411 GHz Corner Cube Mixer.

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At the extremely high frequencies above 300GHz where fundamental waveguides and l/4 circuits are unpractical it becomes easier to use oversized waveguides and structures evolving quasi-optical components and Gaussian beams rather than the traditional fundamental mode waveguide components.
A very simple, and well known, radiating element the long wire antenna is useable here to gain some size as a wire with 4l at 411GHz has 2.9mm long. By using such a radiator and a fast enough diode it is possible to build a mixer or a detector for these high frequencies where technology and techniques begin to resemble optics.
In the present article one mixer, is described. It's design consists of a diode (chip or beam-lead) placed in a 4l open radiating structure know as a corner cube mixer.

Introduction

At the microwave frequency range, the connection leads and packing of semiconductors (and other components) are carefully studied by the manufacturers in order to introduce minimal parasitic reactance and losses. At millimetre wave-lengths, (from 30 to 300GHz) the limitations become severe and semiconductor elements are used in chip form or mounted inside waveguide structures. Above, at sub-millimeter wavelengths (> 300GHz), the size of a fundamental waveguide (0.6x0.3mm at 300-470GHz) is barely suitable to accommodate any usual diode, unpackaged chip diodes are the usual devices at these frequencies however beam-lead diodes may be used in the lower frequency range. Despite the fact that these diodes are quite small, fundamental waveguides are unpractical also as they start to have high losses.
At the frequencies we are interested the wavelength is so small that $\lambda/4$ is quite difficult to make in practice and a fundamental mode waveguide with a diode to be used as a mixer is extremely difficult to realise, also results may be quite poor.
An open radiating structure consisting of a long wire would provide the necessary interface from free space to the mixing (detecting) element. Long wire antennas are well known since the very early days of radio. These antennas are, by definition, several wavelengths long and they provided a simple way of achieving some directivity along with the simplicity of design. Placing the long wire close to a ground plane, or better to a set of reflecting planes it is possible to get only one radiating lobe. The signal generated by this structure could be radiated into free space directly or used to illuminate a larger reflector. Whatever the case all sort of specially shaped reflectors and lenses (both metallic and dielectric) can be used.

Working principle.

The mixing (or detector) element is a very fast schotky barrier diode, placed at the base of a 4 wavelengths long wire antenna, that measures about 2.9mm (4λ at 411GHz). This long wire antenna is placed at 0.93λ from the corner cube apex to provide the desired radiating pattern. This is the classical configuration of a corner cube mixer or detector. The typical radiation properties are sketched on fig 1. This structure has one main radiation lobe at 28 degrees from the vertex that makes quite easy to couple it to the a shaped reflectors in order to form a guided wave or a free propagating wave. Practical radiation properties from real corner cube mixers are somehow critical and may be a lot different from the theoretical properties if some small detail was not accounted during the design. Extensive simulation studies have been done on several corner cube mixer configurations /1/ and the prototype constructed by the author was modelled and simulated by G.Leuterbach AD6FP.

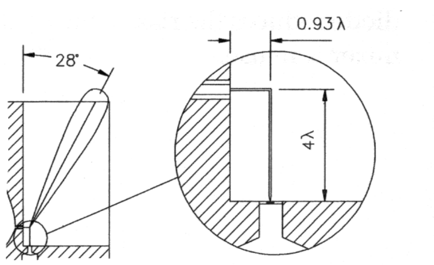

Fig 1 - Typical corner cube configuration and radiation pattern.

At the end of the long wire a chip diode or a beam-lead diode is placed and all high frequencies should be de-coupled at this point. The high frequency is effectively de-coupled at the capacitor formed by the strangled end of the coaxial section. The IF+DC or LO+IF+DC should be connected from the bottom with the appropriate diplexing structure. The harmonic mixer has the most complicated construction set-up as the LO coupling from the waveguide port into the diode must be done while maintaining a path for the IF and DC. Figures 2 shows the configurations of a detector or fundamental mixer while figure 4 details the harmonic mixer configuration.

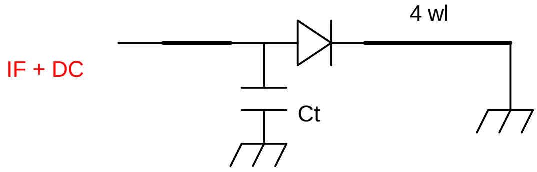

Figure 2 - Fundamental mixer configuration.

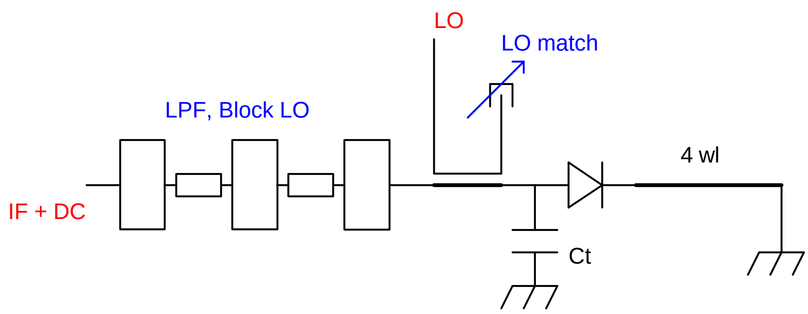

Figure 3 - Harmonic mixer configuration.

Corner Cube Construction.

Most of the work necessary to build this corner cube mixer is in fact mechanical work. In this mechanical design approach the unit was built in two parts, the top contains the corner cube open structure and the bottom has the local oscillator waveguide port and IF/DC SMA connector. If we are only interested in a fundamental mixer or a detector, the waveguide port may be omitted.
The corner cube metal reflector is a critical part to be constructed and a perfect corner is impossible to be done by milling as the tool radius sets the minimum vertex diameter. However, the bottom of the corner doesn't need to establish a perfect mechanical/electrical connection to the corner walls consequently the corner may well be constructed in two pieces allowing it to be done by machining. Nevertheless a single piece corner cube is possible to be manufactured by electro-forming (using a galvanoplastic process) on a perfect cube core. As the electroforming facility was available this was the option used on the prototype, to get everything done the best way possible, in the search for the last dB. The electroformed corner cube was stain soldered to the top block prior to the overall milling and drilling process. After, all the milling and drilling was done according the mechanical plan at the end of this article.
All the mechanical techniques for building such a device are out of the scope of this article but any experienced mechanist would be able to build it from the presented drawings, as long as he can be guided by someone who understand the needs from a microwave point of view.

Diode types.

To operate at these frequencies the diode must have low series resistance and very low junction capacity. Also the parasitic should be virtually non-existent and any length of connection should take part of the 4λ long wire and parasitic capacity should be extremely small. There are a few diode options that may produce some reasonable results at 411GHz.

- Point contact diodes.
This is the simplest form of a metal to semiconductor diode, virtually with no difference from the early radio day's germanium detectors. It consists of a very sharp whisker directly contacting an N type semiconductor. Packaged microwave diodes

like IN21 IN23 IN53 etc were constructed using this technique. The basic diode parameters like contact resistance and junction capacitance depend on several factors but the main determinant one is the sharpness of the whisker and the "luck" of finding a good contact spot. In fact the sharpness of the tip can determine the size of the junction and therefore influence strongly all other parameters. The whisker material is usually tungsten as it is one of the hardest metals usable and possible to sharpen (by galvanic etching) down to a few nanometers tip diameter. The whisker needs to be hard enough to maintain the sharp tip shape and perforate the oxide layer that naturally develops on the semiconductor surface, more it should allow repeating this contact process until a good diode is achieved. With this technique it is possible to make diodes with a few femtoFarads junction capacity and therefore several hundred gigaHerts of operating frequency. At millimeter waves this devices are quite common, for example the best Hughes (now Millitech /2/) detectors and mixers on any band up to 240GHz use this type of diode and have characteristics hardly supplanted by the modern detectors and mixers now available.
Making a good submillimeter diode using this technique is possible however getting the best results would stretch anyone patience to the very limits of human nature.

Practical tips on point contact diode construction.
- The tungsten wire could be obtained from savaging old IN23 diodes or aquired in small quantities at "goodfellow" /3/
- Sharpening the wire to a few nanometers can be done by electro-etching the tungsten tip on a KaOH 10% electrolyte.
- The diode semiconductor chip can be obtained from savaging old Alpha or Macomm detector diodes for the Ka band usually found on 24GHz gunnplexer. The chip can be removed by heating the base of the diode with a soldering iron at about 220C.
- Use the same technique to solder it back were you want. A In based solder with appropriate flux is desirable, but any Sn based solder would do the job at about 290C, but in this case we have to do it quicker to avoid destroying the back metallization of the chip.
-Use a binocular microscope during all the process with about 10x to 50x magnification.
- Searching for a good detector or mixer diode requires the constant monitoring of the diode I/V curve. Any old Tek curve tracer will do, or we can build one rapidly with a low frequency signal generator and a few resistors, placing the oscilloscope in X/Y mode.

- Beam lead diode.
This is the device with closest physical resemblance to the packaged diode as it appears to have a body and two metallic leads but considerably smaller size (50 to 100μm). It consists of a semiconductor chip (Si or GaAs) with two thin ribbons of gold for the anode and cathode connections attached to it. The semiconductor chip has a thin N type epitaxial layer on the top followed by an insulation oxide layer on which both ribbons are attached. The cathode has a large ohmic contact area to the epitaxial N layer (through a large hole on oxide layer) while the anode only contacts the epitaxial layer on a very small point of about 1 to 5μm diameter (through a very small hole on the oxide layer). This small contact hole from the lead to the N semiconductor material is in fact the diode. The only limitation of this type of device for extremely high frequencies is caused by the capacity formed by the anode ribbon to the substrate

material, although recent devices have been optimised to be produced with very small parasitic capacitance.
This type of diode is quite common on devices from 30GHz to 240GHz but rarely found above this frequencies, however there was design examples using this devices at 585GHz /4/.
For our application it is possible to use beam-lead devices with great advantage over point contact diodes, specially when it comes to the reproducibility of the design, however a good point contact diode may exhibit superior performance.
Several types of beam-lead devices may be considered for experimentation at these frequencies namely the HSCH9161 from Agilent or the SBL016 from Farran just to mention two very good and moderate cost candidates (many others are available).

- Dot Matrix Diode

One dot-matrix chip has hundreds of diodes and each of those consists usually of a metal to semiconductor diode in an epitaxial structure. The device fabrication process is somehow similar to integrated circuits. The use of controlled epitaxial growth and doping in conjunction with micro-lithography to define the metal (platinum) to N semiconductor area allow the manufacturer to build the device they really want.
The typical diameter of the diode contact area is 1 to 5μm. A wire tip of 1μm is usually enough to contact the diode and the softness of the gold layer deposited after the platinum makes this contact very reliable. Also some manufacturers make the contact areas recessed with respect with the chip surface (using a layer oxide) this makes quite easy to establish a good diode connection.
This is by far the best chip diode that one can use at these frequencies, and in case of damaging one diode, there is an nearly endless possibilities for instant repair by recontacting to another diode. A few dot matrix diodes are available (at high prices) namely from NMRC, Millitech and Farran (and others).

Some practical results.

Two corner cube mixers were constructed using a local oscillator on the Ka band, aiming for 12^{th} harmonic operation. This selected LO frequency was probably too low to exploit the best conversion losses from the harmonic mixer, however it was done this way to take advantage of the large amount of components available on Ka band. Also because lots of local oscillator power is possible to generate at this band.
It is recommended to use of a local oscillator with good stability and low phase noise in order to allow narrow band receivers preferably in CW mode with 1KHz bandwidth or less. This rules out the use of a free run Gunn oscillator that would require about 1MHz (or more) of IF bandwidth on the receiver side that represents a loss of 30dB and more comparing with the narrow band approach. These considerations leave us with the only option of having a phase locked source or a multiplied source (or a combination of both) from a stable quartz oscillator.
The first diode option was the point contact but obtaining consistent results was very difficult. The main problem was the actual low current I could draw from the diode in the presence of a strong LO signal (showing the presence a high contact resistance somewhere). This made the generation of harmonics very difficult. The resulting diode after several re-contacting sessions was usually a reasonably good detector but

with a very high series resistance. As a detector it operated very well at 1MOhm DC load while at 10KOhm the output was much lower. Fundamental mixer was possible by using a low frequency IF with a very high input impedance IF preamplifier (dual gate MOSFET was used). However providing a reasonable LO power level at 411GHz was still a problem. Using point contact diodes require a great deal of patience and time. Beam lead diodes are now under test and their results look very promising.
The transverter configuration uses the offset-LO technique in order to use the corner cube as a harmonic mixer during reception and as a frequency multiplier during transmission. The actual transverter configuration will be detailed in a different article.
So far, signals were obtained on the bench and there is a high hope in making a 50 to 100m contact very soon.

Concluding remarks.

In this article the highlights for constructing a mixer or detector for 411GHz using a corner cube topology was presented, however some aspects may suffer from lack of detail and may require some additional research for those that are looking into this topics for the first time. Hope this article may constitute the starting point for experimentation on these frequencies, and if this article have triggered your interest on extremely higher frequencies than it accomplished one of its main objectives.
An article describing the transverter in which this corner cube device is used is under preparation and will be presented very soon.

References:

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/4/ - Fixed-tuned submillimeter wavelength waveguide mixers using planar Schottky-barrier **diode**s Hesler,J.L. et al. IEEE Transactions on Microwave Theory & Techniques. v 45 n 5/1 May 1997.