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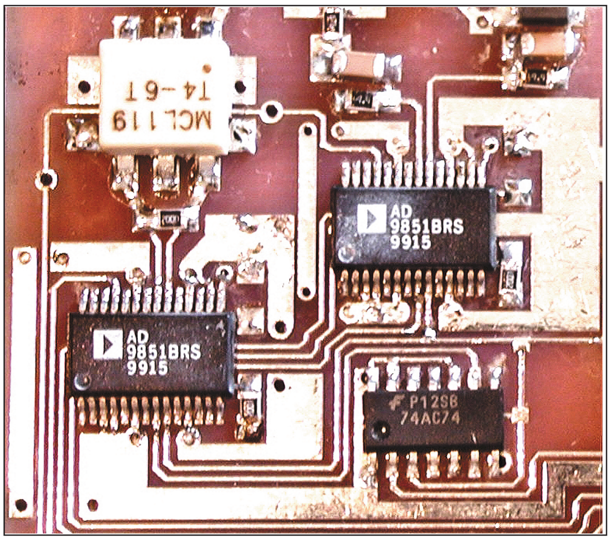
In practice

The N2PK Vector Network Analyser described in September's 'TT' is generating lots of practical questions. Since G3SEK was one of the early constructors, he is answering them here.



With a little practice, even these fine-pitch ICs can be hand-soldered successfully. (Photo: N2PK)

Q I read your comments about the N2PK VNA in 'TT', but what do *you* use yours for? What makes it so indispensable?

A If any of the following applies to you, you'll know instantly why an accurate VNA is indispensable.

- You need to know how accurate your so-called '50Ω' dummy load is, from LF through to VHF. If the impedance isn't exactly 50Ω, you want to know what it actually *is*.
- You need to know the same about my attenuators - I mean, their *actual* impedance and attenuation values.
- You need to know the length, impedance and loss of this length of coax.
- You need to measure the gain and phase shift of this amplifier, from LF through to VHF.
- You need to make really accurate impedance measurements on each vertical in your four-square array, so you can get the phasing absolutely spot-on.
- You need to measure a capacitor value at the actual frequency where you're going to use it. That means you need to know the *effective* capacitance, which is the actual capacitance minus the effects of stray lead inductance.
- You need to measure the impedance of an RF choke, all the way from LF to VHF. You need to know the *Q*, and where all the self-resonances are.
- You need to measure all the parameters of a crystal filter, like I described in the March 2004 column: passband, insertion loss, skirt rejection and frequency-swept group delay.
- You're building your own crystal filter. You need to know *everything* about a batch of crystals - the series and parallel resonant frequencies within a few hertz, the ESR (effective series resistance) and the parallel capacitance.

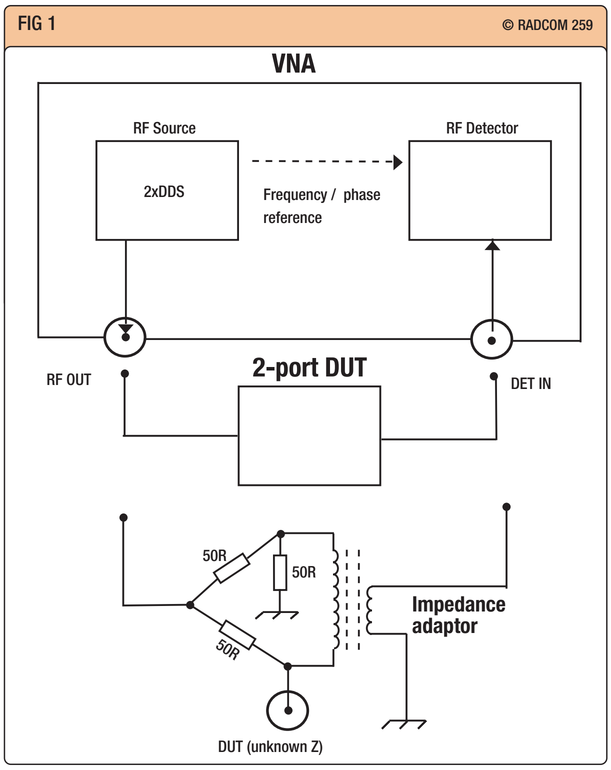
The answer in every case is: "Well, now you can!". This isn't the place to go into the details of specific measurement techniques, but the N2PK VNA can do all that, and more [1, 2]. As W4ZCB puts it: "It's a lab in a box.".

The N2PK VNA is remarkably accurate - in almost all respects, it is the equal of lab instruments that cost several hundred times more [3]. This is largely because, like the professional instrument, the N2PK VNA is computerised and self-correcting. It plugs into your PC, and a range of software is becoming available to drive the VNA and display the results. Before you make a measurement, a computerised VNA leads you through a calibration procedure to measure its own internal errors. When you measure the actual Device Under Test (DUT), the computer automatically subtracts the error data, leaving you with highly accurate data about the DUT. Compared with traditional test equipment, the improvement in accuracy is dramatic. Computing instruments still aren't perfect, but they do increase routine accuracy to a level previously unknown to amateurs.

A particularly clever feature of N2PK's VNA architecture is that there are no setup adjustments. All of its accuracy derives from basic hardware properties: the excellent linearity of the RF detector IC; the stability of the master oscillator that clocks the two DDS (direct digital synthesiser) ICs; and the ability of a dual DDS to generate two carriers with precisely 0° or 90° phase difference across the entire frequency range [3]. If you can overcome any lingering disquiet about there being nothing left to tweak, you'll appreciate why this feature makes the N2PK design particularly suitable for amateur construction.

A VNA is basically a two-port measurement device **(Fig 1)**. It has an RF OUT port and a DETector IN port, and will measure the gain/loss and phase shift occurring in any two-port DUT you connect between them. To make a one-port measurement of impedance, you have to add a bridge adaptor. Several configurations are possible, and Fig 1 shows the general-purpose Wheatstone bridge - the DUT forms the missing fourth leg of the bridge. The input signal comes from the VNA's RF OUT port, and transformer T1 routes the out-of-balance signal to the DET IN port. With the help of the adaptor, the VNA is still measuring the relative loss and phase change between those two ports.

The accuracy of impedance measurements depends on the quality of the open, short and 50Ω standards that you use during the three-step calibration procedure. A favourite trick of RF engineers is to apply the 'open-short-load' (OSL) calibration at the far end of a length of thin coax, because this effectively absorbs the whole length of coax into the calibrated bridge setup. Then the free end of the coax can be dabbed onto a circuit board at any point where an impedance measurement is needed. A similar technique was used to measure the parameters of a crystal displayed in **Fig 2** - here, the OSL calibration was applied to a screw terminal adaptor for the wire-ended crystal, and the calibration standard was a 47Ω resistor. Provided you tell the software exactly what you're using as calibra-



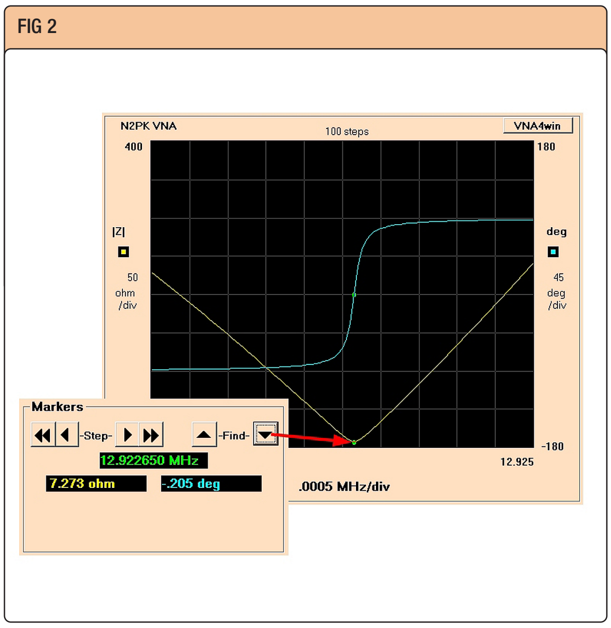


Fig 1
How a VNA measures the transmission properties of a two-port DUT (above), or the impedance/reflection properties of a single-port DUT (below).

Fig 2
Measuring the parameters of a crystal. The software finds the lowest point on the trace, and displays the results.

tion standards, the DUT results will be corrected so they still come out right.

I hope this has given you a first glimpse of the things you could do if you had a Vector Network Analyser of your very own. For more information, please read Paul Kiciak's extensive documentation on all aspects of his VNA design. These and many other background references are all downloadable from the web [1].

Q Where can I buy one? Or where can I buy the parts?

A You cannot buy an N2PK VNA ready-made. This has turned out to be a completely non-commercial project, so you have to build it yourself. Full components lists are in 'Part 2' of N2PK's documentation, but there are some practical problems if you don't live in the USA.

I will try to keep up-to-date information for European constructors on the 'In Practice' website [1]. Gian Moda, I7SWX (a familiar callsign to 'TT' readers), has a stock of PC boards, but some of the components are only available in the USA. Suppliers such as Digi-Key and Mini-Circuits are very easy to deal with over the web, although naturally there are extra shipping costs outside of the USA. Also, some items are subject to minimum order quantities. Don't worry about having to buy 100 SMD resistors or capacitors when you only need three of that value - they really are 'cheap as chips'! However, if you want to buy the master oscillator rather than build it, that is more difficult because the recommended unit is only available in multiples of 10, at $35-$40 each. A number of groups have got together to make bulk purchases from US sources, although large orders are sure to attract import duty and VAT.

Most of the semiconductors you'll have to buy, of course, but thanks to Analog Devices' enlightened policy of providing samples for amateur experimenters, you may be able to obtain the AD9851 DDS chips for *exactly* the right price!

All of these factors make it difficult to budget for the cost of the entire VNA project, but at the current very favourable exchange rates I'd estimate under £100 if you're careful.

In conclusion, purchasing the necessary components from outside of the USA is a bit awkward, but it *can* be done - and above all, it *will* be worth the effort.

Q Please tell me more about the construction. What are the problem areas?

A As you'll have gathered above, you need to know a certain amount in order to use this instrument. Likewise, you need some practical SMD experience in order to build it, so this is not a project for the beginner. As I've said before in this column, with the right tools, most of us *can* do small, fine work like this - but it definitely should not be your very first SMD project.

The main VNA board is factory-made and pre-tinned, which makes construction a lot easier. The construction notes [1] begin with the easier components, and build up your confidence to work with the more difficult parts. By the time you arrive at the stage shown in the photograph on p61, which is the most difficult part of the board, you'll already have had plenty of practice. Even 0.05in-pitch ICs like the 74AC74 (lower right) will seem easy - honestly! The key skills are:

- How to apply solder only where you need it
- How to avoid flooding solder over the rest of the pre-tinned tracks
- How to use solder-wick to pull off excess solder
- How to clean up and inspect your work carefully after each step
- How to re-work any suspect joints.

The two AD9581 DDS chips have an even smaller pin spacing, 0.025in, so they require a slightly different technique. You need to take extra care to position the chip very accurately in place on the narrow tracks, and tack-solder the four corner pins - but after that, you don't even try to keep solder out of the gaps between the tracks. Simply run enough solder along both sides of the IC package to make certain that every pin is well soldered onto its track, and then use the solder-wick to suck away the excess. You'll find it will remove solder from the gaps between the tracks, but not from the joints between the tracks and the IC pins. Clean off the flux, and use a very strong magnifier to check for dry joints or solder bridges. If you're not happy, add more solder and repeat the process. When the board finally looks neat and clean, and provided you have made no errors in parts selection and placement, the whole thing will work first time.

The master oscillator is a different kind of problem. Plan A involves paying $35-$40 (plus import overheads) for the recommended high-performance packaged oscillator which you simply solder in. Plan B costs $25 for a very high-quality crystal (again plus overheads) and a few pounds for other discrete parts. It then involves making your own tiny PC boards, followed by a tricky little exercise in three-dimensional SMD. Having hand-built two master oscillators, I thoroughly recommend Plan A! The only problem, as I said earlier, is organising the $350 minimum order.

Most experienced constructors will be able to build this project successfully... but it does need some SMD skills that you'll have to learn and practise. I'd hate to see anyone get into trouble because they're not ready for this project yet, so please let me warn you one last time: if you don't have *all* the right tools *and* enough experience of SMD construction, then you won't be able to manage it. No matter how much you want an N2PK VNA, please be realistic about your ability to build it. Try some easier SMD projects first, and come back to the VNA in a year or so. ♦

NOTES AND REFERENCES

[1] For details, follow the links from the 'In Practice' website (URL above).

[2] The VNA contains two low-noise DDS signal sources which you can use for many other purposes. Software is available to program each DDS independently, in 0.035Hz steps from 60MHz down to almost DC.

[3] N2PK has made an extremely thorough analysis of errors in this VNA concept, including comparisons with lab-quality instruments. It's all in the documentation [1].