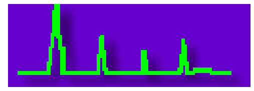
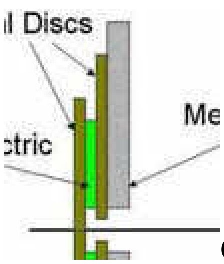
Spectrum Analyzer Updates



Last update, Saturday, June 10, 2000

This part of the web page deals with the spectrum analyzer that Terry White (K7TAU) and I described in QST for August and September of 1998, and the related Tracking Generator appearing in November 1999.

The complete article is now available to be viewed and downloaded in PDF format from ARRL. Go to the ARRL web page and do a search on *spectrum analyzer*. This will then get you to a point where the two part paper can be downloaded.

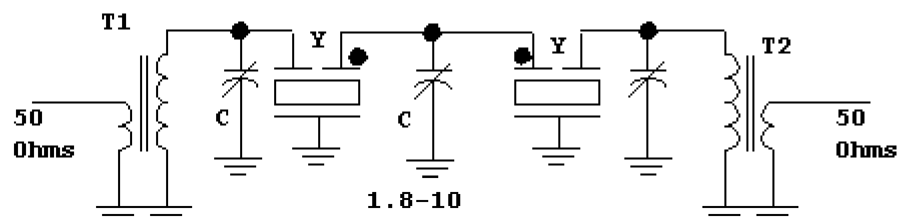


Click this photo to see some tutorial info on the analyzer.

Crystal Filter for 30 kHz Resolution Bandwidth. 4May00

The latest refinement to the spectrum analyzer is a narrow filter using monolithic crystal filter modules from ECS. These readily available parts offer an easy way to get a resolution bandwidth of about 30 kHz, very useful for a variety of applications. (I routinely use a 30 kHz RBW for IMD measurements here at W7ZOI.) This filter is the collaborative effort of Fred Holler,W2EKB, and Jack Glandon, WB4RNO.

The first filter, built by Fred, uses a 4 pole filter set, sold as a set in two cans by Mouser. The filter is designed to be terminated in 3Kat each end. This is realized with 0.5 inch OD ferrite transformers using type 61material. This is a relatively low permeability material (125)compared with some of the more popular mixes, which means that more turns are required to achieve the needed inductance. (Jack also got good results with -43 material, so use what you have.) The 4 pole filter is shown in the following schematic. The filter elements are NOT symmetrical, so dots indicate the end next to the variable coupling capacitor.

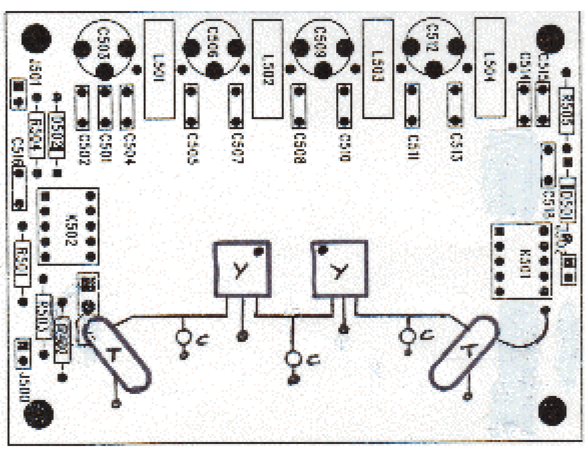


T1,T2: 39t #30 on Fair Rite 5961000301 or Amidon FT-50-61,
link = 5t #24 over other winding.

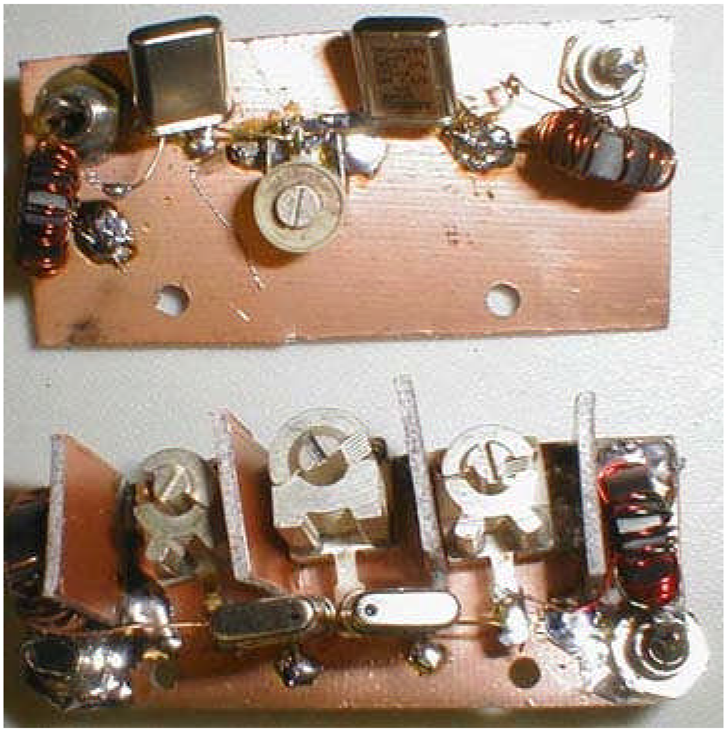
Y: ECS 4-pole filter in two cans, Mouser 520-107-1513

C: 1.8-10 pF, Mouser 242-1810 or similar.

The next figure shows the layout used by Fred on the Kanga IF PC board.



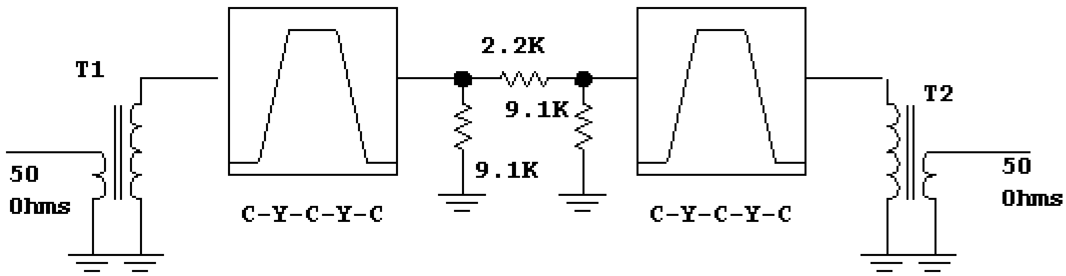
The photo below shows two of the filters that Jack built. Shields were tried between sections, but were not to be needed. The two filters were measured. Then, the two were cascaded and measured again. The results are summarized in the table below.



Atten.	BW-1	BW-2	BW,1+2
6	20	19.6	17.7
10	--	21.3	19.1
20	--	26.3	22.9
30	32.8	37.6	24.5
40	45.2	41.8	27.2
50	--	55.5	30.2
60	70.2	70.9	33.7
70	--	128.4	43.8
80	--	--	46.0

Bandwidth in kHz for various attenuation values in dB.

The schematic below is recommended by ECS when cascading two 4-polesets for an 8 pole response. The attenuator is a 6 dB pad with a Z0 of3K Ohms. Jack has built this topology and installed it in his analyzer. He reports a stopband attenuation over 90 dB.



Many thanks to both Fred and Jack fortheir efforts. The results really look outstanding, especially with 8 resonators. Narrow bandwidth is important in determining resolution. Stopband attenuation should always be at least as much as the on -screen display range. Indeed, even higher stopband attenuation is useful, for the analyzer can be overdriven in some measurements.

(Jan10) Coax Cable Applications in Building the SA and TG

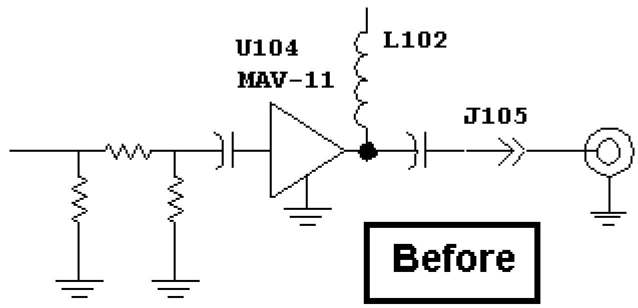
As some of the builders start to get the tracking generator working, we are beginning to see a few problems. Some are severe, but they are solvable.

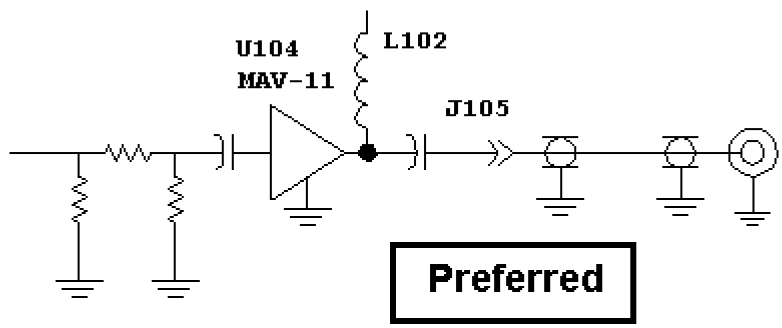
It is important to recognize that the combination of a spectrum analyzer and a tracking generator is a very difficult thing to build, mainly a result of the extreme shielding and signal isolation required. The spectrum analyzer is a narrow bandwidth *receiver* capable of displaying sub microvolt level signals. Yet the tracking generator is a *transmitter* that is always generating a signal that is at exactly the same frequency as the sensitive receiver. With an output of 0 dBm, the TG is at least 100dB higher than the sensitivity of the analyzer, so this is the level of isolation required.

So, how do we get there? Good coax connectors should be used. The SA front-end, the TG, and the SA 2nd LO and mixer should all be in well shielded boxes.The Hammond boxes (1590B and 1590BB) have worked well for this application and are not terribly expensive. All power and control lines in and out of the modules should route through feedthrough capacitors.

In spite of these precautions, problems have been encountered. Here are some things that can help:

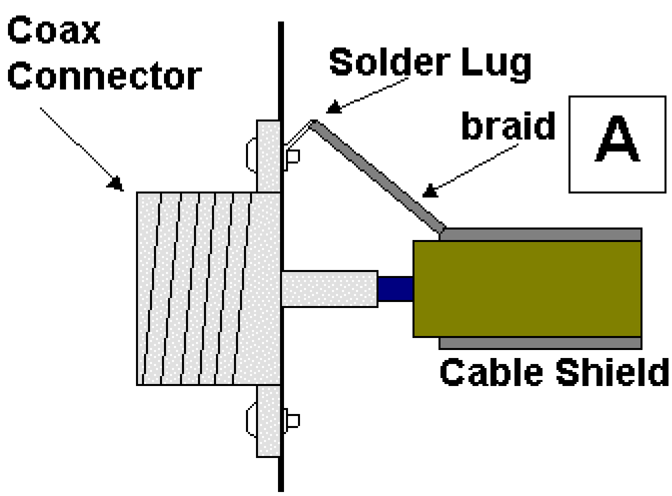
First, the way the figures were presented in the QST articles lead to confusion. For example, Fig. 8 of the August 1998 paper is partially duplicated as the "before" case below. The "Preferred" case is the way we should have shown it.





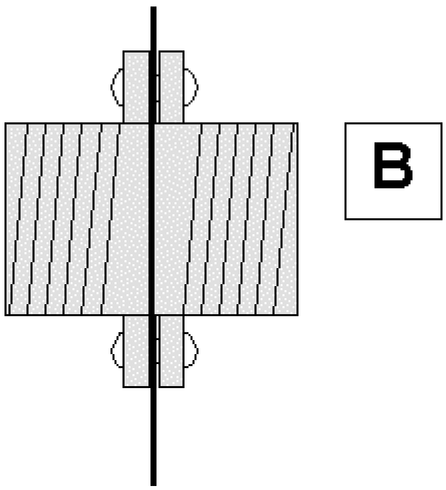
The difference between the two circuits is in the use of coax cable. The before merely showed a wire from the edge of the board to the coax connector center pin while the preferred form emphasizes that coaxial cable should route the signal to the connector. The coax should be grounded at both ends. This was not an ARRL drafting error, but a goof on our part in not being more careful with our schematics.

Signals out of the tracking generator or into the SA front end should occur in a well preserved coaxial environment. This has to do with the way we get from the internal modules to the edge of the box housing the equipment.



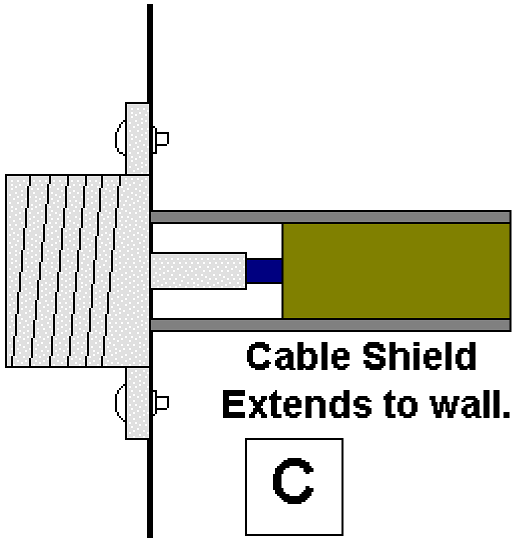
This figure shows the way we often use a coaxial connector. The connector resides in a hole in the panel. The coaxial center wire from, for example the SA low pass filter, attaches to the center of the connector while the braid is attached to the panel with a solder lug. This is a potential problem, a shielding error. There is an open loop. Some signals that are flowing on the *inside* surface of the front panel will be near the connector. These will end upon the same surfaces that carry the signals that are on their way to the SA low pass filter on the inside of the coax. This constitutes mutual coupling between the two surfaces that will intermingle them.

Here's one way to fix the problem:



A bulkhead type coaxial connector is now used to route signals from the "outside world," through the front panel to the coax on the inside of the analyzer reaching the circuit modules. A male connector is needed on each end of the inside cable, adding to expense. Moreover, the bulkhead connector is expensive. But it is worthwhile. Prior to installing a bulkhead connector in my analyzer, I could see a couple of spurious responses from local TV stations. When the bulkhead connector (Fig. B above) replaced the BNC with solder lug (Fig. A above), the spurs disappeared, even when the lid was off the box.

The same effect can be achieved with an extended shield:



Here we extend the shield all the way to the front panel. The extension shown in the figure is rather ideal, for it will come close to preserving the 50 Ohm environment. This s not as vital at low frequencies as is the shielding integrity. It would be suitable, for example, to push the braid up on the cable, solder the inner connector and insulate it, pull the shield back down, and clamp a cylinder around coax to the wall. There should ideally be no gaps in the shield surface such that there is no mutual surface shared by the inside of the coax and the surfaces on the outside. Clearly there is room here for ingenuity.

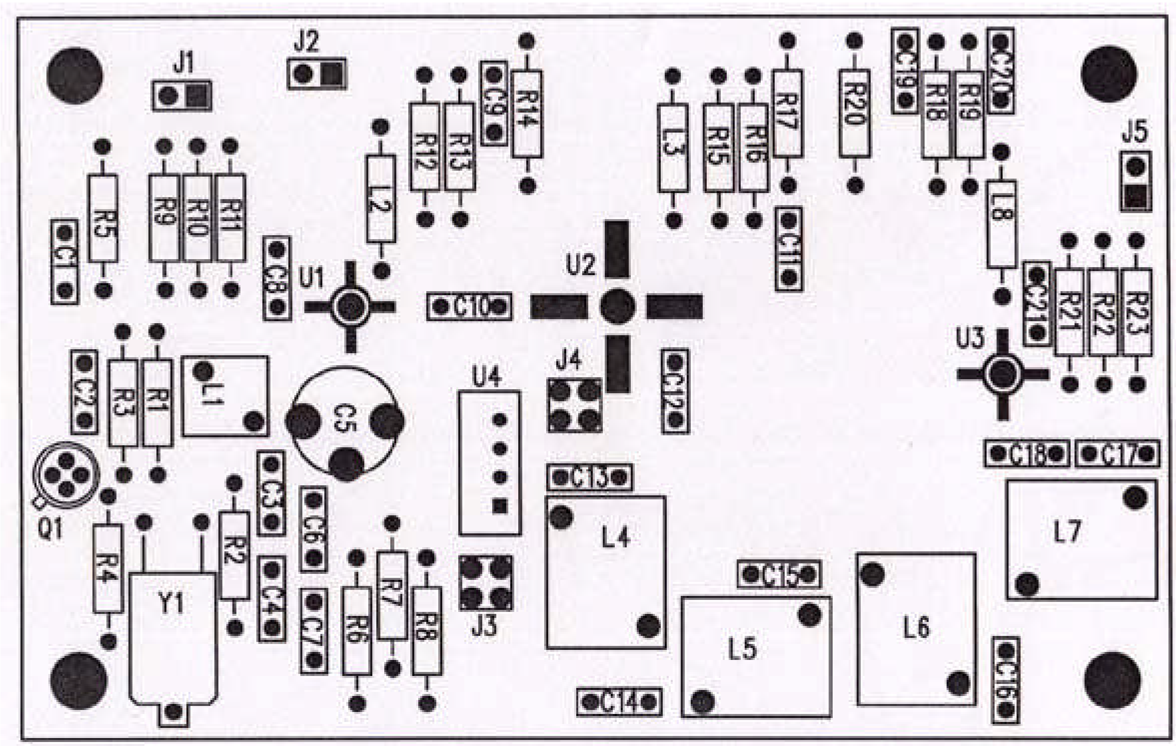
These precautions are important for the analyzer input connections as well as the tracking generator output. The integrity of the cable between the VCO and the tracking generator is also important.

Many thanks to Jack, WB4RNO for his experimental results with the tracking generator.

Not all of the tracking generators built by hams are the simple ones like we have done for low frequencies. For a homebrew TG that covers from DC to 1.8 GHz, take a look at the work of KE5FX at http://www.qsl.net/ke5fx/tr503.html(Feb 9, 00).

Tracking Generator Errors

We have discovered a number of documentation problems with the Tracking Generator. The board itself is fine, but some of the designators are wrong on the sheets going out with the boards. Most of the errors occurred inthe crystal oscillator portion of the schematic. The QST diagram (Fig.2) is OK and should be used for reference. C1 is 470 pF, although not very critical. C2 is .01 or 0.1 uf, again very non-critical. An updated component map is shown in the figure below.



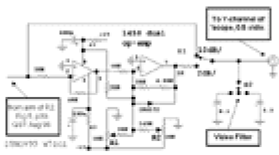
A capacitor, C20, was omitted from the QST schematic. This part is on the board and is a 470 pF disc. It's in parallel with C19. (In hindsight, this was a poor design choice! It's not generally a good idea to parallel two bypass capacitors of differing value, for the inductance of the larger capacitor can go parallel resonant with the smaller capacitor, forming a high impedance at some frequency. A better wideband bypass would be twoor more parallel caps, all with the same value. This was not a critical application and we didn't get in trouble! Whew!)

The "roadmap" above and the schematic distributed with the Kanga boards have J designator to go with the board input/output connections. They are properly shown above and will be fixed in later Kanga schematics. The functions: J1=RF input from VCO, J2=+15 volt supply, J3=Crystal oscillator power test point, J4=LO power test, and J5=RF output. Note that U4 is the TUF-1H mixer.

Many thanks to Masa, JA3FR, and Sam, AE4GX for feedback on these errors.

Adding 2dB per division to the Spectrum Analyzer

The majority of spectrum analyzer measurements are done with a vertical scale of 10 dB per division. The log amp in the analyzer allows one to see about a 70 dB range of signals at any one time with this setting. But, there are many situations when 1 or 2 dB per division would be useful. These include filter adjustment and loss determination, filter and resonator bandwidth measurements, and noise evaluation as part of a noise figure measurement. A circuit to perform this is shown in the attached figure.



Click this photo for a larger view.

The circuit is nothing more than a DC amplifier with a voltage gain of 5. A signal change that formerly occupied 1 vertical division now takes5,allowing one to see smaller changes.

Circuit behavior is evident when you turn the analyzer on and calibrate it: Begin by injecting a -30 dBm signal at the analyzer input with the scale factor set to 10 dB per division. Calibrate the analyzer as before by adjusting IF gain to bring the response to the ***top*** of the screen. Juggle the log gain and IF gain to achieve 10 dB per division, as observed with the step attenuator. Now, with the signal still at the reference level (top of the screen), switch to 2 dB per division. A signal may or may not be on screen, but adjustment of R1 and/or R2 will produce it. You can now decrease the signal in 1 dB steps with a step attenuator and watch the signal drop.

Set the scale back to 10 dB per division and reduce the generator signal to a value that produces a signal just a few dB over the noise floor. Switching back to 2 dB/div and adjustment of R1 and R2 will allow this signal to be observed.

This circuit has a *side effect*. The expanded resolution allows the deficiencies of the log amp to be more easily observed. My present thinking is that it may be time to replace the inexpensive and readily available MC3356 with the superior, but harder to obtain Analog DevicesAD8307 log amp. Whenever one refines a measurement system, the deficiencies become more observable.

The new circuit consists of two cascaded inverting amplifiers. The first has a gain of 2 while the second runs with a gain of 2.5, for a net gain of 5. The use of two inverting stages allows an adjustable offset to be injected while maintaining constant gain. The new circuit is added at the coax connector that feeds the Y-axis signal to the oscilloscope. Use 1or 2% tolerance resistors in this circuit, or at least in the gain determining parts.

The video filter circuit was modified to provide two video bandwidths. The newer one (with the 3.3 uF) allows noise from a noise-diode to be averaged to produce a relatively smooth line, useful in noise figure measurements. S2 is a center-off toggle switch mounted on the front panel.

Construction is not critical. The signals are DC baseband values that have already been detected and filtered, so they are not susceptible to the contamination that might plague RF circuits. I built my amp on a small board scrap using "ugly" methods with the board tucked into a corner of the instrument after operation was confirmed. There is no need to shield this part of the circuit. About any dual op-amp will function well in this circuit. I ran out of front panel room in my analyzer, so R1, R2 and S1are mounted on the side, close to the front panel where adjustment is still easy. S1 is a miniature toggle type.

If desired, the circuit could be configured for 1 dB per division. This would require a DC gain of 10, probably realized with gains of 3 and 3.33 in the two stages. The present instrument produces a 4 volt Y-axis signal. A gain of 3 would crowd ranges, so it would probably be convenient to re-calibrate the instrument for an oscilloscope sensitivity of 0.2 volt/division instead of the 0.5 presently used. This is easily done.

Give this refinement a try. It's simple, but adds a lot to the operational convenience. We have no plans for boards for this--it's just too simple.

Attenuator Part Error. The six input resistors in the 20 watt attenuator of Fig. 16 (Sept. 98 QST, p40) should be 620Ohms, 2 watt, rather than 820 Ohms as shown. Many thanks to Jon, EA2SN.

Harmonic Distortion Measurements

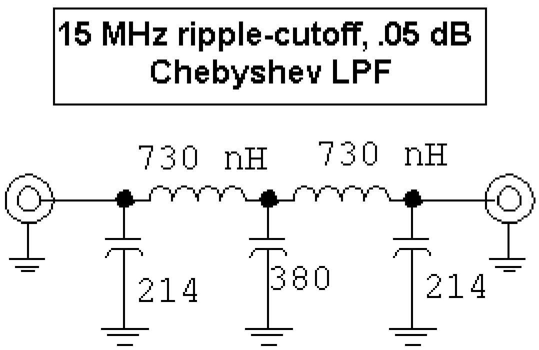
One of the most common measurements we do with a spectrum analyzer is that of harmonic distortion. This seemingly simple chore can be more difficult than we might imagine, for harmonics can be created within the spectrum analyzer used for the measurement.

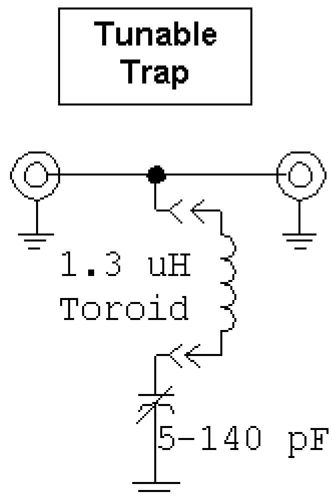
Evaluation of a low power transmitter is an example of harmonic distortion measurement. We assume that the transmitter output power has been measured. A power attenuator is connected to the transmitter to drop the output tolevels that cannot damage the analyzer. Some power attenuators built byW2EKB are shown below.

We must evaluate the spectrum analyzer to determine it's cleanliness before the transmitter can be evaluated. This can be done with easily built outboard filters. The SA that we described in QST was evaluated with the following experiments: First, an HP8654A signal generator was set for a14 MHz output of -20 dBm and attached to the analyzer. For harmonic distortion measurements, the analyzer is always operated with 10 dB attenuation, or more. We calibrated the analyzer to the -20 dBm signal and noted a 2ndharmo<

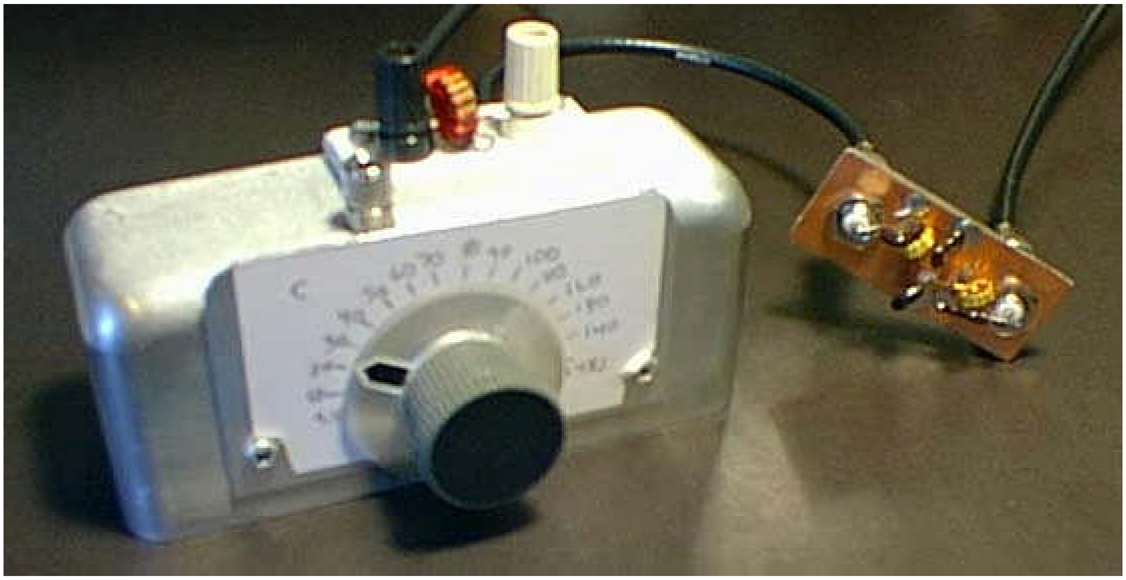
The low pass filter is removed and replaced with a tunable trap. This circuit was tuned to attenuate the 14 MHz fundamental. This signal dropped by 37 dB, leaving the harmonic unchanged. If the harmonic had been generated by the analyzer, there would have been a substantial (well over 37 dB) drop in the harmonic's power level.

The trap was re-tuned to the 28 MHz 2nd harmonic. This dropped that level to -53 dBc, leaving the fundamental power stable at -20 dBm. The displayed harmonic level would not have changed if it had been generated in the analyzer front-end. The filter circuits are shown below:



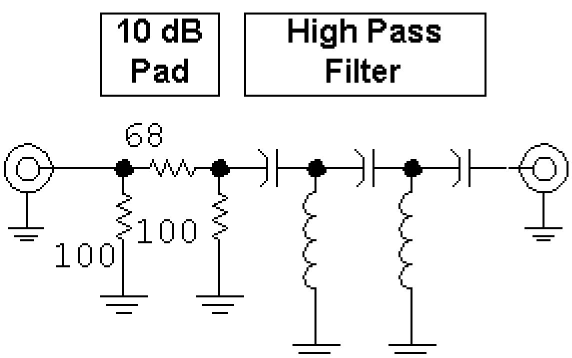


The low pass filter and trap were cascaded and placed between the generator and the analyzer. This combination pushed the 2nd harmonic into the background noise, even with the fundamental 10 dB above the top of the screen. The test set is shown in the photo below:



These measurements have confirmed the cleanliness of the analyzer for harmonic measurements. We can now attach the attenuated transmitter output to the analyzer and meaningfully determine harmonic distortion.

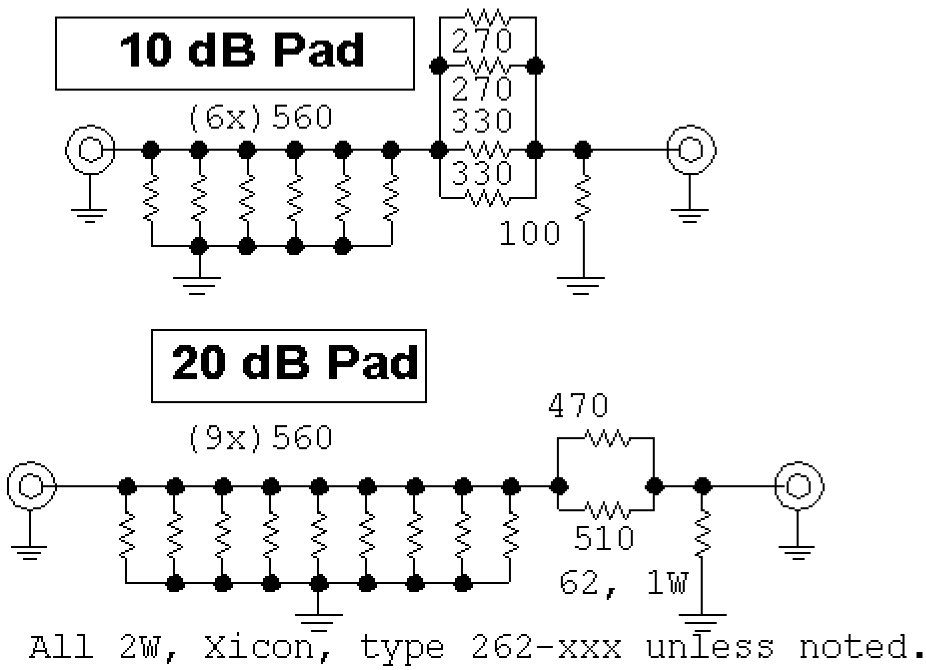
But, what would we do if the analyzer was generating some harmonics in its own front-end? This is a common situation with many commercial analyzers. All is not lost. Harmonics can be evaluated by a two step measurement. The fundamental power is first determined by examining the output of the source being studied. The following circuit is then inserted in the source output line.



The input of this module is a pad with approximately 10 dB attenuation. Analyzer gain must be increased by this amount to compensate for the loss. The extra pad guarantees that the source sees a wideband 50 Ohm load. The pad is followed by a 5th order high pass filter that drives the analyzer. This serves to attenuate the fundamental by 25 to 30 dB if the filter was designed for a ripple cutoff just below the 28 MHz 2nd harmonic frequency. This will probably push the self-generation of harmonics within the analyzer to the point that they are no longer significant.

The tuned trap shown earlier can also be used in this application. It's still useful to insert the extra pad. The function we seek is to reduce the "loud" signal reaching the analyzer that causes the internal distortion.

Power attenuators are needed ahead of the analyzer when testing transmitters. We presented one in the article, but then discovered that the 2 watt AB resistors we used are no longer available, a familiar story these days. But Fred, W2EKB, came to the rescue. He purchased some Xicon resistors from the current Mouser catalog and built a couple of pads, shown below. He used some copper straps to improve the grounding. The circuits were built in the Hammond 1590B boxes. Testing showed that they were clean through 150 MHz. Many thanks Fred !



Using RCA connectors

Here's a great tip for folks fighting the problem of expensive coaxial cable and the even more expensive connectors; a scheme for using RCA connectors. Here's what Barry Lennox sent to us on this subject:

1. Take a 4" pigtail of good high coverage braid (I use silver-plated stuff from RG-400) and sweat it all around the outer metal rim of the phono plug.I have made a little jig from wood and a bit of wire and tube, to support things, and make several

in one sitting as they only take a few minutes, and are very useful to have in-stock.
2. When you need to terminate a cable, bare about 0.5" of the inner, and about4" of the outer jacket leaving the braid exposed.
3. Push the cable inside the pigtail braid (pre-expand it a bit) then use a 4" length of heat-shrink to clamp the two braids together.
4. Finally solder the inner wire to the pin, as normal; and you have a fast and neat connection.

The reason for preparing the connectors and braid ahead of time is to prevent melting insulation. Many thanks, Barry!

Update: I recently needed a cable for an RCA connector and tried this scheme. It works great, although it took some practice on the first connector. (Oct 99)

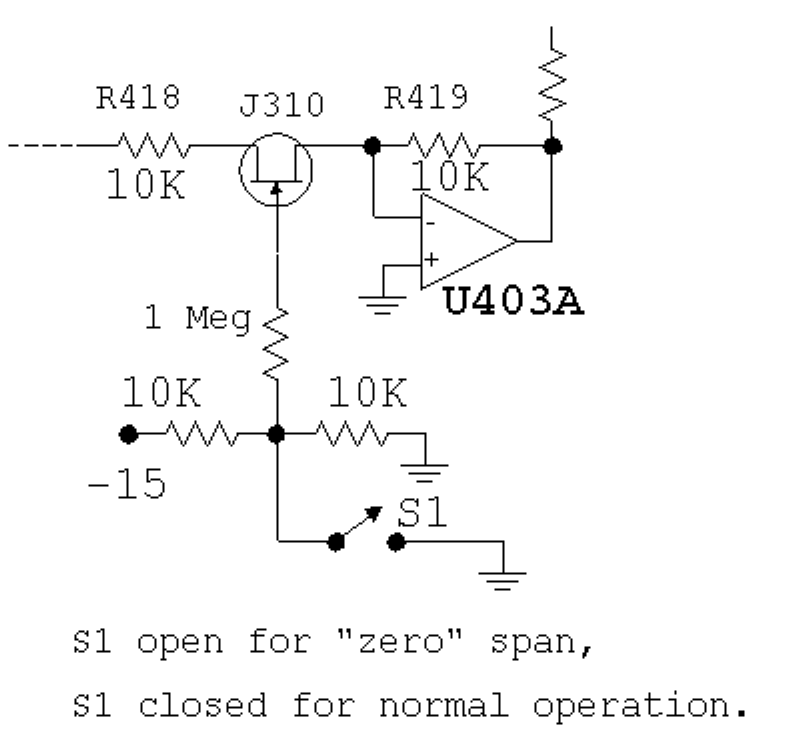
MAV-11 pinout: Some of the data sheets that went out with the Kanga boards were in error with regard to pinout for these parts. The dot is on pin three, which is the output pin in the MAV-11. The information in the paper was correct.13 Feb 99.

A Block Converter

Our lab includes a tunable block converter. This consists of nothing more than a POS200 VCO (approximately 100 to 200 MHz), a three dB pad, and a SBL-1 mixer. The mixer was available in the junk box and can be driven directly from the POS mixers. A front panel pot tunes the VCO, allowing the VHF range to be hetrodyned down to the analyzer baseband. The pad is in the signal path, bringing the overall conversion loss to an even 10dB. Other mixers and VCOs will allow other parts of the spectrum to be examined. No schematic is presented.
The converters are used with an external step attenuator. 13Feb99.

A Zero-Span Mode.

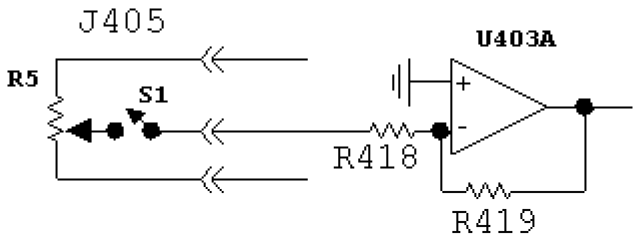
A common feature in commercial spectrum analyzers is a "zero span" mode. This mode merely eliminates the sweeping of the VCO, turning the analyzer into a receiver that is tuned with the center frequency control. This is especially useful if you wish to measure the local oscillator with a frequency counter to establish center frequency. The zero-span mode is realized in our box by placing a switch in the path from the sweep generator to the VCO. This is easily performed with a JFET switch as shown in the figure



This modification has been added to an analyzer built by Jim Cotton,N8QOH, at Western Michigan University. Jim used an ECG457 FET as a replacement for the J310 suggested. As Jim points out, about any N channel JFET should work fine. A small error occurs when the sweep is stopped that causes about a 20 or 30 kHz shift in VCO frequency, but this is not a problem with wide resolution bandwidths. The tracking generator sample output from the VCO is counted when the zero-span mode is active. Many thanks for the feedback Jim!

If you want to see Jim's analyzer in detail, his web page has a wonderful collection of photos, including inside shots of most modules. Nice job Jim!

Fred, W2EKB, suggested an even easier mod to achieve the "zero span" modification. This is shown below:



Alternative Zero Span Modification, suggested by Fred, W2EKB

This variant has the advantage that no change is required on the time base board. Many thanks Fred!

Component Collections:

Circuit boards and Parts "Kits" are available through Kanga USA for both the spectrum analyzer and the tracking generator. These are not kits in the traditional "Heath" sense, for they have no step by step instruction manuals. For more information go to http://www.kangaus.com/

Parts Problems--Sources for Purchasing.

Some folks have encountered parts procurement problems. I have had good luck with special items by ordering from Future Active Electronics, Inc. They have local offices all over the country, but they are a mail order house. I was able, through Future, to buy Motorola MC3356P chips, Analog Device IF chips, J310 JFETs, to name just a few items. I've had friends within the industry also offer positive comments about these folks. Try1-800-655-0006. A US address to obtain a catalog or place an order is Department SF1, 41 Main Street, Bolton, MA 01740. Future Active is an international company with outlets in several countries. Some outlets WILL NOT sell in small quantities.

Quartz Crystals are always a problem these days. The classic source that we could all depend upon in the past seems to have dried-up for the amateur market--they now have a minimum order that is just large enough that it is not possible to purchase just one crystal at a time! But, as is usually the case, anew supplier shows up to take over. My new choice is Hy-Q International. Their web address is http://www.hy-q.co.uk/ After getting to the home page, go to the appropriate country. The phone number in the US is 606-283-5000.Standard delivery time is 3 weeks (which they met with my order), the price sare very competitive, and they didn't flinch at my wanting to order a single crystal.

The LO crystal to order is a 5th overtone, HC-49, 20 pF (not critical) 0-50 ° C , 10 ppm Temperature drift, 5 ppm Calibration accuracy. This is what I ordered, but few parameters are critical in this application. One could even get by with a free running LC oscillator in this application.

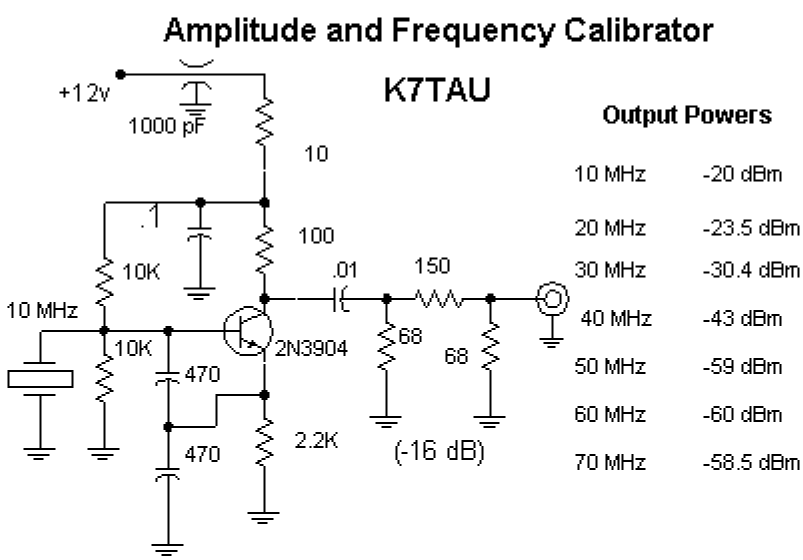
Two crystals I ordered arrived and were tested (Sept. 15th). They both came up without problem with the same output power that was extracted from an earlier crystal. The frequency I measured was just over 1 kHz below 100 MHz, which is well within the specifications that I used when ordering. It's a *thumbs up* vote on Hy-Q from W7ZOI.

T301 is10 bifilar turns on an Amidon FT37-43 or similar ferrite core. Wire size really doesn't matter and #28 is fine. This is not a critical part use whatever ferrite you have in the junk box. (Thanks to KG0SB, KA7EXM,and others who caught this.)

A Crystal Calibrator

The analyzer that was photographed for the QST article was the one that Terry built. He's the resident master craftsperson around this part of the world. His analyzer included the calibrator shown below.

This circuit is a crystal controlled Colpitts oscillator with output extracted from the collector, a point in the circuit that is rich in harmonics. The pad (16 dB in Terry's analyzer) is adjusted to provide an output of-20 dBm at the 10 MHz fundamental. If you want to add a pot to adjust the amplitude, replace the 150 Ohm resistor in the pad with a 100 Ohm pot and100 Ohm series fixed R. The calibrator is *calibrated* against a high quality signal generator, if available.



Assorted Comments and Errors

In Figure 9 ,J12 should be shown connecting to J3, Figure 8; J13 connects to J4 in Figure 7. *tnx to Bill Dawson, K6VPE* via W1VD via N1FB at ARRL.

MiniCircuits MAV-11 ICs are used in three places in the analyzer. They are biased with a pair of paralleled 220 Ohm resistors. The power dissipation in a single 110 Ohm R would exceed 1/4 watt. Note that the dot on the MAV-11 goes with pin 3, the output.

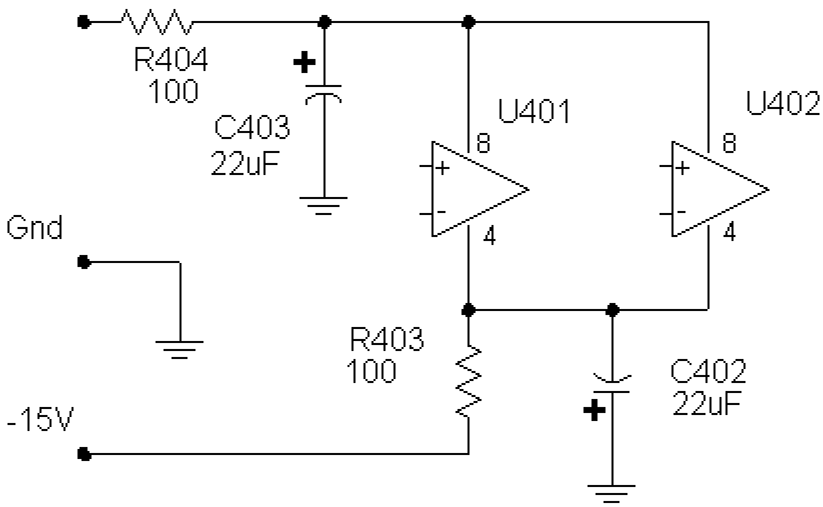
The question of a narrow, homebrew crystal filter has come up in discussions. We will do some experiments and report the results here. Right now, it looks like 3 kHz is about as narrow as you should go. Even then, the filter should be one with 2 to4 crystals, ideally with a rounded peak shape. You don't want the same flat topped filter here that you might use for communications. If even narrower bandwidths were used, the first LO would need to be phase locked to a stable reference. The crystal filters we used were from a local surplus source and are not generally available. The analyzer is practical, even without the crystal filter, so you can add it later.

A commercial crystal filter could be used. The builder would then have to add matching networks at the filter input and output to transform from 50 Ohms to the impedance that the filter "wants." The networks, even if they use toroids, may need some shielding to keep one network from coupling to the other.

The 10 MHz filter board includes a 4th order LC bandpass filter for the wider resolution bandwidth. The board layout was done for 8 mm variable capacitors, but the QST schematics called for the 10 mm plastic variables. The larger parts still fit on the board.

The **10 MHz L/C filter** is easily moved to 10.7 MHz, if you happen to have crystal filters at that frequency. To move the LC filter, changeC504 and C513 from 120 to 110 pF, and shift C507 and C510 from 180 to 160pF. Many thanks to Steve, AA7U.

Figure 2, the Time Base, had a colossal mistake in it. In the upper left corner of the figure we find that the +15 volt power supply is grounded. We really didn't want to do this, and the boards do not include this "feature." The correct schematic is shown below ina figure that presents just the power supply connections for U401 and U402.The 3rd op-amp, U403, has its own similar de-coupling network. Many thanks to reader Nicholas Caruso!



Many thanks to all the builders who have offered feedback.