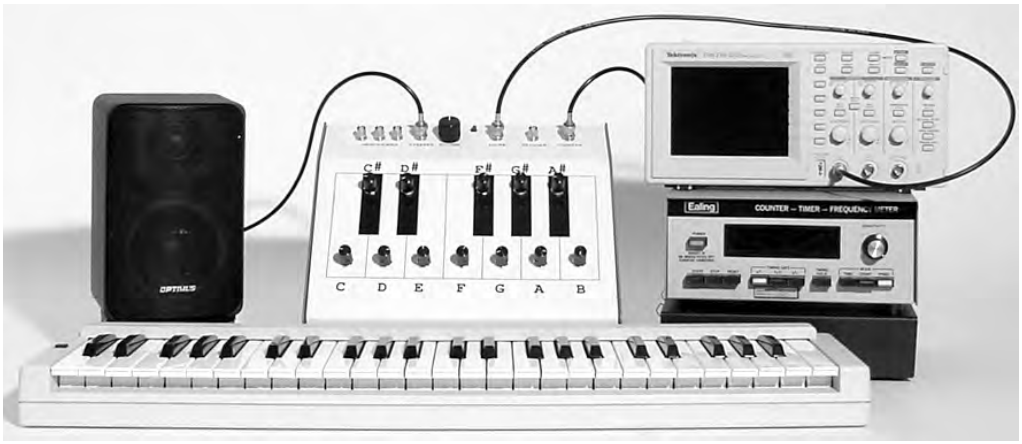
Lab 11
Musical Scales

Purpose: understand the numeric relationship between the frequencies of the western scale. Explore the difference between just and tempered tuning. Understand transposition. Understand the difference between major and minor scale.

Equipment:
We built keyboards which can easily be tuned by the students by means of 12 ten-turn potentiometers. The frequency ratio between octaves is fixed at 2, and is not adjustable.
The frequency of each tone (when played by itself) is read on a frequency meter, whose output is connected to an oscilloscope and headphones or a loudspeaker.



Experiments:

1. Tune the keyboard to the just scale. First the students make a table of frequencies by using triades (4:5:6 ratios), based on a frequency of e.g. 200 Hz for C. They tune C-E-G accordingly, then D-G-B, finally F-A-C, and listen to the full scale to find the familiar Do-Re-Mi scale (i.e. C-major).
2. Sensitivity to small changes in tuning. This, of course, is subjective to each student. They detune e.g. G and play the scale to find how close they get in setting G without the aid of the frequency meter (and without playing a cord). Then play a cord to find that the tuning is much more sensitive, i.e. tuning matters a lot more in polyphonic music than for a single instrument?
3. Why black keys? Students are asked to play a triad starting on E (ask
4. students, if E-G-B would work? NO, one needs to tune G#).
5. Ask the students to figure out why there are two places where there is no black key between adjacent white keys.
6. There are problems with the just scale: for example, is D-A in tune? Listen and look at oscilloscope picture, comparing C-G to D-A.

7. Tempered scale (all 12 semitones with equal frequency ratios): tune keyboard using tempered frequency table. Some students will hear, and all can see on oscilloscope, that now the major third C-E is out of tune.
8. Transposition: what are the tones of the scale in D necessary to preserve the previous sequence of whole tones and semitones?
9. Minor scale: play white keys starting on A (= minor scale). What is the sequence of whole tones and half tones? List tones for C-minor. Listen to major vs. minor key.

Comments:
This lab is not without problems: students love it or hate it, depending somewhat on their interest in classical music.
On the technical side, the problem is that the construction of the keyboards requires lots of man-hours. In addition the equipment is somewhat rigid in the sense that the spectral composition of the tones can not be changed. Pure tones are not desirable, because theabsence of higher partials (no overtones) means that pronounced beats are missing when playing e.g. chords in tempered tuning. A better solution would be to use a computer store tables of output voltage vs, time for each key of thekeyboard and using a rapid table-look-up. One of our teaching assistants made a promising start using Linux, but he graduated before completing the project. This certainly would be worth pursuing.