Data Transmission Through a Long Single Wire Phone Line
Brian Pease

Abstract

Bill Stone uses Single Wire Telephones (SWT) to coordinate between Base Camp and deep underground camps during his Mexican Sistema Cheve Expeditions. Each cave camp has one or more Android tablets used for surveying and sketching with TopoDroid software. On the last Expedition a successful experiment was run to send messages and survey data from Camp 1 to Basecamp using direct TTL baseband signaling with UARTs. Bill asked me for ways to improve the system to serve remote camps as far as 15km away.

I Created an approximate model of the single wire and the (poor) grounds used in the cave. The model will pass 300 baud data from 15km, likely less in the real world. Poor series connections, poor grounding, and especially leakage to ground from bare spots may pull the 5V TTL signal below the 1.4V switching threshold. I looked into boosting the signal to ~12V with automatic transmit/receive switching. I finally put this aside.

Next I looked at creating my own modem using Exar FSK transmit and receive ICs, which use sine waves on 2 audio frequencies and can be driven directly from the existing UARTs. This approach is fairly complex with initial analog adjustments and the need for an L-C bandpass filter to improve noise immunity. I was not satisfied with the performance.

I then looked into using “sound card” modem software with the Android tablets, using the 4-wire mic/headphone jacks to input & output audio tones. Only one software package is available, called **andFLmsg** which has a variety of robust audio data modems, and special features for transferring error-free messages. I designed and built a pair of passive prototype interfaces to connect the tablets (or a smartphone) to the single-wire line with automatic T/R switching, adjustable receive gain, and direct audio monitoring. These simple interfaces appear to work well with the tablets, applying > 16V p-p on the line, with reception down to a few millivolts even in the presence of atmospheric noise of greater magnitude.

I then built 10 data interfaces for Bill.

History

During Bill Stone's last Expedition, Kristen Anderson used USB/UART adapters (with FT232R ICs from ftdichip.com) with the same android tablets used with the TopoDroid cave surveying program to successfully send data from Camp 1 in Sistema Cheve, Mexico 1.2km into the cave from the entrance, to Base Camp on the surface1.2km from the entrance, using the single-wire line used for their Single-Wire/earth return voice Telephones (SWT). 5V TTL data was transmitted, with about 4V reaching the Base Camp receiver, which had the standard 1.4V TTL switchpoint. She used software called **FTDI UART Terminal,** available on Google Play. Kristen tested up to 9600 baud, which is quite fast. Due to coordination issues, it was not possible to test from Camp 2 (~2.3km further in from Camp 1) to Base Camp. I was told that there was no local man-made noise whatsoever, but probable atmospheric noise and possibly electrical noise from water where the wire hangs in waterfalls.

USB to TTL UART with FT232R and 5V signal option, powered by USB port with OTG adapter
Fig 1

Improving data communications

Bill Stone, the expedition leader, asked me if this simple system could be improved to allow data transmission over much longer distances, such as the additional 2.3km to Camp 2, 3km more between camps 2 & 3, or even as far as15km.

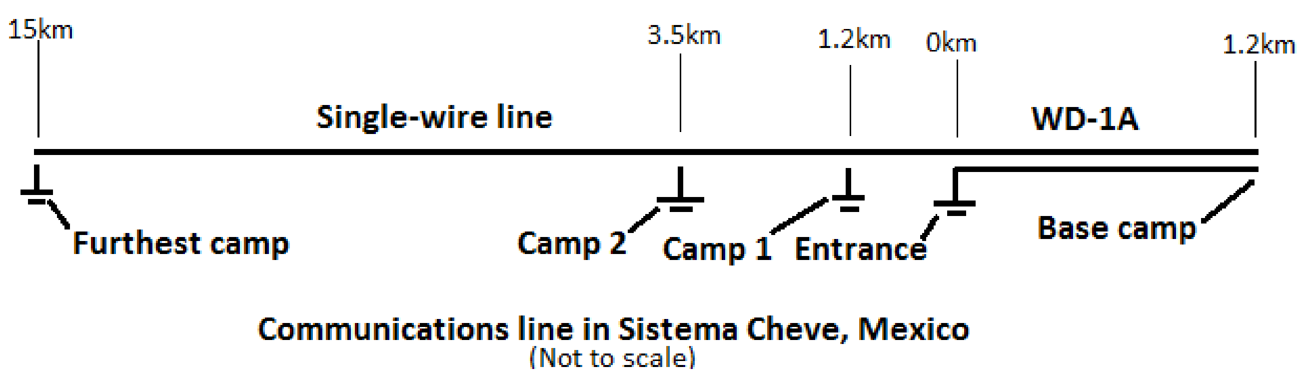


Fig 2

I asked about the wire transmission line, then about grounding. The wire in the cave consists mostly of 22 gauge single conductor copper or two conductor aluminum or copper/steel field phone wire with the 2 conductors in parallel. Much of the distance has 2 wires in parallel, connected together at each joint. Two conductor ~#22 copper/steel parallel-wire field phone wire is used from the entrance about 1.2 km to base camp, with one conductor grounded to a rigging bolt at the entrance. The ground at Camp 1 is a rigging bolt plus bare wire buried in dirt. Camp 2 has a better ground with a bare wire in a nearby water source.

Modeling the 3km Line

My first comment was about the grounding, which may be (barely) adequate for the voice phones but not for reliable data transfer. Using Dave Gibson's equation for the resistance between 2 ground rods, I found that the resistance to ground of a single rigging bolt 4” long by 3/8” diameter in typical limestone of conductivity = .005 S/m was 1190 Ohms, and likely much higher in the real world. Clearly the bolts are not good grounds! A large electrode surface area is what is needed. Gibson's simple equation for the resistance between two hemispheres buried flat side up flush with the ground (or water) surface at any large spacing is R = 1/(pi x conductivity x radius) where R is Ohms, cond is in Siemens/meter and radius is in meters. A single hemisphere 0.4mtrs in diameter would have R=100 Ohms to ground. A thin sheet of stainless foil or sheet 0.4m square should be similar, especially when buried or submerged in water because both sides are exposed. I recommended using large SS sheets in pools of water, or buried in moist dirt as a second choice, for all grounds. 50 Ohms would be even better.

My next step was to create a simple model to roughly approximate the transmission line characteristics of in-cave wire. I made several somewhat arbitrary assumptions, using a dartboard:

- That the average distance of wire from the cave wall is 1 meter (closer won't work in NEC4.2)
- That the average wire diameter is 2mm (total of 2 wires in most places).
- That the line resistance is 24.2 Ohms/km, equivalent to two #22 copper wires in parallel.
- That I have good grounds of ~8 Ohms at the entrance & cave camps (so could ignore them while creating the model!).
- That the conductivity of the limestone is typical, .005 S/m.

I then modeled a 100m length of this line in the NEC 4.2 Method of Moments antenna program at 1kHz and determined the impedance of the line with an open and short circuit on the far end. The characteristic impedance was 1269 + j1399 Ohms (Z_0=1888 Ohms). Z_0 decreases with frequency at audio frequency, Z_0=sqrt(R/2*pi*f*C). The NEC 4.2 program input for the short circuit case (in state of the art 1960s punch card format!) for this line is below. CM=comment, GW=straight wire.

```
CM Simulation of 100m single wire line 1m above ground
CM from x = -100m to origin.
CM Assume 2mm dia wire, 24.2 Ohms/km DC resistance.
GW 1,100,-100,0,1.5,0,0,1.5,.001 ! 100m wire along neg X axis.
GW 2,1,-100,0,1.5,-100,0,0,.001 ! 2mm dia wire to gnd surface at -100m.
GW 3,5,-100,0,0,-100,0,-50,.001 ! 2mm dia gnd stake 50m long at -100m (~8 Ohms).
GW 4,1,0,0,1.5,0,0,0,.001 ! 2mm dia wire to gnd surface at origin
GW 5,5,0,0,0,0,0,-50,.001 ! 2mm dia gnd stake 50m long at origin
GE -1,0 ! Gnd plane present.  Wires can extend below the surface.
LD 0,1,0,0,0.0242,0,0 ! The wire is 24.2 Ohms/km DC, .024 Ohms/mtr,half of #22.
EX 0,1,2,1,10.0,0 ! 10 Volts peak at 2nd segment of 100m wire
FR 0,1,0,0,.001,0 ! 1 kHz test frequency.
GN 3,0,0,0,13,.005 ! Standard Earth conductivity and permittivity
XQ ! Execute code
EN ! Stop
```

I obtained open and short circuit impedances at 1kHz, then created the simple model for 100m of wire at audio frequencies shown below.

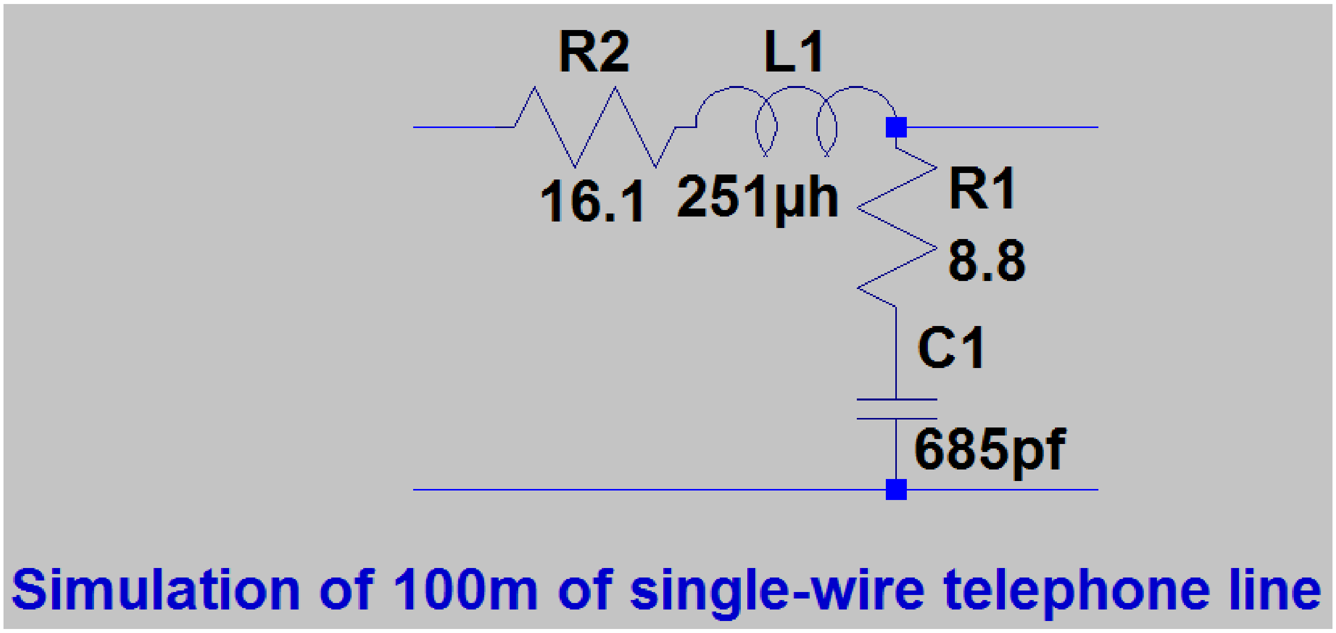


Fig 3

Also using 1kHz data, I also created a model of the WD-1A 2-wire “zip cord” style field phone wire. The characteristic impedance is Z_0=736 Ohms at 1 kHz, lower than the single wire line.

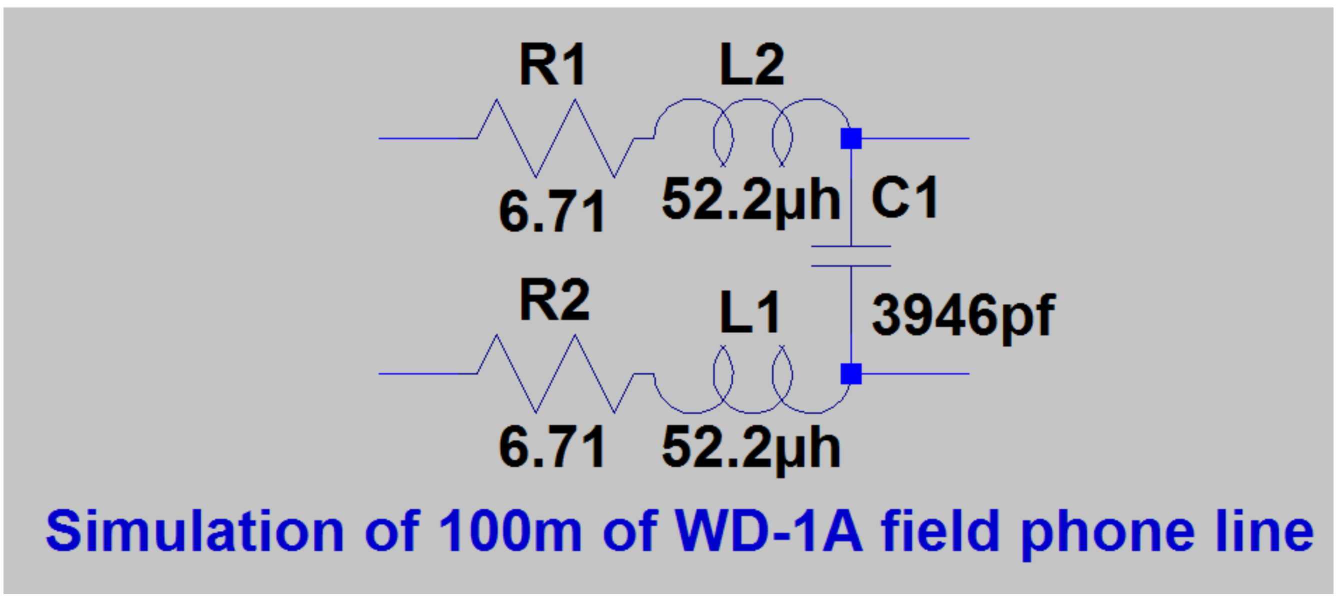


Fig 4

I used these models to create a model of 15km of single-wire line plus 1.2km of field phone line for the run to base camp in the LT Spice electronics simulation program by simply chaining 100m models in series. Modeling a transmission line this way for audio frequencies may seem like overkill, but the run time of each simulation was only a few seconds, so why not? I changed the grounds to 1000 Ohms to be closer to what was really in the cave. In the real world the line beyond each camp would not be disconnected while sending data to base camp, thus each camp must drive the entire line.

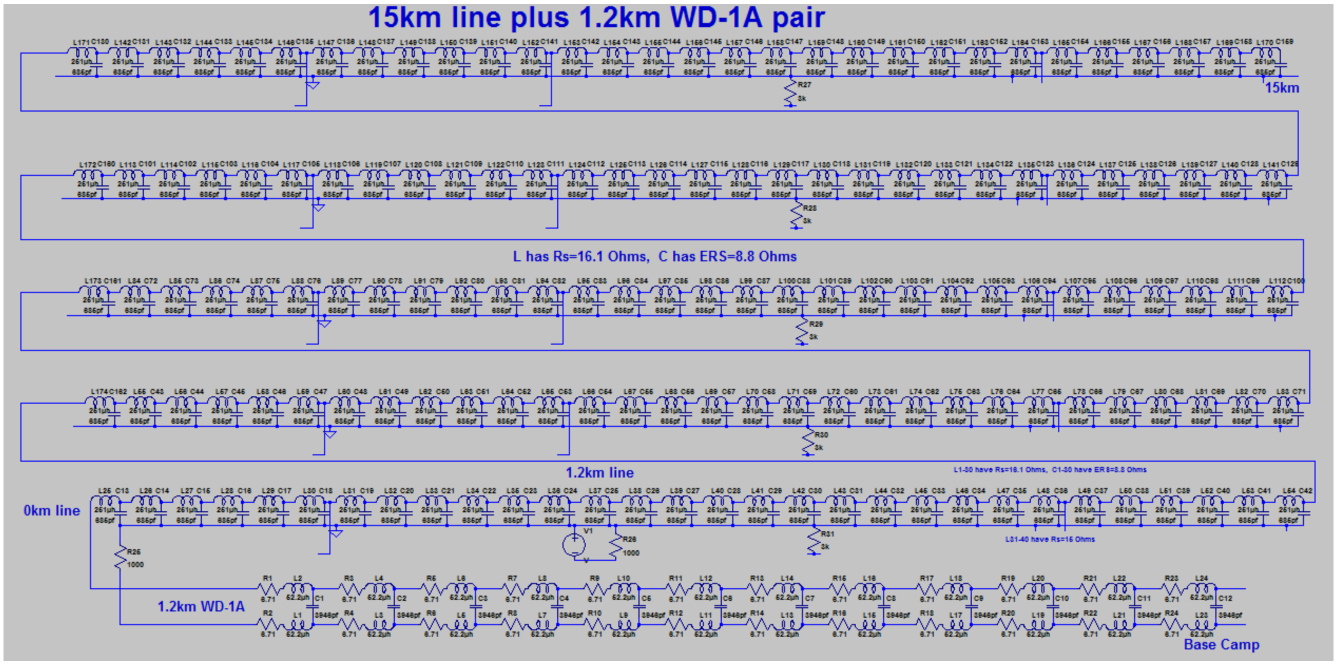
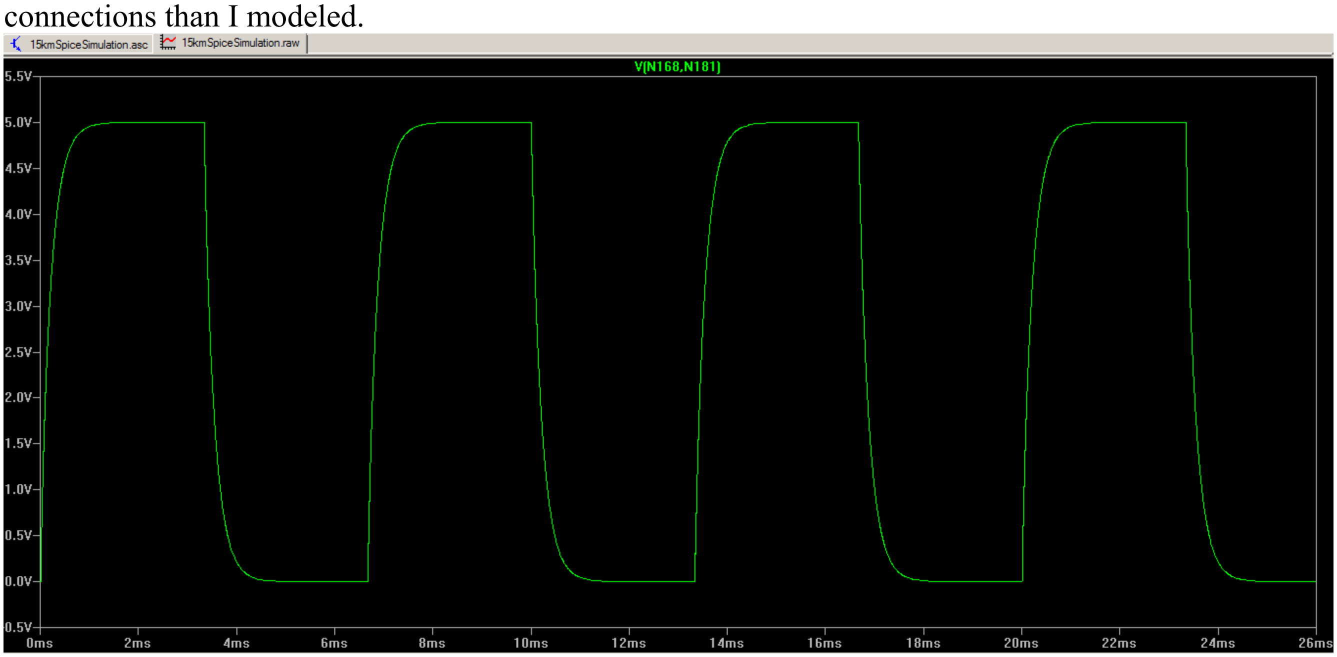


Fig 5

Time Domain Simulation

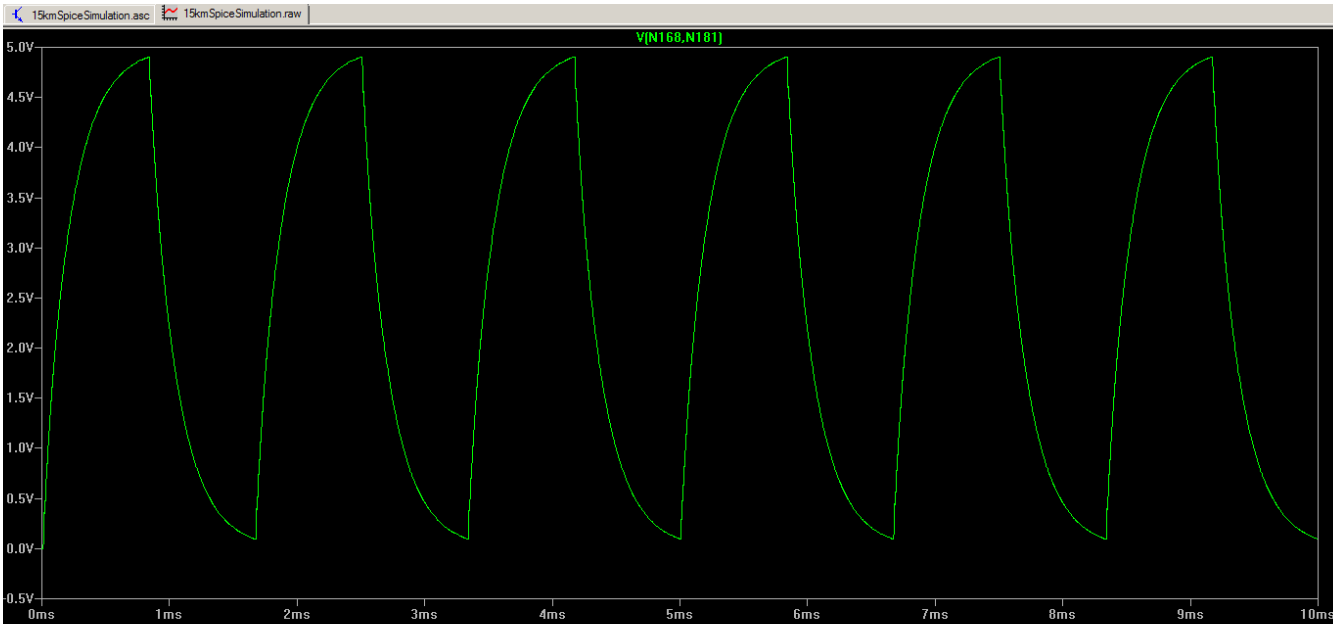
This is the (ugly) point where digital meets analog! I simulated driving the entire 15km line (in both directions!) from Camp 2 with a 300 TTL baud signal using a 5 Volt 150Hz square wave with 10ns rise and fall times. I assumed that the receiver at base camp did not load the line and that the line had no extra series or shunt resistance. Kristen observed a 4V p-p output from Camp 1. She must have had serious actual loss to ground somewhere along the line, a bad connection, or even poorer ground connections than I modeled.



Camp 2 to base camp at 300 baud on a perfect line

Fig 6

Next, I repeated the simulation with five 5000 Ohm leakage loads scattered along the 15km line to simulate bare spots. The actual line is likely worse than this. The TTL signal dropped to 2.9V p-p but would certainly still decode. I then tried the next higher available speed, 1200 baud, with no leakage loads.



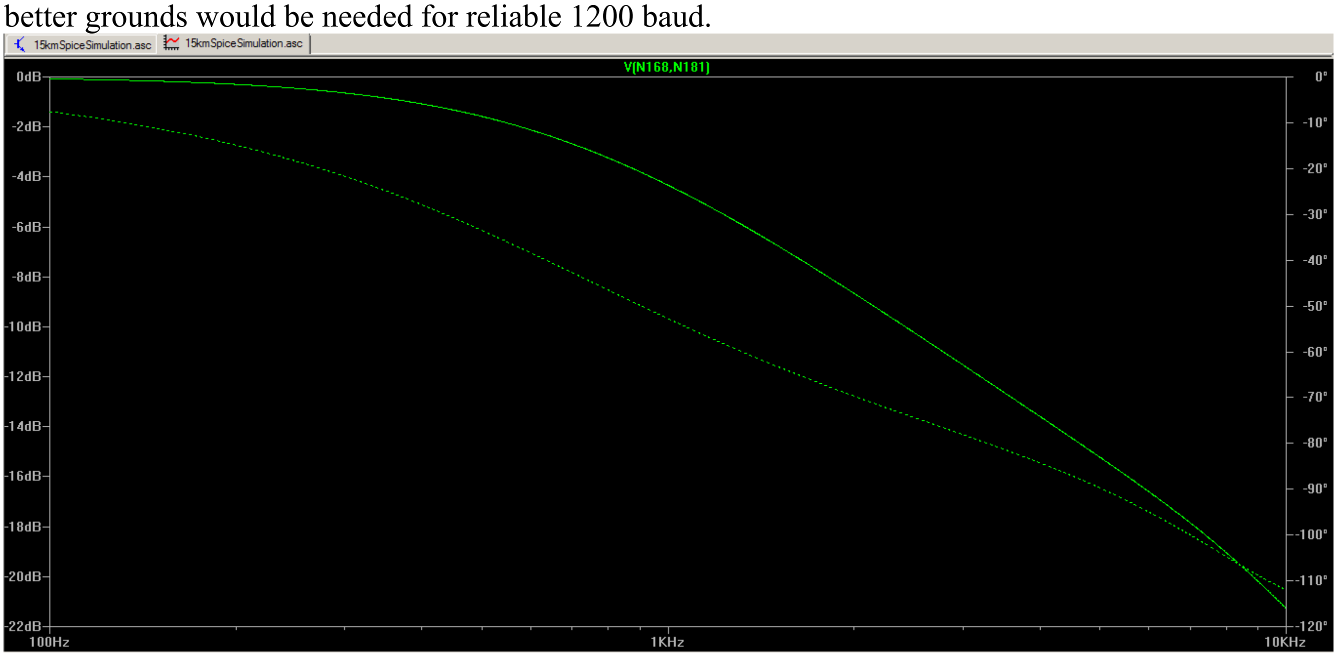
Camp 2 to base camp at 1200 baud on a perfect line with 1000 Ohm grounds

Fig 7

The rise and fall times appear to be too slow for 1200 baud TTL to decode reliably. Much of the problem lies in the large shunt capacitance of the 15km line in parallel with the line to base camp. The 1000 Ohm grounds are also partly to blame.

Frequency Domain Simulation

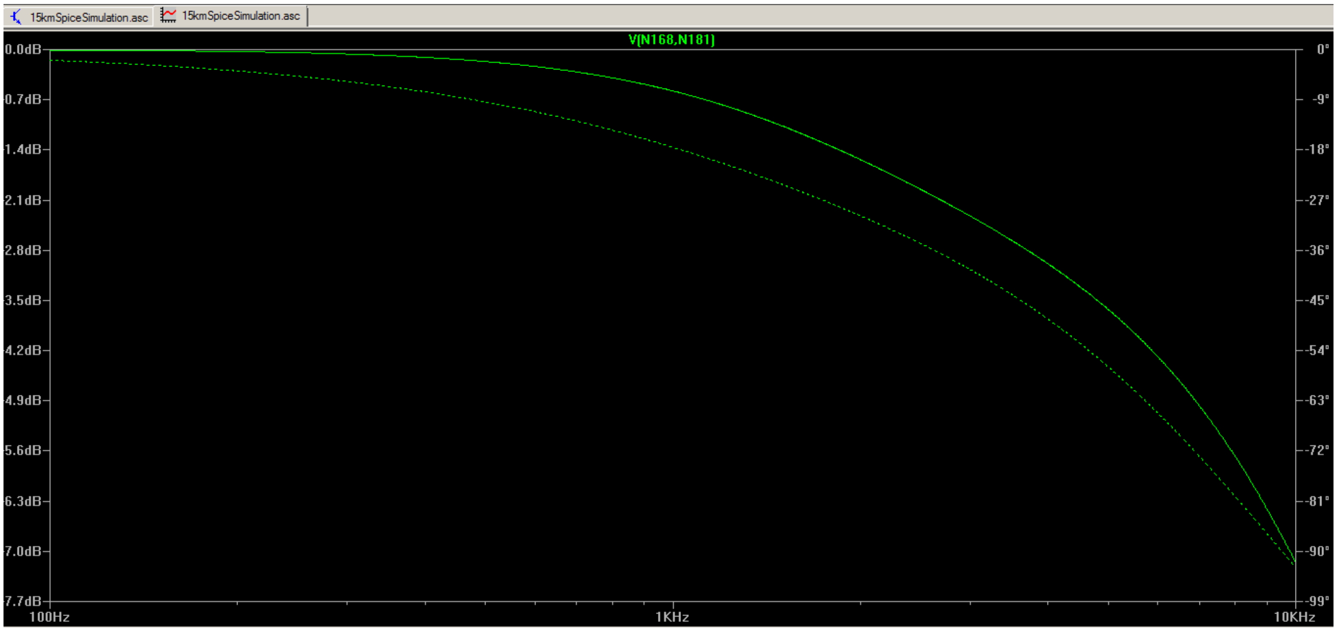
The frequency response of the line from Camp 2 to base camp is shown below. The -3dB point is 755Hz, which Nyquist says should pass 1510 bits/sec (baud here) in a perfect world, but clearly better grounds would be needed for reliable 1200 baud.



Frequency response from Camp2 to base camp with 15km conncted and 1000 Ohm grounds

Fig 8

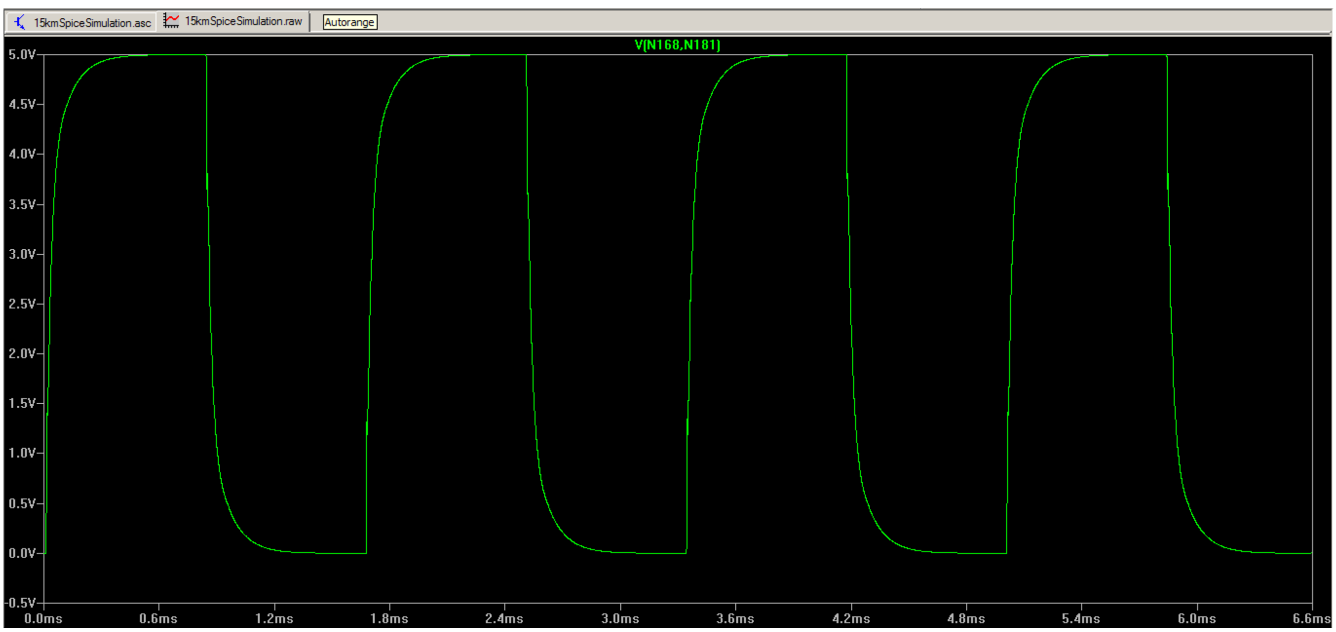
I then changed the 2 grounds to 200 Ohms each. The improvement in frequency response was dramatic, with -3dB now at 4000Hz! Clearly this is a major reason to improve the grounding at each camp, which should also improve SWT voice quality by boosting the higher voice frequencies.



Frequency response from Camp2 to base camp with 15km conncted and 200 Ohm grounds

Fig 9

I then tried 1200 baud once more but with the 200 Ohm Grounds



Camp 2 to base camp at 1200 baud on a perfect line with 200 Ohm grounds

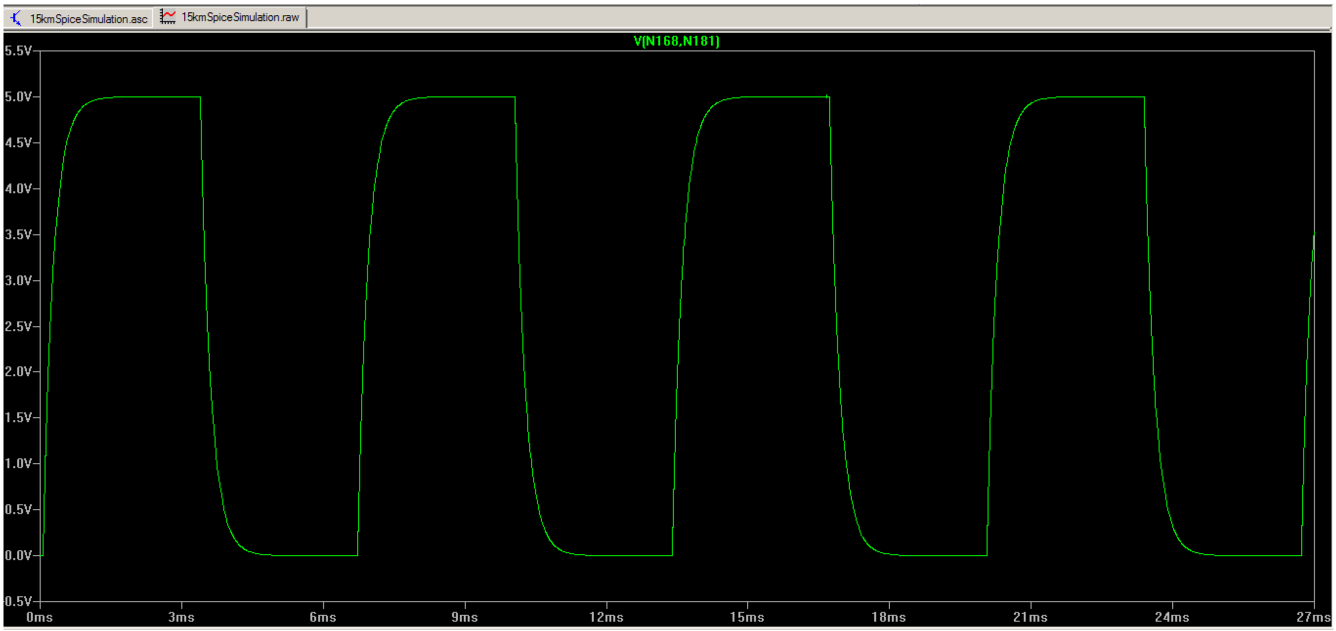
Fig 10

The improved grounding now allows 1200 baud TTL from camp 2, on a perfect line.

Modeling the 15km Line

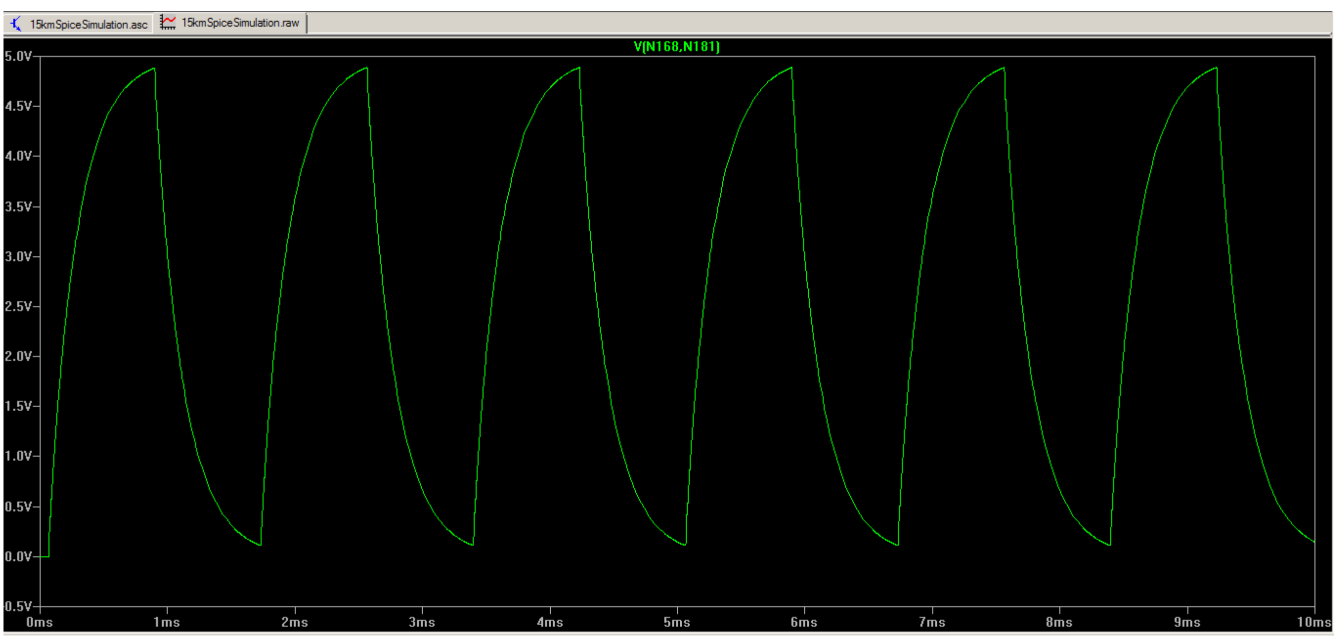
The goal is to transfer digital data to and from much more distant camps, so I next simulated driving the15km of single wire plus the 1.2km of 2-cond wire on the surface from the 15km end. Here I assumed that the grounds have been improved to 200 Ohms each.

Time Domain Simulation



15km to base camp at 300 baud on a perfect line with 200 Ohm grounds
Fig 11

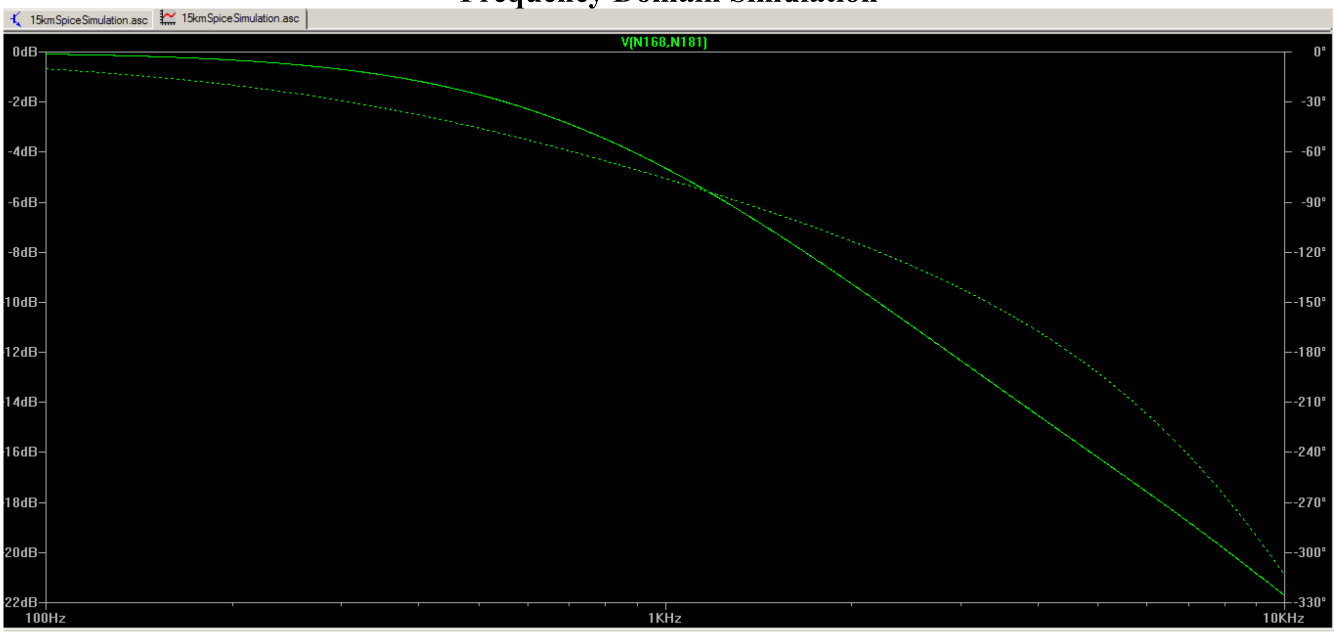
Clearly 300 baud TTL will work on the 15km simulated perfect line with good 200 Ohm grounds. I also confirmed that 300 baud would work with 1000 Ohm grounds Next I tried 1200 baud on the same line.



15km to base camp at 1200 baud on a perfect line with 200 Ohm grounds
Fig 12

1200 baud TTL from 15km would be marginal at best.The rise time is too slow to work at 4800 baud, the next faster baud rate. The likely reality is that there is considerable line shunt loss, poorer frequency response, and greater line series resistance, which would upset the timing and probably reduce the signal amplitude below the 1.4V switching threshold.

Frequency Domain Simulation



15km to base camp Frequency Response on a perfect line with 200 Ohm grounds
Fig 13

The frequency response of the full 15km line is -3dB at 712Hz which gives a Nyquist rate of 1424 bits/sec (baud here) maximum in an ideal world. This hurts voice also. The -3dB response with extremely good 50 Ohm grounds only improves to 820Hz, showing that 200 Ohms must be close to the improvement limit.

Thse tests were done with a high impedance base camp receiver. Frequency response improves with a load placed across the line at base camp, at the expense of reduced signal strength. A 1000 Ohm load puts the -3dB point at 2750Hz, but with a -11.1dB loss of low frequency signal strength. I also tried using five 5000 Ohm leakage loads spread evenly along the 15km line, with no load at base camp. This extended the -3dB point to 1600Hz, with a -8.3dB loss in signal strength. In reality, the bare spots in the cable will likely improve the frequency response enough without additional loads. The signal loss can be handled by designing data and voice equipment with extra gain margin, which I did.

Interesting Lessons From Telegraphy

I looked into early (mid 1800s) long distance telegraphy, which transitioned to a single wire with Earth return very early. They used large metal sheets buried vertically for grounding. Some used multi-cell Earth Batteries which used pairs of electrode materials such as zinc and copper, which would produce about 1 Volt/cell. They also were aware of **Telluric** (from Latin for *Earth*) DC currents in the Earth, the primary source being changes in the Earth's outer magentic field that is altered during daylight hours by the solar wind. It is maximum mid-day. In The US and Mexico the flow is North-

South, with positive polarity to the North. The magnitude is typically a few mV/km but can be much higher during solar storms. Some telegraph stations apparently used the diurnal Telluric current to augment their batteries! This required a very long wire. There are at least 10 other sources of DC and very low frequency AC ground currents, including lightning and ground water movement.

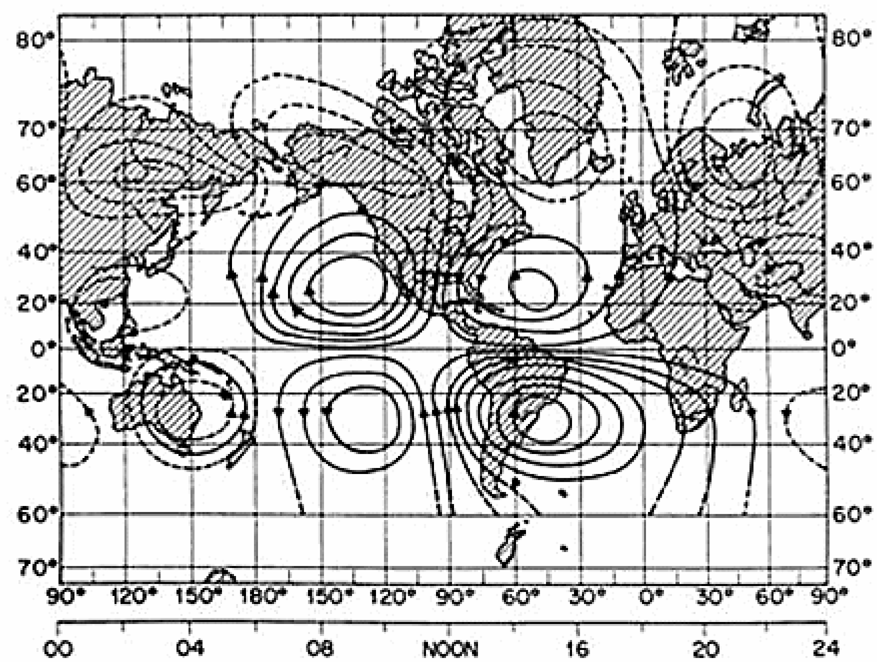


FIGURE 16.1 Planetary-scale distribution of telluric currents according to Gish (1936a, 1936b) at 1800 GMT.

Fig 14

I learned 2 things from telegraphy that apply to our single wire system. First, use the same type of metal for all grounds to reduce the "Earth Battery" effect, which will cause a DC voltage offset that will affect (even prevent) switching in a baseband TTL system and also cause corrosion. Stainless steel sheet is probably the best choice. Second, the Telluric current effect could be significant with very long lines with equipment grounded at each end, where several hundred millivolts DC offset could stop a baseband TTL link from working.

I spent considerable time trying to design on an interface circuit that would do automatic Transmit/Receive (T/R) switching, allow manual control of DC offset to counter the Earth battery and Telluric effects, and provide a larger signal (~12V) for long lines, without needing extra batteries. I have not yet breadboarded the circuit and turned to other approaches.

The Audio Tone Modem Approach

At this point, I thought that a modem approach with AC signals might be better, especially for longer lines, where ones and zeros are represented by audio tones. I thought of the vintage Exar FM modulator and demodulator chips, the XR-2206 FSK modulator and XR-2211 FSK demodulator. The USB UART used for the baseband link could directly feed the modulator and accept the output of the demodulator.

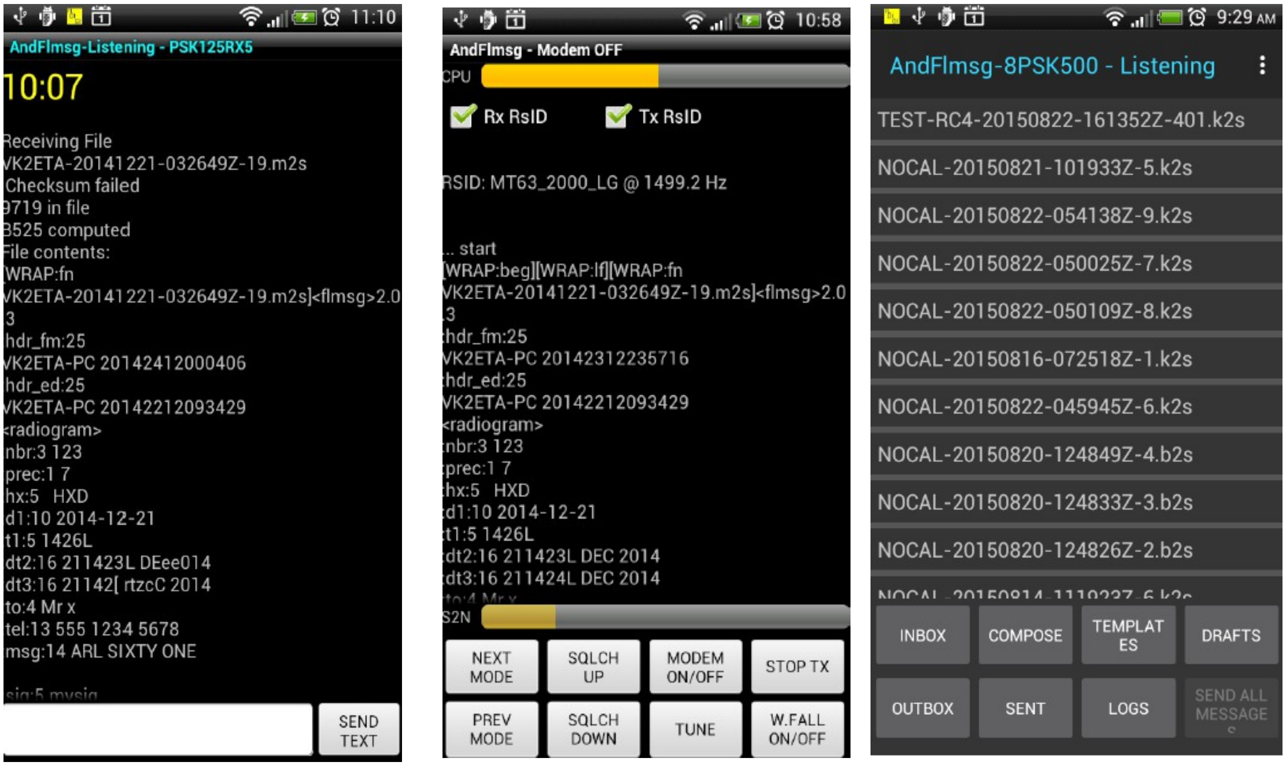
The 2206 uses an R/C tuned oscillator that switches between the one and zero frequencies and converts the result to a sine wave output. The 2211 receiver uses a Phase Locked Loop (PLL) to lock onto the incoming signal and outputs a one or zero depending on the frequency. The PLL lock circuit can also light a carrier-detect LED to show that there is an incoming signal. I breadboarded a 2400 baud modem using recommended high 8560 and 10160Hz tones to reduce timing jitter. This would work down to about 2mV p-p input with no noise present. I introduced some noise from the output of a VLF voltage probe antenna with a 25kHz LP filter, which is similar to what might be picked up by a long wire, even underground. This caused a lot of timing jitter and false triggering. The main interference was from the million Watt Navy station on 24.0kHz in Cutler, Maine. I live in northern Vermont. I built an L-C low pass filter for the demodulator with -3dB at 10800Hz that helped. The modem sort of worked in the noise with about 80mV p-p input signal.

I decided to abandon this approach as too complex, with a lot of tuning and adjusting. Also, I learned that the bandwidth of the line was too low for these high tones. I then looked briefly at the vintage 1200 baud Bell modem chips, which still remain a possibility.

The "Sound Card" Software Modem Approach

Next, I thought about using "sound card" modem software with the existing tablets to directly transmit and receive sine wave audio frequency modulation. There is very little Android modem software available. In fact, the only real possibility was a free app called **andFLmsg**, which incorporates dozens of digital text/data "sound card" data modes used by Ham Radio operators on Windows computers, along with the ability to send formatted messages (with checksums) that are automatically saved if received perfectly. The software is intended for portable use by Ham emergency messaging services and unfortunately does not include the general file transfer capability or the ability to break a long message into packets and automatically ask for repeats of packets not received correctly, all of which is included in the much larger and more complex Windows version. **AndFLmsg,** v 1.3.11, is found as an apk file at w1hkj.com or at sourceforge.net/projects/fldigi/files, and must be downloaded, then "sideloaded" onto the Android device after setting the appropriate permissions. Both sources also have an up-to-date quick start guide and user manual.

AndFLmsg is excellent and bug-free, with state of the art DSP modem choices with digital filtering, some with Forward Error Correction (FEC), interleaving, and special coding to avoid errors with weak signals and interference. Most of the data modes are centered on the same 1500Hz default audio frequency, which gives us a large selection of fast modes or slow/sensitive ones. A key feature is called **RSID** (Reed Solomon Identifier). It is a short preamble attached to the beginning (and optionally the end) of each message that tells the receiver to automatically switch to the data mode being being used for the transmission, and also to the correct frequency (not an issue for us). **RSID** uses the slow MFSK16 mode with FEC, so that it is received correctly nearly 100% of the time. There is an optional "waterfall" display of the spectrum of incoming signals. Another feature is an adjustable squelch that can be set high enough to prevent printing random characters on noise while in receive mode. The software remembers all of it's settings when it is shut off, so it comes up in the last mode, squelch setting, etc. Also, one can create a short list of preferred modes which makes switching modes much easier. There are 3 main screens, shown here.



Terminal Screen Modem Screen Message Screen

Fig 15

For our purposes, the Terminal screen can be used to type short "chat" or test messages. If the message is first highlighted and copied, it can be re-used over and over for testing. It also displays incoming messages, including any errors. On modem screen we can see everything that is decoded including **RSID** and random characters from noise.. We can also change to a faster or slower mode, set the squelch to "just" not print random characters with no signal present, and view a waterfall display of the received signal to help set receive gain. The message screen is where we can choose a blank message form such as *blank* or *plain text*, compose a message or paste into it, and save it to the outbox for transmission. Sent messages are copied to the Sent file and can be copied back to the outbox if it is necessary to send again. We can also look at the Inbox for any messages received while unattended. The base camp tablet can be left on the line all night and any messages from the cave camps can be read the next morning.

Acoustic Tests With No Hardware

For my first tests, I passed messages acoustically between a tablet and a phone using a mode called MT63-2000LG, which spreads each symbol (letter) out in frequency (500-2500Hz) and in time (~6 seconds) which effectively avoids data loss from echos and room noises. It is used by emergency services to pass data traffic over VHF/UHF voice radios with no extra hardware at all, and could likely do so over a single wire voice telephone (SWT) link. It works amazingly well at 20 baud, which is 200 five-letter words/minute (WPM) plus spaces. It should be possible to use this technique to transfer data (slowly!) over the Single Wire Telephones <u>with no extra hardware at all</u>, if the phones are working well.

Designing a Passive Single-Wire Line Interface

Most Android devices have a 4-wire mic/headphone jack for sound in/out. I was able to design a simple passive modem interface to allow 2-way communication over a very long single-wire line with automatic T/R switching and adjustable receive level. I included simple high pass and low pass filtering to reduce interference from powerline harmonics and from AM broadcast stations, especially at night. The prototype box is 3 x 2 x 1 inches.

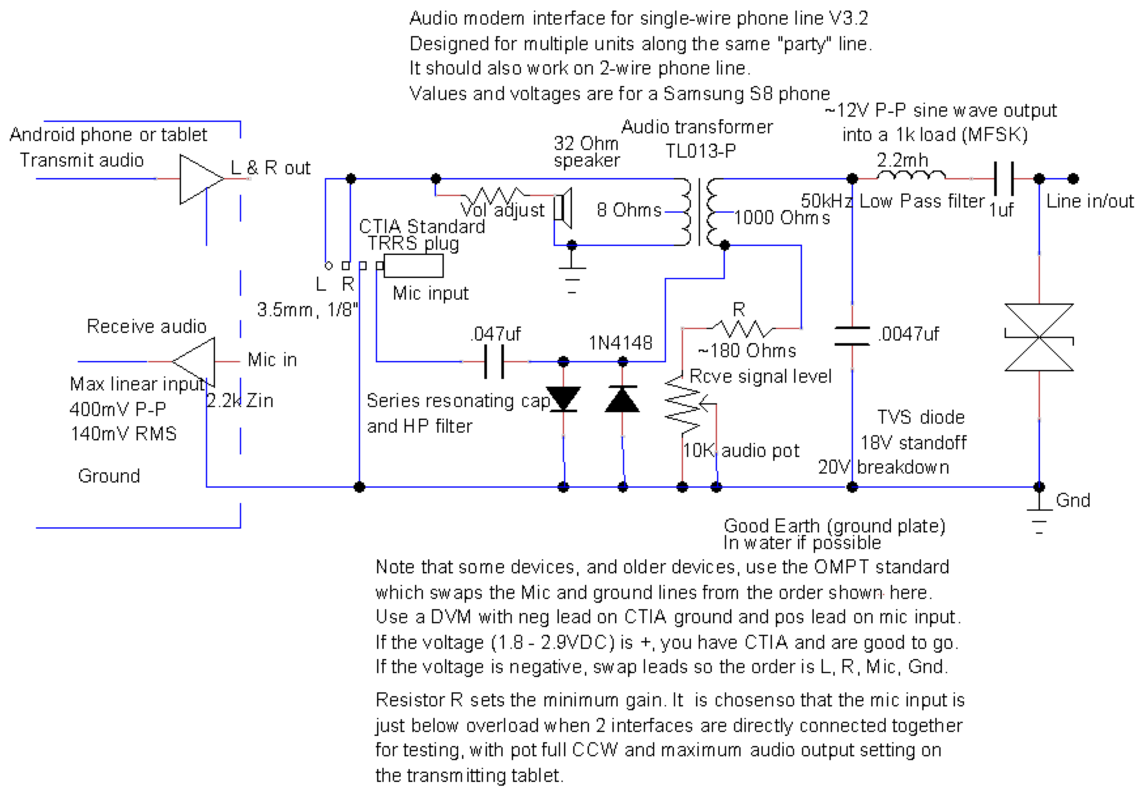
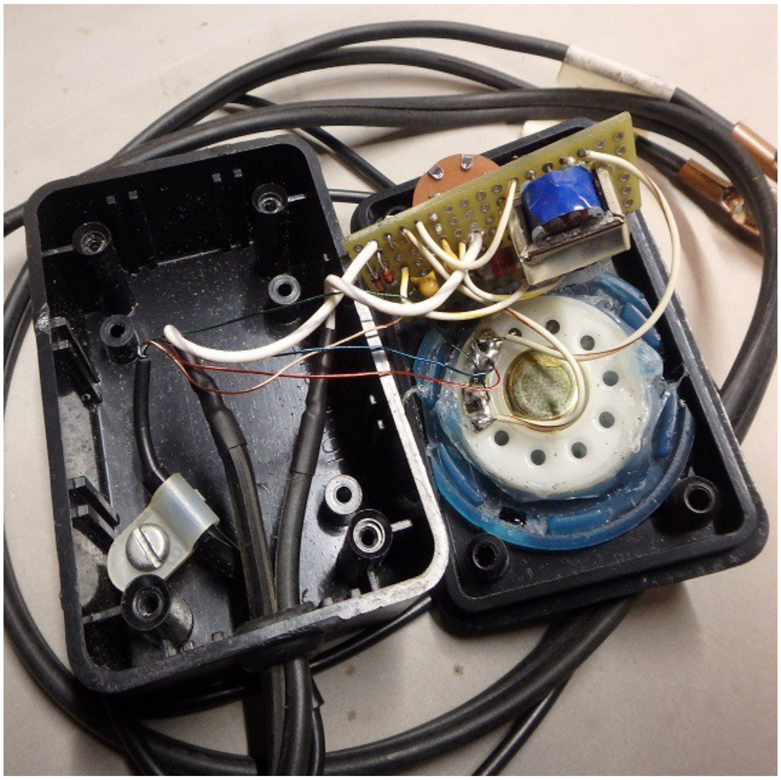


Fig 16

Fig 17
Prototype Interface with receive gain control



Prototype Interface Showing the vintage NOS transformer
Fig 18

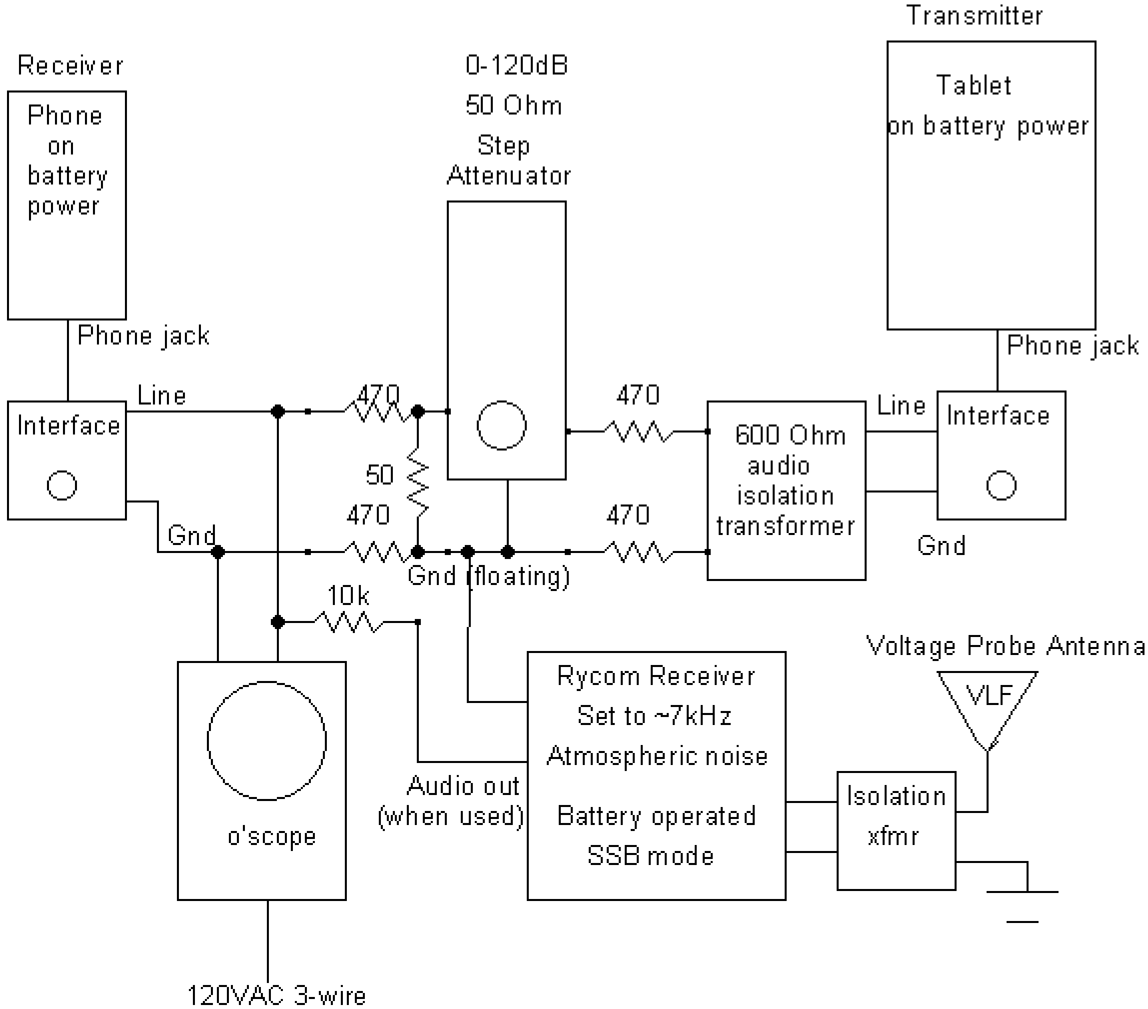
For transmitting data, the Android device is first adjusted for maximum audio output in *Settings*. Many devices turn down the audio level each time they are fully turned off. I actually get 25V p-p open circuit into the line out of my Invidia Shield tablet, with 16.5V p-p into 1000 Ohms. The new Samsung Tab 2 Active tablets Bill will use put out 12V p-p into 1000 Ohns. This is much more than a classic SWT. The 1N4148 diodes complete the transmit circuit and protect the mic input. There is a capacitor on the line input to prevent diode conduction from stray DC voltage on the line and also a Transient Suppression (TVS) diode to protect the tablet. The micro loudspeaker gives audible evidence of transmission (and evidence of proper transmit level, with practice).

When receiving data, the transmit audio amp is shut off, reverting to a high impedance. The .047uf capacitor broadly series resonates the 0.59 Henry transformer secondary to roughly1500Hz to maximize the received signal, and also acts as a high pass filter. The Receive level control is needed because several volts of signal will be present on a good line, which will cause the 1N4148 diodes to conduct and overload the mic input. Plenty of extra receive gain is available in the case of a poor line with bad connections or much leakage to ground.

The receive input impedance is roughly 3000 Ohms, varying with frequency. This is high enough to allow creation of a “party line” with several units online at once in receive mode, and one transmitting. It is easy to check for a clear line with a SWT.

Testing Data Transfer on a Lossy Single-Wire Line in the lab

I devised an attenuator to act as a long (very poor) transmission line between my 2 Android devices so that I could compare the performance of the various modes in transferring files. I eventually arrived at the odd circuit shown here, which provides a 1000 Ohm match at each end with the ability to add attenuation in 10dB steps. There is 28dB of “built-in” attenuation (measured) when the step attenuator is set to 0dB. The Rycom receiver was used in the second set of tests to add realistic atmospheric noise. The scope was used as a check that the attenuator was working and to monitor the induced noise.



SETUP FOR WEAK SIGNAL DATA TRANSFER TESTS

Fig 19

Table 1 shows the results of my first test, with roughly 10mv p-p of 11kHz atmospheric noise with bursts to 30mv p-p plus some 120Hz visible. This was before I added the antenna isolation transformer. These were the modes that worked with the most attenuation in their WPM speed range. **MFSK** is MultiTone Frequency Shift Keying where a single tone is shifted in frequency at a constant amplitude. The **Domino, Olivia,** and **Thor** modes also use MFSK but with sophisticated "tricks" to improve performance in noise and varying channel conditions. **PSK** uses one or more continuous tones that are shifted in phase, mostly 180 degrees. PSK is amplitude modulated to reduce bandwidth. **MT63** uses 64 simultaneous PSK tones and is a wideband mode for it's speed. A table that lists all of the modes (a subset of the Fldigi modes) is at http://w1hkj.com/FldigiHelp-3.21/html/mode_table_page.html . Not all are included in **andFLmsg**, which does however have some newer variants not listed in the table.

Note: When comparing transmission speeds with the UART baseband mode, WPM (Words/min) here is the equivalent of the UART baud rate, ie 200 WPM here is 200 baud (bits/sec) in the UART system. A "word" is 5 characters plus one space character.

Table1

Mode	Baud	**WPM**	BW (Hz)	Modulation	Line Attenuation
MT63-2000LG	20	**200**	2000	64 x 2-PSK	-58dB
MFSK16	15.6	**58**	316	16-FSK	-68dB
MFSK64	63	**240**	1260	16-FSK	-68dB
MFSK128L	125	**480**	1920	MFSK	-68dB
Domino EX88	86	**614**	1600	18-FSK	-58dB
Domino EX44	43	**312**	1600	18-FSK	-68dB
Domino EX22	21.5	**160**	524	18-FSK	-68dB
Olivia 16-2000	125	**80**	2000	16-FSK	-78dB
Olivia 8-2000	250	**116**	2000	8-FSK	-68dB
Thor 50x2	48.5	**176**	1800	50-FSK	-68dB
Thor 100	97	**352**	1800	100-FSK	-68dB

Modes that were able to send "*testing1234567890987654321end*" successfully more than once.

-68dB corresponds to a received signal of 6.6mv p-p, or 2.3mv rms. Adding the antenna isolation transformer cleaned up the audio frequency atmospheric noise, so I did a second test with roughly 10mv p-p noise with higher bursts to 100mv p-p. The results are in Table 2.

Table 2

Mode	Baud	**WPM**	BW (Hz)	Modulation	Attenuation
MFSK16	15.6	**58**	316	16-FSK	-68dB
MFSK32	-31.3	**120**	630	16-FSK	-68dB
MT63-2000LG	20	**200**	2000	64 x 2-PSK	-58dB
BPSK125	125	**200**	125	1-PSK	-58dB
PSK125R	125	**110**	125	1-PSKR	-68dB
PSK31	31.25	**50**	31	1-PSK	-68dB
Domino EX22	21.5	**160**	524	18-FSK	-68dB
Domino EX44	43	**312**	1600	18-FSK	-58dB
MFSK128L	125	**480**	1920	MFSK	-58dB

Modes that were able to send "*testing1234567890987654321end*" successfully more than once.

I did one more similar test to find other candidate modes. One thing I found was that some modes will work with a very low squelch level and not print random characters. This makes them easier to use and reduces the problem of having the squelch set too high on a "low squelch" mode.

I decided to test the best modes found by sending real survey data in the form of a Walls .srv file, which was opened in a text editor, then copied & pasted into one of the **andFLmsg** standard message forms. The software computes a checksum for the message, which, if received perfectly, is automatically stored in the inbox of anyone who receives it. The incoming message, errors and all, is displayed on the **Terminal** page (and the **Modem** page) as it is being received. The audio atmospheric noise was roughly the same level as before, but now derived from ~7kHz RF. Each mode in Table 3 successfully passed the ~4000 byte message with zero errors. There are other modes that were close in performance, but I had to make a decision for simplicity. **AndFLmsg** can be limited to just these modes.

Table 3

Mode	Baud	**WPM**	BW (Hz)	Modulation	Attenuation
MT63-2000LG	20	**200**	2000	64 x 2-PSK	-48dB
Olivia 8-2000	250	**116**	2000	8-FSK	-58dB
Domino EX-22	21.5	**160**	524	18-FSK	-58dB
Domino EX-88	86	**614**	1600	18-FSK	-48dB
Olivia 16-2000	125	**80**	2000	16-FSK	-68dB

These 5 low-squelch modes were chosen as the best at passing long error-free messages in noise

With very poor line conditions, Olivia 16-2000 might get through, very slowly. With good line conditions Domino EX-88 is almost 8 times faster. These are all slow compared to Kristen's short 9600 baud link to Camp 1, but these can operate in noise on long lines at very low signal levels. All but MT63 are FM modes that can tolerate receive overload, making receive gain settings less critical.

If the line is in good shape, and not noisy, the following very fast mode in Table 4 might work.

Table 4

Mode	Baud	**WPM**	BW (Hz)	Modulation	Attenuation
BPSK125X12	1500	**2400 (!)**	2000	12-PSK	-58dB, but no noise

This low-squelch mode has amplitude modulation. Receive Gain must not be set too high.

All that remains is to test them in real cave conditions at Sistema Cheve!

Using Android Tablets as High Performance Substitutes for MichiePhones

At this point I had another brilliant idea. Note the measured frequency response of my interface in the plot below.

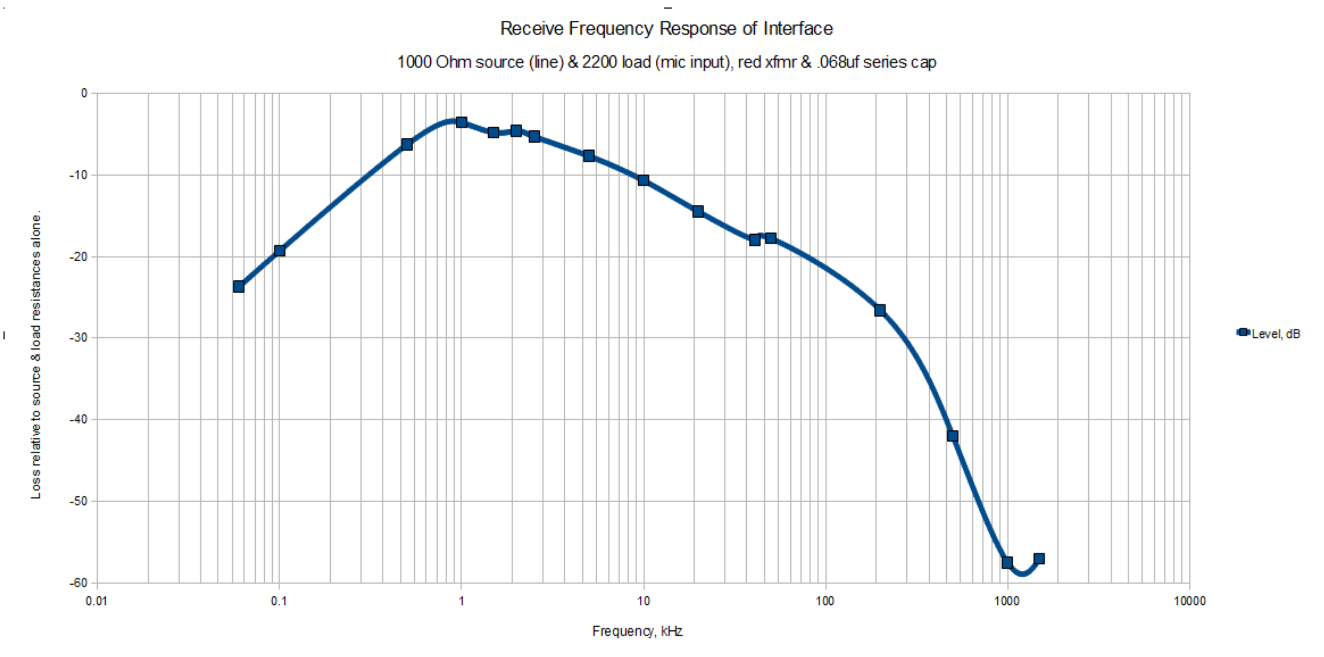


Fig 20

The -3dB points are about 400Hz and 4000Hz, which gave me the idea to try to use the Android tablets with their built-in mics and speakers as a high performance substitute (and backup) for the Single Wire Telephones. The data modem interface will work for voice as-is. All that is required is a simple app that normally listens on the external mic input, connects to the internal speaker, and has a PTT button that switches to the internal mic and external headphone output when you wish to talk! I have not found an app that does this. Kristen is looking into creating one. We could have a big capability for a little bit of software. This could also be a simple way to monitor the line for voice or digital activity. This has not yet been done. Let me know if you can help.

Appendix A
The Interfaces built for Bill Stone

Fig 21

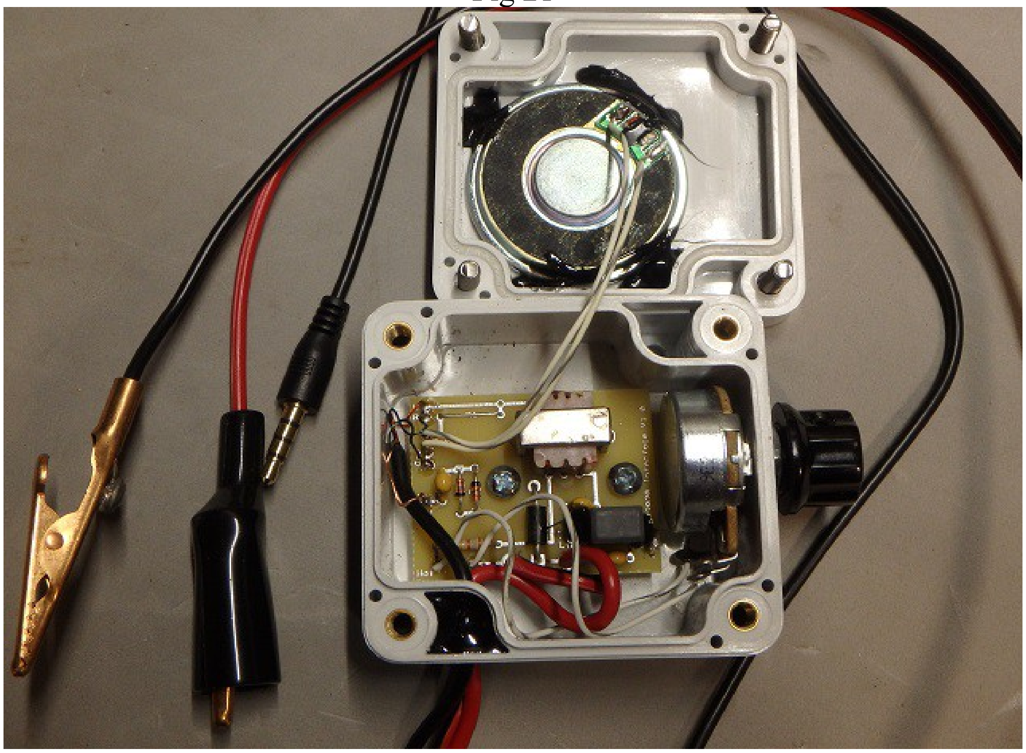


Fig 22

The 10 “production” Interfaces that I built for Bill Stone's Cheve Expedition are electrically identical to my prototypes, but are ruggedized for (hopefully) long term cave use. The 1/4” gain control shaft has a #78 o-ring, which is pressed tightly by the knob to prevent accidental rotation and act as a seal. The PC board is mounted on internal studs. The loudspeaker has a plastic cone, but is also mounted inside the box with no opening to the outside. This makes it very inefficient but truly waterproof. The wires fit in drilled holes. Black Shoe Goo was forced up into the cavity from an existing hole below. It took many days for this thick “potting” to set. I added more Goo on the outside (not shown) to act as strain reliefs. The box has a silicone gasket and SS screws with brass inserts. The alligator clips are genuine NOS solid copper Mueller BU-60, with screws to allow field repairs. The NOS black insulator really should be red, but this was all I could find. The PC boards are double-sided with plated-thru holes from ExpressPCB. The tranformers and inductors are from Ebay.

The PCB layout with external wiring, a schematic with part numbers, and a parts list with suggested sources, are shown below.

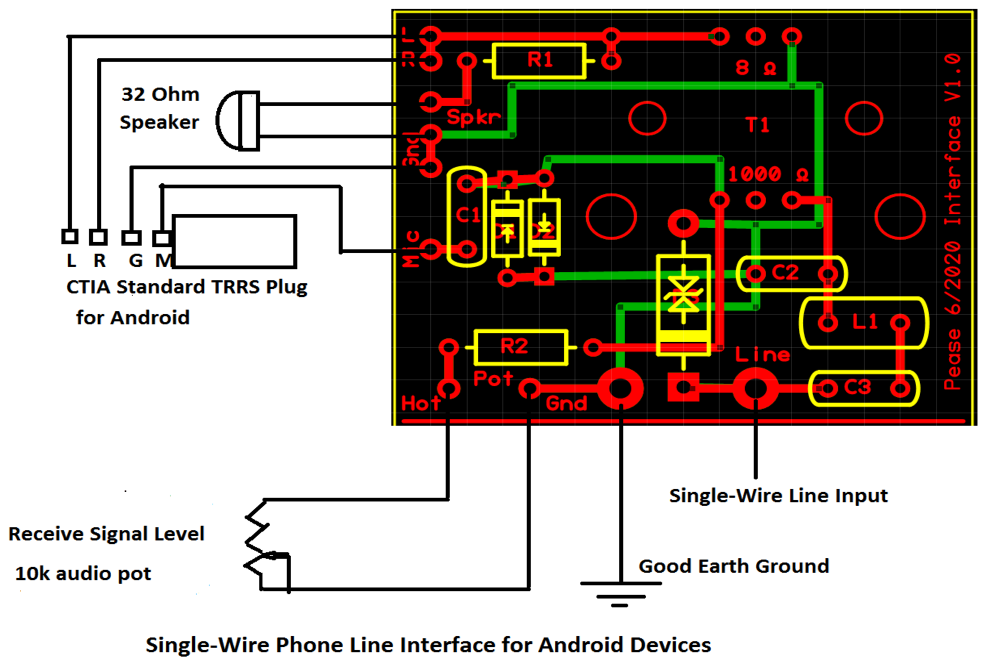


Fig 23

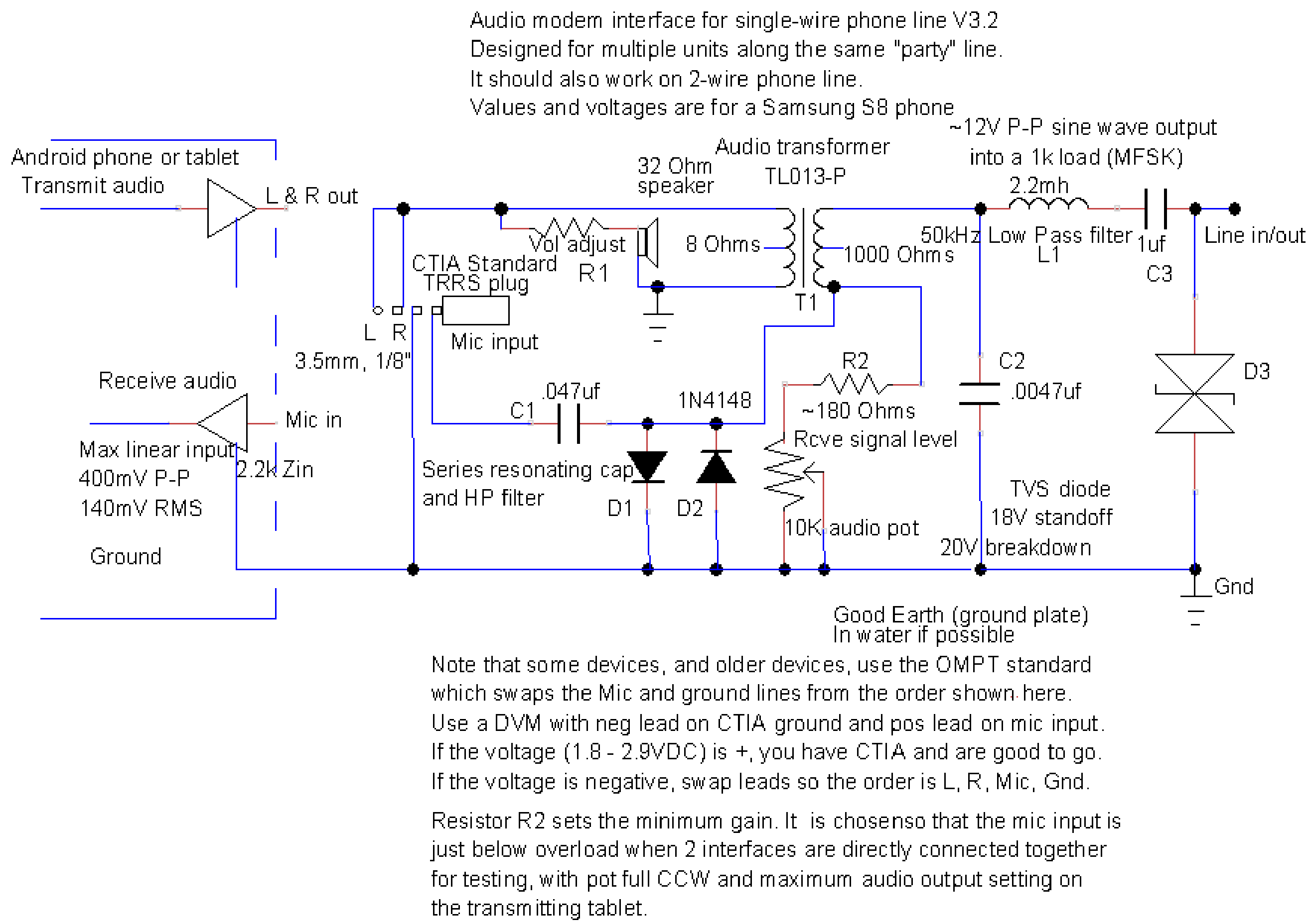


Fig24

Parts List for one Interface

	Quantity	Item	Part Number/Source
	1	Polycarbonate NEMA box	WP-20, polycase.com
	2	PCB mounting screws, M3-6	Junkbox or polycase.com
	1	4-wire male-male TRRS cable, 3 ft (1m) long, phone plugs both ends	Ebay
	2-3 ft (0.7-1m)	2-conductor #16 gauge speaker wire	Ebay
	2	Solid copper alligator clips	EBAY Mueller BU-60
	1	Insulator for Line clip (red preferred)	EBAY Mueller BU-62-0 (black)
	1	#78 o-ring 1/4x7/16x3/32”	Ace Hardware or Lowes
	1	PC board or prototype board	I can have boards made if there is demand
D1,D2	2	1N914/4148 diodes	Ebay
D3	1	18-20V bidirectional TVS diode	Ebay (Littlefuse SA20-CA) or DigiKey SC18-CA-E3/54GICT-ND)
L1	1	2.2mh shielded inductor	Ebay 14 Ohms DC, 1MHZ self-res, 35ma max, or Digikey 732-4211-ND

	1	1.5" dia 32 Ohm speaker, plastic cone	parts-express.com CE38MB-32
	1	10k Ohm audio taper pot, 16mm dia	Mouser 858-P160KNPC15A10K or similar
	1	Knob for 1/4" shaft	Parts-express.com Z408608
R1	1	Just use a zero Ohm wire!	
R2	1	180 Ohm 1/4W carbon film	From assortment or DigiKey
C1	1	.047uf 50V ceramic,0.2" lead spacing	" " "
C2	1	.0047uf 50v " " "	" " "
C3	1	1uf 50V " " "	" " "
T1	1	8 Ohms to 1000 Ohms audio xfmr (center-tapped, but taps not used) With the Xicon 1200 Ohm xfmr, it is possible that the CT (300 Ohms) might be a better choice (untested).	NOS Radio Shack, marked TO013-P or RS 273-1380 with long wire leads Mine are from Ebay 10/$12.50 Mouser has a Xicon 42TL003-RC xfmr 8-1200 Ohm CT for $2.64 ea