Eddy Current Detection with Linux

- UKUUG Linux2004, Leeds
- A. R. Perry
- alex@pamurray.com
- http://candetect.sourceforge.net
- Linux for low cost eddy current detection
- Finding nails in your walls & cracks in your aircraft using a full duplex sound card and some wire

APMurray

Outline – Frequently Asked Questions

- What is CanDetect anyway ?
- What is Eddy Current (EC) Testing ?
- Why use a computer sound card ?
- What sensitivity does this achieve ?
- How do two coils look inside walls ?
- How does a circuit board inspect an aircraft ?
- Which wire designs are worth building ?
- Where is the code to make measurements ?
- What are the future plans ?

APMurray

What is CANDETECT ?

- Corroding
  - Aluminium slowly corrodes in salty and humid air
- Aircraft
  - 5000 repair stations, 163000 small aircraft in the USA
- Non Destructive
  - Minimal damage, to permit frequent inspections
- Evaluation Tools
  - 340000 (a third of a million) aviation technicians in the USA
- Eddy Current Tester
  - Induce electrical currents in the metal to find cracks

Approach to being low cost

- The CanDetect project uses ordinary sound cards
- It monitors the environment by magnetic induction
- The sensor can be as simple as some wire loops
- The software sends and receives magnetic signals
- The application can build as a bootable Linux floppy

What is Eddy Current Testing ?

- Apply a changing magnetic field to a piece of metal
  - This causes electricity to invisibly flow in a loop inside
  - This so-called eddy current has to stay inside the metal
  - It cannot get across cracks or through corrosion, etc

- So we have a current loop, how do we know where it is?
  - Any electrical current generates a magnetic field
  - The shape of the field depends on the path of the current
  - Simply measure magnetic field of the eddy current where it conveniently extends outside the metal

Creating and detecting magnetic fields

- The magnetic field is generated by electrical current
  - There is field going in a circle around each short bit of current
  - Add up all the bits of field from all the bits of current

- The magnetic field is detected by electrical voltage
  - A change in the field across the wire generates a voltage
  - If the field doesn't change, there will be no voltage
  - Add up all the voltages along the wire to get the total

- Have to make sure that the field is always changing
  - Swap the direction of the electrical current regularly

Interesting pieces of metal

- The screws and power cables in your walls
  - Don't want to hang a picture by putting its nail through a cable
- The small tab on the door or window
  - The coil on the door frame is used to trigger an alarm
- The metal structure of an aircraft
  - It should stay intact from takeoff to landing
- The moving core of a LVDT (position sensor)
  - The manufacturing tool wants to know where it cuts/welds

Why does Linux help

- All those applications are for products
  - They have embedded computers for decision making
  - The algorithms are often changed and improved
- Linux is a popular embedded kernel
  - Ideal for low cost products, because no royalties
  - No hard real time support, but that's fine for this
- It's nice to have the same kernel on the desktop
  - Makes writing code and porting it to the target easier
  - Much larger pool of developers and consultants
- The code is small, easily fits on a floppy or flash chip
  - Linux kernel can be recompiled to optimize its feature set

Small and cheap Linux computers

- Required features of a small computer
  - Hardware multiply for processing the signals
  - Heavy math or display updates must not block audio
  - Must have full duplex sound at 16 bits
  - Other than that, almost any processor

- The ARM port of Linux looks good, being used in PDAs
  - Many PDA chipsets only simplex, or 8 bit duplex
  - Or documentation ambiguous/inadequate
  - Battery charge must not change electrical performance
  - That is actually a challenge, depending on electronics design

Why use a computer sound card ?

- They can generate programmable analog waveforms
  - On one, two, four or even six electrical outputs
  - Most offer 1 V drive from less than 100 ohms
- They can also retrieve analog waveforms
  - On one or two electrical inputs
  - Most accept 0.1 V at much higher impedance
- Some of them can do both at the same time

- Why does every computer have something like that ?
  - Maybe you can't sell a computer if it can't play games ...
  - People expect games to make lots of interesting sounds

Full Duplex – not always available

- More complexity to play and record simultaneously
  - Hardware could have bugs, driver might not be written right
  - Not needed to play all games, though often can be helpful
  - Problems may not impair sales a lot and might not get fixed

- Full duplex is popular for Internet phone calls
  - Similar situations too, such as multi-user gaming
  - But people accept noisy low quality for voice calling
  - So full duplex might work but be too poor for CanDetect

- Linux lets us fix the driver when there's problems
  - We can't fix hardware, but we can only choose it ...

Test and choose the best sound card

- Linux has drivers for many different sound chips
  - Two products may have the same chip, but different boards - one boards may have less noise than the other one
  - Those differences will be invisible to the Linux driver
  - The only way to find out is to actually do the testing

- Tests should measure the actual analog performance
  - Make sure the sound card really does run in full duplex
  - Collect data for a minute or so and compute statistics
  - Some chips warm up when being used in full duplex
  - Such a temperature change can cause a lot of drift

- Repeat until a good card is found ...

APMurray

Running the sound card tester

- The test may be automated, just a program to run
  - Could boot from floppy, but not all laptops have floppy drives
  - Could use a CDROM, but it is hard to change the program
  - Also, there is nowhere to store the results from the test
  - Easier to use NFS to run the program and store results

- Most people prefer to have a GUI when testing
  - Modify Knoppix or equivalent to add the test program
  - This means mastering and burning CDROMs until it works

- Network boot avoids all those disadvantages
  - Many can boot at once (no need to make lots of CDs)

LTSP – run the test program everywhere

- Linux Terminal Server Project – has the infrastructure
  - It converts each computer you netboot into an X terminal
  - Leave all test programs and result storage on one server
- One change to client's /etc/rc.local on the LTSP server
  - Runs the test program from NFS and writes the results to file
  - Choose the filename from, for example, the client IP address
  - When test is completed, immediately reboots the computer
- To test, simply network boot all available computers
  - Some can use PXE, others need a floppy with EtherBoot
  - After triggering the network boot, no reason to wait around
  - All results will be ready for comparison within minutes

Linux offers hardware independence

- CanDetect still uses the Open Sound System (OSS)
  - All models of sound card basically look the same
  - Work in progress to transition CanDetect source to ALSA

- Linux treats sound interfaces on the USB bus the same
  - Use several sensors without needing additional PCI slots
  - The external bus separates the computer and sensor further because the sensor plugs into the sound card, not the computer, and the computer can be a strong source of magnetic noise !

- Potential to add support for expensive DAS boards
  - At my day job we use a 12 output and 12 input port board

Sound card experiences

- Careful choice, but not price
  - No audible hiss from microphone at full volume
  - Full duplex capable (recording during playback)
  - 16 bit operation (because 8 bits is way too few)
  - Most PCI cards are ok, but ISA are not
- Maestro 2E sound chip, in a notebook, works well
- CMI8738 from C-Media is acceptable, no issues
  - Used in the obsolete NIC, that booted from CDROM
- TI PCM2900, a USB audio chip, has low noise
  - But, under Linux, randomly swaps the input channels around
- Via82cxxx, has not yet correctly operated a probe

Problems with Linux drivers

- USB audio
  - This is a generic class driver, supporting many vendors
  - Texas Instruments PCM2900 – Random record channel swaps
  - Software workaround to determine whether they're swapped
- Via82cxxx chipset
  - OSS 2.4.25 and 2.6.7 – Full duplex never actually plays sound
  - ALSA 2.6.7 – Fragments are two sizes, data not synchronous
  - Software workaround is to keep measuring synchronization

What sensitivity does this achieve ?

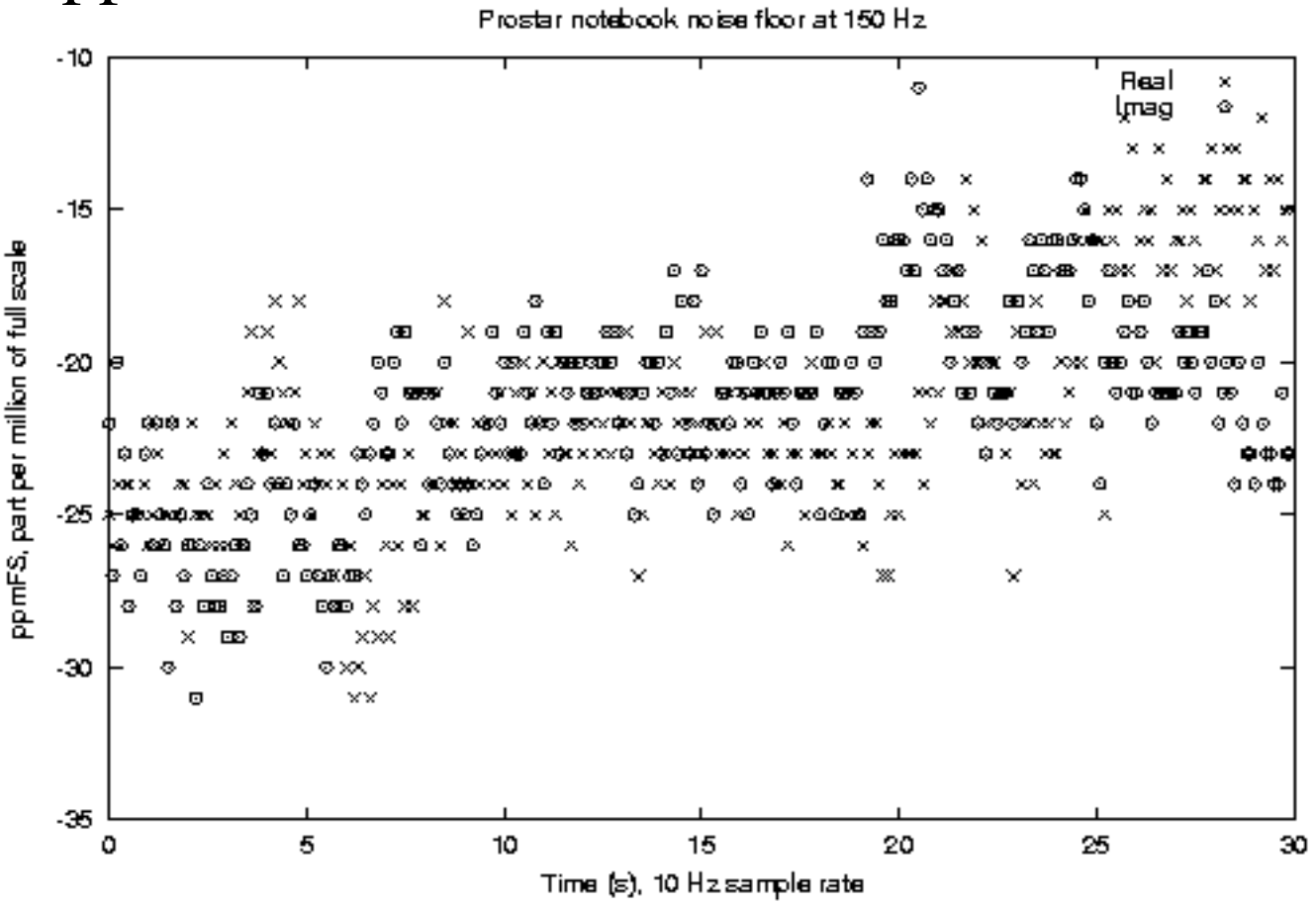
- Sound cards use sigma-delta conversion
  - They take millions of readings per second on each channel
  - These are digitally combined together and averaged
  - After averaging, a 16 bit integer is reported to the computer
  - Usually 32000 times per second, about every 31 microseconds

- Computer software can do more averaging if it wants
  - Combining four readings into one – is like an extra bit
  - Doing the combination four times gives us four extra bits
  - So the data can also be 20 bit integers, 30 times per second

- 20 bit integers can count up to a million
  - Data have resolution of one part per million (ppm)

Maestro chip, 150 Hz silence

- Carrier 150 Hz for 30 sec
  - Noise 0.87 ppm/rtHz, Drift 0.15 ppm/s, Offset 21.6 ppm
  - See? 1ppm – works.



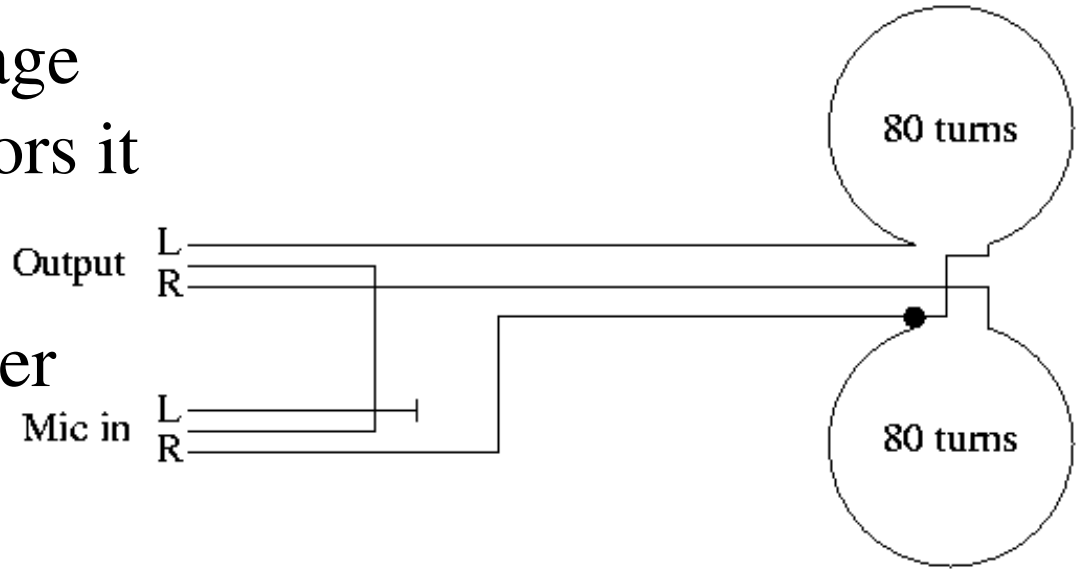
APMurray

Comparison with other measurements

- < 2 digits — Analog moving needle voltmeter
- 2 digits — 8-bit A/D, such as in an old ISA sound card
- 3.5 digits — Most modern handheld digital voltmeters
  12-bit A/D installed in cheaper computer cards
- 4.5 digits — Std lab bench voltmeters, usually with lockin
  16-bit A/D in a high quality data acq cards
- 6 digits — What we're achieving with a Linux computer
  can see incredibly subtle signals and changes

How do two coils look inside walls ?

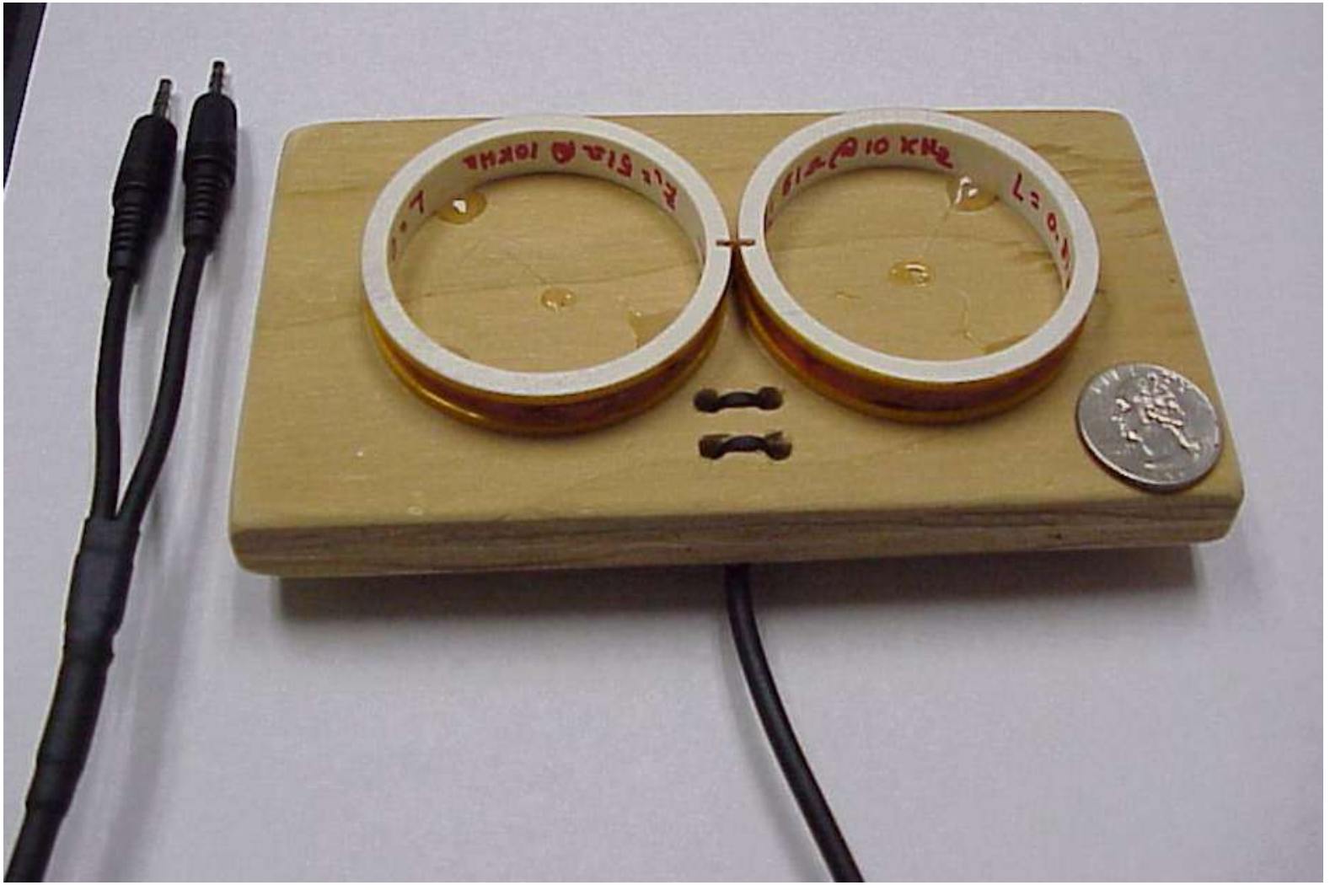
- Coils driven in series
  - Current provided differentially using two output channels
  - Both are pushing that magnetic field into the wall
  - Same current in identical coils; midpoint stays near zero
- Both coils detect response of course
  - The midpoint is the average
  - One input channel monitors it
- One closer to the metal
  - That coil's voltage is larger
  - Software measures that



APMurray

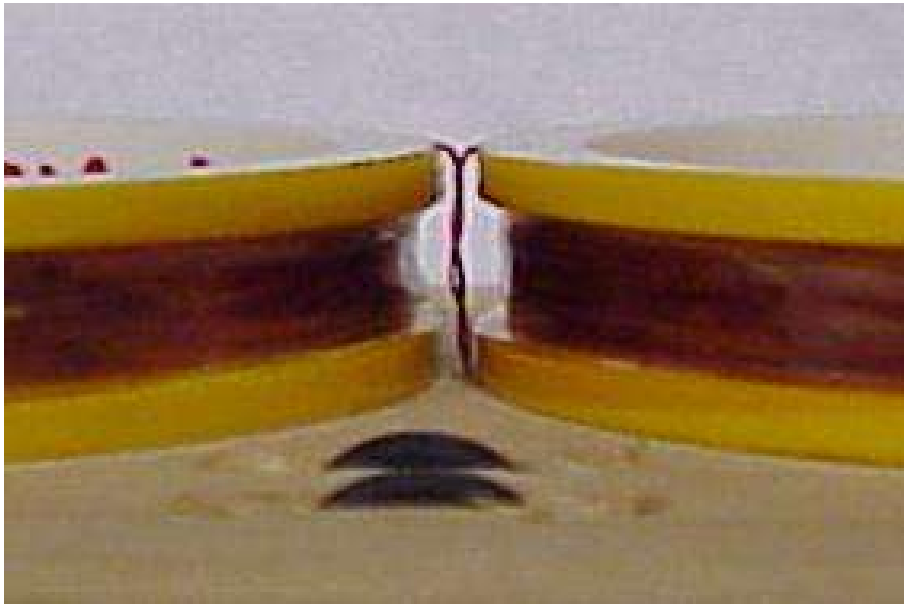
Homemade probe – overview

- Two coils, glued to a piece of wood
  - An audio patch cable, cut in half, for speaker and mic

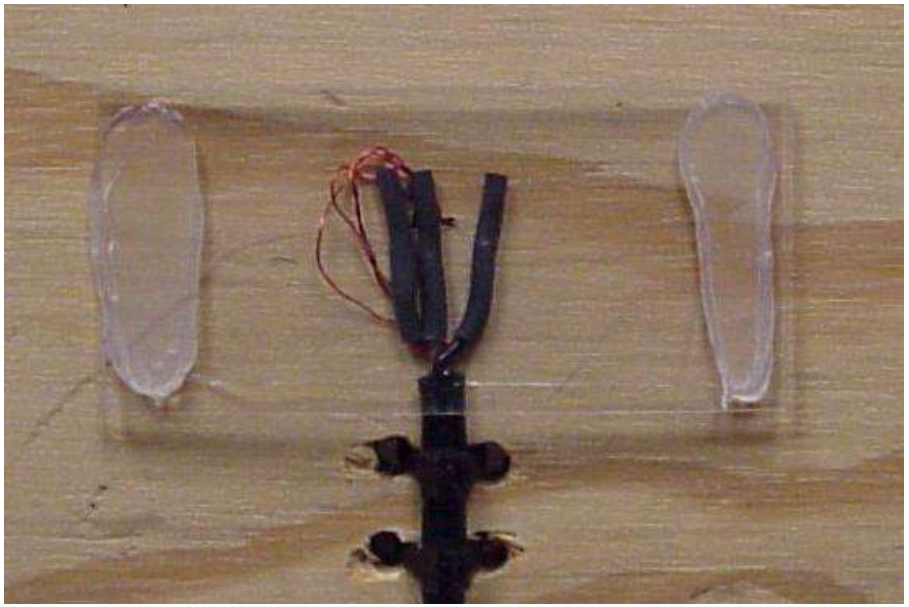


Homemade probe – detail views

- The neat windings are visible
  - Covered with tape for protection
  - The four wire ends from the coils pass through a hole in the wood



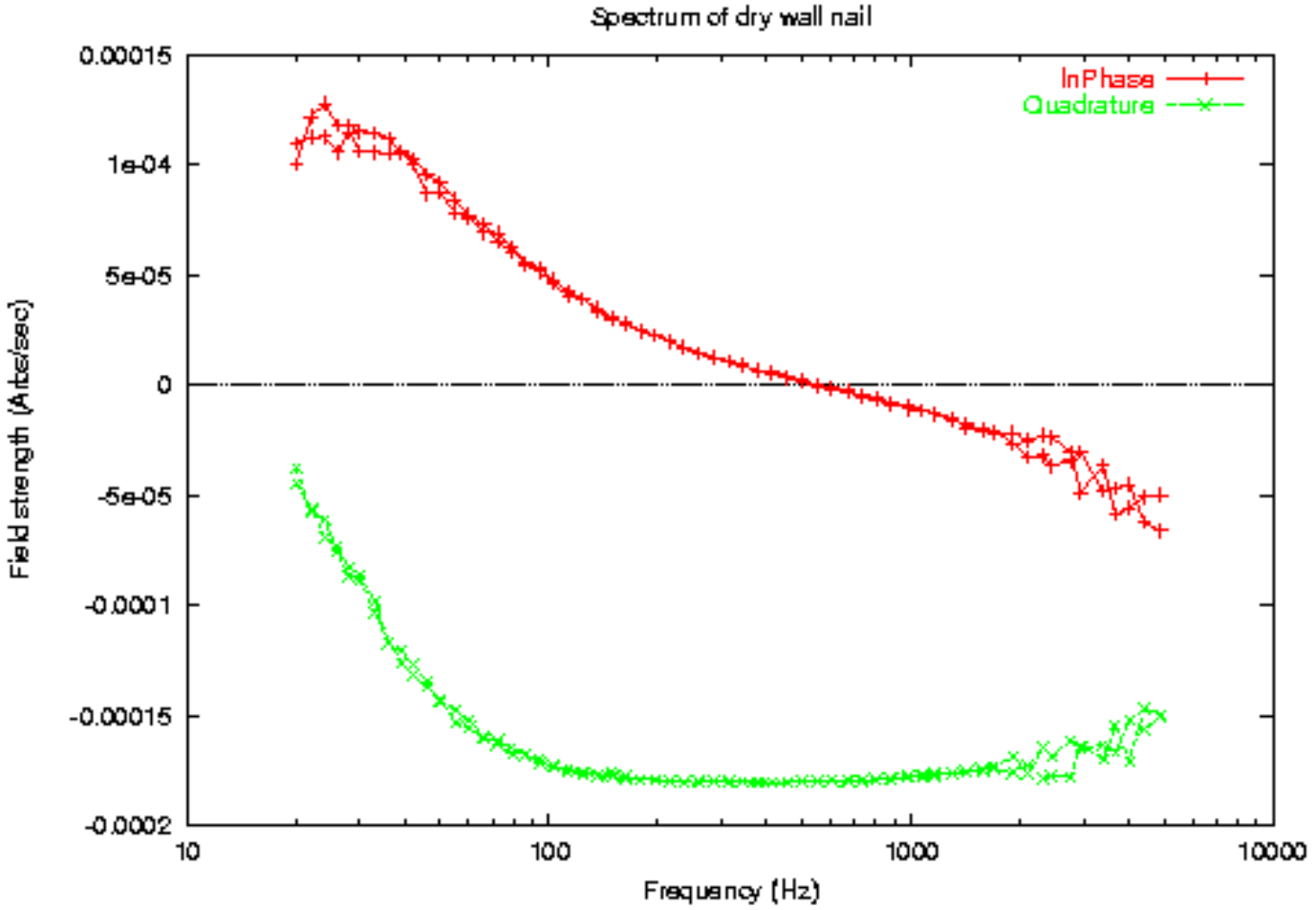
- Patch cables connect to coils
  - Simply soldered together
  - Heat shrink tube for insulation
  - Transparent cover for protection
  - Avoids damage during transport



- Two tie-wraps for strain relief

Frequency sweeps are easily scripted

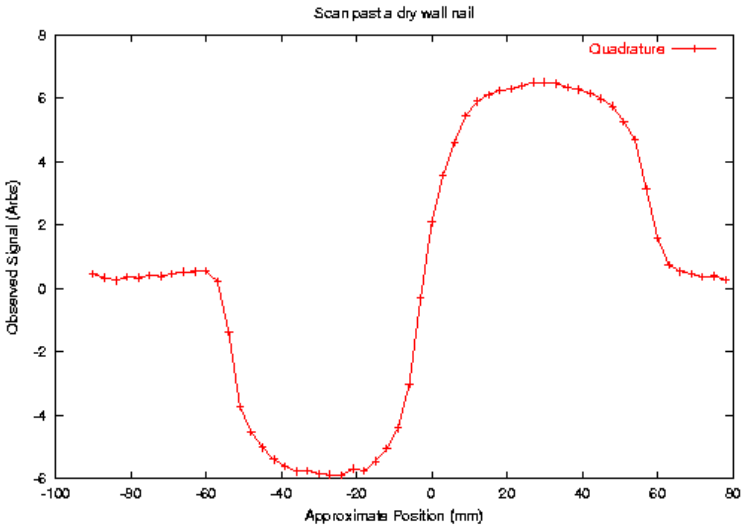
- Dry wall nail – magnetic response at many frequencies
  - Suitably big anywhere between 100 Hz and 1kHz



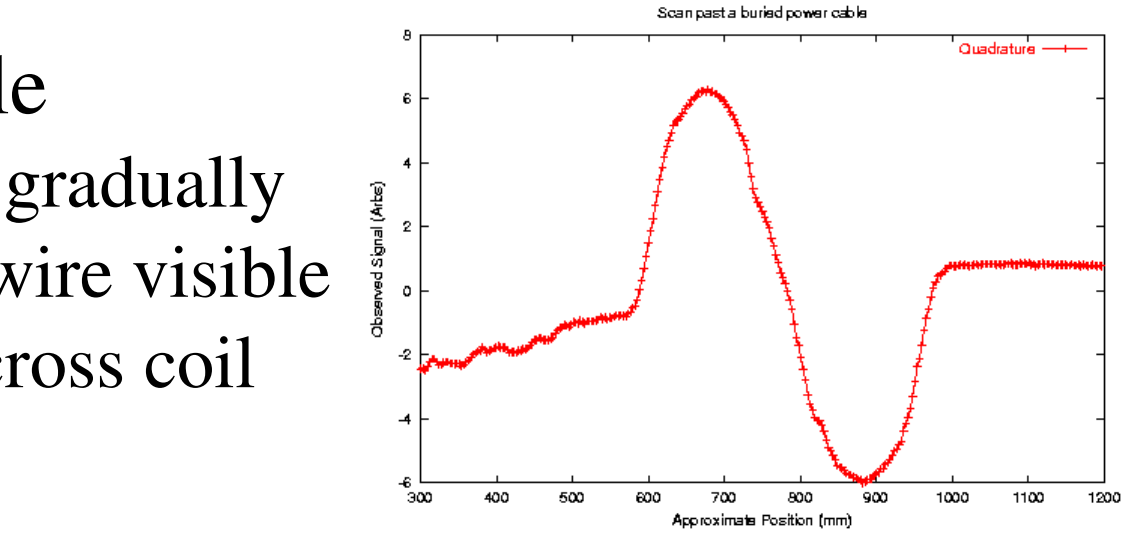
APMurray

Signal from sliding probe along wall

·This is the dry wall nail
- Signal strength changes rapidly
- The nail is inside the loop, or not
- Negative for one coil
- Positive for the other



·This is for a power cable
- Signal strength changes gradually
- Depends on how much wire visible
- Changes as wire goes across coil



·Easy to find midpoint ...

APMurray

How does a circuit board inspect aircraft ?

- Cracks tend to grow out of one rivet towards the next
  - The eddy current has to try to flow between the rivets
  - If it doesn't, the current path would not changed by a crack
  - The magnetic field has to be pointing along the rivet line

- A flat magnetic field can be made by two spiral patterns
  - One clockwise and one anticlockwise, next to each other
  - These are not used to receive – we're only look in one place
  - A separate small coil measures the field out of the surface

- Coils are not very good at the low frequencies
  - Prototype uses a special MR sensor instead of the small coil

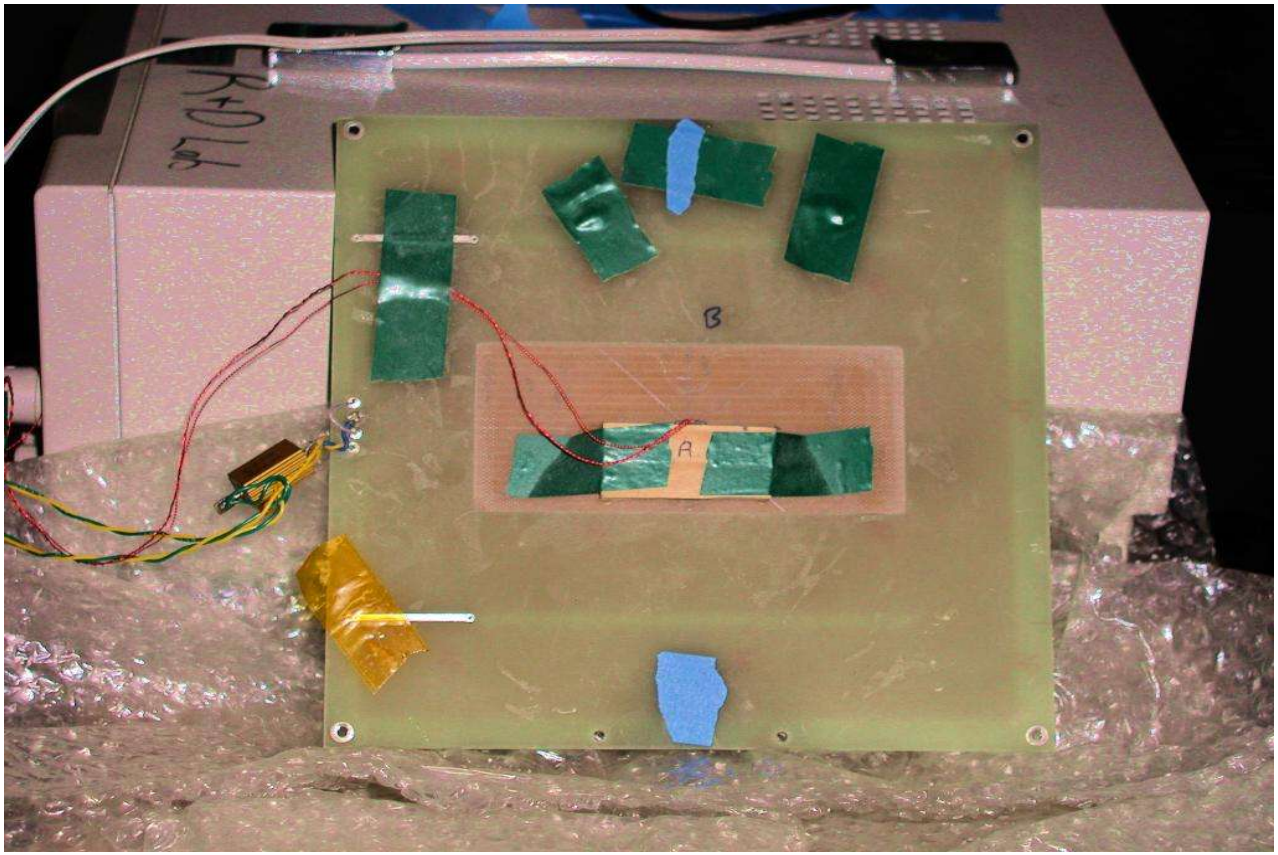
Probe design for rivet rows

- Optimized for cracks on rivets at low frequencies
  - This prototype was designed/built by Dr W.F. Avrin

- Cheap circuit board
  - A: the MR sensor
  - B: one of the spirals

- Green/yellow wires
  - Spiral current drive

- Pairs of red wires
  - Sensor power/signal



APMurray

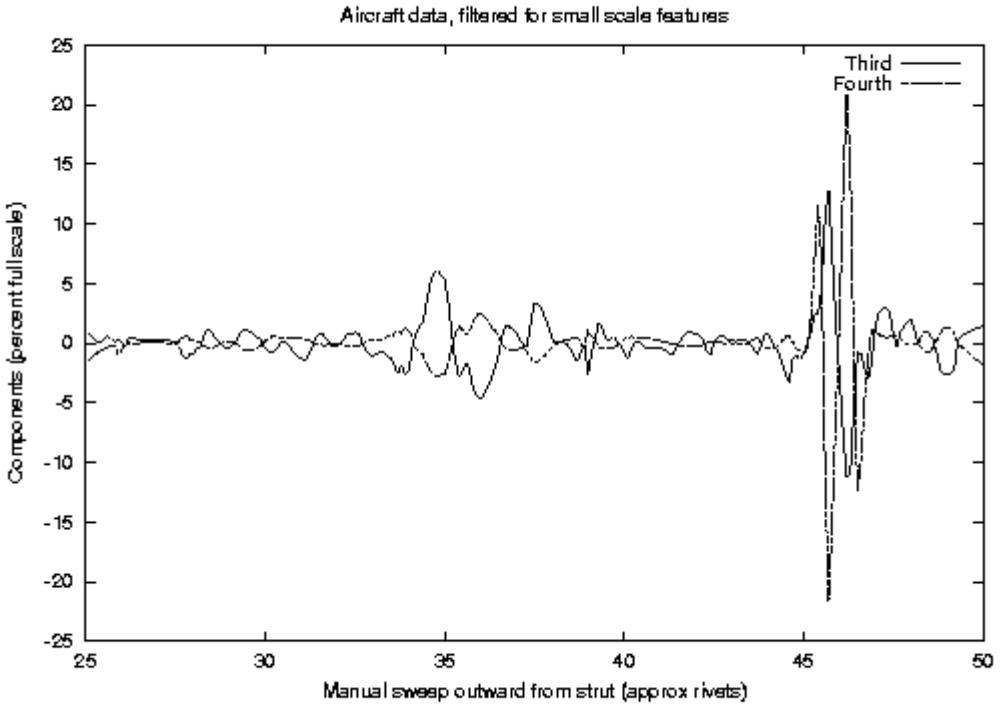
Cessna 172 measurement setting

Underside of C172 right wing

- Track is right to left
  - @25: starts right of the right hand access panel
  - @34: passes the right row of rivets
  - @46: left row of rivets
- Manual motion was 1 sec/rivet

Aircraft scan – High spatial freqs

- 3: High freq at 0 deg, shows the rivets
- 4: High freq at -45 deg, absence of crack



Simulate – is the design worth building ?

- It is easier to simulate a new design idea than to build it
  - The design can then be adapted/improved before being built
- Python's numeric and scientific libraries can do magnetics
  - Compute the coupling between all coils and pieces of metal
  - Coupling data can be analyzed by “gnucap” if necessary
- Such coupling calculations need lots of CPU power
  - Each position and shape of the metal is a separate calculation
  - This is an ideal case to solve with a Linux-based cluster
  - MPI and similar is not needed, an OpenMosix kernel suffices

Probe designs – proving that they work

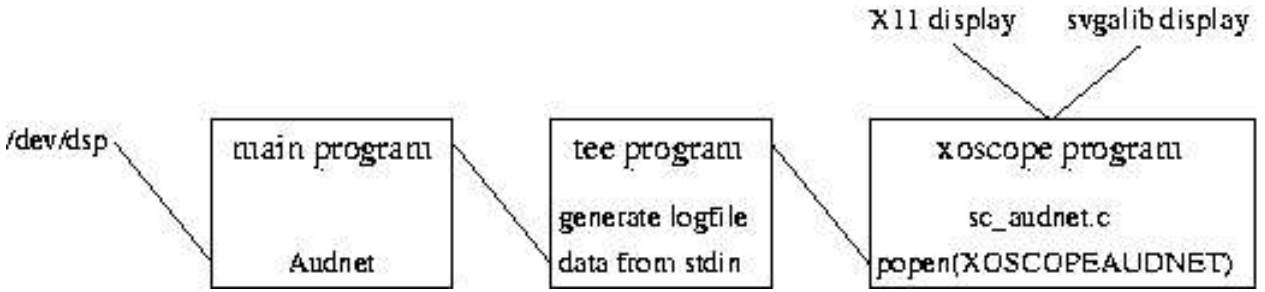
- Test data and qualification trials are necessary
  - Proving that a given probe is reliably detecting a given flaw
  - Before it is safe for anyone to use or rely on the results from it
  - Mistakes cost lives on any aircraft or infrastructure inspection

- It is usually necessary to have multiple probe designs
  - To ensure that all the different flaws are reliably detected

- Much more effort goes into qualification than into design
  - So it is really important to get the design right first

Where is the Code ?

- A script connects four programs
  - Greatly simplifies customization
- Main program reports all measurements
  - First two columns are intended to be useful in real time
- Tee program ensures a record is kept
  - Post-processing, such as using Octave and/or GnuPlot
- XOscope program provides scrolling display
  - Allows user to optimise measurement activities



Low level library – AudNet

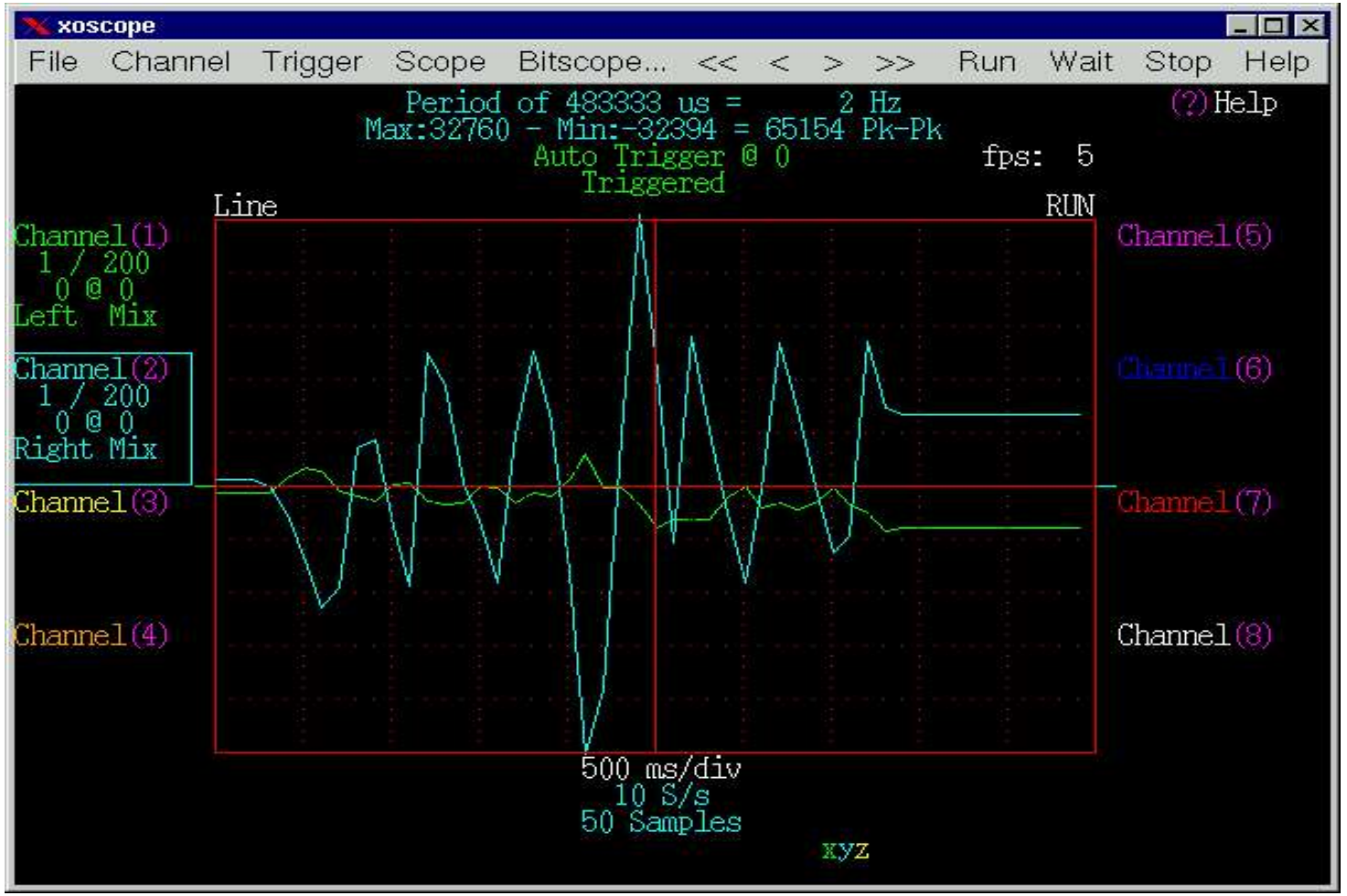
- Operates the sound card
  - Precomputes a backlog of outgoing audio data
  - Keeps track of the list of pending sound fragments
  - Retrieves and processes recorded incoming data
  - Matches incoming data to associated outgoing data
- Manages multiple requests
  - Each has defined repetition and set of output waveforms
  - Application adds references to requests into a queue
  - Permits multiple parameters to be measured on a rota
- Adaptive operation is easy
  - As results become available, change future queue content

Diagnostic application – xoscope

- xoscope was originally an oscilloscope
  - Monitors signal source for a trigger condition
  - Then grabs a waveform fragment to be displayed
  - But it discards the input signal when display busy
- Probe capable of continuous movement
  - The discarding causes occasional data gaps
  - Modification necessary to the standard source code
  - Thus, CANDETECT uses a patched version of xoscope
  - Patch doesn't work against recent CVS releases though
- XOSCOPE only plots 10 ppm of the full scale
  - No loss of resolution in recorded data files

Real time display, in use

- Dynamic range of 10000 available i.e. 80 dB
- Graphs scroll to the left, variable speed



A PMurray

Why is Linux needed ?

- Multiplatform
  - Desktop and lab workstations for development
  - Handheld, laptop and embedded computers for production
  - All have exactly the same kernel/API, not just similar
- Multidevice
  - Many sound card drivers, all sharing a simple code API
  - Standard support for up to eight installed sound cards
  - One computer making many simultaneous measurements
- Easy development
  - Network boot, LTSP, CD boot, NFS, UML, etc
  - Remote service infrastructure and network audio
  - Use of low latency patches permits adaptive algorithms

What are the future plans?

- Address issues with drivers for popular sound chips
  - Need software to work with almost any modern laptop
- Update library to use API for ALSA instead of OSS
  - OSS is now legacy and support will degrade over time
- Package software for inclusion in distributions
  - Enables it to be built into subsequent live CD images
- Extend algorithms for tracking the sensor's position
  - Makes it easier for the user to know where data was taken

Conclusions

- Linux enables stable sub-ppm performance
  - Because its latencies never enough to pause audio stream
- Direct connection of probe feasible with sound card
  - Eliminating the cost and complexity of additional electronics
- Computer can also be used for other tasks
  - Instead of buying a dedicated NDE system, reboot an existing Windows-based workshop data retrieval station