# V.21 FSK Modulator

Introduction

In this lab you will modify the program you wrote to generate RS-232 serial data waveforms so that instead of a bipolar NRZ waveform it generates a 300 bps FSK waveform that complies with the ITU-T V.21 standard.

To test your program you will output the generated FSK waveform to a telephone-line modem that is hooked up to the PC via a serial port. The modem will demodulate the FSK signal and, if you did everything right, display your name on a terminal emulator running on the PC.
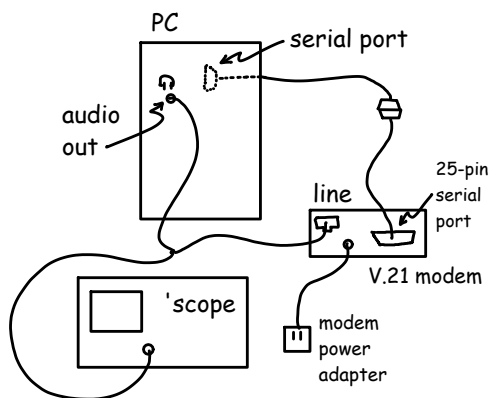
V.21

A copy of the V.21 standard is available on the course web site or from http://www.itu.int/rec/T-REC-V/en/.

Signal Levels

The V.21 modem specification allows a maximum output of 0 dBm and says that typical connections have attenuations of from 5 to 30 dB. You should set the level at the modem input to -6 dBm.

Frequencies

V.21 uses a different pair of frequencies in each direction. Use the frequencies for the station originating (placing) the call: 980 Hz for a mark ('1') and 1180 Hz for a space ('0').

Software Changes

Modify the C program you wrote for the RS-232 lab or modify the code in lab8incomplete.c on the course web site so that:

- it computes and outputs 8-bit signed samples of a modulated V.21 FSK signal instead of 8-bit signed samples of an RS-232 waveform.

- the data rate is 300 bps and the sample rate 9600 Hz

- your waveform begins with one second (300 bits) of mark ('1') to allow the modem to detect the carrier

Note that your FSK modulator only varies the signal (carrier) frequency so that the frequency follows what would have been the voltage on the RS-232 line. All other aspects of the character format such as the use of start and stop bits, bit order and bit duration are unchanged.

The diagram below shows the *frequency* (not voltage) as a function of time. There should be one second of 980 Hz tone followed by 3.3 ms of 1180 Hz tone for the start bit, then 3.3 ms of either 980 Hz or 1180 Hz tone for the LS data bit, etc:
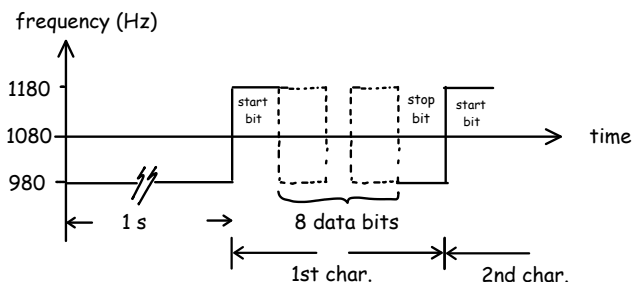
There are various algorithms you can use to compute the sample values for an FSK waveform.

However, your algorithm should generate a signal that does not have phase discontinuities between bits (it is "phase continuous"). The diagram below shows an example where the phase is continuous between a bit at a low frequency and one at a higher frequency as well as an example where there is a phase discontinuity:

phase discontinuity

correct   wrong
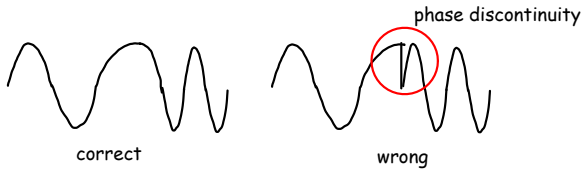
Here is the pseudo-code for one method that produces a phase-continous FSK signal:

1. initialize a 'phase' variable to zero

2. for every sample output to the file:

   (a) increment the phase by the phase increase per sample corresponding to the carrier frequency (mark or space) being generated.

   (b) compute the cosine of the phase and scale it to the range ±127

   (c) write this sample value to the output file

You will have to write multiple samples for each bit.

The hardware implementation of this algorithm is known as a Numerically Controlled Oscillator (NCO) because it computes the waveform of an oscillator numerically instead of using an analog oscillator circuit.

You will have to determine the appropriate phase increment per sample[1]. You will have to increment the phase by one of two different values depending on whether the mark or space frequency is being generated. This in turn depends on whether you are outputting a 0 or 1.

You can use a `float` value to keep track of the phase and use the function `cos()` to compute the cosine of the phase. `#include` the file `math.h` to include the function prototype for `cos()`. You will have

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[1] Hint: Frequency is defined as phase difference per time increment. The time increment in this case is the time between samples.

to convert the value from `float` to `signed char` before writing it to the file. The phase variable's value needs to be retained across calls to `writebit()` so the phase variable must either be declared *static* or outside of a function.

The output file should be opened in binary mode. Otherwise a carriage return character (0x0d) will be inserted after every linefeed character (0x0a). Use the following syntax for the `open`:
`f = fopen ( "waveform.txt","wb" ) ;`

An incomplete version of the code is available in the file `lab8incomplete.c` on the course web site. You can use this as a reference when writing your own code but you don't have to.

Try to avoid repeating code. Move replicated code to a function and call it as necessary.

Procedure

Compile and run your program to generate the `waveform.txt` file containing the FSK signal using the same software (Notepad++ and tcc) and instructions as in the RS-232 lab.

Plug the audio cable into the audio output port on the front of the PC. Connect the scope probe ground clip to the yellow lead and the probe to the violet lead. Enable voltage and frequency measurements.

Load the waveform into Audacity as in the previous lab and start continuous playback. Look at the waveform on the scope and adjust Audacity's volume control (beside the speaker icon) for a signal level of about -6 dBm.

Connect the PC's audio output to the modem's *line* (not phone) port. You will be supplied a cable that has an RJ-11 jack on one side and bare wires on the other. Polarity does not matter. You can use the scope probe's clips to hold the wires together.

Connect the 9-pin RS-232 cable from the back of the PC to the 9-to-25 pin cable on the bench. Connect the 25-pin end of that cable to the RS-232 port on the modem.

Connect the modem's power adapter to the modem and 120VAC power.

Run Teraterm as in the previous lab except that the baud rate must be set to 300 bps.

Type the following commands in the Teraterm window. These commands will be sent to the modem

and configure it for V.21 modulation and then have it "pick up" the phone line and begin receiving data:

- type ATZ (followed by Enter) to reset the modem. If the modem receives the command it will respond with "OK".

- type AT&FLNB15 to: set the factory default settings (F), reduce the modem's speaker level (L), disable speed negotiation (N), and enable V.21 modulation (B15),

- type ATA to have the modem go "off-hook" and connect to the phone line input

After a few seconds the modem should detect carrier, print CONNECT and start demodulating the FSK-modulated data and sending the data to the PC over the RS-232 serial interface. You should see your name displayed on the terminal. Take screen captures of the Teraterm output and the 'scope screen (including voltage and frequency measurements) for your report.

A known-good test waveform is available in the file lab8testwaveform.txt on the course web site. If you have a problem you can use this waveform to determine if the problem is with your waveform or somewhere else (Audacity or Teraterm settings, signal levels, ...).

You can check the frequency and voltages of your waveforms using the scope. You can capture a complete waveform (a total of about 2 seconds, depending on the length of your string) and then use the horizontal time and position controls to "zoom in" on different portions of the waveform. You can use the cursor and measurement functions to check that the various waveform parameters are correct.

Pre-Lab

Hand in the answers to the following questions and a printout of your code before the start of the lab:

(1) What is the power of a sine wave of amplitude A? What amplitude corresponds to a power of -6 dBm if the modem's input impedance is 600 ohms?

(2) What phase increments per sample will result in the V.21 originate mark and space frequencies for a sample rate of 9600 Hz?

(3) How many samples per bit are required for a 300 bps waveform sampled at 9600 Hz?

(4) What will happen if Teraterm is configured to read more data bits than are generated by your software? Fewer?

Modify your RS-232 code (or modify the supplied incomplete code) as described above so that it generates the samples of an FSK signal with the appropriate frequencies and baud rate.

You should try to have a working program before the lab because you will probably not have enough time to figure out how to modify the code *and* complete the procedure given above during the lab period.

Lab Report

Submit a report in PDF format to the appropriate dropbox on the course web site. The report should include the usual identification information (name, ID, section, lab, title, date), a copy of your code including any additional changes you made in the lab, a screen capture showing the Teraterm window with your name displayed and a screen capture of the 'scope showing voltage and a frequency measurements on the screen.