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Fun with Voltage-to-Frequency Converters

These converters have many applications. Consider using one in a project.

A voltage-to-frequency (VFC) converter is a type of voltage controlled oscillator. It is often only useful at lower frequencies and may have a narrow pulse output instead of a nice sine wave or square wave. I used them in many applications over the years. I will describe several to give you an idea of how you may use them to benefit your own projects.

Many of these examples render signal measurements into audible signals that the user hears. This allows the user to perform other tasks that may require visual attention such as making precision adjustments while listening to the relative results of those adjustments. This method offers resolution better than that available from the close examination of an analog meter because the human ear is very sensitive to small changes in frequency or pitch.

Remote Photocurrent Measurement

The application was to measure the photocurrent of a photodiode at a remote receiver in a free-space laser communication link circa 1978. I steered the laser telescope at the transmitter telescope and used the photocurrent measurement to optimize pointing. A trans-impedance amplifier turned the photocurrent from the receiver into a voltage to control the frequency of VFC that in turn drove a loudspeaker transducer from an old acoustic modem in a rubber cup (remember those?) that attached to the microphone of a telephone handset. I controlled the frequency range to vary between 300 Hz and 3000 Hz to accommodate the telephone system. A telephone link carried the audio from the receiver back to me at the laser transmitter so I could optimize link performance by maximizing the audio frequency and thereby the received optical signal level. It was a simple and effective solution to my problem.

The ICL8038[1] is the first chip I used as a VFC. Intersil called it a Precision Waveform Generator and Voltage Controlled Oscillator. The ICL8038 worked up to 300 kHz and had the decided advantage of simultaneous sinusoidal, square and triangle outputs. That made it more of a function generator chip than a VFC, but it's the first one I used. It is obsolete now and frequency control by a voltage was not straightforward, so I recommend against using it and provide no schematic diagram.

Better choices today are the National LM331[2] and the Analog Devices ADVFC32.[3]

[1]Notes appear on page 10.

These are both much simpler to interface and very linear. I prefer the LM331 because it is in an 8 pin DIP package and works with a single supply voltage from 4-40 Vdc while the ADVFC is in a 14 pin DIP and calls for symmetrical ±15 Vdc supplies. Analog Devices also makes the AD7741, which is in an 8 pin DIP and takes a single +5 Vdc supply, but I have no experience with it.

All of these are super linear, at least to the degree that you can read an input voltage by displaying the output frequency on a frequency counter if you scale the input voltage range and output frequency range accordingly. Figure 1 is an example from the LM331 data sheet that shows the setup and suitable component values.

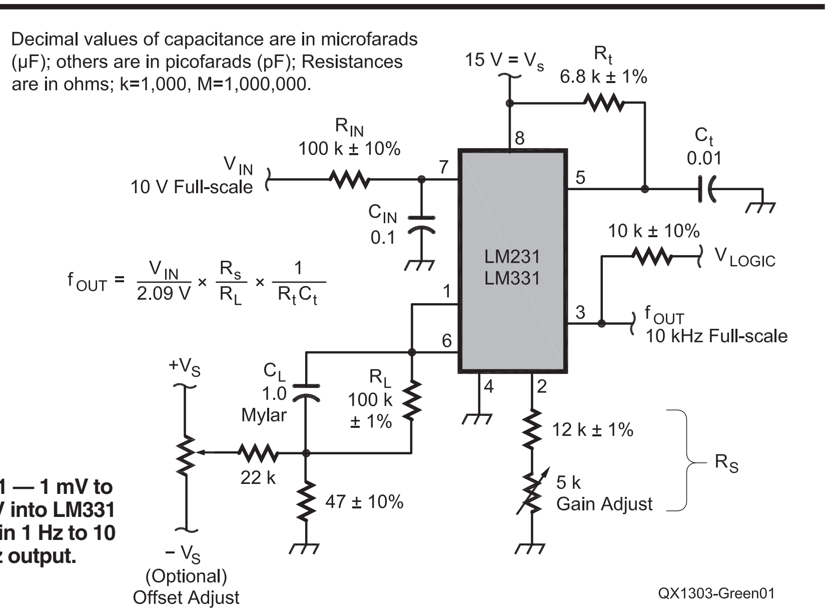

Figure 1 — 1 mV to 10.000 V into LM331 results in 1 Hz to 10 kHz output.

Audio Link

The ADVFC32 and LM331 data sheets show they are also able to serve as frequency-to-voltage converters. Figure 2 shows a fiber optic link I built in which an audio voltage modulates the frequency of a first ADVFC32 that in turn modulates light pulses into an optical fiber. A second ADVFC32 accepts pulses from the optical receiver to regenerate the original audio waveform. Think of this as an exercise in optical isolation. The input limiter helps maintain FM transmitter deviation in a desired range.

The BERT Trick

Both the LM331 and the ADVFC32 output narrow pulses. There is little audio energy in low duty cycle pulses, so the waveform is unsuitable for listening. There isn't much to hear. I had the same problem with bit-error-rate testers. These instruments monitor the performance of serial digital communication links and output a narrow one bit wide pulse each time an error occurs. At 1 Gbps that pulse lasts only 1 ns. Most people lock their eyes on the error counter display to determine error rate or when errors occur. It's pretty hard to make useful adjustments while you monitor the display. Instead, I chose to listen to the errors. Simply feeding the error pulses to a toggle flip-flop yields a high duty cycle waveform with lots of audible energy[4] as in Figure 3. The same trick works with these VFCs. A toggle flip-flop divides the frequency by two and converts the pulse train to a 50% duty cycle square wave.

Alternately, a Don Lancaster trick divides the frequency by 10 and synthesizes a decent sounding sine wave.[5] All audible solutions below use one of these frequency divider tricks to convert a train of narrow pulses into audible waveforms.

Another Photocurrent Measurement

The next project was another photocurrent measurement. This one utilized the sensitivity of the human ear to sense very small changes in pitch. I sent a fixed amount of unmodulated light into an optical fiber and used this instrument to indicate how much light came out the other end. The relative measurement was so sensitive that bending the fiber caused a noticeable decrease in the audible frequency due to the light lost in the bend. I intended this as a way to monitor fiber bending and strain when fiber is pulled during installation, where it often breaks. This method indicated a dramatic decrease in audible frequency before the fiber would break and so give the installer a chance to back off and try something else.

I patented this method.[6] My company sold it to another party who subsequently paid the maintenance fee that will keep this patent in force until 2015.

Radio Frequency Signal Strength Measurement

I designed and built a field strength meter that indicates higher power as a higher audio frequency pitch. The circuit is simply an Analog Devices AD8307[7] log-detector with 500 MHz response driving an LM331 VFC and toggle flip-flop. The output voltage of the log detector represents the logarithm of the RF signal input strength, compressing a wide dynamic range input into a couple volts of output swing. Applying that voltage to control the frequency of an oscillator in the audio range provides a simple and effective way to communicate the signal value to your ear. I constrained the audio frequency range to between 300 – 3000 Hz to match telephone

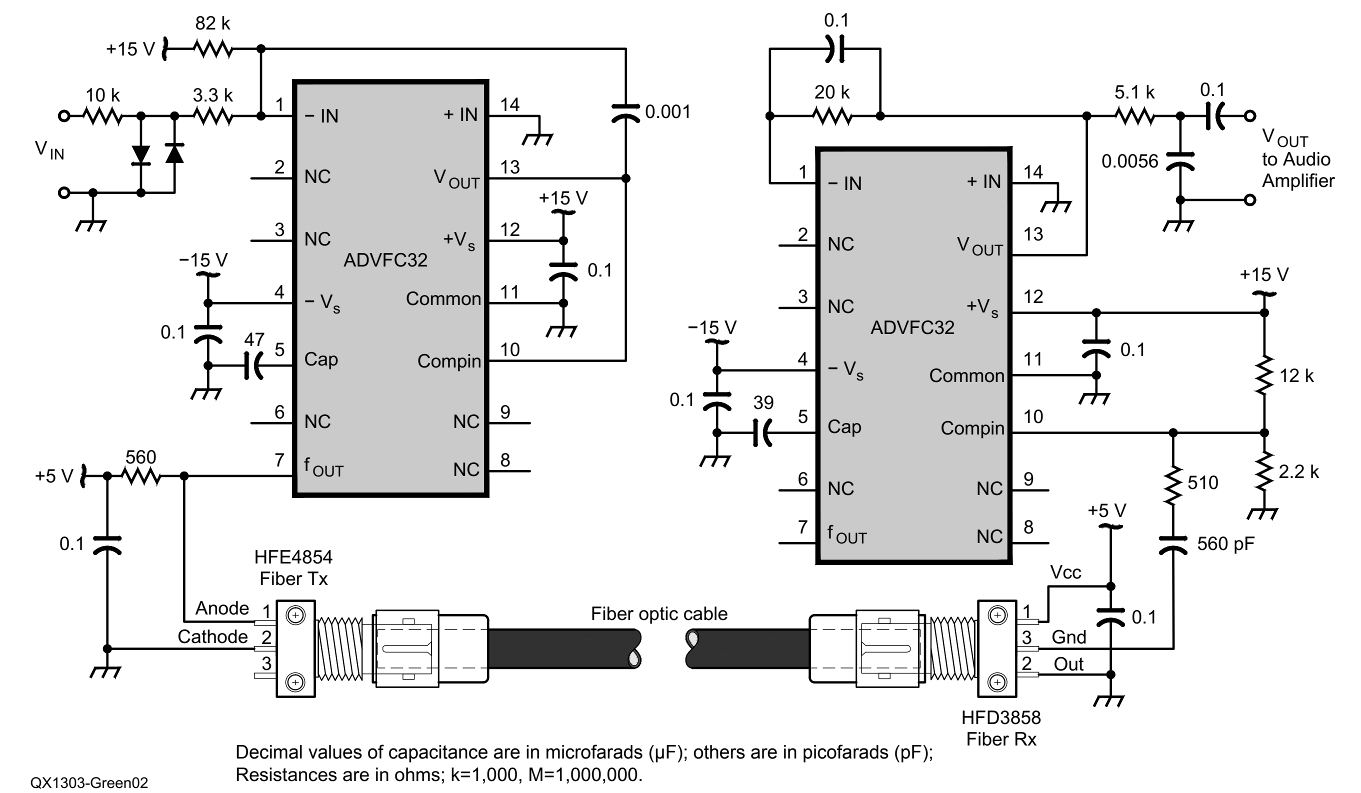

Figure 2 — The fiber optic link uses ADVFC32s to transmit and receive audio.

line and FM transceiver capabilities.

The human ear easily differentiates very small frequency changes, allowing very high resolution and high sensitivity to small changes. Sensitivity to amplitude changes is very much poorer, as the human ear is able to resolve variations of about 1 decibel which corresponds to about –20% or +25%.

I meant this to be an instrument for the amateur radio community to make remote measurements of relative field strength. I thought it would prove useful to measure radiated signal level at some distance from the transmitting source, perhaps for antenna comparisons or to see if an antenna tuner adjustment is real and not a phantom dip in VSWR. In the shack, you would read the meter of an ordinary instrument, but remote operation requires a way to return the measurement data to the user while making adjustments that affect the remote reading. Conversion of the field strength reading to a varying audio frequency signal allows return of the measurement data via a phone line or an audio modulated FM radio link. Rotate an antenna and listen to measure the effect in the far field.

I walked around my workplace with the prototype and listened to different sources of RF. When I heard the data exchange as the RF reader interrogated my employee badge, I got the idea that this could become a cell phone and wireless detector. That might prove useful to sense such devices operating where they shouldn't. I built up another prototype based on an AD8313 log detector with 2500 MHz response to sense cell phones and wireless. With it I could tell which laptop had its wireless enabled when I walked up and down the aisle on a commercial airline flight with headphones connecting to the unit in my pocket.

Because airlines want RF emitters turned off, and because I worked for an airplane company that offers incentives for intellectual property, I patented this method as well.[8] Again, you can look at the details in the patent online.

This is what I built into the two Altoids tins in the article "Hints & Kinks: Altoids Times Two" that appeared in *QST* and the *ARRL Letter*.[9] Figure 4 is an excerpt from the patent. The decision circuit and light emitting diode indicator never existed and were an "attempt at completeness" by a patent attorney whom I will be glad never to work with again.

Company attorneys discouraged me from publishing actual schematic diagrams, but this is fairly simple to understand from the discussion. My hope is someone will notice this and license it for manufacture and sale. I wouldn't benefit, but I am grateful for the benefits already received during my years of employment.

For extending the AD8307 logarithmic detector to work at low frequencies, refer to my *QEX* article "Fully Automated DDS Sweep Generator Measurement System".[10]

Digital Multimeter Accessory

This last project is a fairly recent attempt to overcome the worst problem of digital multimeters (DMM), the lack of a decent analog indication. Digital meters offer precision, resolution and accuracy that old moving needle analog meters never could. Analog meters did excel at indicating relative increases and decreases in magnitude.

Some DMMs add a crude bar graph display to indicate relative magnitude, but these are worthless except for large variations. No one would use such a display for any fine adjustment.

The use of a VFC in this application offers resolution that exceeds the resolution available from the moving needle of an analog meter. This is an obvious improvement, yet no vendor offers such a capability. Adding this to a DMM gives precise analog information that enables a user to perform adjustments that maximize or minimize any measurable parameter without even having to look at the DMM!

I set out to build an accessory for a DMM to demonstrate the concept. The nice thing about a DMM is that it performs all the scaling by converting all possible input signals, whether current, voltage, resistance, or any of a number of other parameters, to the range of the internal digital meter. This was ±200 mV for my demonstration unit. I added a gain of 10 before the VFC input to accommodate a 200 mV input range.

At this point, there is no advancement to the state of the art, and anyone can reproduce it.

Then I added three improvements that I thought would be desirable in a DMM.

1. I added an absolute value circuit, so that the VFC receives only positive going signals from the input.

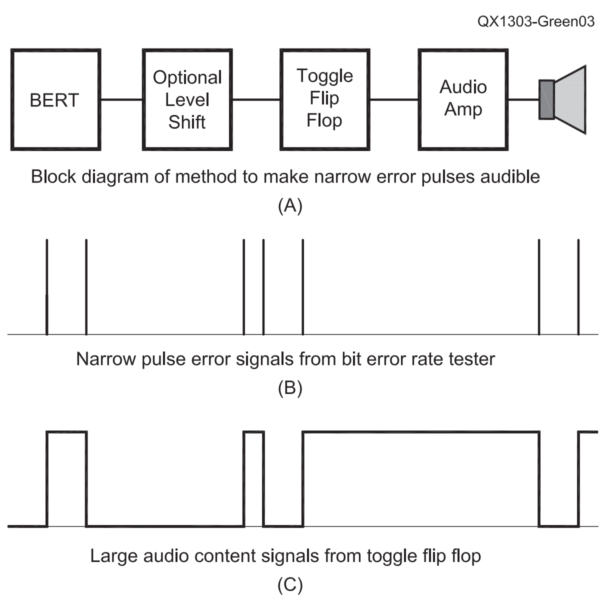

Figure 3 — A method to make narrow pulses audible.

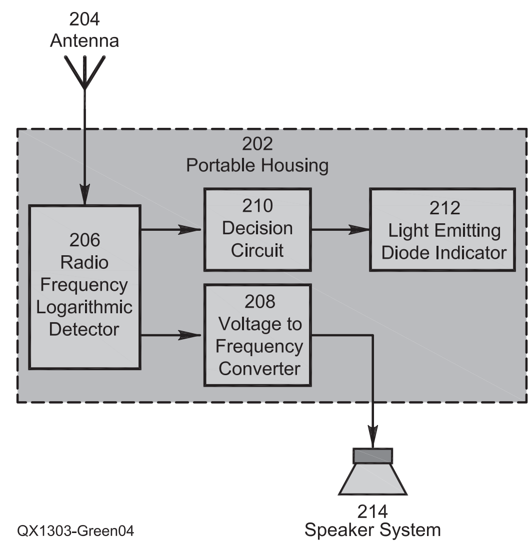

Figure 4 — A method and apparatus for detecting radio frequency signals.

2. I sensed when the input is negative and used this signal to change the way the audio sounds when the input goes negative to be able to tell the difference when listening. I tried switching between different waveforms such as sine waves and square waves and then settled on tremolo. When the input signal goes negative, a low frequency oscillator interrupts the voltage indicating waveform. This was very effective and much simpler to implement.

3. At the suggestion of my co-inventor, I added a squelch circuit to turn off the output when it wasn't changing. This turned out to be difficult to implement, but it makes for much less annoying operation.

We applied for patent protection on these key features. Figure 5 from the pending patent application[11] provides a general description.

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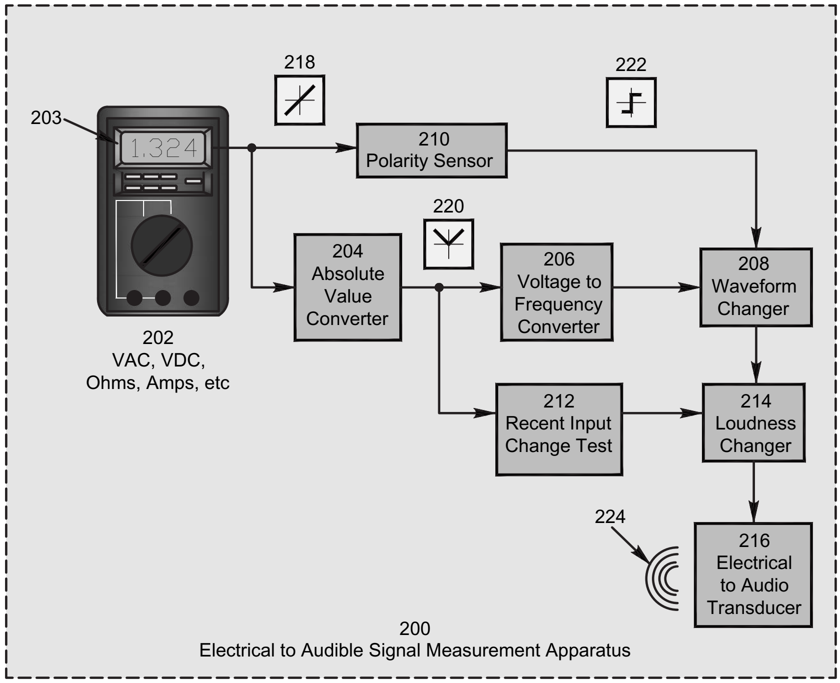

Figure 5 — An audio frequency device for audible eyes-off measurements.

Online Patent Information

Note that you need a TIFF viewer plug-in for your Internet browser to view the actual images of a patent or patent application on the USPTO website. The USPTO recommends several free TIFF viewers.[12] Of these, I have the best results with AlternaTIFF.[13] Without a TIFF viewer you can only read the text of a patent or patent application.

The message buried in this article is that you can search and read patents online. The USPTO site and the TIFF viewer are free. A huge amount of information resides on the site.

Eighteen months after the USPTO receives a patent application, they publish it on their website, whether or not they ever grant patent protection, and usually while the application is still pending. Did you know that? That's the deal you make to get patent protection. You explain and make obvious how your invention works, the USPTO makes it public and then they may or may not award patent protection. The adjective "patent" means readily visible, intelligible, or obvious. At that point, the information becomes public. If the USPTO agrees that the invention is sufficiently unique, they grant patent protection and you or your company gain exclusive rights for a number of years, while you pay increasingly larger fees to renew it.

So when you research a field of technology, consider looking among applications as well as patents. You can search on the names of known inventors, companies and areas of technology and look into what your competitors are doing. See the next great thing.

The USPTO also has a site called PAIR for Patent Application Information Retrieval that tells the licensing status of each patent and application and whether patent protection is expired for non-payment of fees.[14] PAIR even shows the correspondence between the patent examiner and the applicant's patent attorneys. It is all public information.

In Conclusion

Consider the utility of VFCs in your projects. You can send analog signals over a digital link, and you can listen to signals as they change. Enjoy!

Dr Sam Green, WØPCE, is a retired aerospace engineer. Sam lives in Saint Louis, Missouri. He holds degrees in Electronic Engineering from Northwestern University and the University of Illinois at Urbana. Sam specialized in free space and fiber optical data communications and photonics. Sam became KN9KEQ and K9KEQ in 1957, while a high school freshman in Skokie, Illinois, where he was a Skokie Six Meter Indian. Sam held a Technician class license for 36 years before finally upgrading to Amateur Extra Class in 1993. He is a member of ARRL, a member of the Boeing Employees Amateur Radio Society (BEARS), a member of the Saint Louis QRP Society, and breakfasts with the Saint Louis Area Microwave Society. Sam is a Registered Professional Engineer in Missouri and a life senior member of IEEE. Sam holds sixteen patents, with two more patent applications pending. Contact Sam at **w0pce@arrl.net**.

Notes

[1] **www.intersil.com/data/fn/fn2864.pdf**
[2] **www.national.com/ds/LM/LM231.pdf**
[3] **www.analog.com/static/imported-files/data_sheets/ADVFC32.pdf**
[4] "Bit error rate test accessory makes errors audible", Samuel Green, *Rev. Sci. Instrum.* 72(12) 4472 (01 Dec 2001).
[5] *TV Typewriter Cookbook*, Don Lancaster, ISBN 0-672-21313-3, pp 180-181, (Jan 1976).
[6] **http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=5729335.PN.&OS=PN/5729335&RS=PN/5729335**
[7] **www.analog.com/en/specialty-amplifiers/log-ampsdetectors/products/index.html**
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[9] **http://www.arrl.org/arrlletter?issue=2009-10-15**
[10] Fully Automated DDS Sweep Generator Measurement System, *QEX*, Nov/Dec 2008, pp13-22.
[11] **http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PG01&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.html&r=1&f=G&l=50&s1=%2220100079131%22.PGNR.&OS=DN/20100079131&RS=DN/20100079131**
[12] **www.uspto.gov/faq/plugins/tiff.jsp**
[13] **www.alternatiff.com/**
[14] **http://portal.uspto.gov/external/portal/pair**

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