IMPROVING THE SPEECH INTELLIGIBILITY IN AN AIR-TRAFFIC CONTROL ROOM

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ABSTRACT Poor speech intelligibility in an air traffic control room is frequently a result of many, quite different causes and occasionally leads to complaints of the controller personnel. The paper describes a sequence of successful tasks performed in a local control room. The initial measurements included an investigation of the background noise (caused by fans, air condition, computer and radar equipment) and performance checks of the electronic audio and communication equipment with respect to the audio transmission behavior. The spectral composition of the noise as well as the characteristics of the audio communication path between the controllers and the pilots (which showed a loss of spectral information in the audio band due to built-in notch filters for the suppression of control tones) required adaptations of the amplitude behavior of the amplifiers through user adjustable tone controls. The radar console fans, which contributed significantly to the overall noise floor of the room, underwent a substantial reconstruction by replacing the tight mounting with an elastic double suspension, reducing the noise level by 50%. Finally, a possible source of untimely fatigue of the controllers during their working hours has been found in strong spectral components of the noise above the audio band, radiated by numerous video monitors in the control room through vibrating components excited by the line frequency of the video signal.

1. INTRODUCTION

Speech intelligibility in air-traffic control rooms is of prime importance. In case of complaints by the controllers themselves or by the pilots concerning communication difficulties, both the acoustic properties of the control room and the communication channels are to be investigated.

2. ACOUSTIC PROBLEMS IN THE AIR-TRAFFIC CONTROL ROOM

Guidelines for the design of the control room are set by some basic prerequisites given by the equipment (consoles, computers, displays), by requests from the controller staff and, naturally, by the layout (dimensions) of the room itself.

The configuration of the equipment changes from one control room to another, depending on the priorities ranked by the management. In many cases, the computer equipment has to be placed in the control room right behind the controller. Electronic hardware still needs cooling, therefore quite a number of cooling fans will be operating in the room. There are low noise fans on the market, but the high demands concerning reliability often forbid the use of low power/low noise modules, which in most cases are directed to the consumer market (personal computer, hi-fi-equipment). Industrial fans provide sufficient cooling for the hardware (up to 200 cubic meters per hour), but contribute significantly to the noise floor of the room.

In our case, a short inspection of the internal hardware structure of the radar console unveiled a poor setup of the main fans. The fans were attached directly to an aluminum cooling device with fins, which in turn was fixed without any mechanical damping to the main frame of the computer. Therefore the vibrations were coupled to the front panel and the display and created a constant hum and noise right on the workplace of the controller. Initial measurements using a noise meter with A-law amplitude weighting revealed a noise level of 44 dB for a single console in a training room and 55 dB in the controller room with 13 out of about 25 consoles working.

For an overview of the spectral composition of the noise, an FFT-analyzer has been used for tests in front (fig.1) and on the back (fig.2) of the radar console.

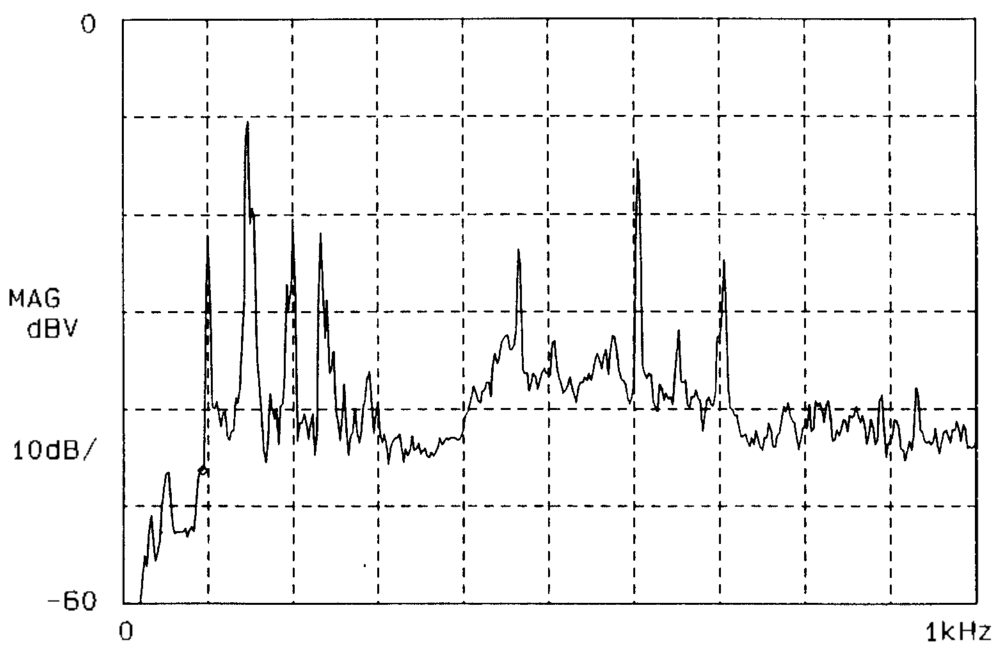

Fig.1: Spectral distribution of noise in front of radar console

In comparing the graphs that show the level of spectral components between 0 and 1 kHz, it can be seen that the basic component caused by the fan (230 Hz, as a result of the 2750 rpm and a 5-leaf configuration of the fan) an some harmonics can be found on both sides of the console. A 145 Hz line (fig.1) originated from the vibrating front panel excited by the fans through the frame of the radar computer.

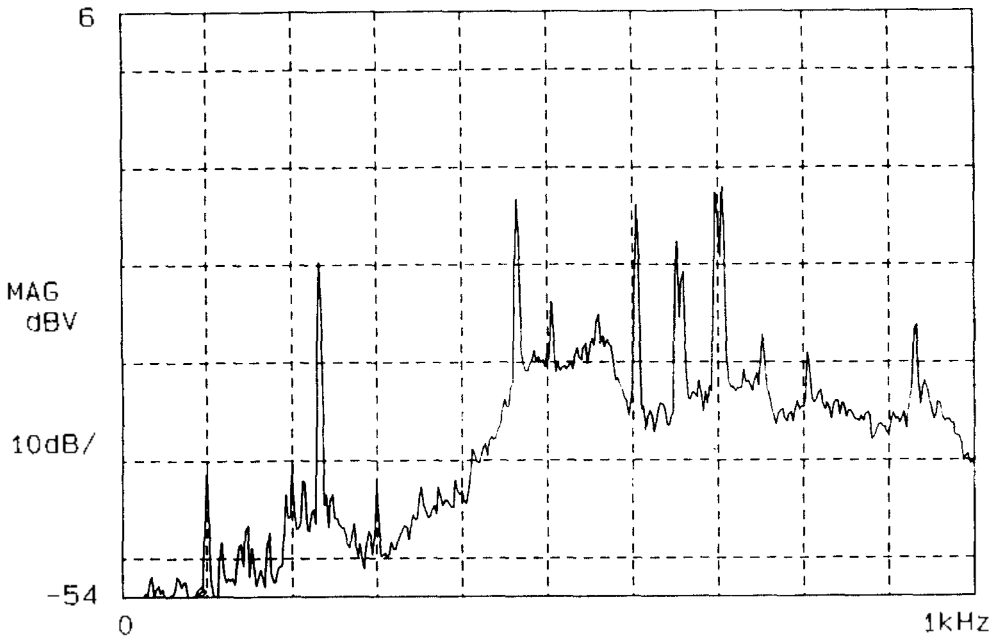

Fig.2: Spectral distribution in rear of radar console

Less important, but in no way to be neglected, were some other noise contributions by copy-, telex- and even coffee machines, by the air condition and simply by moving personnel.

By installing an elastic double suspension for the fans - about 100 of them were operating in times of busy air traffic - the basic (broadband) noise level has been cut back by 4-5 dB, which in turn lowers the noise-burden for the controller significantly by eliminating 60-70% of the original noise energy.

Fig.3 (note the different vertical scale when comparing with fig.1 and 2), showing the spectral distribution of the noise in front of a thus improved version of a radar console, demonstrates hum free operation (almost no vibrating front panel detectable at 145 Hz), which significant smaller 230 Hz and 460 Hz components.

Spectral components originated from the transformers that are part of the horizontal deflection circuits of the data monitors could be found and verified in the 17-25 kHz range, with top levels 35 dB above the noise floor (fig. 4).

Little can be found in literature about the fatigue caused by frequencies at the upper end or above the audio band when continuously present for extended periods of time. However, by replacing these older monitors by modern high resolution displays will shift these components well above the audio band, less stress on the controller can be expected.

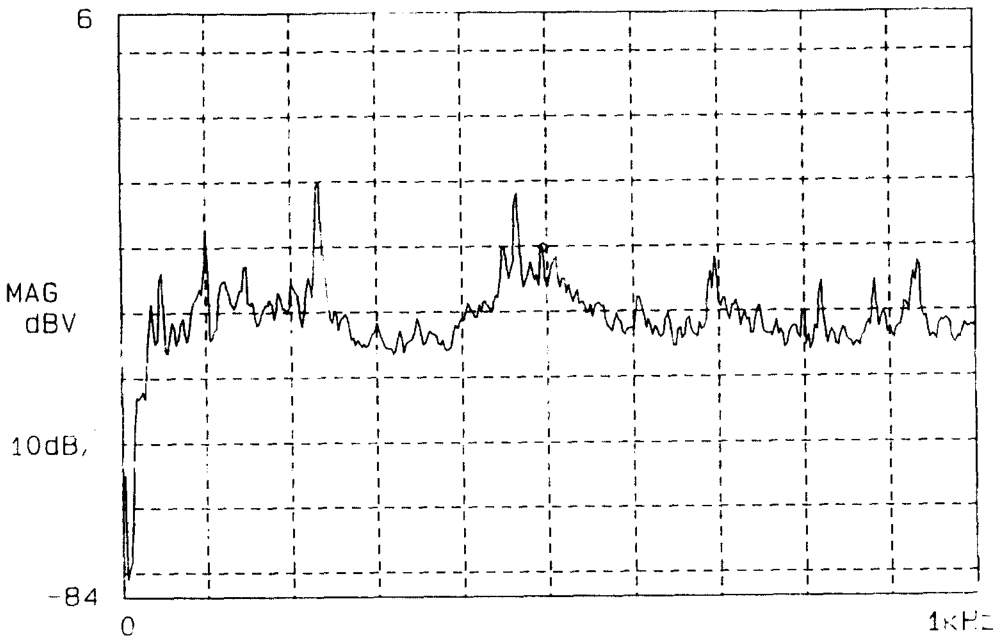

Fig.3: Improved noise behavior (spectral distribution) in front of radar console

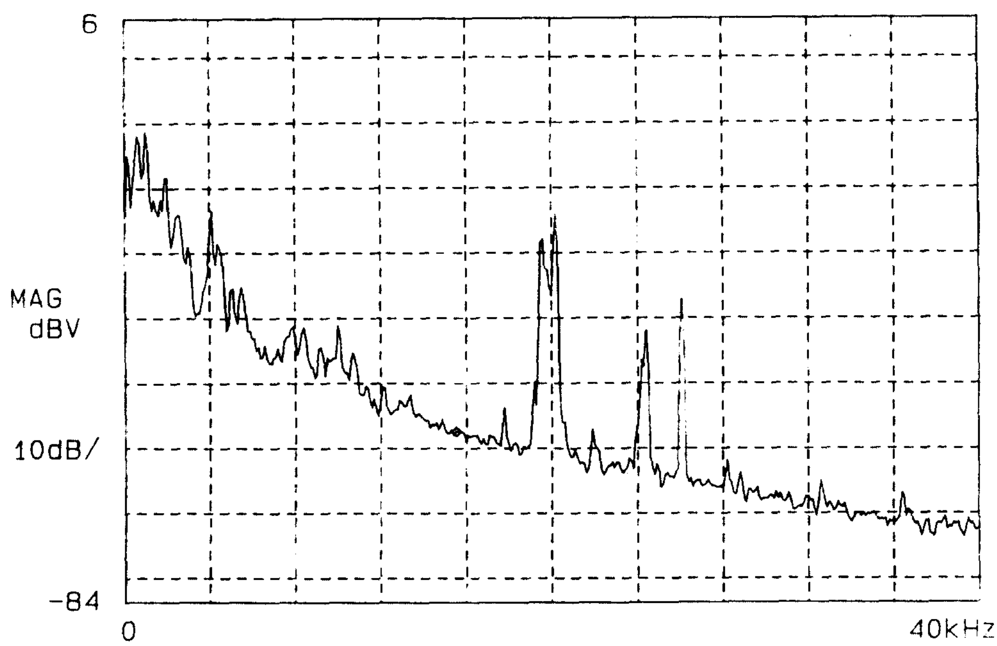

Fig.4: Spectral components of noise due to monitors

3. PROBLEMS ALONG THE COMMUNICATION CHANNEL

The audio frequency part of the communication path - restricted to the band between 300 Hz and 3.5 kHz - has been investigated (the RF section seemed to work without major problems). For RF channel switching purposes, a dual tone (1260 and 1380 Hz) control circuit had been implemented within the audio channel. To eliminate these two frequencies for the actual speech channel, a steep notch filter is a must (fig.5).

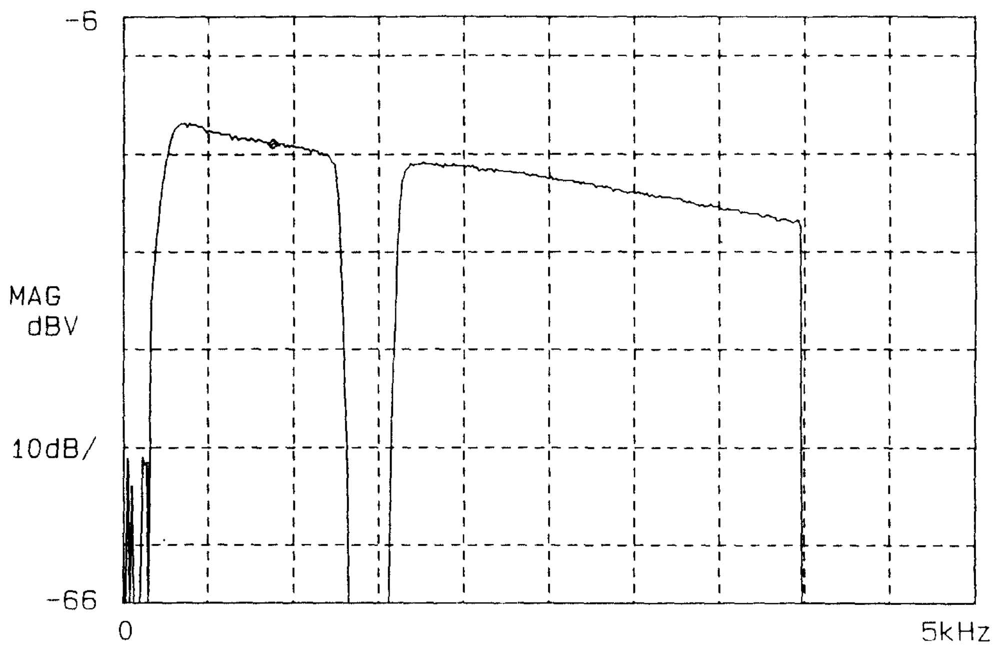

Fig.5: Notch for control tones within the audio speech band

Naturally, bandstop filters of high order usually deteriorate the phase behavior of the adjacent audio band. This deficiency is audible.

It has been suggested that - for future new designs - the section of the audio band containing the control tones should be shifted above or at least to the upper speech band limit to avoid a deterioration of the first, crucial harmonics of the (male) voice band.

In addition, the amplitude characteristic of the different speakers built into the consoles varied substantially. The subjective evaluation of the speech reproduction quality of the speakers by the controllers varied even more, depending on where the listening took place. For the control room it turned out to be very effective to provide the controller with an tone control device consisting of a filter that enables both enhancing or weakening of the middle area of the voice band, with adjustability of both the center frequency (between 1 and 3 kHz) and the level (+/-12 dB). In most cases, the controllers preferably emphasized the amplitude behavior around 2 kHz with as much as 6-8 dB.

This only applied to the control room, with a substantial - though improved - noise background.

No filter was required for the supervision room where the speech communication was recorded and played back occasionally.

The controllers generally pointed out that the speech reproduction from the tape, containing the same voice material as perceived from the speakers in the control room, seemed to be better understandable and with a less aggressive frequency composition. In fact, applying the tone controls mentioned earlier and set to 2 kHz and +6 dB, less acceptance could be accomplished, and the sound reproduction was described as being "too sharp".

Fig.6 gives an idea of the spectral components of both the original ("Live") speech signal in the control room and two recorded versions of the same content by showing a 3-dimensional view of the relation between frequency, time and amplitude.

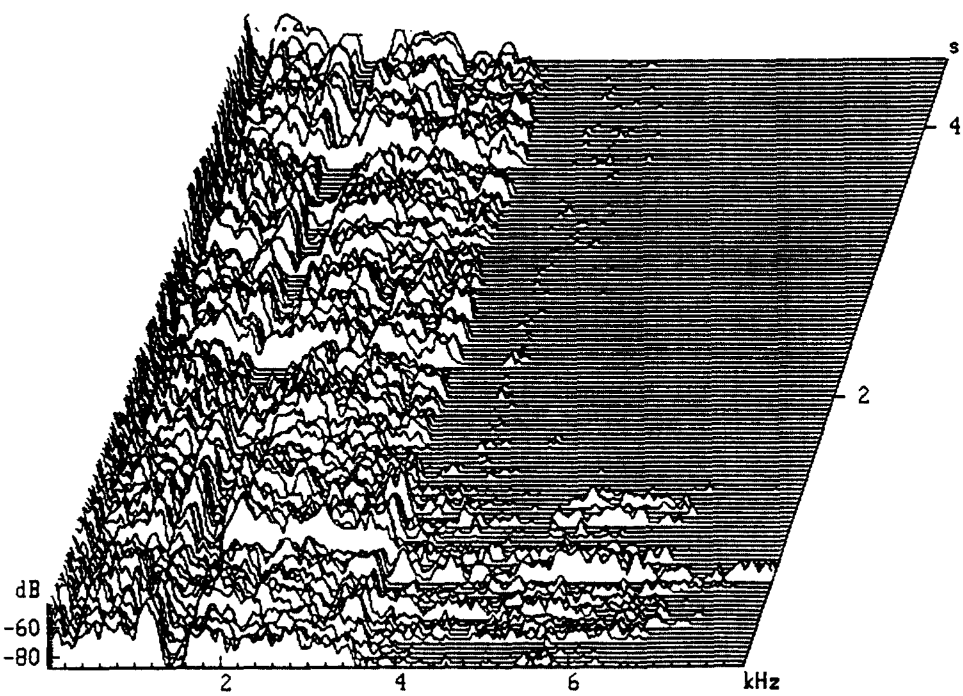

Fig.6: Spectral components of "live" and recorded speech signal

The horizontal axes represent the frequency range and the recording time, respectively. The speech sequence had a duration of 1.5 seconds and consisted only of the word "Cyprus". It can be seen that the first "live" signal from time 0 to time 1.5 contained quite a lot spectral components above the speech band, whereas the recorded versions from time 1.5 to time 4.5 are restricted to the actual voice band.

A different approach in demonstrating noise components is given in fig.7.

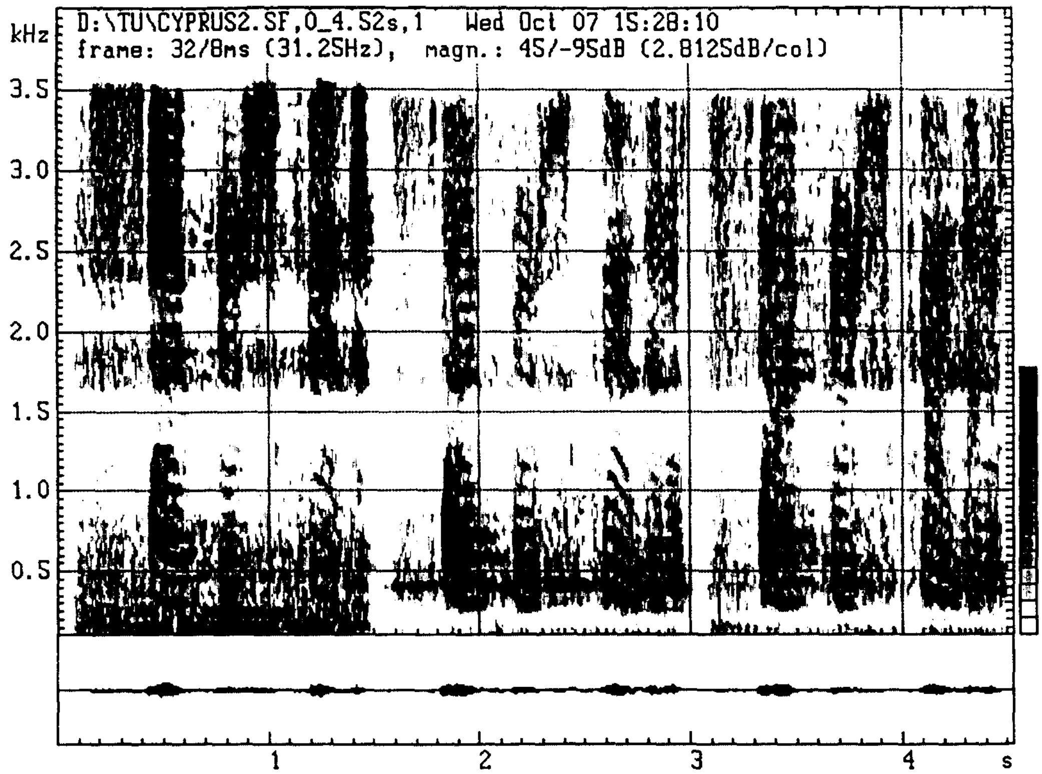

Fig.7: Spectral distribution of "live" and recorded speech signal

Here, darker portions mean higher spectral intensity. The horizontal axis represents the time, the vertical axis the frequency, this time extending only to the speech band edge of 3.5 kHz. Low components, e.g. from the fans, can be seen in the "live" section below 300 Hz and within the time slot of 0 to 1.5 seconds, Naturally, no components are recorded in the supervision room where the speech signal is directly transferred to tape. The influence of the mid-band filter applied to the control room equipment causes the slightly darker section between 0 and 1.5 seconds and above 1.5 kHz. The suppressing behavior of the notch filter for the control tones is easily detectable around 1.4 kHz (unfortunately, the graph is erroneously shifted a little to higher frequencies, the notch should be close to 1300 Hz).

4. SUMMARY

Poor speech intelligibility in an air-traffic control room is frequently a consequence of various different problems of mechanical, acoustical or electronic origin. The solution usually is a combination of minor improvements, with tasks covering the complete signal path and considering every piece of equipment involved as a possible source of noise.