They Never Told Me Not To
an innocent is seduced by centimeter waves

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Abstract

Microwave communications on Phase 3D promise unprecedented performance and ease of use, but to the vast majority of radio amateurs, microwaves are totally mysterious—even irrelevant.

This paper is the story of how one amateur learned a bit about microwaves, from 1296 MHz to 10.5 GHz, with the help of new and used components, classic designs, straightforward application of modern components, and, for good measure, the occasional stupid design.

Résumé

La satellite Phase 3D nous promettra des communications à micro-ondes des performances élevées, plus facile que jamais à utiliser. Mais selon le plus grand nombre des radioamateurs, les micro-ondes sont des choses mystérieuses, sans grand interet.

Voici l'histoire d'une radioamateur, et comment elle a appris un peu des micro-ondes. En effet, toute la gamme de 1296 MHz jusqu'à 10 GHz, assistée par des composants neufs et d'occasion, des montages classiques, des réalisations simples des composants moderns, et bien sûr, de temps en temps, des montages stupides.

Introduction: Why microwaves?

Are microwaves the future of amateur radio? I'd sure like it if they were—just think of what you could do with them. *Really* high-speed data. Local chit-chat with high-quality audio and nifty control capability. Applications nobody has thought of yet. Heck, those AMSAT folks are even launching a satellite with microwave capability.

But few amateurs have any experience above 450 MHz. For microwaves to be useful, people need the same sort of easygoing familiarity that most hams have with 2m FM, or 20m SSB. The only way to achieve this is to try it and see. Play with microwaves. Put things together. Enjoy the fact that they work, or figure out why they don't. Break them. Fix them. Modify them. Understand them. Absolutely standard amateur radio, in other words, except that the wavelengths are measured in centimeters, and not tens of meters. I set myself this learning experience as a piece of personal research, and this is a report of some of the trouble I've caused.

This paper has several sections: getting information, getting parts, wideband 10 GHz equipment, no-tune transverters, simple applications of modern components, and a summary of the lessons I've learned.

Getting information

Information is key to any activity, and amateur microwave communication is no different. The main sources of information on microwaves are reference books, conference proceedings, specialized books, magazines, the Internet, and Elmers. Only by accessing most (if not all) of these sources can you find the information you need.

Reference books: These are often professional books, and sometimes out of date. They can be expensive. They are written for professionals, and the technical level may intimidate some amateurs.

Conference proceedings: These include the excellent *Microwave Update*, regional conferences like the Central States VHF Society, and collections like *DUBUS*. They are an accessible source of information, written by amateurs for an amateur audience. In the past these have been highly specialized documents, going out of print quickly. Perhaps it's time for some reprints. Or for a collection of articles. This information is too good to waste!

Specialized books: These include publications like the RSGB's *Microwave Handbook* [ATUR—**A**ll **T**he **U**sual **R**eferences—please see the *References* section of this paper] and the ARRL's *UHF/Microwave Projects Manual* [ATUR]. These books, while sometimes expensive, are necessary background material.

Magazines: General amateur radio magazines have little microwave content, with the exception of the *Above and Beyond* column in *73 Amateur Radio Today*, written by WB6IGP. The RSGB publish the *Microwave Newsletter*, and have a Microwaves column in *Radio Communication* written by G3PFR, editor of the RSGB's *Microwave Handbook*. More specialized magazines include *DUBUS* and *UKW Berichte*, which may be more familiar in its English edition *VHF Communications*. The professional magazines like *Microwaves and RF* are fascinating and highly educational. They are also ultimately heartbreaking when you consider the price tag of the test equipment in the ads.

The Internet: The net is growing explosively, and it is particularly useful to a far-flung lot like amateur microwave enthusiasts. Useful resources include the Ham-Microwave mailing list, various web sites, and so on. Since the addresses change from time to time, please do a search to find current information.

Elmers: While this has been a traditional way of sharing information, microwave radio amateurs are so rare that I mention in-person Elmering for completeness only. Elmering via the Internet (see above) can be very effective, however.

Getting parts

Amateurs have been complaining about the availability of components for decades. I am mystified by this: parts are easier to get than ever before, and offer unprecedented performance and convenience. They aren't even very expensive after allowing for inflation. The issue appears to be that electronic components are no longer sold in every shop: other than Radio Shack, only major cities have comprehensive electronic component dealers. In practice, all this means is that I buy components by telephone, and wait a few days for a parcel to arrive. In all my amateur radio work, *one* parcel has gone missing, and when I notified the supplier, they shipped a replacement that day, no questions asked.

I have never had any difficulty purchasing components from suppliers in other countries. The worst Canada Post have ever done to me is charge me GST, plus their handling fee, which tends to be greater than the tax I'm paying on the shipment. This is sometimes the only convenient way to obtain "European" components, like BF961 transistors (a very nice VHF dual-gate MOSFET). Different countries have their own peculiarities: suppliers in the United Kingdom tend to take every credit card known to commerce; Visa was until recently called "Carte Bleue" in France; suppliers that take American Express (outside of the U.K. and U.S.A.) are extremely rare.

If you travel, try visiting some of the local firms. To me, Paris is a city of amazing electronics stores!

I have tried to avoid an excessive dependence on surplus equipment. The supply is at best erratic. It may be drying up. Few areas have any decent surplus dealers, though I have visited some brilliant shops in places like Silicon Valley, Dallas and Orlando.

Bands and modes

My microwave experiments have had two goals in mind: to learn something about microwaves, and to have equipment ready for Phase 3D. These goals coincide with 1296 MHz and 2304 MHz no-tune equipment that can be easily retuned to 1269 and 2400 MHz. These goals do *not* coincide with 10 GHz Gunn-based equipment—which has no application to Phase 3D communications, but which is an excellent way to get started with microwaves. Some choices have been based on equipment availability—like the two C band Frequency West brick oscillators that I purchased at a swap meet. They will eventually become the LOs of 3456 MHz equipment.

I have not attempted S or C band uplink equipment. The techniques are specialized, and the components (barring good luck at surplus dealers) are expensive. For the moment I will stick to 435 and 1269 MHz uplinks, where uplink power is inexpensive and idiot-proof. My terrestrial microwave work involves tens of milliwatts, which is plenty for what I want it to do.

I have no preference on the modes I use. Some have satellite applications. Some don't. This is not an issue on the lower bands (*e.g.* 2m FM vs. SSB); why should it be so on microwaves? "Appropriate modes" will change with the passage of time. Professionals use many modes, including wide-band FM and PSK. So can we: with satellites that look increasingly like bent-pipe repeaters, why not (other than power budget concerns) use any mode that will fit in the satellite's passband?

10 GHz: the easy band

My first microwave communications were in this band. I set an initial budget of 100 dollars for two stations (to make sure that I would have somebody to talk to), and came in substantially under budget. Here's how I did it.

Getting going

My first real microwave gear came from the usual source: a swap meet. I noticed a box full of ex-intruder alarm Gunn diode oscillators, with detector diodes in their feed horns. I bought two units as cheaply as I could and happily carted them home.

My primary reference for 10 GHZ wide-band equipment remains *Practical Transmitters for Novices* [Case95], a book aimed at U.K. Novice licensees, who have access to a segment in this band. Following the instructions in the book I verified that the Gunn oscillators both worked, and estimated their operating frequency. This turned out to be approximately 10.6 GHz, typical for Doppler intruder alarms. I retuned one unit to 10.2 GHz by adjusting the its tuning cavity, and after convincing myself that it was on the correct frequency, adjusted the other one to 10.3 GHz.

My "test equipment" makes the accuracy of these figures debatable, but the 100 MHz difference between them is accurate, since they are operating like Gunnplexers, where the Gunn oscillator that you transmit with does double duty as the receive LO. I chose an IF of 100 MHz to make use of available FM transistor radios, but IF breakthrough caused me to change my IF to 90 MHz. The modulator is trivial, adding a few millivolts of audio to the well-regulated Gunn diode power supply. For good measure I added an MMIC preamplifier to the receive side, using a MAR–6, a MAR–3, a 7808, and some components salvaged from junk cellular telephones. I laid out a little microstripline PC board with a ruler, drafting tape and guesswork. It works fine.

Does it work?

Of course! The audio quality rivals FM broadcast, and with small dishes or horns, these units can work any non-obstructed terrestrial path. Since very little of the circuitry is frequency-sensitive, the choice of modulation is open. I want to try X band ATV!

What now?

I'm starting to experiment with more elaborate receive equipment. Among other things, the Gunn unit detector diodes are grossly overdriven, limiting their performance. Also, low-noise preamplifiers are not possible. I purchased a pair of converted Ku band TVRO LNBs from a source in England. They have GaAsFET front ends, with noise temperatures in the 80 to 100 K range. They are already converted to 10 GHz with 9.0 GHz LOs, for an L band IF of 1000 to 1500 MHz. They are intended for use with a surplus satellite television receiver, but for experimental purposes I tacked together a very simple converter with some Mini-Circuits components from my junkbox: a MAR–6 preamplifier, a TUF–5 mixer and a POS–535 VCO. I didn't have anything in my junkbox that would oscillate at 1100 MHz, but knew that the diode mixer would respond on the 3rd harmonic of its LO. So I tuned the oscillator to 366.66 MHz, converting 10.2 GHz signals first to 1200 MHz in the LNB, and then to 100 MHz in my little converter. I initially christened this the Stupid Converter, because it cuts so many design corners, but still works. Sort of. Others have suggested the Geoduck Converter, because the input coax (a cut-down CATV cable) is white, and looks like a geoduck's foot.

One day I may move to a more benign IF like 70 MHz, popular in professional circles. While I may modify a faithful transistor radio, it may be easier to build a simple FM receiver. The only way to do this today is with subsystem ICs, an approach that does not seem to be well covered in the amateur literature. Other than the datasheets for the ICs themselves, the only useful references I've found on the subject all seem to come from Europe, for example, [Bajcik92], [Bajcik94] and [Lemmens96]. Others report success with even simpler receivers, like X band superregenerative receivers [Jamet97]. I wouldn't mind better frequency stability, and know a number of ways of achieving it (injection locking, AFC, etc.).

My X band setup is less than optimal, but *does* work, it worked the first try, and, stupid though it may be, it's a place to start. A system that works, however inefficiently, can always be a tool for testing and evaluating systems that work better.

No tune on 1296, 2304 and 2400

A really good idea

It seems so simple: by designing filters for 50 ohm input and output impedances, and interconnecting them with 50 ohm mixers and MMIC amplifiers, you can assemble systems out of building blocks that have very little reason not to work. But it took several developments to happen: hairpin filters on PC boards that can be etched precisely. Those 50 ohm MMICs, at a price amateurs can afford. And somebody to pull it all together.

Now that this is done, we amateurs can benefit from the work done by the no-tune transverter designers. Since the critical part is done once the PC board is etched, all that we need to do is add the remaining parts to the board, test it, and use it. Since the filters are already matched to 50 ohms, we can use *any* 50 ohm components between them. Since the boards are dimensionally stable, we can cut them up, use the components to make other things (or test stages in isolation), and fit the pieces back together.

It all sounds like a dream come true. Books for beginners recommend the no-tune transverters as an easy way to get on microwaves [Case94], [Campbell92]. Best of all: it's true. These things work.

I tried it

My no-tune transverter experience extends to KK7B's 1296 MHz transverter, and to WA8NLC's 2304 and 2400 MHz versions [ATUR]. The 2400 MHz version is the LO and receive side of the 2304 MHz converter. Not knowing what I was doing, I bought one complete kit, and a second set of boards. In this way I could build a transverter from a proven design that would have a very high probability of working. I could then use it to test the results of my own experiements on the victims...ahem, other boards.

The only component that has ever given me any difficulty is the KK7B local oscillator board [ATUR], which starts with a crystal oscillator in the 90 MHz range (you use an FM radio to tell if it's oscillating) and multiplies it by 6 to around 540 MHz. I've built three of them on various frequencies, and while the crystal readily oscillates on the correct frequency, I seem to get odd frequencies (and low output) out of them until I tweak the diode multipliers.

It is, however, pretty obvious when they work. I have found an older UHF television receiver (the continuous tuning variety) to be a handy broadband relative power indicator. The 576 MHz output of the 1296 MHz transverter LO board, for example, comes in on channel A31, and you can easily see changes in signal strength.

My assembly technique is good enough that I have never fried any components. Nor have I ever lifted any traces off the boards—a concern on the teflon 13 cm boards. Not at all bad for somebody who had never worked with this technology before.

Updates

The no-tune transverters date back to the 1980s, and in the meantime people have gained a great deal of experience with their strengths and weaknesses. Experience has taught people how to make better transverters. Some updates are based on new technology, like MMICs that were not available at the time of the original design [Kostro96]. Others are based on engineering and operational experience, like regulated MMIC power supplies [Ward93], and shielding things that radiate RF [Campbell94]. Some have pushed no-tune technology to X band [Orban96]. An important new technology is prepackaged computer clock oscillators, some of which are available in useful frequencies. These oscillators are simpler to use, cheaper than an equivalent circuit made out of discrete components, and work every time [Campbell95]. They're even more compact. Campbell's article is also a useful overview of design decisions in the no-tune transverters, with indications of future directions.

My no-tune transverters all have cut traces and additional components, little daughterboards and shielded filters. Some have LOs based on computer clock oscillators. Do they work any better? They appear to; I don't have test equipment for anything more than qualitative comparisons. Bragging rights are, of course, another matter entirely.

Simple stuff

Commercial interest in microwave communication is producing a steady flow of interesting new components. These components are aimed at mass-produced consumer products, so they are cheap, robust, and easy to apply. These components include low-noise amplifiers, power amplifiers, mixers, phase locked loops, and more. Examples include the ERA series of MMICs from Mini-Circuits, MMIC amplifiers internally matched to 50 ohms, with useful gain to X band. Mini-Circuits make a wide variety of other components, including mixers. National Semiconductor make PLL chips useful to 2.5 GHz. Hewlett-Packard make GaAs MMICs useful to X band. *Everybody* makes various chips for S band applications.

The simplest S band downconverter I've been able to come up with uses an HP MGA–86576 GaAs MMIC [Ward94] and a Mini Circuits SKY-5G mixer on a little PC board. I simplified the circuit by considering just what image response the converter needs, knowing that I will use it with a directional antenna. Since the antenna is pointing at the sky most of the time, the odds of anything other than noise being on the image frequency and in the antenna's pattern are remote. Since we are dispensing with image filtering, the choice of IF is open. Noting that we are receiving a 2400 MHz signal (24*100), if we choose an LO frequency of 2376 MHz (24*99), we have an LO frequency that can be generated from a standard 66 MHz computer clock oscillator module (24*99 = 36*66). For compatibility with available PC boards my LO uses a 74AC04 tripler to 198 MHz, an additional tripler to 594 MHz, and a final quadrupler to 2476 MHz. The circuitry will be familiar to users of the KK7B and G4DDK microwave LOs [ATUR], also [Campbell95].

The 24 MHz IF affords no image rejection with any reasonable filter, and so carries the price of a 3dB degradation in the signal-to-noise ratio. How will this work with Phase 3D?

You can approach this in one of two ways. Obtain the information on Phase 3D's orbit and S band transmitter and do formal link budget calculations. Or compare the known performance of OSCAR 13 S band equipment (for example, [Miller92]) and extrapolate to a very simple converter receiving Phase 3D signals. Either way, don't take my word for it. Please try it yourself. Even better: try both ways, and compare the results. Best of all: build it and get on Phase 3D.

Another simple to use device is Motorola's MRFIC2401, a complete low-noise amplifier and down-converter in a single SO–16 package. It requires very few external components to make a 2400 to 144 MHz converter (the recommended IF range is from 100 to 350 MHz) of respectable performance. Having been designed for portable telecommunications equipment, its current requirements are miniscule. The performance is much the same as the MGA–86576/SKY–5G converter, which is to be expected, because the LNA in the MRFIC2401 has similar specifications to the MGA–86576.

The RF portions of both these converters are extremely simple, but their local oscillators are complex. Is there a better way?

Lessons learned

What have I learned? A summary:

It works: Microwave communications provide efficient, reliable, highly predictable communications with modest antenna and power requirements. They will be a delight to use on Phase 3D.

Parts are available: There are many suppliers of generic electronic components, and a handful who sell more interesting RF components. Cherish them! In this age of direct international dialling and credit cards, I define a "local supplier" as one on the same planet as myself. While they are geared toward OEMs, I have often found local industrial distributors to be receptive to friendly, polite requests.

New and neat parts: Commercial interest in wireless communications is growing explosively, and we can benefit from this. Since designers want to be able to make money for their employers as quickly as possible, the new components are easy to use, and are often already matched to 50 ohms. All you have to do is string them together, like the building blocks they are. All semiconductor manufacturers have their datasheets online now, making it easy to obtain information. Do it!

The HUH?! factor: I sometimes feel like I have just arrived from Vega when I try to discuss microwave amateur radio with other hams, whose usual response is blank stares. What is the origin of this disconnect? What can we do about it?

The Narrowband Preoccupation: While we can send and receive SSB and CW on the microwave bands, and these are sometimes the best modes, they are not *always* the best modes in all circumstances. The microwave bands are tens—even hundreds—of megahertz wide, room for all kinds of useful and interesting signals. Some are starting to express concern that the steep learning curve of narrow-band equipment is hampering the growth of microwave amateur radio [Dixon97]. I routinely receive email informing me that WBFM is Just Not Done Anymore. I beg to differ.

Use what you have: I made my first X band frequency measurements with a ruler, a piece of unetched PC board and a multimeter. While this is not the most accurate measurement, it is far better than no measurement at all. I made my first L band power measurements by counting the number of paces until the transmitter would no longer break the squelch on a hand-held scanner. Again, not a perfect measurement. But it's a place to start. Don't be embarrassed. I'm not.

Band occupancy: With commercial interests eyeing our bands, we *must* make use of them to have any justifiable claim.

Just do it! What are you waiting for?

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Production note

I created this paper with Donald Knuth's typesetting system TEX, running on a 66 MHz 486 PC under the Linux operating system. The published version used fonts from the ITC Souvenir family; this version uses Times-Roman and Helvetica.