Hot Iron # 116

End May / Start June 2022

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CQ-CQ-CQ

Theory ain't everything: from Eric Nichols, KL7AJ : *"SWR meters make you stupid"*

In days gone by - - -

"You were likely to make a useful accidental discovery from time to time. Theory is great, to a point. It helps explain what you already have discovered by accident, but it doesn't often lead to new discoveries, at least on its own. You need to get knocked on your keister a few times and singe a few eyebrows to really understand radio."

This puts me in mind of Michael Faraday, the original - possibly - arch experimenter. Nature is a very shy girl; she hides her secrets well and only show glimpses sufficient to attract further approaches. You can take thing theoretically far; you can wrap volumes of abstruse mathematics around Nature's gifts, but never forget that our feeble human maths is but a fleeting shadow of the truth hidden deep in Nature.

As any business manager will tell you, "it's not theory that makes results: it's the end product, the bottom line, the working system that makes the World go round". Maths and physics can get us a long way into sneaking a view of Nature's secrets: but, never forget, they both are mere tools in your kit, not the controlling influence. Ohm's Law is well and good, it helps us sort out problems, design circuits and think through a faulty system, but it is merely a convenience, a short cut to what is actually happening in these components, not the command that tells Nature how to behave.

Nature is far deeper and more mysterious than we hominid apes can ever understand (or imagine); the Universe wasn't designed for our benefit or entertainment, so respect Nature in all you do!

Receivers

From Kevin, ZL3KE

…. who wrote an email to me which I think is well worth sharing: it might bring a few more amateurs "into the fold" of appreciating super-regen receivers:

"I've previously played quite a lot with what could be described as the
'standard' FET super-regen circuit i.e. the grounded-gate one that's
been published in various articles over time. Remember the old PW "CQ2"?
And of course Roger G3XBM has provided more recent inspiration having
used this circuit in his 2m "Fredbox" and related 6m/10m designs, see:
https://sites.google.com/view/
and
https://sites.google.com/view/

I've generally had good results with this circuit but it does seem to
need a half-decent FET and preferably "ugly" construction to get
repeatable performance at VHF/UHF. By far the best results I obtained
generally were with a 2N4416 (TO-72 metal can, with the can
spot-soldered directly to the ground plane). I still have a few of those

2N4416s somewhere! These days a J310 or similar would seem like an obvious candidate - have used U310s (metal-cased equivalent) on a couple of occasions with good results. (Hint: thin enamelled copper wire wound round a plastic encapsulated device, secured with super glue, hot melt or wax and earthed can imitate a "canned" device for use at VHF / UHF… on bottles, too, when screening can unavailable. Ed.)

The "dead spot" problem I found was mainly related to antenna coupling, and the use of an untuned preamp/buffer stage (either CG FET or CB bipolar) lightly coupled to the detector largely eliminated this in the several circuits that I built. I wouldn't build a super-regen without such a preamp now, unless it's being used as say an IF stage where the loading conditions on the main LC tuned circuit can be more closely controlled.

I found that the characteristics of the RFC in the source of the FET can be more critical than you might think. What's needed of course is a high enough impedance at the working frequency. I once had this circuit working as a fixed-tuned 10.7MHz IF, but found that instead of an RFC I needed to use a tuned 10.7MHz parallel tank circuit (old 10.7MHz IFT) in the FET source lead, instead of an RFC (very good at a single frequency but due to the high-Q resonance, no good if you need significant tuning range). These days I have the luxury of a spectrum analyser with tracking generator and I look for an RFC out of the junk box which has a low-Q parallel self-resonance reasonably close to the intended frequency of operation.

Having said all that I'm keen to experiment with a bipolar circuit with audio reflexing, as one downside of the CG FET circuit is that it needs a highish-gain audio amp. I look forward to seeing your published circuit.

I derive more enjoyment from playing with these simple and almost forgotten circuits than I ever got from designing high-performance and increasingly complex VHF/UHF radio systems for the likes of Racal, Codan and Tait (that could sometimes be likened to chainsaw juggling - fun at first but can age rapidly...). I know a number of professional RF engineers who do this kind of thing (and/or playing with thermionic stuff) as an antidote to the day job. It's a funny old game.

Anyway enough waffle from me already! Cheers & 73,
Kevin
ZL3KE"

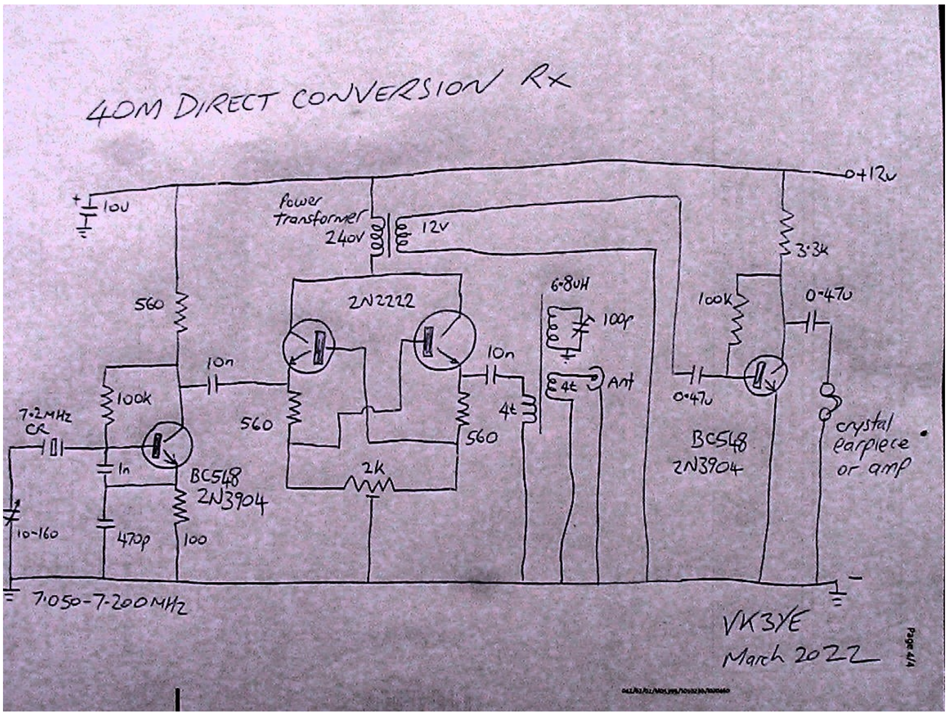
Peter Parker's cross coupled transistor experimental DC Rx

Peter Parker, VK3YE, wrote to me:

"Thanks Peter,

Yes it's for publication. The main shortcoming is the use of the transformer. You can get away with just a resistor but audio is less. I've tried various other transformers and there's some odd effects. I think it's possibly more promising as a balanced modulator or in a simple transverter but I haven't tried it yet. High level balanced modulators were popular around 1960 as a cheap way to get on SSB but there have been few if any solid state versions published. But a version using this configuration with two BD139s followed by an IRF510 PA could be an interesting DSB or digital modes adapter for a CW tx".

Peter's circuit:



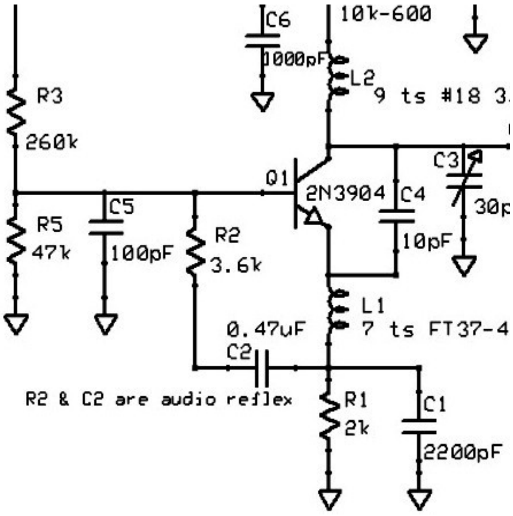
Peter noted that this "cross coupled" circuit appeared in "Amateur Radio Techniques" by Pat Hawker, G3VA. I had the circuit in a bench notebook from years ago, as well as the cross coupled triodes. I've a suspicion cross coupled pentodes can be used too.

I must have thought the circuits worth noting at the time, as well as some notes about the "Gilbert cell" - a clear derivative of this circuit.

Rush boxes and reflexing

I'd written to Kevin about a reflexed super-regen circuit, using bipolar NPN transistors: I must have knocked up dozens of these little beasties over the years and I had one running on 23cms at one stage. I wrote in reply to Kevin:

"*One thing I will add (for what it's worth) is that a few correspondents have told me that they have "dead spots" and erratic operation using jfet's: this might be because jfet's have specs as wide as a barn door, and consistent oscillation can't be guaranteed. I like to use high Ft NPN transistors in a super-regen "reflexed" circuit - I'll put a note in Hot Iron # 116 that you have a super-regen project in the pipeline and suggest my favourite circuit as a possible alternative.*" So 'ere tis!



Super-regen addicts (yes, once you build one of these damn things, and hear for the first time a single transistor providing >100dB gain you'll not stop playing with super-regens!) will recognise the typical features: an emitter (source) choke; the quench generators R1 and C1, the RF decoupling of the base connection and the emitter to collector feedback capacitor.

Note the inclusion of R2 and C2 - these feed the audio signal that's present below L1 back into the base circuit which is earthed at RF signal frequencies, making the oscillator a grounded gate type, and a common emitter audio pre-amp all-in-one.

I claim no originality for this circuit: if any reader recognises it, please let me know and I'd be most grateful. I think it formed part of a 6m transceiver but I can't be sure.

A fascinating resource is at: http://zpostbox.ru/super_regenerator.html#google_vignette

...where you'll find some simple and interesting circuits.

The Bond Box

Here's the classic transceiver original, which Terry, VK5TM told me about:

Hi Peter.

Re the QST Bond Box circuit - you can download the whole mag with article here https://worldradiohistory.com/

Cheers

Terry, VK5TM

Thank you to all the readers who sent me emails about this absolute beauty of a mobile VHF transceiver. It's a superb design by Doug DeMaw, dating from the late 1960's, and well worth a go with modern components and updates. It's on page 11 of QST issue 8 , 1968, HERE or if the link won't work for you, https://worldradiohistory.com/Archive-DX/QST/60s/QST-1968-08.pdf .

The skill involved in designing the Tx / Rx switching - the downfall of many transceiver projects - is simple and straightforward: indeed it prompted my memory for an item later in this edition.

Transmitters

Hot Iron's magnificent archivist, Frank Barnes, W4NPN, pointed me to an article which details specifically the construction of valve power amplifiers and earthing techniques, see:

https://www.w8ji.com/designing_ham_transmitter.htm

This is the absolute Mutt's Nuts of the job: a magnum opus of sound engineering in an amateur scenario and is vital reading for all bottle power amplifier enthusiasts. It brings memories of repairing some equipment, which relied on the earthing around the power amplifier stages being exactly as the manufacturer had built it.

Each power amplifier had a hefty brass bolt for earthing and return current connection, and the tags that went on this bolt had to be in the right order, or the stage would burst into parasitic oscillation at some point. Stan had told me; I forgot and got a couple of lugs in the wrong order. This caused power stage return currents to pass through more sensitive driver amplifier earthing, thus unwanted feedback from the μV drops in the earthing stack. Easily done, but I didn't forget again!

Similarly, when a lug crimped on a cable parted company from the copper cores (don't ask…) a fork lug, rather than a full circle lug was used as a repair. This gave bother when a new valve was fitted; the stage was only marginally stable as the new bottle had plenty of g_m and hooted at the least provocation. A new heavy gauge full ring lug fitted, and screen grid decoupling capacitors replaced for good measure whilst we were in there put the job back on track.

Never take on grounding or return current design without some deep thought, and plenty of testing!

Medium Wave "local" transmitters

We've talked about that typical trade off paradox of "local" MW transmitters; designed to give a MW signal in a very small radius (no more than, say, 20m) as beloved by Harry Lythall, SM0VPO.; and of course very applicable to Top Band operation over considerably longer distances (plus possible interference to next door's electronics).

Harry pointed out to me that modern pocket sized audio recorders and the like are very capable stereo devices: this means that TWO audio channels are available for use.

Thus TWO low power "local" A.M. micro-transmitters could be modulated with different material, recorded on ONE device. Neat, huh?

Not that I condone copyright infringement, music ripping or unlicensed transmission over the airwaves…!

As Harry wrote to me:

"*Hi Peter, yes, please feel free to use any info or ideas. One small addition is that an MP3 player has two stereo channels. There is absolutely no reason why you cannot take two mono recordings (Radio Caroline and Radio Luxenbourg, perhaps) and save the MP3 file as a 2-channel mono recording. You only need one MP3 player to feed two transmitters and have 2 stations on your AM "local" service*.

ECL / PCL 80 series triode - pentode transceivers

I came across a design years ago which used the (then) very popular triode / pentodes of the ECL 80 / PCL 80 series, much beloved by record player audio and frame output TV scan amplifier designers of yesteryear. Yes, these bottles are particularly useful for transmitters, and, nowadays, the PCL (300mA TV series connected heaters) bottles are cheap as chips and lots of "NOS" available.

"So what's new?" you ask… well the design I recall was a full **transceiver**, comprising a regenerative receiver using the triode as an RF amplifier with twin tuned circuits, feeding the pentode as a tuned regenerative detector plus audio output via reflexing. The transmitter was a Colpitts crystal oscillator - which if I recall gave a very clean note - and used screen grid modulation from a carbon microphone; the power supply switched to give more "ooomph" on transmit, and stabilised with voltage regulator tubes on receive. I recall "borrowing" a carbon microphone from an office telephone for lower audio noise!

I built one; it used a 12 pole rotary switch to change the circuit from transmitter to receiver and vice versa. I was amply warned that the wiring and layout would be the critical thing: "stick exactly to the layout and wiring harness diagram" quoth Stan, which I duly did.

It still took a fair bit of tweaking to get it to perform, but it was an excellent little project, and here's the kicker: does anyone have any notes, or better, a link to the original article? I think it was in a magazine; PW, Short Wave mag, I can't honestly recall, but it would be very much appreciated and bring my eternal gratitude to the sender!

WW2 TRD sets: not a PWM "secure" system?

After the Nazi occupation of Western Europe, after 1939, UK "stay behind" units of essentially civilians were trained to become resistance fighters, to tackle the invasion forces and be a "pain in the 'arris" to occupying troops. They built remarkable disguised hideouts, some under ash piles, compost heaps, scree slopes and farm middens, and they were issued radio transmitter / receivers, the TRD sets, designed so the occupying forces could not eavesdrop on the conversations.

Many ideas as to how these sets worked, a common theory being they used a super-regen receiver "back'ards" as a transmitter - injecting audio at an appropriate point causing the quench frequency to vary in proportion to the audio, this being a primitive pulse modulation, the super-regen set receiving the signals would synchronise onto the quench frequency and demodulate the audio.

Why not examine the TRD circuit schematic, or the actual transceivers themselves, you might ask? Because, once the "stay behind" resistance groups were disbanded in 1944 / 5, all the TRD's were dumped into a disused (and unknown) colliery shaft in Lancashire, and many tons of wet concrete dumped on top so the secret of the TRD sets would be secured forever.

I've tried a few experiments using valves as close as possible to the WW2 bottles, and although I built some fairly potent VHF / A.M. sets, running on 60 – 65MHz, I couldn't get pulse modulation, be it pulse position, width or anything else. I had conversations with Tim Walford (of Walford Electronics fame) and several other interested parties and the general position was the circuit / technique was (for ongoing security reasons?) just plain unavailable.

So, it was with surprise I came across a reference that not only had information about the TRD sets, but chassis layouts, operating and antenna notes and other details. See:

http://www.wftw.nl/111%20TRD%20%20v%201%2000%20.pdf

This is a welcome relief: it puts to bed most of the guessing and wondering, and forms the basis of a dandy 6m or (in the UK) 4m A.M. transceiver. Obviously, no need (unless you're a purist) to replicate the 6 volt lead acid battery / vibrator power supply - the specification was, if I remember right, a 72 Amp Hour battery, and this would be one hefty beastie, far from portable!

Power Supplies

From Bob Liesen, WB0POQ

"Peter,

Loved the story in the latest "Hot Iron" (# 115, Ed.) *about finding a HV transformer with a shorted turn.*

I remember years ago working on early color TVs with their enormous power transformers and learning very early on that low B+, a buzzing transformer and LOTS of heat coming off it, meant the customer had a big bill coming to replace that beast-O-iron.

Fast forward to a few years back......I work for a company that makes a product that incorporates an in board signal transformer. That is, on two of the internal layers there are two small copper foil spirals with a hole cut through the PCB to insert one leg of a U core. This transformer is used for galvanic isolation betwixt two parts of the circuit.

When the VERY high permeability U cores are inserted through the holes in the PCB, the inductance of this small coil is around 30uH. With no cores in place it is about 1uH or less.

Part of the production process is to do an ICT (in circuit test) to measure the inductance of this coil.

Well at one point the alarm bells went off as many of the boards were failing this ICT test with measured values around 1uH.

The engineer who was my supervisor, (nicest guy you'd ever want to meet, and VERY smart) assigned me to figure out what was going on.

I got some failed boards and set off to find the cause.

I first speculated the U cores were wrong. Nope, they checked out. Well could something be wrong with the circuitry attached to the windings? Nope, isolated the windings from other circuits and still had bad values.

Hmmmmm.....shorted turn???

I took two U cores, wound 6 turns of wire on them (same number of turns as in the in board transformers) and measured the inductance. Got about 30uH. Shorted one turn to its adjacent neighbor.....1uH.

So.....I go to my supervisor and tell him the coil(s) have a shorted turn. I get the look like when your dog turns his head on his side as if to say "You want me to do WHAT!?" He had no idea what I was talking about. I explained that with a high permeability core, all the turns are so tightly coupled that shorting two shorts them all. Still no idea. So, I took him to my bench and hooked my two cores wound with wire to an LCR meter and demonstrated what happened to the measured inductance when I shorted one turn to its neighbor. He stared at the fixture for a moment, and said......"Well....I see what you are doing here, but I don't understand it, so we are going to look for the cause somewhere else."

We spent the next 2 weeks trying to tie the failure to temperature, humidity, phase of the moon and wind direction. No joy.

So, I took a sample board stripped of components down the road to the PCB manufacturer. (Ahhh the days where your suppliers were on the same continent). They had a machine that could sand layers off a multilayer board to reveal inner layers and asked him to post me a picture of the layer with one of the coils on it. I then headed to a meeting back at my office to plot the next round of testing to find the problem (was it pressure, radiation, extraterrestrial intervention??).

In the midst of the meeting I got an email from the board manufacturer with a picture attached. I opened the picture and smiled an ironic smile. Two of the engineers were at the white board

plotting the 6th derivation of Gauss's field equation, and I piped up......"Can I show you something?"
"Yes, go ahead" one said in an impatient voice.
There on the screen was a 6ft x 6ft image of a cute little spiral of copper with a HUGE RAGGED CHUCK-O-COPPER between adjacent turns, I turned to my supervisor and asked.........."Are you STILL going to tell me it is not a shorted turn?"
To his credit, he responded "Yup, you nailed it"
The board maker was not using sufficient agitation in the etching process and as this was an unusually delicate etch, they left copper in place where it did not belong.
In the future I got presented with somewhat less of the dog's head on its side looks.
There is simply NO substitute for getting into circuitry when you are young stupid and foolish....getting bit, burnt, and gassed teaches volumes more than sitting in a classroom deriving the 6th derivation of Gauss's field equation.

Bob WB0POQ"

Discrete regulators far better than IC types?

From Zetex, comes a design for a discrete regulator that out-performs the usual "IC" types. This can be scaled ansd populated with any devices you have to hand, not specifically Zetex types: but from experience Zetex devices not only "do what it says on the tin" but a whole lot more. - they are noticeably robust and withstand overload magnificently.

I would recommend you look up the whole AN51 application note for a full desription, by clicking this link and using the "GO" box, upper right. (Note: Zetex is now part of Diodes Inc.)

You'll find application notes of interest to the radio amateur in the library - have a look! The following is very gratefully taken from AN51:

AN51 Precision voltage regulation for ultra-low noise applications
Isaac Sibson

Issue 1 - October 2007 1 www.zetex.com

"Introduction
A simple discrete regulator circuit using Zetex voltage references and transistors can realise performance levels that are beyond IC regulators, whilst being of reasonable cost and with very little board space overhead. Although Integrated Circuit (IC) regulators dominate the marketplace through their combination of simplicity and low cost, there are situations where lower noise and better regulation are requirements for the highest level of circuit performance. In applications where performance is critical and efficiency and cost may be of a lower priority, such as data conversion in audio and video, instrumentation and low noise power for clock circuits, this discrete circuit can be immensely useful.

This application note details the design of a high-performance discrete regulator and shows how to easily tailor it for new or existing designs."

It's a simple question...

...but rarely, if ever, answered! "How many µF's do I need for the smoothing capacitor for a ripple voltage of XXX?". Easy, huh? Whoa there, Tiger, just think a moment about what's being attempted here: we have full wave rectified AC coming from our bridge, a shunt capacitor for "smoothing" and a load in parallel with the shunt capacitor to be fed with relatively "smooth" DC - i.e. with little ripple, mostly pure DC, plus very little AC.

To achieve perfectly flat, ripple free DC, with no AC component to drive any variable load (up to the limit of the circuit) *instantly*, requires an infinite gain amplifier that produces zero noise, and reacts in zero time. If you have of one of these I'd be very much like to know about it!

Most practical designers know from experience that if you want a 12 volt DC supply, at a couple of amps load current, you'll need 4700µF - 10000µF or thereabouts, and that's exactly where we leave the topic, yes? Well, what about that confounded nuisance, who wants to build a "direct conversion" receiver, eh? What's being asked for is considerably less ripple: even a few mV's are a bit much when we're looking at powering an audio amplifier with gain approaching 80 - 90dB!

It's often suggested that fitting a voltage regulator to the output, the ripple a'top the DC will be "chopped off" by the regulator: but, when tried, although the ripple is reduced, the voltage regulator isn't providing dead smooth, glass level DC. What gives?

Well... say hello to the real World! The regulator has to run its internal electronics from the power fed into the "input" pin, which has ripple: the manufacturer quotes "ripple rejection" figures, so acknowledges the basic problem: the regulator cannot provide a perfectly flat smooth DC - it can't be done. Why? Consider the job the regulator has to do: it continuously monitors the input voltage and changes the conductance of a power transistor to maintain a fixed output voltage. The power device that is the series regulating element has to be driven on it's base (or gate, if it's a power mosfet) by the internal electronics - all of which are subject to the ripple voltage to a greater or lesser extent. Every device in the control circuitry inside the regulator is susceptible to ripple on the input: differential amplifiers eliminate much of this ripple by common mode rejection, but each active device has capacitance (base - emitter, collector - base and collector - emitter), that the (AC) ripple loves to flow in and out of; and the power device is notoriously slow (try making a 2N3055 work on 200kHz!). I've only ever seen voltage regulators working at MHz rates in Harry Lythall's (SM0VPO) voltage regulator 78L05 amplifier:

http://sm0vpo.altervista.org/tx/317-tx.htm?

...where Harry uses an LM317 adjustable regulator as the active device, to 14MHz or thereabouts. This indicates the active power transistor is indeed a capable HF power device!

The point I'm making is that no voltage regulator will "chop off" ripple: yes, they will reject a fair amount of ripple, but a direct conversion amplifier at 90dB gain will easily pick up the AC ripple.

Of course, you can add more smoothing µF's, but you'll run into problems with huge capacitors appearing as a short circuit at first switch on. Soft start circuits are one solution, but the rectifiers get a hammering on every charging cycle as they have less and less time to deliver the top-up charge, to replace that discharged into the load. This can be a very big spike of current - and cause all sorts of hum problems as low impedance earthing may be hard to achieve, and big current spikes have masses of harmonics just itching to cause trouble.

It's a fair approximation that the basic relationships apply: $C \times V = i \times T$; this is the relationship between capacitance, volts, amps drawn and time the discharge takes place by calculating the energy stored in energy in Joules. C is in Farads, V is volts, I is the current in amps and T is the time between the charging pulses. For example, µF (10^{-6} Farads); Volts corresponds to the ripple, as shown by the capacitor voltage falling on discharge after each charge pulse; I represents the current drawn from the capacitor by the load in Amps; T is the time between charging pulses (50 Hz, full wave rectified, is 10mS or 10s seconds.

Components

Epitaxy - how transistors are made

Conundrums, conundrums: bipolar transistors are very mixed little beggars, they need extremely conductive silicon to keep the Collector - Emitter volt drop as low as possible (<200mV if possible), yet need high resistive silicon to get gain and low leakage amongst other things. So how do you make a transistor that in one breath is both highly conductive and highly resistive? That’s two polar opposites! Answer: use an extremely thin layer of high resistivity silicon deposited on top of highly conductive silicon substrate, that’s how - and there you meet the idea of epitaxial deposition of silicon.

The problem is, you can’t just plaster some high resistivity silicon on top of a substrate. Oh, no, life isn’t that simple! The silicon crystal lattice has to be preserved for the transistor to work, right through all the device layers. This means you need to heat the silicon substrate upon which you’re building transistors to just under melting point: thus there is enough thermal energy for the new silicon being deposited to “key into” the substrate lattice, and grow atom upon atom in exact locked crystal alignment. The temperature to do this is around 1173 ºC, but modern devices are using molecular beam and other esoteric technologies to run epitaxy at much lower temperatures.

There are many variations of the silicon lattice orientation, the Miller Indices describe the silicon crystal: 100, 110, 111, and so on. You can find some basic background into silicon device manufacturing and crystals at: https://www.youtube.com/watch?v=vQjdUzhFqA4

Suffice to say, the process to make epitaxial silicon takes place in a hydrogen atmosphere, the silicon wafers sitting on a graphite susceptor to accept the RF power from a coil below - much like an induction hob in a domestic kitchen, but a wee bit bigger - like 350kW of RF! The susceptor in the machines I worked on was 24” diameter, an inch thick, made of graphite coated with silicon carbide, to withstand the extremely corrosive atmosphere of hot hydrogen, plus a silicon source gas, like silicon tetrachloride or dichlorosilane. The heat breaks down the source gas(es) into silicon and hydrochloric acid vapour, which back etched the deposited silicon to a slight extent and demanded that exhaust gases of extremely hot hydrogen and hydrochloric acid be handled with some serious plumbing in thick wall stainless steel pipes, valves and toxic gas scrubbers to remove the hydrochloric acid and cool the hydrogen below it’s flash point before being released “up the flue”.

The one thing I haven’t mentioned is the dopant gases: you need these to make the deposited silicon N type or P type, depending on the devices being manufactured, These include Arsine (AsH3) phosphine (PH3), Stibine (SbH3) for N-type silicon; diborane (B2H6) for P-type. These gases are used in tiny quantities, and a good thing too: they are as lethal as bullets in parts per million concentrations. If you can smell them, you’re most likely on your way to a pair of wings!

They are very dangerous gases indeed; hydrochloric acid is nasty, but at least you’ve a chance of surviving if you’re unlucky enough to inhale some. Not the case with metallic hydride dopant gases that make the silicon P or N type! These are toxic in the extreme: inhaling a few parts per million results in death - as quick as a bullet.

Controlling, metering and safely disposing waste gases, materials and scrubber water is a tricky job demanding regular maintenance and testing; it's not unknown for gas scrubbers to develop small air leaks and explode without warning. Breathing apparatus is mandatory as is a working knowledge of high power RF, kV's and feeders made from ¼" thick wall copper tube, 6" diameter connected to a changeover switch (so one reactor can be heating up whilst the other is cooling down to be unloaded). The valve used was one mighty bottle: an RS3150CJ triode from Siemens.

With some tweaking of the feedback and tickling the filament supply, the epitaxy reactors I maintained regularly ran 18kV on the anodes, 270 amps in the directly heated filament cathode, 20+ amps in the anode, at around 100 - 700kHz. Mind you, over-running them at these levels they didn't last long; the filament sputtered tungsten off which resulted in the filament Amps falling as the wire got thinner. Boosting the filament transformer got a few more hours running, but eventually the filament just couldn't do the business and it was new bottle time.

Happy days!

Psst… having bother with that overtone crystal?

Trying to VXO an overtone crystal? Or that dratted oscillator won't start on high overtones? Try removing - or not fitting in the first place - the earthing wire to the tin case; and try a subminiature style cased crystal. The reduction in stray capacitance to ground might just do the trick.

Audio Topics

Speech processing

It's accepted audio technology that speech processing can give an extra OOMPH to your transmissions: but too much compression, clipping or limiting sounds - well, being honest - lousy to the receiver's ear. No matter what modulation system you're using, filtering to keep within acceptable transmitted signal bandwidths is important; as is no "flat topping" or other distortion. It just makes the received audio very hard to understand. Therefore, it's important to keep the speech quality as good as possible, without the limiting introducing too much distortion, yet coming into effect very quickly on spikes and releasing just as quickly so no faint signals are lost.

This is exactly the conundrum hearing aid designers face every day, and as amateurs we can learn a lot from these designs. After all, they try to make signals audible for those with hearing problems, just as amateurs try to dig faint signals out from noise, and limit loud noises, just as amateurs take phones off a bit quick sometimes!

A design I came across whilst hunting for a resolution to the paradox of distortionless compression with bandpass filtering "Q" and centre frequency that can be adjusted "on the fly" uses 3 OTA amplifiers: Operational Transconductance Amplifiers, where an input voltage controls an output current. The design is for micro sized on-chip amplifiers, but building with discrete chips is of course perfectly feasible so long as the amplifier specifications are similar enough. The design is at:

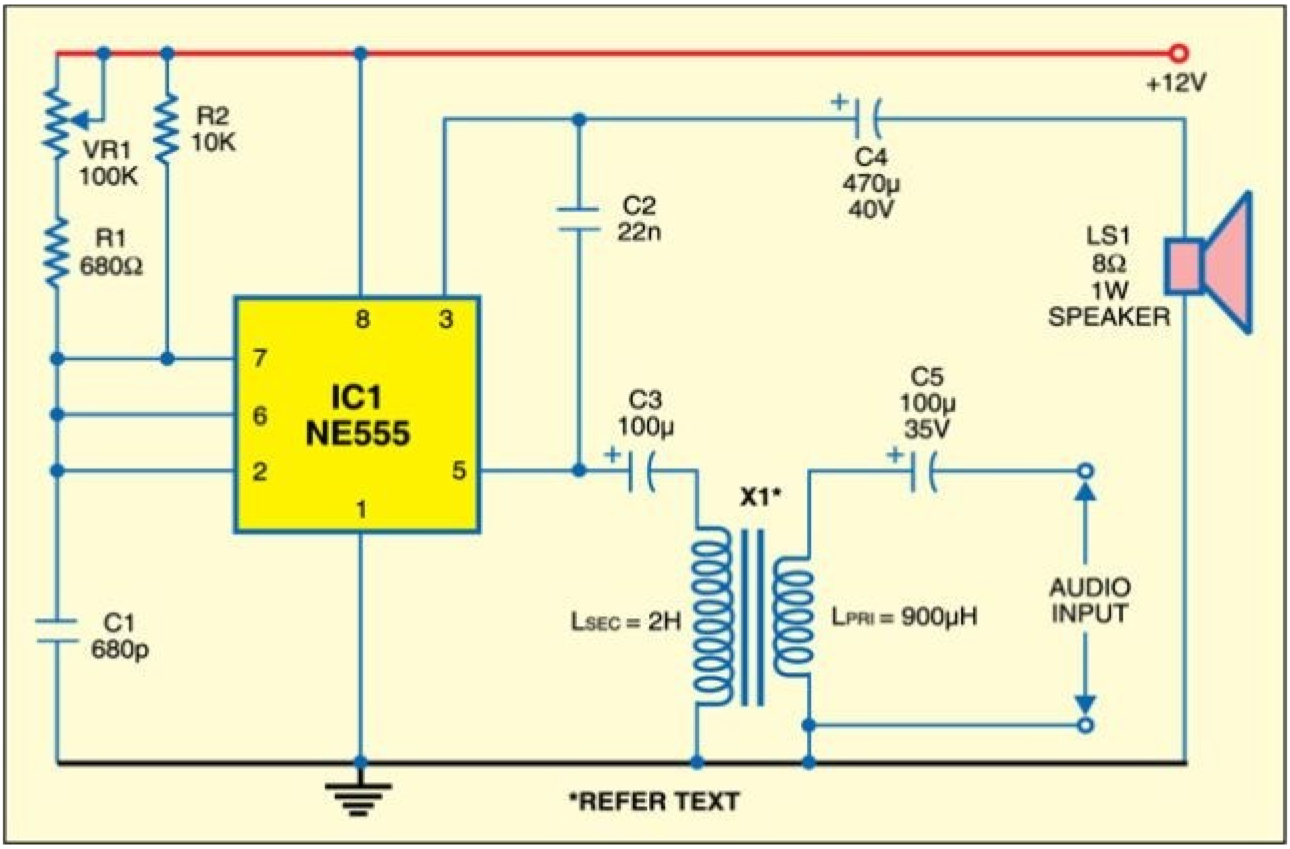
https://cpb-us-e1.wpmucdn.com/sites.dartmouth.edu/dist/f/1307/files/2017/06/A-Bandpass-Filter-With-Inherent-Gain-Adaptation-for-Hearing-Applications-r88h6p.pdf

The limiting is especially noticeable: the circuit need barely one cycle of audio frequency to “attack” and “release”. Amateurs could learn a lot by studying the hearing aids now being designed. After all, the most important part of a receiver is the listener’s ear, you can have all the fancy RF techniques you like, but if the signal can’t get into the listener’s brain via his ears “it ain’t no good to nobody”!

Another 555 PWM audio amplifier

We’ve visited this topic a couple of times but this design has an interesting twist: instead of driving pin 5 (control voltage input) with audio, this design uses a transformer to achieve higher audio drive on pin 5 for more output “OOMPH”. The transformer isn’t noted - but I’m thinking a miniature 5k to 8 ohm job, run backwards for step-up duty, will generate more pulse width modulation on the output.

Please note that the 555 appears in various disguises; the internal construction can vary quite dramatically from one maker to another. As ever a bit of “cut-n-try” will be needed! If any reader has the original of this diagram / article, so I can “refer text” then it would be very useful; the purpose of C2 is a bit of an oddball too as I can’t see the point of feeding hefty switching pulses back to the control voltage input an thus into the audio transformer.



Test Gear and Fault Finding

Psst… Need a Spudger?

Yes, a spudger is a good friend to amateurs: for opening those damned snap fit electronics cases or gizmos there is nothing better! They are cheap as chips, and oft used by the mobile phone fraternity for getting into those portable electronic nightmares.

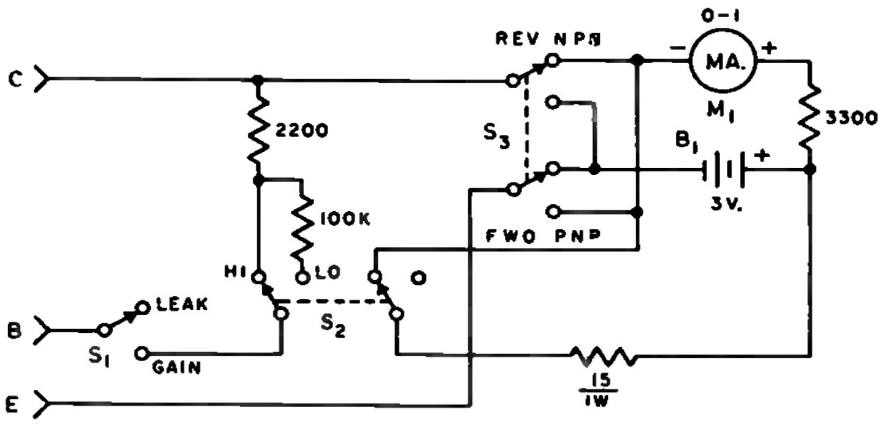
Our friends at Wikipedia say "A spudger or spludger is a tool that has a wide flat-head screwdriver-like end that extends as a wedge, used to separate pressure-fit plastic components without causing damage during separation."

So now you know, a quick Goggle search will bring up many variations for your delectation!

A simple transistor tester

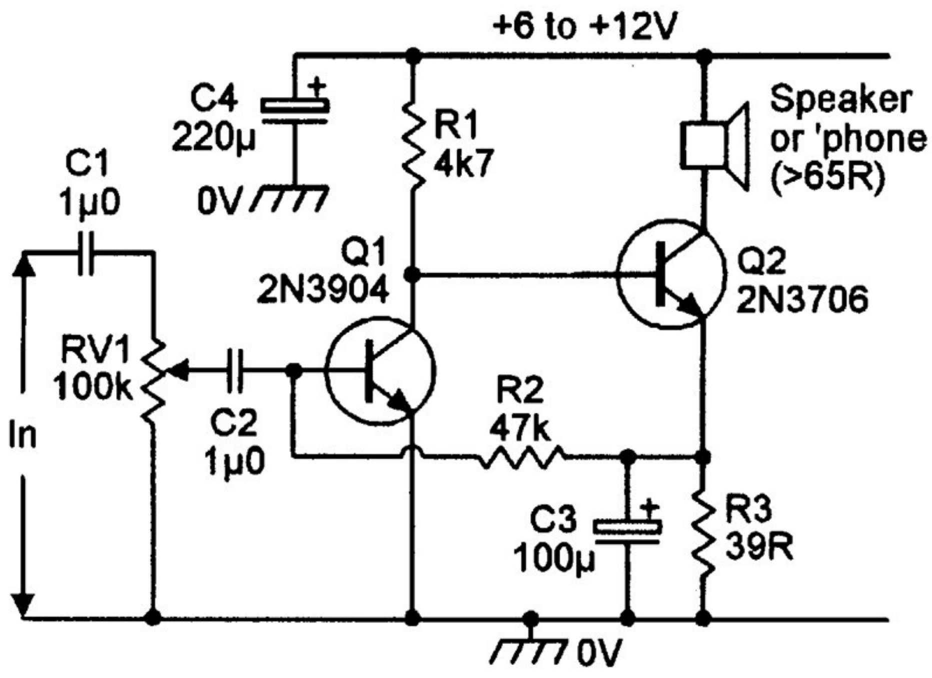
This design is dead simple, and with appropriate supply voltages, can deliver go / no go testing and a basic leakage test. Whilst modern silicon bipolar transistors are virtually leakage free, those junk box items might have suffered static damage or be just plain knackered, so a quick test to check (keep this little box on the back of your bench with some of those weeny croc clip leads for instant connections and a "push to test" button switch). The design is more or less generic but the diagram I believe is from an ancient QST or ARRL year book, to whom I give my thanks.

Note the design can be adapted to power mosfets: feed the top of the 2200 ohm base bias resistor from a pot connected between "C" and "E" , the wiper providing a variable voltage to the "B" terminal to bias the gate "on" so the actual bias point for conduction can be found. The mosfet Drain => C, Source => E, Gate => B.



The first thing to test...

...in a "dud" circuit, is the *power supply*. Be it motor boating, noise, distortion, whatever, TEST THE POWER SUPPLY IS DELIVERING THE EXPECTED VOLTS ON LOAD. I would bet 95% of all faults, in a previously functioning circuit or system, are power supply issues! It's wisest to start at the power supply output(s) and then diligently track the volts downstream to every destination. Take a look at the circuit below (it's from the bipolar amplifier cook book, many thanks). It's a nifty audio amplifier that forms the basis of many audio output stages.



You can see the supply voltage is 6 - 12 volts… well, is that what you read on your Whizzo Multi-Meter, set to read DC Volts, with your meter negative probe on the power supply "0 volt" negative output terminal, to measure:

- the power supply positive output terminal
- the positive plate of C1
- one end of R1
- at least one terminal of the speaker

If, and ONLY if, you get all these readings as correct, can you be sure the positive power supply is reaching all the points of the circuit. Similarly, with your meter negative probe on the power supply "0 volt" terminal do you read zero or thereabouts - a few mV's is OK, it indicates the volt drop along the return leg - on the following nodes:

- the chassis connection of the input - usually the screen connection of the input cable
- one end of RV1
- the emitter of Q1
- the negative plate of C3
- one end of R3

If, and ONLY if, all these voltages are a few mV's (which helpfully illustrate current is flowing back to the power supply) can you be sure the circuit is being supplied with the required volts to function as the designer planned. If the circuit still misbehaves, then go deeper in fault finding, keeping these facts to mind:

- the most common component to cause bother is an electrolytic, they dry up, lose µF's, develop a high series resistance.

- Electro-mechanical items wear out, drop to bits, melt under fault conditions (imagine the effect of the wire from the speaker to Q2 collector shorting to 0 volts?).
- variable resistors are notoriously short-lived: keep that in mind, those who would use potentiometer connected variable resistors to control varicap tuning - they can be the source of some very weird faults as the wiper losing clean contact to the track can create a non-linear (rectifying) element in the circuit.

Only once you've proved the power supply is good, and power is getting everywhere it should, do you dive in and start analysing the circuit and it's corresponding node voltages. The above is a very simple circuit; imagine if you're faced with a much more complex circuit, and on several PCB's for instance?

ALWAYS do your power supply checks as illustrated and you'll nail most faults in double-quick time. That doesn't sort out all problems, I accept; but you'll eliminate a huge amount of trouble - once you've eliminated all possibilities, whatever's left, however improbable, must contain the problem. Well, it always worked for Sherlock!

Resistance Signature Analysis - "cold testing"

Most multimeters are good for testing "ohms" - use that capability to help you identify areas where faults lie, by testing whole blocks of circuitry: get those probes across the electrolytic (or input power Molex connector, etc.) that's the de-coupling capacitor for that section! The idea is that the entire block fed from those points will have a resistance reading that you can compare to the value you read when the circuit was working properly. Well, you DID measure and note it when it worked fine, didn't you? And watch your meter's polarity on ohms test: some meters reverse the polarity. Test a known good diode to quickly reveal the prod polarities. The only snag is you have to wait for the electrolytic to charge; but it's a small price to pay as you're testing a huge block of circuitry.

Take the little audio amplifier above as an example. Connecting your meter on ohms across C4, power OFF of course, then allow C4 to discharge for a few minutes - the time is exactly that needed to brew a mug of tea - and you should read R1 (4k7)+ Q2 base emitter + R3 (33R). If it's much different than this, your one test has identified a possible fault.

You can go further than this: look at Q1, and test on ohms, negative probe still on C4 negative, each pin of Q2. The base should read ~ 47k; the collector should show 4k7 + Q2 base-emitter + 33R, but you'll probably see C4 charging up, swamping the ohms reading for a few moments; the emitter should be solid zero ohms. If you had noted the results in a chart <u>before</u> putting the circuit into service, you could compare your results and see if any degradation has occurred. Make a simple spread sheet or chart, and note the resistances to 0v. And test to +ve supply from each pin or node for future reference.

Taking this further, you can test IC's by noting resistance readings from every pin to both ground and supply volts, and comparing with "working" results taken previously. It's a good idea to use your meter in a low test voltage mode which can't forward bias a PN diode junction; many IC's have clamp diodes on input and output pins to avoid damage from static, over-volts and the like which might swamp the resistances. This is a very powerful test algorithm; but you can see if it's done purely by hand, it can be very time consuming (to say the least). A work colleague of some years ago (thanks, Ray W.) found that ohms testing across the power supply pins of an IC would find duds: this is particularly true for CMOS digital IC's, they are virtually open circuit unless faulty. These were, mind you, the old 4000 series; I haven't tried this on TTL or 74CXXX chips. I tended to do a quick ohms test round all the output pins; a blown output "totem pole" driver would show either short to +ve / Vcc or ground. This technique finds op-amp output faults too.

These techniques are used in computer controlled "bed of nails" test stations to identify dud PCB's, and can fault find to component level, indicating the dud part with a spot of light or an ink dot. As amateurs we don't quite need this level of automation; but resistance signature analysis is a very powerful tool for those involved in amateur radio gear test and servicing.

Use some standards...

When building gear, it's a great idea to standardise your wiring, like below:

Wire Colour	What it does
Yellow	Heaters
White	Cathodes
Grey	AGC and Negative grid bias supply(s)
Red	HT Positive supply(s)
Pink	Stabilised Screen supply(s)
Black	HT Negative supply
Blue	Control Grid
Green / Yellow	Chassis Earth

Where two different voltage sources are employed for AGC and Bias then number "ident" sleeves (or coloured insulating tape "collars") are fitted at appropriate points along a wire run, i.e. after entering a screened box or sub-chassis - the collars following the resistor colour code, and fitted as thin strips of insulating tape cut from the wider roll. Thus a grey wire with black collar = bias supply zero; with brown tape collar, bias supply one, and so on. The same identification is used where two (or more) positive supplies or two (or more) screen stabilised voltages are employed.

Control grid wiring might often be in screened cable, so again coloured insulating tape collars are used as screened cable doesn't often come in any colour other than black.

Transistor circuits rarely need such identified wiring; but red for positive supply and black for negative is a good idea, saving time and effort in fault finding or, that most frustrating job, de-bugging a circuit you've just designed and built.

It's a fact, beyond doubt, the hardest faults to find are wiring errors or construction errors *you've done yourself*. The human psyche that prevents you from fault finding your own work!

Antennas

From Frank Barnes

who prompted me to see some notes on antennas, this I did, so take a look at:

https://www.qsl.net/va3iul/

which would take a lifetime or two to absorb, and...

http://www.w3pga.org/Antenna

...which would account for a few more lifetimes too! All good stuff: “seek and ye shall find” is a good principle!

Condensation in "balun" antenna matchboxes

It’s one of those perennial questions: do I drill a "vent" hole in my bottom-of-the-mast matching unit / transformer / balun / what-have-you? What you’re really asking is about condensation and Relative Humidity. It’s a topic not many amateurs understand, but a few words of explanation and a look at what our friends in the power distribution (overhead lines division) do might help.

Here’s the gist of it. You’ve made a neat “matchbox” that does the business for your super new Whizzo Wonder Sky Blaster, and you want to box it up neat and tidy to (1) stop the kids sticking fingers, sticks, the dog’s tail, etc. into the works; (2) keep next door’s cat / ferret / kids / dog from doing something “orrible” in it (and themselves); (3) preserve the electrical magic smoke by keeping the lashing rain and gales that we call summer here in the UK out; (4) stop condensation causing short circuits and corrosion. I think that’s about it, but no doubt your location will have other nasties just waiting to get at the matchbox innards.

Some basic facts for consideration: air, the stuff we breathe, has water in it, as water vapour, and this water creates the “humidity”. The amount of water air can carry depends on the air temperature: warm air holds more water than cold, and the air pressure. If you try to put too much water vapour into air, or the air temperature drops, or pressure falls, then the air can’t hold the water vapour: liquid water condenses on surfaces. This is called “saturation”, the air has so much water it can’t take any more. Thus we measure how close air is to condensation (saturation) by “Relative Humidity”: that’s the % of saturation the air currently is. 100% Relative Humidity = condensation, and that’s an end of it. Until the weather turns warmer, warm air can hold more water than cold, so the condensation becomes water vapour in the air.

Now all that means one thing: if you mount your matchbox in a sealed box with a small vent hole, then as the weather turns cold of an evening, the air inside will dump it’s water as going cold has saturated it. The air inside has a connection to the air outside, and that, in the UK, is generally pretty much wet. So a vent hole guarantees condensation, that’s a fact. As atmospheric pressure changes, air with water vapour in it is forced into the enclosure; vice versa when outside pressure falls, air is drawn out. Consider too the diffusion of gases: no matter how small the hole, molecules of air and water vapour will intermingle - and the smallest hole will allow millions of air molecules to pass to and fro!

Now consider no vent hole. The cables are entering and exiting via sealing glands, no outside air can get in, or water for that matter. Will there be condensation inside the box on a very cold night? “Yes” if the box was sealed up with humid air inside, “No” if the box was sealed up in a very low humidity environment. How can you create a very low humidity environment? From dried compressed air, or nitrogen, like they do when making double glazing sealed units. Not an easy job for the amateur! You can buy desiccant material, which is designed to soak up water and hold it, so you can assemble your matchbox in your kitchen, bung in a bag of desiccant and seal her up tight as a drum: the job's a good 'un, if (and it's an enormous IF!) the box seals are completely air tight (not easy, no sir).

Enter our power distribution engineers, and let's see how they handle 415 volt 3 phase electricity on overhead lines, up on top of poles. The use **big** ceramic covers to protect their joints and lead-ins, open to the elements at the bottom, water tight at the top, the outside air can blow freely around them. Rain doesn't bother them; the high voltages are safely up inside the ceramic covers. Nor does temperature; being wide open, the air in the covers is at the same temperature as the air outside, and pressure: no problem there. The only time flash-overs happen is when dirt in the air makes a conductive path across the insulation, but this is rare as the dirt tends to fall due to gravity and won't stick to the dry (and draughty!) surfaces up inside the ceramic covers.

The answer is, for amateur matchboxes, mount them in the top of an inverted waterproof box, with an open bottom covered with mesh and / or gauze. Run your wires in and out through holes in the mesh, forming drip loops appropriately to prevent water ingress but the box being closed at the top and the components tucked away up inside, you won't get problems.

Make your coils from enamelled wire and use transformer varnish (from various online sales outlets) to coat the windings, seal carefully all coax cable ends but keep in mind employing quality BNC ("Bayonet Navy Connector") or , if you can get them, TNC ("Threaded Navy Connector") or gasket N-Types; form the coax into downward facing loops to deter water ingress into the open ends - but DON'T coat variable capacitors (for obvious reasons…).

The open bottom lets the innards breathe, the box above keeps the rain off, and the mesh keeps the kids and bugs out. Hopefully!

ATU / matching and Cos φ, the Power Factor

Don't over-think it, low dipoles and multiple "fan" dipoles for other bands adjacent modify the impedances far more than anything else! VNA's and the like are all well and good, but if your SWR reading is around 2:1 you're not going to get much return for the effort in getting it lower. It's very easy to get waylaid by measuring everything in sight, then trying to decipher the results. I'd bet my shirt that as the weather changes, the wind blows the wires, next door erect a steel mesh fence, your "exact" measurements are way off!

Most amateurs far prefer the ATU / matching network to be adjacent to the transmitter: inside, warm and dry, easy to tweak is thought better than going outside to adjust the match at the aerial. This means you've no idea what's going on in the coax - or what's actually getting to the bit of sky wire that's doing the radiating. One thing you are sure of: your coax in this situation isn't a feeder - it's part of your sky wire, with RF on every surface! The antenna starts immediately after the matching unit, so put it at the feed point of your antenna!

Albert Einstein is alleged to have said "make things as simple as possible; but no simpler" and that's good advice. You can measure any variable you want, with whatever esoteric gizmos you fancy; it's the translation of those measurements into real life electrical components that's the hard bit!

Truth be known, you only need basic tools, and some electrical engineering knowledge to find out where the optimum conditions are with your antenna. If you add at the feed point some equal capacitance to each half of your dipole and the indicated match improves, your dipole wires are too long; if adding capacitance makes the match much worse, they are too short. The electrical engineering behind this is proven: it's all to do with resonance and AC theory. For your dipole (or single wire half wave end fed come to that), the best radiation occurs when the wire is a resonant multiple of $\frac{1}{4}\lambda$ - be that mechanically OR electrically - and is described as Power Factor by electrical engineers. Power Factor describes watts i.e. when the wire is truly resonant. If the wire is too long, it's inductive and the Power Factor falls; similarly if the wire is short, it's capacitive and the Power Factor falls.

Only real watts radiate, any capacitance or inductance still draws current, but out of phase with the voltage: it's reactive current and won't radiate! Reactive power is measured in VAR's, “Volt Amps Reactive”, and it's your job to ensure you maintain a Power Factor of near as you can to one. For reference, Power Factor = cos φ, and Watts = VI cos φ where φ = the phase angle between amps and volts. If the amps are in phase with volts, then cos $\varphi = 1$. All watts, zero VAR's!

Electrical engineers frequently have to compensate for poor inductive Power Factor loads - motors are notoriously inductive and cause bad lagging Power Factor on the distribution network. This is a universal AC theory: it doesn't matter whether its at 50/60Hz, or 1 GHz, Power Factor still applies! To correct poor inductive (lagging phase angle) Power Factor, electrical engineers add some VAR's of opposite phase (leading phase angle) so the reactances cancel out, leaving pure watts being drawn from the distribution network. In radio terms, to cancel out inductance (lagging Power Factor), add capacitance (leading Power Factor) in equal amounts thus creating a purely resistive load (resonance). These are fundamental relationships of AC theory, and are just as true for amateur radio operators as to power electrical engineers.

Keep in mind that this gets the best resistive load; and that load might not be 50 ohms! Maximum power transfer occurs when the resistance of the transmitter equals the resistance of the load; you might need a transformer (of some form) to match the antenna to the transmitter. The radiated signal will be highest when these resistances are equal, so you've two jobs to do: (1) get rid of the reactive component of your antenna and (2), make sure the antenna resistance equals the transmitter resistance (usually 50 ohms, but can differ in some instances - particularly home brewed gear).

SWR can make you stupid...

...is an article written by Eric Nichols KL7AJ: I asked Eric if I could quote it, he was happy with that, and commented it was part of a bigger project. The article is - to put it mildly - superb. I've been involved with transmission lines of one sort or another all my working life, and Eric's simple descriptions and examples make transmission lines much more understandable.

I mentioned to Eric I was thinking about antenna tuning as “Power Factor Correction” (see previous, above) and he agreed with me: it's a universal AC principle and applicable at any frequency, and describes getting as many real watts into a sky wire as possible just as much as correcting the lagging Power Factor of an induction motor.

That's the gift of amateur radio: although RF power can be an unruly beast (if you let it) she still has to dance to the music of the Universe, and a few basic electrical principles go a long, long way to understanding what's really happening.

I have put a link to Eric's article HERE. It's from eHam, whom I thank very kindly. If the link won't work for you, see: https://www.eham.net/article/23317

Balanced or unbalanced?

Imagine the scene: you've a transmitter feeding an antenna via a twin wire feeder, and you're concerned that the currents in each of the feeder line wires aren't equal; i.e. the line is unbalanced. The same principle - sort of - applies to coax, the signal is supposed to be entirely contained inside the outer screen.

Frank Barnes, W4NPN, pointed me towards Lloyd Butler's (VK5BR) work on measuring line currents: see HERE or if the link won't work:
http://users.tpg.com.au/ldbutler/Line_Diff_Long_Meter.htm

Lloyd's system is to insert toroidal current transformers into each line (or coax inner & outer) and observe any difference - this difference being taken to be the "unbalanced" current. Lloyd gives a simple schematic which shows how the current that represents the imbalance returns to the transmitter without going through the appropriate feeder path.

This is very similar (if not identical?) to a modern "ELCB" safety trip: it looks at the live and neutral currents, and if any difference in either causes a trip, this being assumed to be earth leakage. The measurement is made by a single toroid current transformer, the currents flowing "forward" being cancelled by the "return" current, the magnetic fields from each current cancelling. This is to ignore standing waves, as these don't bother 50 / 60 Hz ELCB's - the wavelength is 6000km / 5000km! I think unbalanced twin wire feeders will show a reading equal to the imbalance if the twin feeder is passed through a single current transformer.

One other thing crosses my mind. As Eric Nichols, KL7AJ, points out in his write up about SWR meters, it's a fundamental fact that a wire can't have two different voltages on it in one place (or two different currents, for that matter). It's an interesting measurement that Lloyd proposes on coax cables: measuring the core and screen currents by separating the screen from the core into two separate wires, each going through a toroidal current transformer causes me think of how coax works by skin effect keeping the RF current on the OUTER of the INNER (core) conductor, and the INNER of the OUTER (screen) conductor.

The RF energy travels in the insulating medium between inner and outer conductors, guided and constrained by the conductors; it manifests itself in currents *on the surfaces* of the coax conductors. Lloyd's measurement to see if RF current flows in the coax core and a smaller proportion of this current returning in the screen because of imbalance in the antenna load (by an external wire and resistor *outside* the current transformer to create artificial leakage perhaps?). I believe a *single* current transformer would give an imbalance reading, as per the ELCB imbalance principle.

I have absolute respect for Lloyd, I'm sure it's me that's missed or misread something. Maybe I'm oversimplifying things… and that's *exactly* what Einstein tells us not to do!

I'd welcome any feedback, please feel free to enlighten my darkness.

Lightning strikes...

I worked on contract for a security alarm manufacturing company in Rossendale, in the Technical Support group and in between phone calls from customers I analysed faulty items returned. One aspect of this work was examining dud land line telephone diallers. These devices had to comply with British Telecom regulations as BT (Now “Open Reach”) are quite fussy about what’s connected to their network.

This work taught me some salient facts about lightning strikes - either striking directly onto the phone line or induced in the line by nearby strikes. These I list below:

(1) Direct strike: dialler blown to smithereens, nothing much left of gas discharge tubes, spark gaps, wiring, PCB, et al;

(2) Induced over-volts: Some bits of the dialler still in one piece but with big holes in IC’s, circuit boards, gas discharge tubes blown to bits, PVC wires blown apart with no insulation left.

Now some simple engineering facts I observed in my working life:

- A spark to jump 1” needs 30kV between needle points; from flat plates or wires you need considerably more;
- Lightning strikes contain vast energy: take a look at the copper bars used to Earth the lightning rod on a tall building or church spire;
- Gas discharge tubes can shunt not too many Joules of energy before they explode, see <u>HERE</u>;
- Gas discharge tubes are slow to switch on;
- Forget zeners - they are but mere chaff in the wind when hit with a few HV Joules;
- Spark gaps (like a ¼ λ stub, for instance) need plenty of kV’s to flash over, and once arcing can have many hundreds of volts across the arc, all of which impinge on your radio gear;
- A PCB holding gas discharge tubes and the like connected to a sky wire is likely to explode / catch fire / vapourise in strike conditions;
- The strike, in running to Earth to equalise the electrostatic charge induced in the ground, can cause Earth wires of adjacent equipment to inject many hundreds of Volts (if not kV’s!) right up the circuit board’s Earth connection (it’s called “ground bounce”). Recall Corporal Jones in Dad’s Army: “They don’t like it up ’em - they DO NOT like it up ’em!” Certainly true for PCB’s!

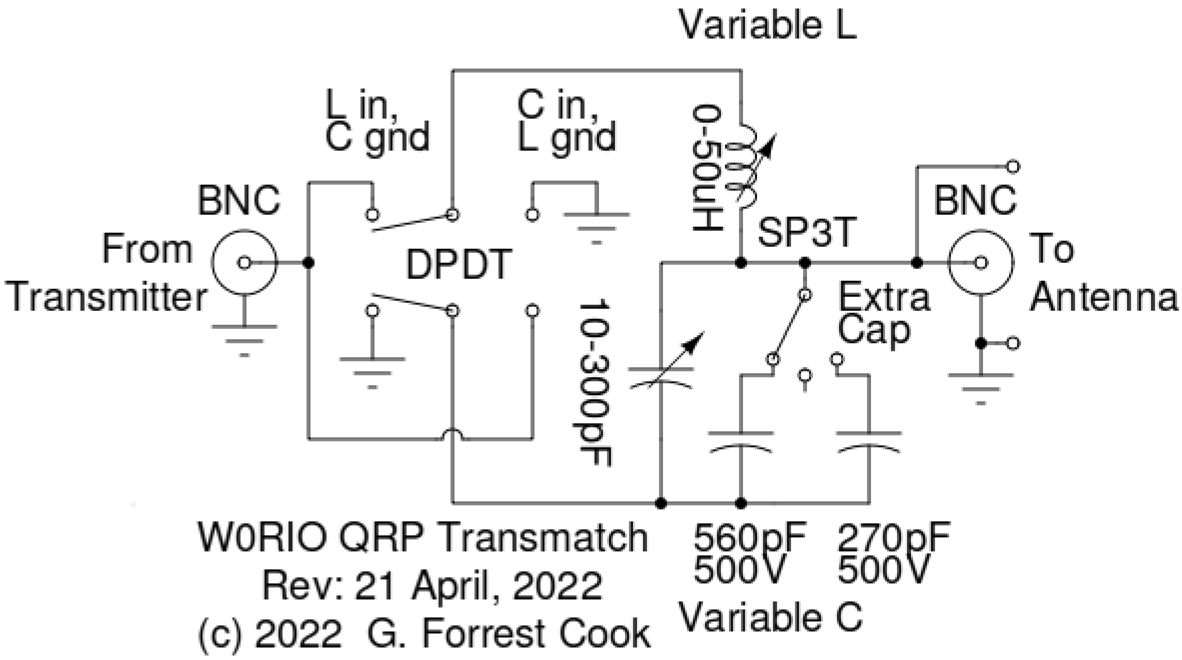
In short, if you live in lightning alley and get a lot of strikes every lightning season, don’t muck about: switch your amateur radio gear to valves, as at least they don’t object to a few kV’s and withstand flash-overs without too much damage.

Slowly induced or wind generated static charges, which can easily be many kV’s on an outdoor dipole, it’s a very good idea to connect each antenna element and feeder(s) to a deep planted Earth rod - (which any half decent antenna installation should always possess) via 1 - 10 MΩ hefty HV resistors (NOT tiddly ¼Watt jobs).

An ATU of thorough pedigree…

From that very capable constructor, Forrest Cook, presented below:

QRP Antenna Tuner



Introduction

This project is a QRP (low power) antenna tuner (trans-match) for use in the short wave amateur radio (Ham) bands (3-30 Mhz). It allows a wide variety of antennas to be connected to a low or medium power transmitter or transceiver. When the circuit is properly tuned, the maximum transmitter power will be delivered to the antenna. The tuner is normally is used in conjunction with a standing wave ratio (SWR) meter, this meter may be built in to some transmitters. This is an updated version of the circuit, one extra switch has been added to greatly increase the tuning capabilities. See the Original Circuit for reference, note that the photos are from the earlier version of the circuit.

This tuner is fairly efficient and it is very simple to build and use. With the parts shown, the maximum power through the unit is approximately 50 watts. The tuner is small enough for backpacking and is useful for matching many of the types of antennas that one might set up on a camping trip.

The tuner can be used for getting a more perfect impedance match to an antenna that is resonant at or near the frequency that is being used. It is also useful for using an antenna that is designed for one frequency (band) with a transmitter that is set to a different band. A good rule of thumb is that it is usually much easier to run a lower frequency antenna with a higher frequency transmitter than vice versa.

Theory

The purpose of a trans-match is to match the impedance of a transmitter, typically 50 ohms, to an antenna system with a different impedance and reactance. A trans-match can add series or parallel capacitance and inductance to produce a more resistive (non-reactive) load to the transmitter. The circuit in this trans-match consists of a variable inductor in series with a variable capacitor (L-network). The transmitter typically connects to one end of either the variable capacitor or the variable inductor. The antenna connects to the junction of the inductor and capacitor. The input and output connections can be swapped for more matching possibilities.

Construction

The tuner was built into an old aluminium project box that had been used for at least one prior project as indicated by the numerous holes. This box was just large enough to hold this tuner circuit, a larger box would make construction easier. A rectangular piece of aluminium was added to the front of the box to cover up some of the old holes. Several new holes were drilled in the box for mounting all of the components required by this project.

When laying out the parts, it is a good idea to leave room around the sides of the variable coil and capacitor to prevent RF arcing. Be sure to keep both sides of the variable inductor insulated from the box, you may need to use insulated bushings (non-conductive washers) on the inductor's shaft. The variable capacitor should also be isolated from the box, insulated washers were used to mount the capacitor's shaft to the box. Insulated shaft couplings can also be used if you have them. Use heavy hook-up wire to connect the various components together, 18 gauge or heavier tinned copper wire is recommended. Use the shortest wire lengths possible. Teflon insulation can be used on the wires, although it is optional.

Use

Connect the transmitter output to an SWR meter, connect the SWR meter output to the input of the antenna tuner, and connect the antenna to the output of the tuner. An SWR meter that has two meter elements is much easier to use than one with a forward/reverse switch and a single meter element. Antennas with a coaxial feed line can be connected to the BNC output connector. Random wires and antennas with balanced feed lines can be connected to the banana jacks. An external balun transformer can be inserted between the tuner and a balanced feed line if one is available. The transmitter should be connected to a good earth ground at its chassis if a ground is available. Random wire antennas will typically work the best if a counterpoise wire is connected to the ground terminal and run in the opposite direction of the antenna wire.

With coax-fed antennas, the best location for an antenna tuner is the point where the coax feeds the antenna, or as close to that point as is practical. This can usually be achieved with vertical antennas. With horizontal antennas such as dipoles, it is usually difficult to mount or adjust a tuner that is located at the antenna feed point, so most people will locate the tuner on the transmitter side of the coax. When using a dipole at a frequency that is not at a resonance point, the coax will become part of the antenna system and will vary the radiation pattern.

There are two normal ways to use the tuner, feeding into the inductor or feeding into the capacitor. Either of these two methods can be selected by the DPDT switch. The antenna is connected between ground and the junction of the inductor and capacitor. In cases where a good match cannot be found, it may be possible to find a match by connecting the transmitter to the antenna connector and the antenna to the transmitter connector.

Start by feeding the transmitter into the inductor with the DPDT switch. Set the extra capacitance switch to 0 (center), adjust the variable capacitor to near the minimum capacitance. Adjust the inductor to near the minimum inductance. Transmit a CW carrier and observe the SWR reading. Adjust the capacitor and inductor and try to find a setting where the forward power peaks and the reflected power dips. If the best match is found with the capacitor at the maximum value, switch in either the 270pf or 560 pf capacitors and re-adjust the variable capacitor and inductor. If you still cannot find a good match, change the DPDT switch to the other setting to feed the transmitter into the capacitor, then start the tuning process again. Once you achieve a good match, make a note of the trans-match settings for the particular frequency and antenna combination for future reference.

A well-matched condition is usually associated with a dip in the swr reflected power that coincides with a peak on the swr forward power. In some cases, the reflected power will dip but the forward power will not be at its peak value. If this happens, you may get more power to the antenna by tuning for the max forward power while accepting the fact that there will be a small amount of reflected power. When using a tube-based transmitter with a PI output network, it may be necessary to find the best match with the antenna tuner, re-tune the transmitter's output tank, then tweak the antenna tuner for the peak match.

If your transmitter has an adjustable output power level, it is a good idea to adjust the antenna tuner using low power. When a good match has been found, increase the power and re-adjust the coil and capacitor for the lowest SWR. Be careful not to leave the transmitter on for too long in the unmatched condition, doing so can damage a transmitter's output transistors. Tube-based transmitters are generally better able to handle mis-matched conditions for longer periods.

Caution: higher power transmitters can generate high voltages within this circuit, don't touch any of the internal wiring or the antenna wires when the transmitter is operating. If the roller inductor's adjustment shaft is connected to the inductor's wiring, the shaft should be mounted so that it does not come in contact with the metal box. The set screw on the knobs may become electrically hot during use, it is a good idea to cover them with a drop of hot-melt glue or candle wax after the screw has been tightened.

Parts

- variable inductor (roller), approximately 0-50 uH
- variable capacitor, 0-300pf or 0-360pf, can be scavanged from an old tube radio
- DPDT switch
- SP3T rotary switch (or center-off SPDT switch)
- 270pf, 500V silver mica capacitor
- 560pf, 500V silver mica capacitor
- two BNC connectors (or PL-259, the connector that won WWII, if you prefer)
- two banana jacks (optional)
- two insulated plastic knobs
- miscellaneous screws, nuts, and washers
- solid hook-up wire, 18 gauge or similar
- aluminium box, big enough to contain all of the components

The variable inductor may be difficult to find, the best places to look are at ham radio swap fests and surplus electronics parts companies. Variable inductors are preferred since they can be fine-tuned easily. A fixed inductor with switched taps or a flexible wire with a clip lead on one end can be substituted. If you plan on using a fixed inductor, an air-core type is recommended. A toroidal ferrite core inductor will also work, but the core may absorb some of the available RF power.

See Wikipedia's Antenna tuner article for more background information and Ulrich L. Rohde's (N1UL) antenna tuner circuit which can tune a wider range of antenna impedances. Ulrich Rohde has also published a more detailed article (zip) in German.

Mr. Veritasium and his "question"

Whether or not this is a deliberate "teaser" or a genuine attempt to enlighten the darkness prevalent in electrical engineering, I don't know; this is an area of electrical theory "where there be dragons", and a lot of very strange people (that's me included, I should add) who deal with that electronic hinterland that is "neither fish nor fowl" as Shakespeare has it - the World of fast pulses and transmission lines.

As radio amateurs, we are more or less familiar with bunging RF signals down transmission lines and reflections, SWR and the like: but keep in mind a pulse, with an edge time of 1nS, represents a bandwidth to transmit it without distortion of (roughly) 2 divided by the 10% to 90% rise time. Thus a 1nS rise time edge requires a circuit of bandwidth capability of 2 divided by1 x 10^{-9}; i.e. 2GHz. That's well in the microwave region, just as a 1pS rise time represents a bandwidth of 2 divided by 1 x 10^{12}Hz, a staggering 2THz.

You might think generating such speeds is well beyond practical means; well, you can do it by using a small blob of mercury and a needle as a switch: the mercury has an incredibly fast open and close electrical characteristics. I don't recommend you play with liquid mercury; it's a shortcut to the Mad Hatter's mix of craziness and toxicity. No, just get a "mercury wetted" relay, that will do just fine. Of course, the switch might be fast, but you've got wires and connections to get the signals in and out of such a switch, and that's the added L, C, & R that drops the speed. The switch itself is incredibly fast.

Mr. Veritasium posed a question on YouTube that involved - at first glimpse - two 300km long open wire transmission lines, to connect a battery to a light bulb. This is a theoretical light bulb; it responds instantly, and needs only the merest sniff of juice to light her up to full brilliance. The question was, "how long after closing the switch does it take for the light bulb to illuminate?".

See: https://www.youtube.com/watch?v=bHIhgxav9LY and my diagram #1 (below a bit)

My initial thought was to look at the time delay round the loop, i.e. two one second delays - but no, this isn't what is proposed. The positioning of the bulb and the switch are the key: Mr. Veritasium proposes the time delay for energy to cross the 1 metre space between the switch and lamp is the delay; about 3 - 5nS (roughly a foot per nanosecond).

Now consider my picture #2. This shows the condition of the switch, lines and lamp after connecting the battery. The positive side of the battery has now made all the wire marked "+" positive with respect to the short wire connecting the switch wiper blade to the battery (voltage source) negative.

The switch closes as shown in my picture #3; the falling edge races out to the right, current flowing to neutralise the "+" charge on the wire and eventually the negative edge reaches the lamp, after surmounting the discontinuity caused by the folding at the right hand end. Once the edge has reached the lamp, there is full battery volts across the lamp, and she lights up to full brilliance.

Meanwhile, Mr. Veritasium believes, the electric field created by closing the switch crosses the 1 metre gap, and initially lights the lamp (maybe a bit dim…!) in roughly 3 - 5nS. This I struggle with; any capacitance across the 1 metre gap to a very short length of wire between battery negative and switch wiper will be orders of magnitude less than the line capacitance, both line to line and line to earth (roughly the same as free space, 8.854 pF per metre). Mr. Veritasium thinks the electric and magnetic fields cross the 1 metre gap after t = 0 and this proves the whole of the energy is transmitted more or less instantly, not in the wires, but in the E and H fields across the 1m gap.

Due to the storm of protest Mr. Veritasium aroused with his thought experiment, he set up a short line version of his theoretical circuit, and by using a fast oscilloscope, produced what he claimed to be proof of his concept. I've seen these signals and measurements in his video: he used - as far as I could see - single point 'scope probes, the type where you clip an earth lead to the "common" and touch the tip of the probe to the point being examined. A low level step appeared on the oscilloscope screen a few nS before the expected exponential rise of voltage which eventually produced full power at the lamp terminals. Mr. Veritasium could have used a fully differential 50 ohm probe set, that needs no earth clip "common" connection - but these are as rare as hen's teeth, and (probably) wouldn't "prove" his point - or did he "float" his oscilloscope, and thus pick up noise?

The whole point of measurements in an experiment is that the measurements don't disturb or alter the experiment in any way. This is ignored in Mr. Veritasium's experiment: indeed, he significantly alters his results by having the oscilloscope and probe leads draped all over the critical bit of the circuit. The outer screen of the probe leads would easily pick up the "wanted" signals (see Ivor Catt's notes on "crosstalk" at: http://www.ivorcatt.co.uk/em.htm) and these "wanted" signals, coming into the load resistor (that replaced the "magic" light bulb) from opposite directions, thus would ADD in a differential probe; not to mention dangling 20pF / 1M-ohm oscilloscope probes on the end of an open wire line. One other point: just where does Mr. Veritasium connect his oscilloscope probe "ground" clip(s)? Battery negative? I think not; this would shunt the 300km line with the probe's 1M-ohm and 20pF!

Too many questions, a dodgy experimental measurement, absence of a clear diagram to show how the measurements would not disrupt the results expected. Not good, not no how!

We now get the situation in my picture #4: all the right hand line is now at battery -ve potential; all the left hand side is at battery +ve potential. The lamp is fed by current from the battery and a magnetic flux surrounds the wires; as does an electric field between the different potentials. Note however the capacitance to earth. The right hand side I've lumped as one big capacitance: if the switch is opened, and in light of this capacitance, how long does it take for the lamp to extinguish?

All this is a re-iteration of the "for and against" discussions Ivor Catt suffered way back in the 1970's; thankfully Ivor's work is now fully accepted and is available on line at:

http://www.ivorcatt.co.uk/em.htm

which I thoroughly recommend you see.

This was a “bible” for those of us who struggled with nS / pS laser LED driver circuits went to for help. Ivor had nailed the problem, found the proven historical background from Oliver Heaviside’s work and applied it to printed circuit boards, capacitors, inductors, semiconductors and the like. The energy in an electrical circuit is indeed in the fields surrounding the wires, which guide the energy from a source to a load just as a waveguide or a coax cable guides RF. I would strongly recommend you read Ivor’s work, and keep it in mind if you’re finding “weird” effects in printed circuit boards, cross talk, ground bounce errors and the like. Ivor was spot on the money 50+ years before Mr. Veritasium!

As was Tektronix, by the bye… take a look at the Tektronix model 109 pulse generator, a device used a’plenty by yours truly in my formative years, see: https://w140.com/tekwiki/wiki/109 .

The interesting point is that when the contacts of the relay Tektronix used to discharge the “charged” line closed, the pulse moved both into the “empty” uncharged line to the right, and into the “charged” line to the left to reflect off the open circuit left hand end. The nett result is an output pulse twice the duration of the delay line, and half the voltage charged on the line.

We were using pS pulses in semiconductor and LED manufacturing, production & test every day with good results. You can learn a lot by looking at what engineers did yesteryear, and find respect for those who trod in those dark hinterlands all that time ago.

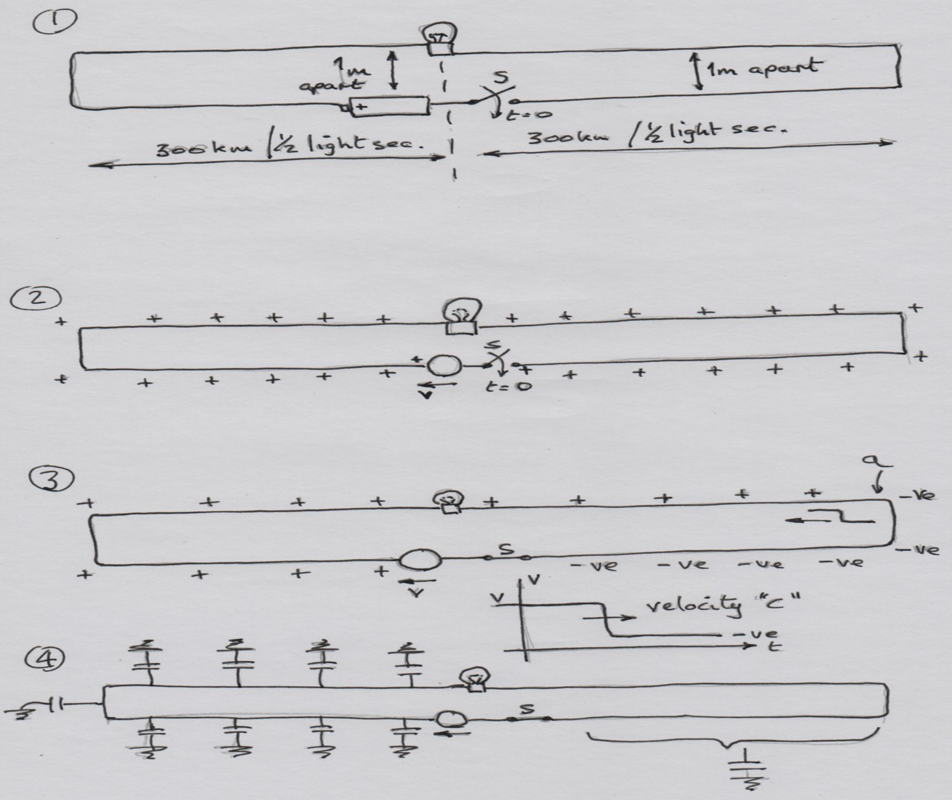
An experimenter (see: https://www.youtube.com/watch?v=2Vrhk5OjBP8) set up a line, and found similar but not exactly the same results as Mr. Veritasium; but, for me the interesting point is around 19.34 in this video: this clearly shows the negative going reflection from a deliberate open circuit in the right hand end of the line. By introducing deliberate reflections, the time delays around the circuit can be seen and thus what is exactly happening displayed.

An interesting version of the Veritasium circuit is the Blumlein configuration, much beloved by high energy thyratron users, typically on large particle accelerators, cyclotrons, and the like. This next reference shows merely a sample; the co-axial lines used can be very complex in higher energy pulse generators, much beloved by the Mega-Watt laser crew, who inhabit some very strange electrical lands indeed.

See: http://www.kentech.co.uk/index.html?/tut_blumlein_pfl.html&2

and: https://www.researchgate.net/figure/Circuit-diagram-of-the-basic-Blumlein-pulse-forming-system-with-one-closing-switch-only_fig1_5404010

If any Hot Iron readers are in contact with Mr. Veritasium, please pass on my thoughts!



1
1m apart
S
t=0
1m apart
300km / ½ light sec.
300km / ½ light sec.
2
S
t=0
v
3
a
-ve
S
-ve -ve -ve -ve
v
V
V
velocity "C"
-ve
t
4
S