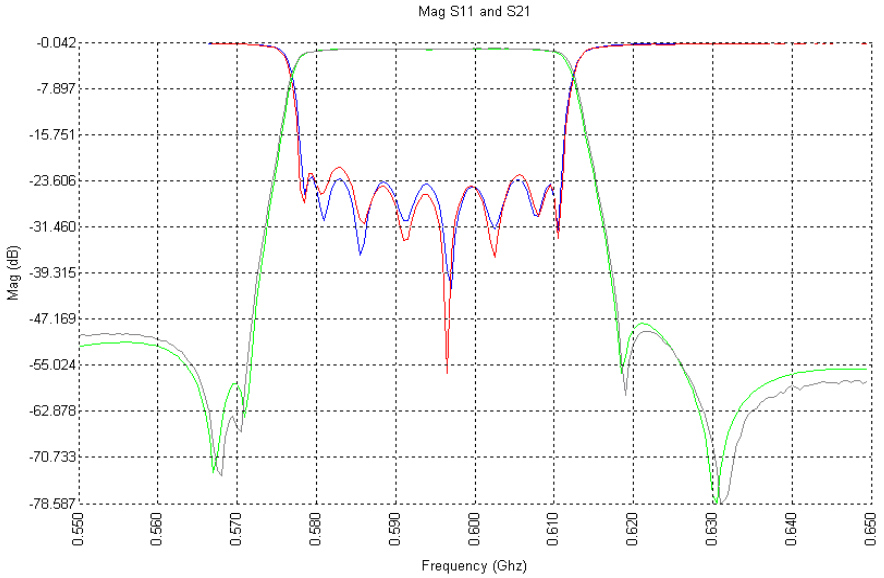
- Mobile Base Station Diplexer
  - 10-3 x 12-3 @ 1900MHz, screw: M5
  - Tune time: 1.5 hour average

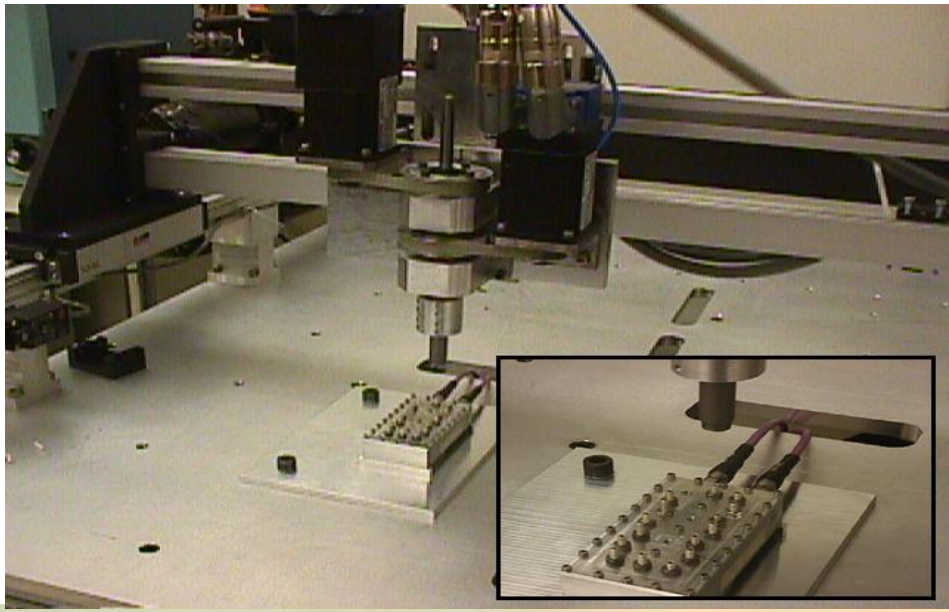




Alpha Trial #2

- Compact Filter
  - 8-2-2 @ 600MHz helical , Screw: 2-56 Hex
  - Tune time: 0.5 hour average





Observation from Alpha trials

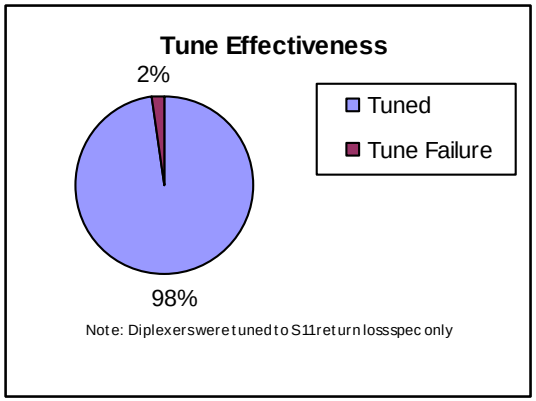
- What impact tuning speed
  - Loose tolerance of screw, nut and bushing from cheap hardware
    - Performance changes when the nut is locked
    - Discontinuity in tuning direction $\Rightarrow$ totally confuse the tuning algorithm
  - Oscillation in searching for local minima
    - Quasi real time relationship between the driving mechanism and measured response causing oscillation about the local minima, directly impact the tuning speed
  - When to stop tuning
    - Finished a prescribed sequence or pass minimum spec
    - When is good enough
    - When to call it a failure

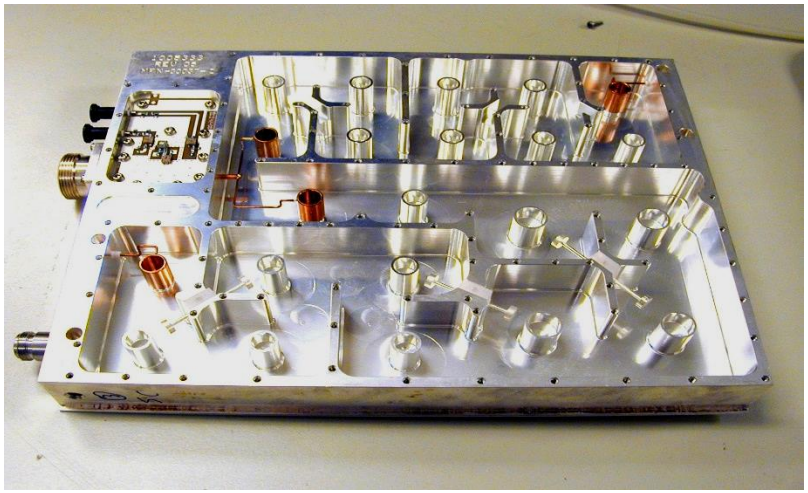
Solution to the problems

- Adaptive tension control on the co-axial tuning servo take away the sloppiness of tuning hardware
- Gradient based Adaptive sampling to minimize oscillation
- No sure fix for discontinuity in tuning direction. Problem is always due to workmanship deficiency. Create event detection algorithm and use build-in diagnostic to find best alternate solution.
- Stop tuning once return loss peaks at band edge are well define and average return loss is better then a prescribed target
- Consider tuning failed once tuning time is longer then a prescribed duration

Beta Trial

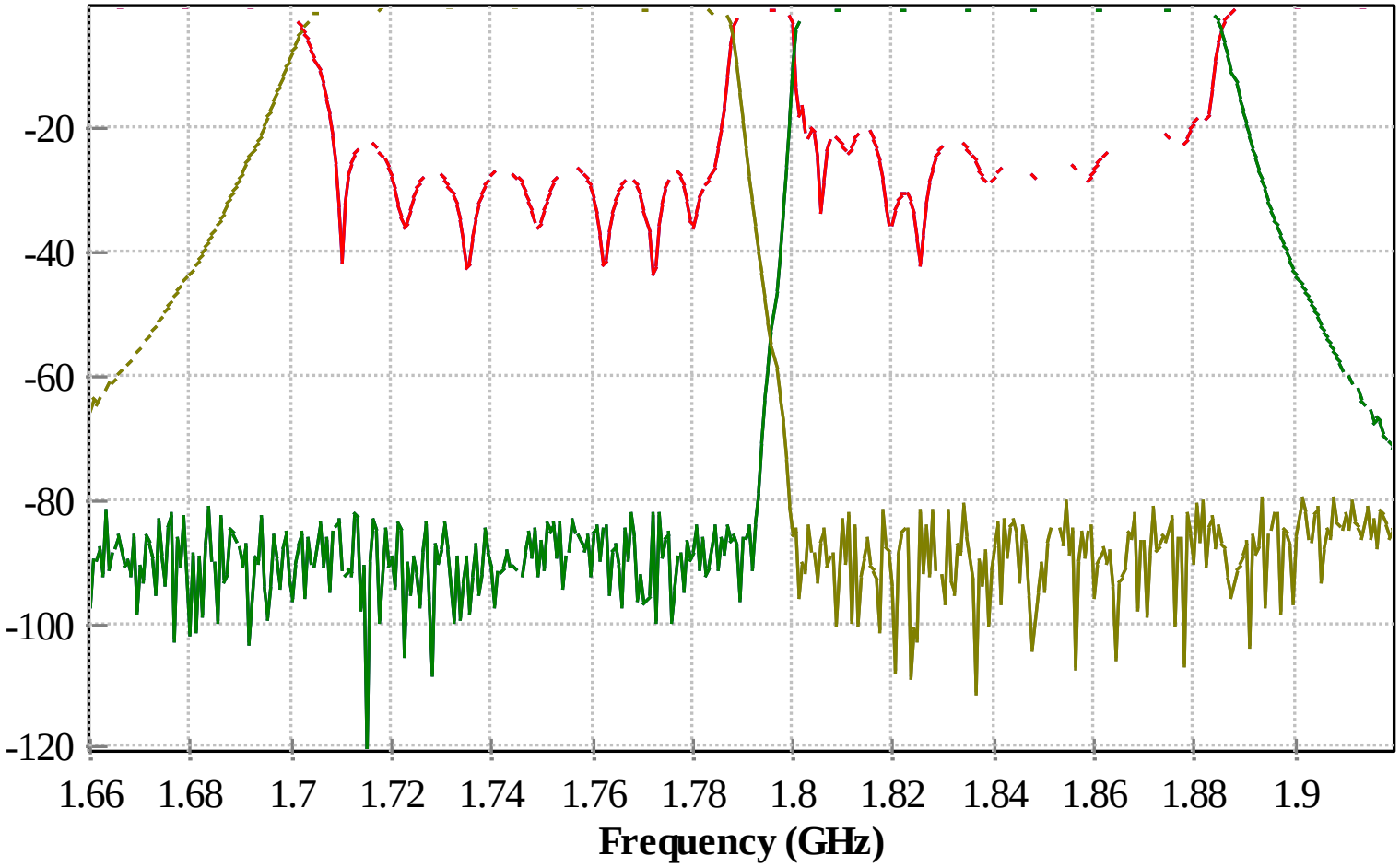
- 10-3 x 12-3 @ 1800MHz, M5 Torx screw
- Tune time: ½ hour average
- Batch size: 49
  - 48 Successful tuning runs
    - Pass preseted 20dB RL target
  - 1 Failed tuning run
    - bent probes – assembly issue



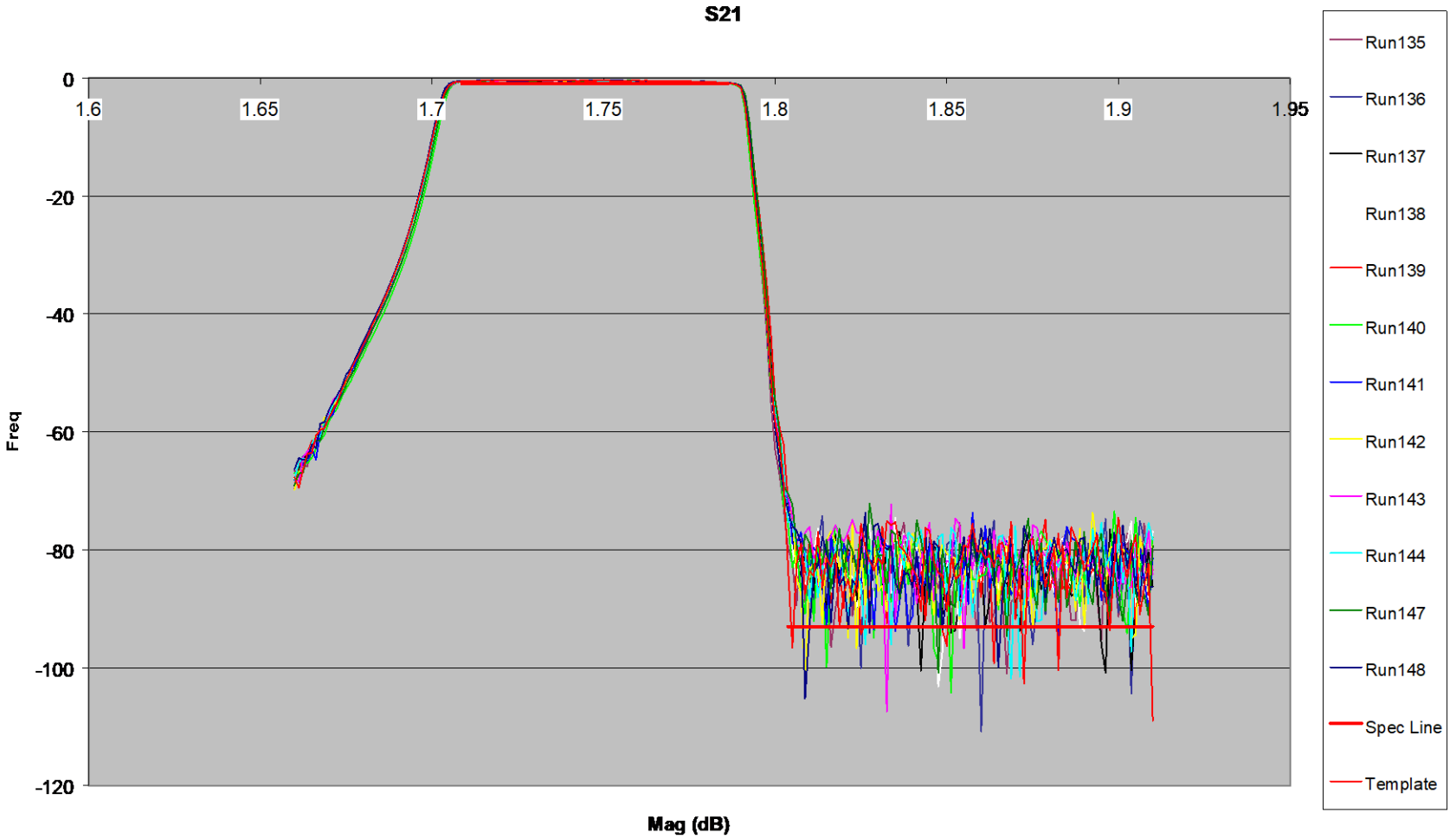


Typical Tuning Results

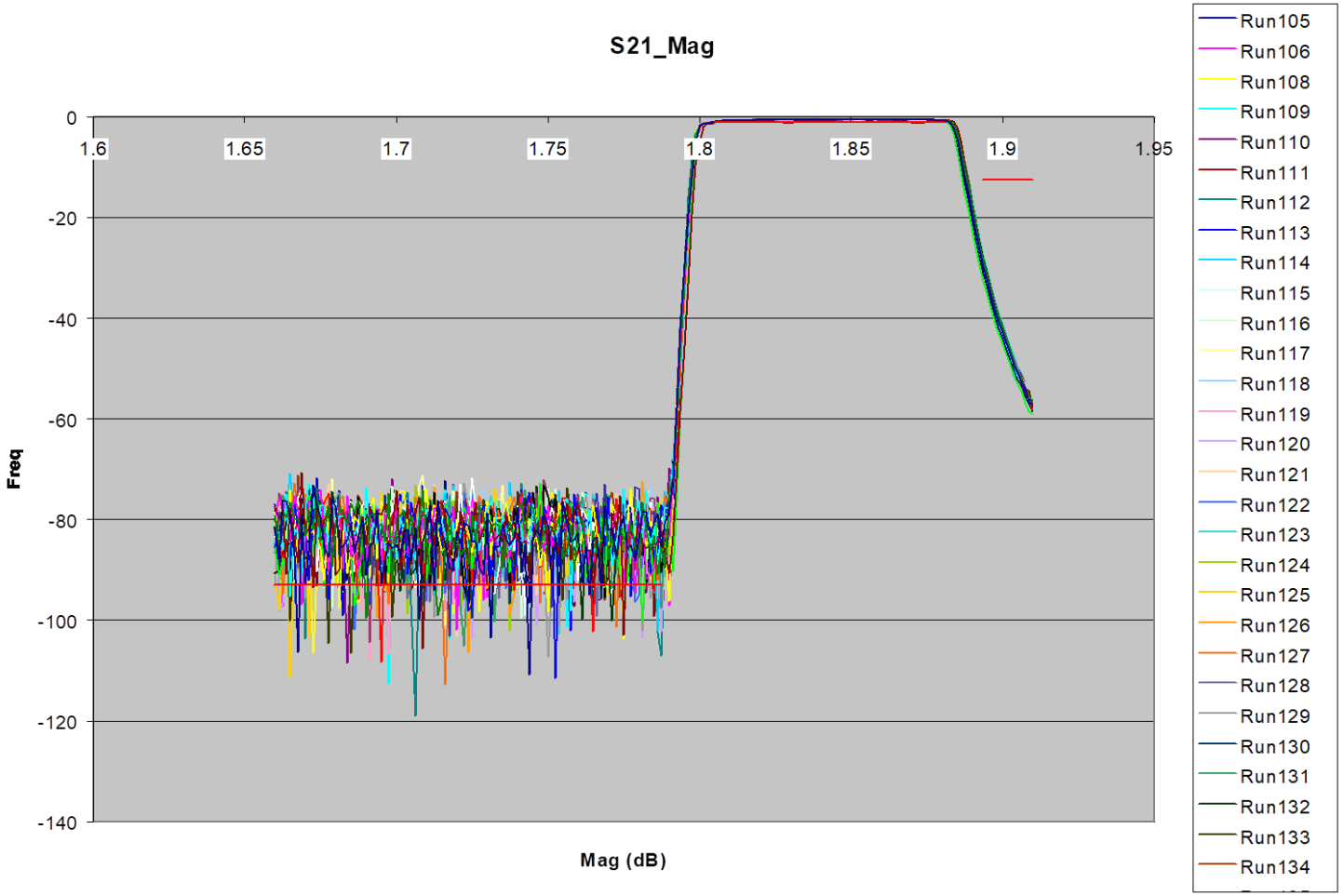
Diplexer |S11| & |S21| Simulation & Measurement



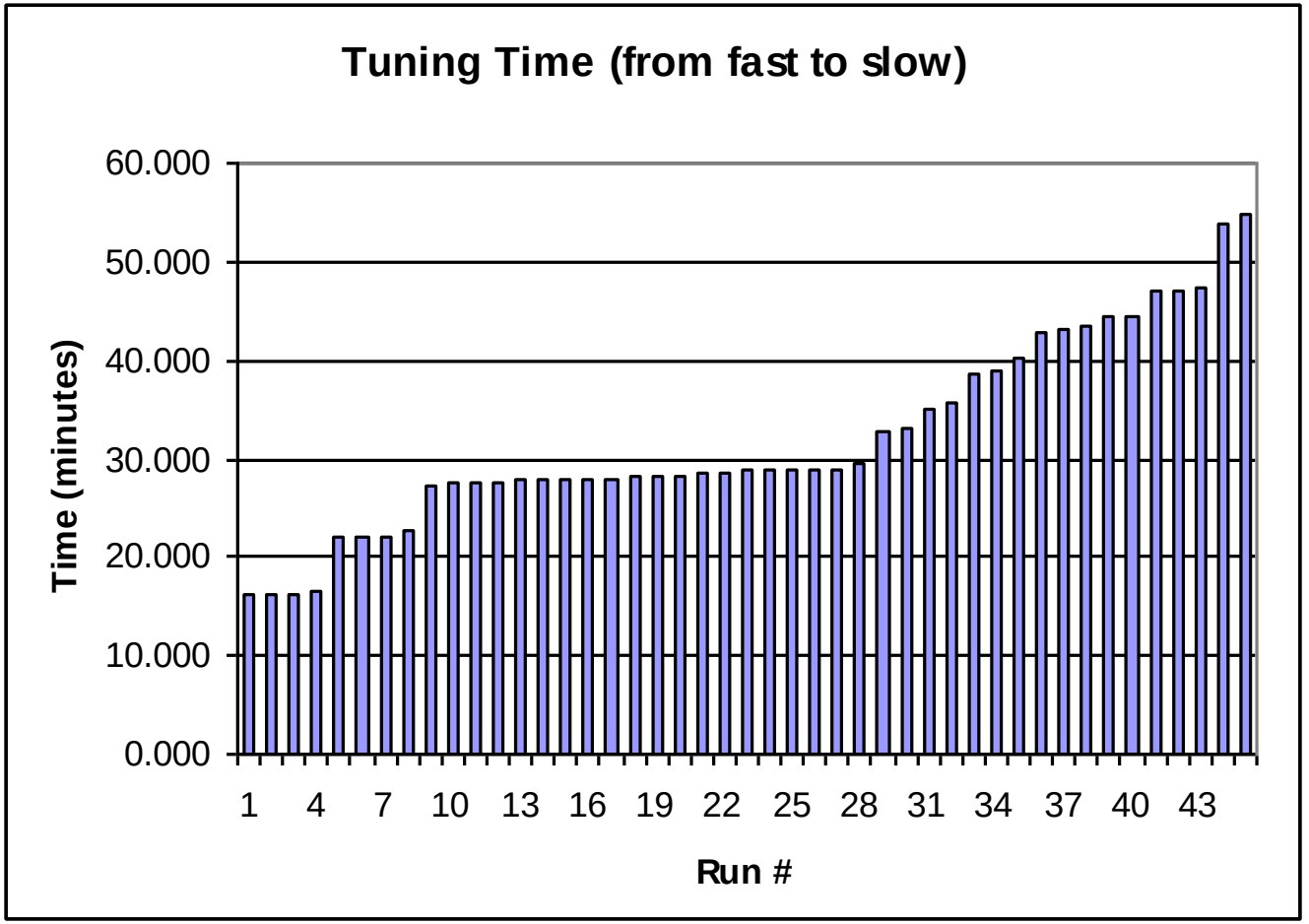
Consistency of Tuning Results



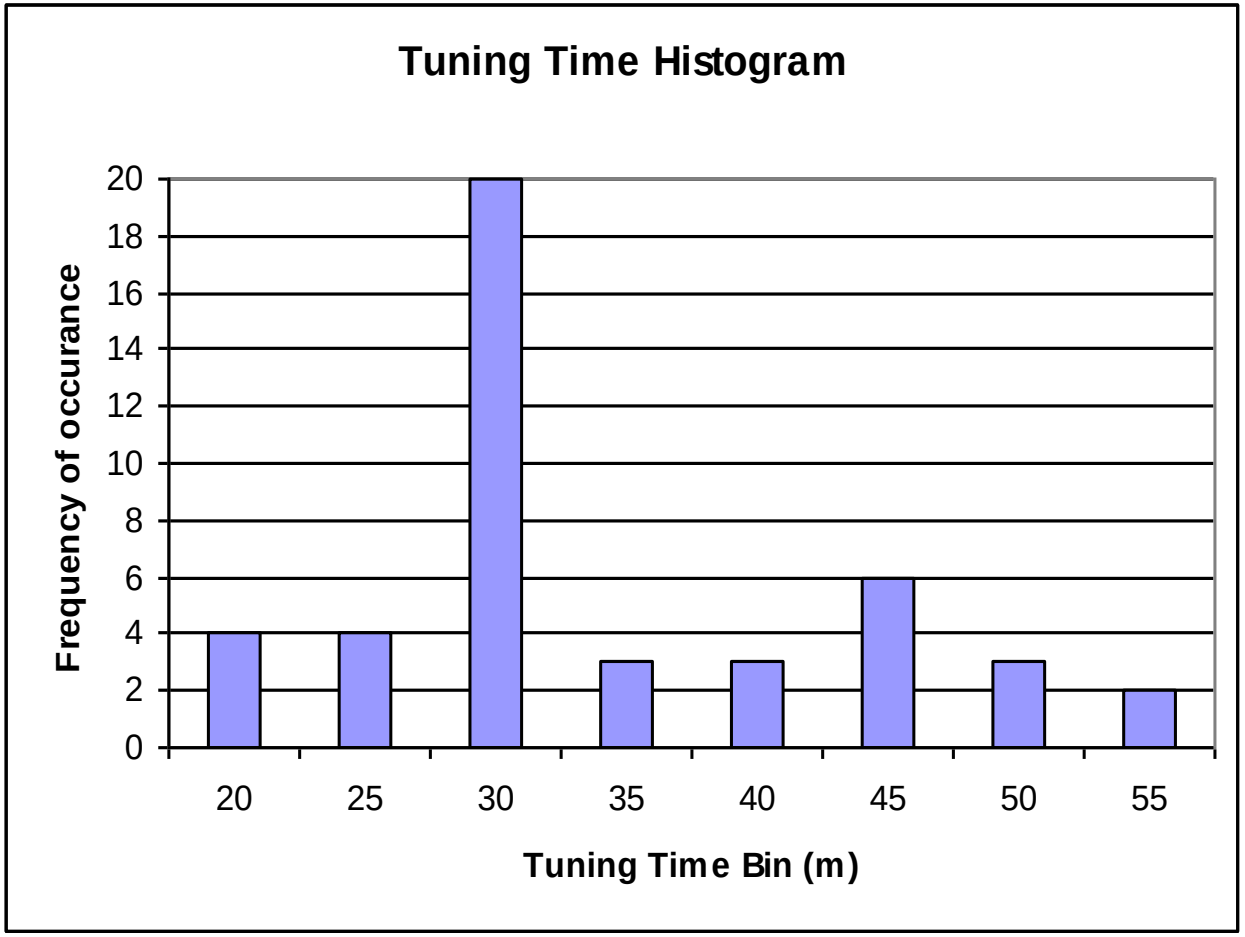
Consistency of Tuning Results



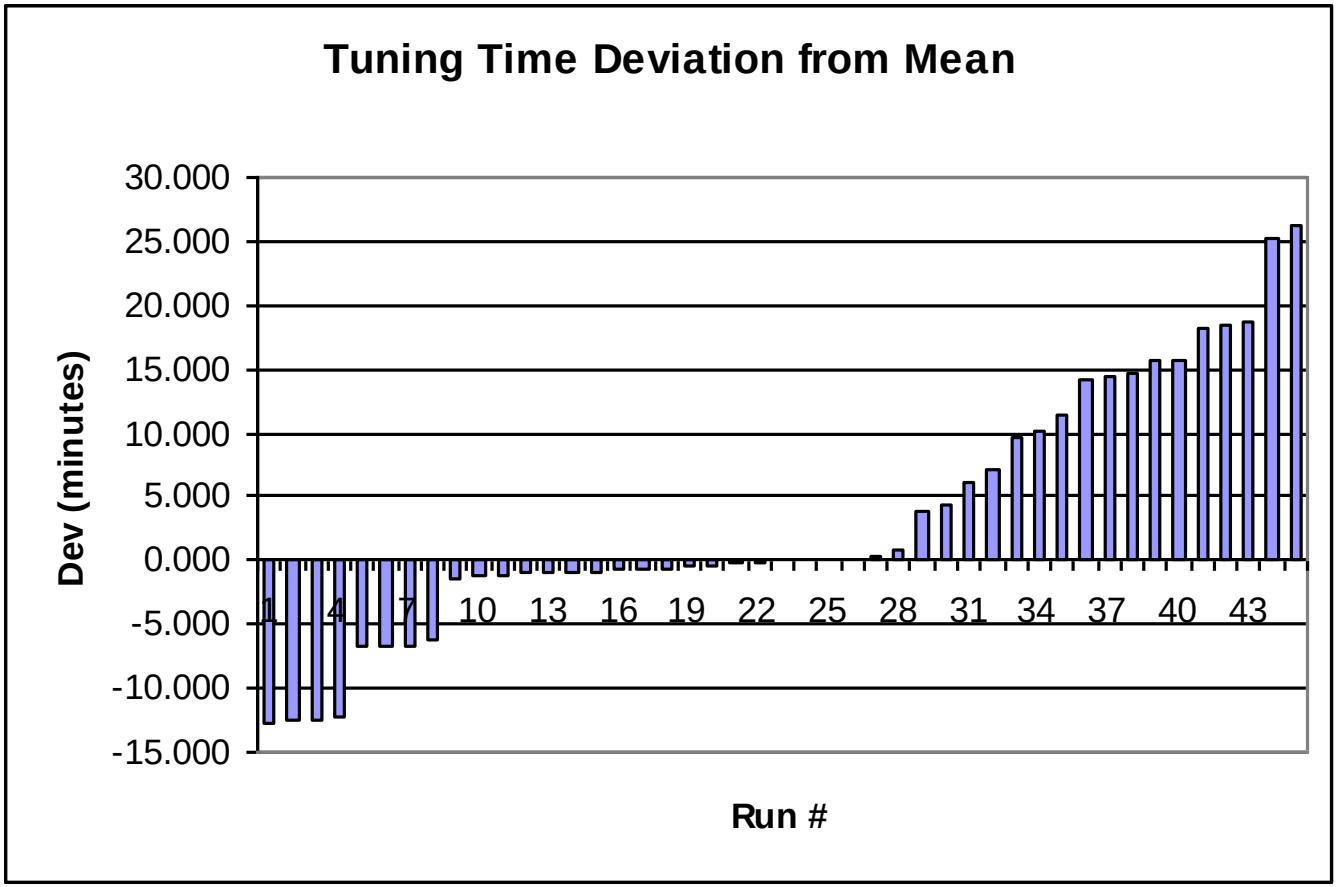
Tuning Time


Tuning Time (from fast to slow)
Time (minutes)
60.000
50.000
40.000
30.000
20.000
10.000
0.000
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
Run #

Tuning Time


Tuning Time Histogram
Frequency of occurance
0
2
4
6
8
10
12
14
16
18
20
20
25
30
35
40
45
50
55
Tuning Time Bin (m)

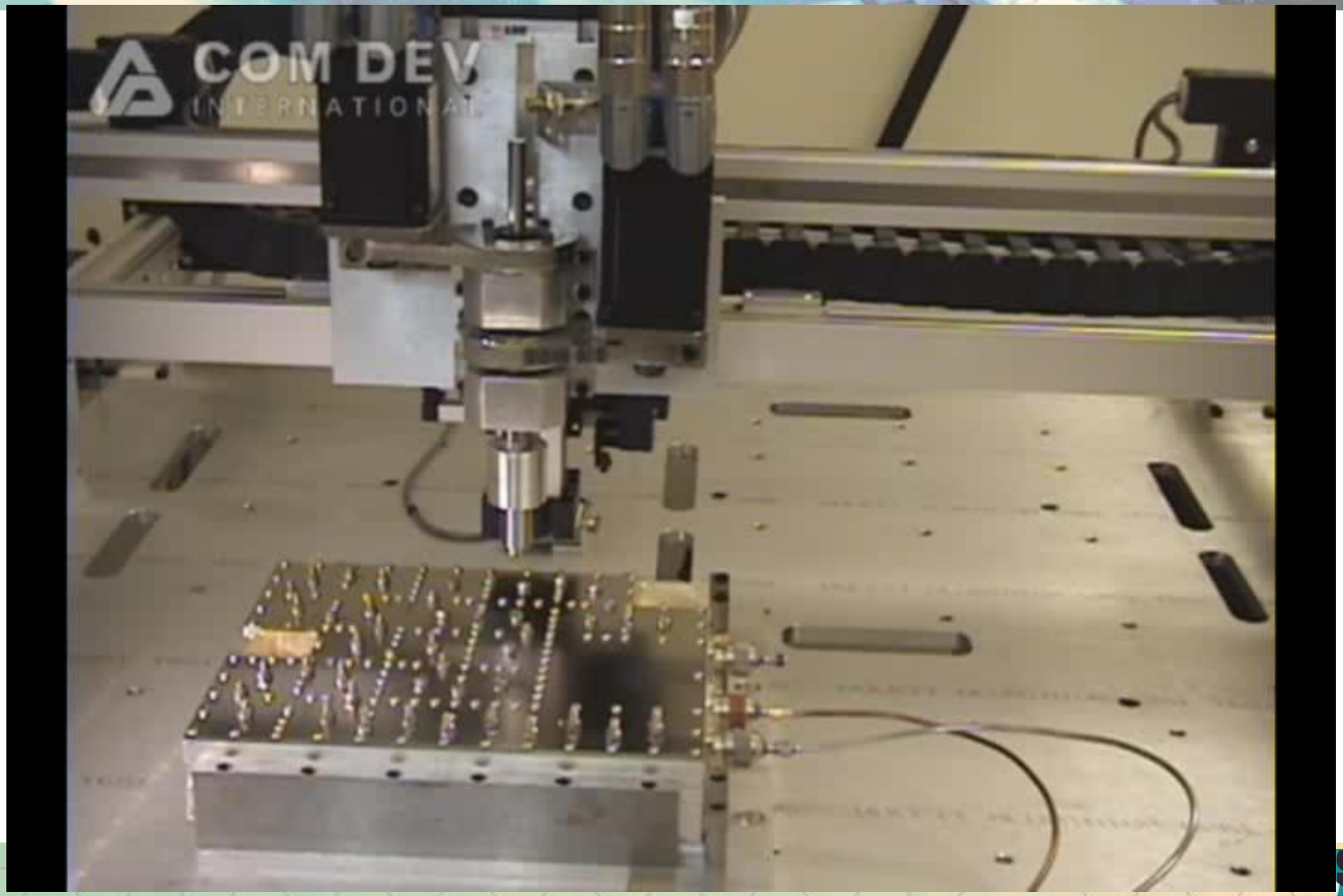
Tuning Time


Tuning Time Deviation from Mean
30.000
25.000
20.000
15.000
10.000
5.000
0.000
-5.000
-10.000
-15.000
Dev (minutes)
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
Run #

Observations

- Most effective to tune brand new assemblies
- Consistent in assembly is critical
  - I/O couplings
  - Cross coupling probes
  - Tuning time is directly proportional to the assembly quality (consistency) of the diplexer

RoboCAT the Movie



Conclusion

Automatic robotic filter tuning machine is now a reality that can provide real cost and time saving for the filter industry