A Microwave Fourier Transform Spectrometer in the Region between 26 and 36 GHz

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We present a first set up and tests of a microwave Fourier transform spectrometer above 26 GHz with some features differing from the instruments in the lower frequency bands.

Introduction

We report an attempt to extend microwave Fourier transform (MWFT) spectroscopy to frequencies above 26.4 GHz. We found that spectroscopy in the time domain used in [1–6] is superior to conventional Stark spectroscopy in respect of resolution and sensitivity [7–8]. As many investigations of rotational spectra especially of light molecules need higher frequencies we planned to extend the frequency range. The availability and costs of certain microwave components and instrumentation restricted a simple transfer of the design from lower frequency bands for a first set up of a spectrometer by which the feasibility of the method can be shown.

Experimental Set Up

The polarization of an ensemble of dipolar molecules by a microwave carrier pulse and the following detection of the transient molecular emission signal was possible by a set up given in Fig. 1 in principle and Fig. 2 in detail. The MW pulses were produced at half the frequencies (1)* needed for polarizing the molecules and subsequently frequency doubled (2).

So parts of the MWFT spectrometer in Ku-band (12.4–18 GHz) could be used. By this method MW pulses of a carrier frequency are selectable between 26 and 36 GHz to polarize the sample in the cell (3). The molecular transient signal is superhet detected by unit (4) and transferred to the data processing unit (5).

A more detailed display is presented in Figure 2. A Ku-band signal source (1) and (2)** was phase stabilized by the synchronizer (3) to the local oscillator source (40). (For more details see below). The frequency and power of the signal MW can be monitored by the counter with integrated powermeter (10) and adjusted in power by the attenuators (6) and (8). The MW pulses with a minimum length of 10 ns are formed by the PIN-switches PS 1, PS 2, (13) and (14). The time diagram is given in Fig. 2 of [5].

A 0°/180° phase shift needed for the phase alternating pulse sequence method (PAPS) [6] is achieved by the biphase modulator (15), (16). The carrier frequency of the pulses is doubled by using the second harmonic of the travelling wave tube amplifier (TWTA) (17). We obtained an output power at (21) of roughly + 10 dBm. The isolator (18) designed for Ku-band protects the TWTA from MW pulses reflected at the taper (19) and was selected for low attenuation in the band above 26.4 GHz. The V-band PIN-switch PS 3, (21) suppresses the TWTA noise and reduces together with the PIN-switch PS 3′, (12) the leakage of continuous microwave through PS 1 and PS 2 during

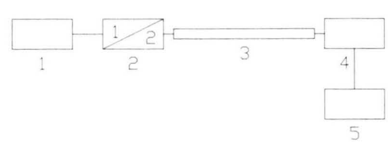

Fig. 1. General set up of a MWFT-spectrometer in the range of 26 to 36 GHz. 1 Phase stabilized MW source from 13 to 18 GHz and pulse generation; 2 MW frequency doubler; 3 Sample cell; 4 MW superhet detection system with a phase stabilized local oscillator from 26–40 GHz; 5 Data processing unit.

* The numbers in parentheses refer to Figure 1.
** The numbers in parentheses refer to Figure 2.

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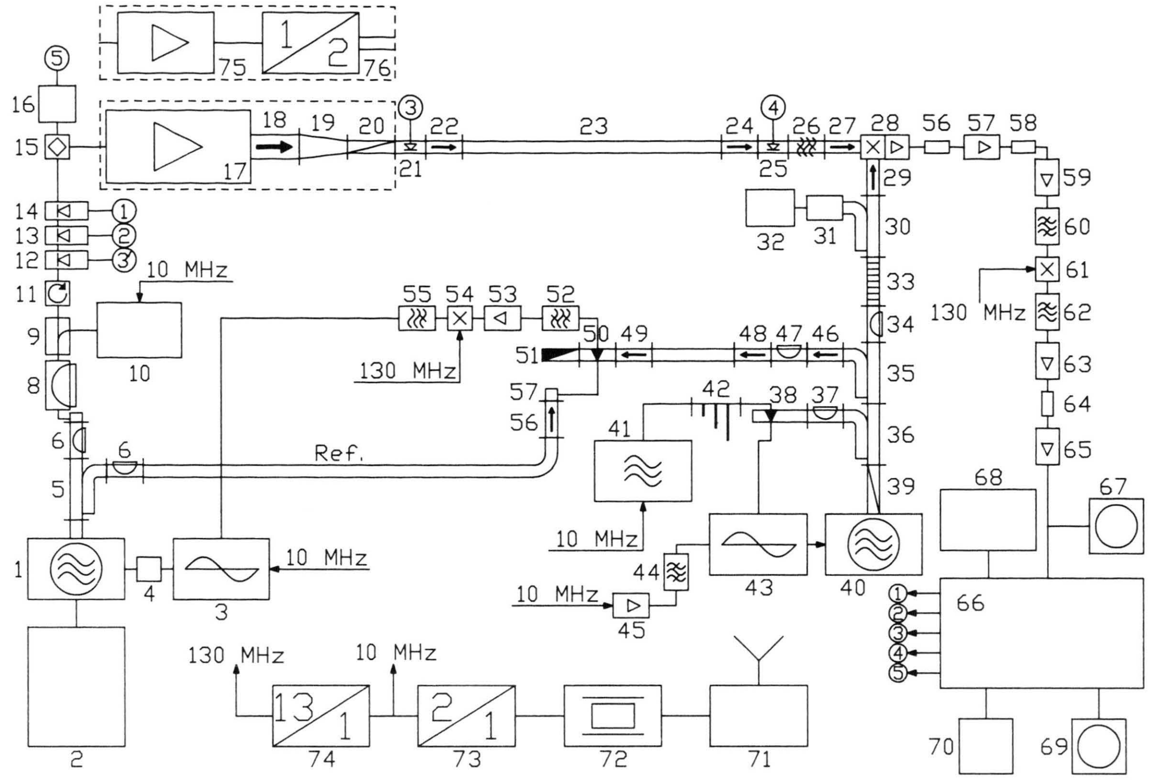

Fig. 2. Detailed set up of a MWFT-spectrometer from 26–36 GHz. BW: Bandwidth; IF: Intermediate frequency; V: V-Band, 26.4–40 GHz; Ku: Ku-Band, 12.4–18 GHz.

1 Signal source, BWO 12.4–18 GHz, Ku-band, Watkins Johnson (WJ) 2056-20
2 BWO power supply, Heinzinger; HNS 4000-01, HNCS 600-10, TNS 10-30, TN 100-20, TNS 200-20
3 Synchronizer, Schomandl FDS 30
4 Matching network
5 Directional coupler, Ku, 10 dB
6 Waveguide variable attenuator, Hewlett-Packard (HP) HP P375A
7 Waveguide to coaxial adapter, Suhner 3101
8 Coaxial variable attenuator, 4–18 GHz
9 Coaxial directional coupler, 20 dB, Narda
10 Counter with powermeter, Systron Donner 6030
11 Isolator, Microtek I124K18A2
12 PIN-switch with driver, HP 33144A and equivalent to HP 33190B
13 see 12
14 see 12
15 Biphase modulator, WJ M79C
16 Current driver for 15, 5mA
17 Travelling wave tube amplifier, 20 W, Hughes 8020H04
18 Waveguide isolator, Ku, selected for low loss in the range of 26–40 GHz, Pamtech PHG 2109
19 Waveguide adapter, Ku/V-band 12.4–18 to 26.4–40 GHz
20 Waveguide twist
21 PIN-switch, V, AEG PS28HHI
22 Waveguide isolator, V, Trak 2571-1810
23 Sample cell, V, (length 2.7 m) with windows and vacuum system
24 see 22
25 see 21
26 Waveguide filter, HP R362A
27 see 22
28 Waveguide balanced mixer with integrated preamplifier, V, Spacecom FkaU
29 see 22
30 Waveguide directional coupler, V, 10 dB, DeMornay Bonardi (DBD)-675-10
31 Power sensor, V, HP R486A
32 Power meter, HP 432A
33 Flexible waveguide, V
34 Waveguide variable attenuator, V, DBD 430
35 Waveguide directional coupler, V, 20 dB, Flann 22 132-20
36 Waveguide directional coupler, V, 10 dB, FXR U610CF
37 see 34
38 Waveguide mixer, V, HP 11971A
39 see 20
40 Local oscillator, sweeper, V, HP 8690B + HP 8697A
41 Synthesizer 5-2700 MHz, Rohde & Schwarz, SMPD
42 Tristubtuner
43 Synchronizer, HP 8709A
44 Bandpassfilter, 20 MHz, BW 1 MHz
45 Amplifier, 30 dB gain, Avantek GPD 461, 462, 462 used as doubler
46 see 22
47 see 34
48, 49 see 22
50 Waveguide harmonic mixer with diode 1N53, V
51 Waveguide termination, V
52 Bandpassfilter, 160 MHz, BW 10 MHz
53 Amplifier, gain 40 dB, Amplica USL401
54 IF Mixer, Mini Circuits ZAY3
55 Lowpassfilter, 110 MHz
56 Attenuator 10 dB
57 IF-amplifier, 38 dB gain, RHG ICFH160LN
58 Attenuator, 3 dB
59 IF-amplifier, 23 dB gain, RHG ICFV16060
60 Bandpassfilter, 160 MHz, BW 20 MHz
61 IF-mixer, Mini Circuits ZAD1WH
62 Lowpassfilter, 55 MHz
63 Amplifier, 25 dB gain, Avantek GPD 461, 462
64 Attenuator, 3 dB
65 see 63
66 Analog to digital converter, averager and experiment control unit, 10-, 20-, 50-, 100-ns sampling intervals, 1024 data points, 25 kHz repetion rate maximum [11]
67 Oscilloscope
68 Computer, Texas Instruments 990/10
69 Oscilloscope
70 X-Y-recorder
71 Normal frequency receiver, Rohde & Schwarz XKE2
72 Quartz frequency standard, 5 MHz, Rohde & Schwarz XSD 2
73 Frequency doubler
74 Frequency multiplier
75 Microwave amplifier HP 8349B
76 Microwave frequency doubler, HP 83554A

Erroneously the numbers 56 and 57 have been used twice. Centre of Figure: 56 waveguide isolator, Ku 57 see 7.

the measuring period. The sample cell (23) is enclosed by isolators (22, 24) of low VSWR to reduce pulse reflections. The PIN-switch PS4, (25) isolates the detection system during the MW pulse. The switching transients of PS4 were reduced by the bandpass filter (26). The isolator (27) is inserted to suppress reflected local power transmitted through the mixer (28). The mixer is fed with microwave power from the local oscillator (40), which is phase stabilized by the synthesizer (41), the harmonic mixer (38) and the synchronizer (43).

The local power, which can be adjusted by the attenuator (34) is monitored by the power meter (31), (32). The signal oscillator is phase stabilized to the local oscillator by the mixer (50), the amplifier (53), the IF-mixer (54) and the synchronizer (3). The molecular transient signal is down converted by the mixer (28) into a band centered at 160 MHz, amplified (57), (58) and again down converted by the mixer (61) into a band centered at 30 MHz. The signal is A/D converted and averaged by the transient recorder (66) and Fourier transformed by a computer (68) in the usual way [5]. The instrument (66) provides also the experiment control. All frequencies are referred to the station DCF 77 Mainflingen by the receiver (71), regulated quartz oscillator (72) and multipliers (73) and (74).

In a second version the TWTA (17), the isolator (18) and the taper (19) were replaced by an MW-amplifier (75) and doubler (76), delivering + 7 dBm.

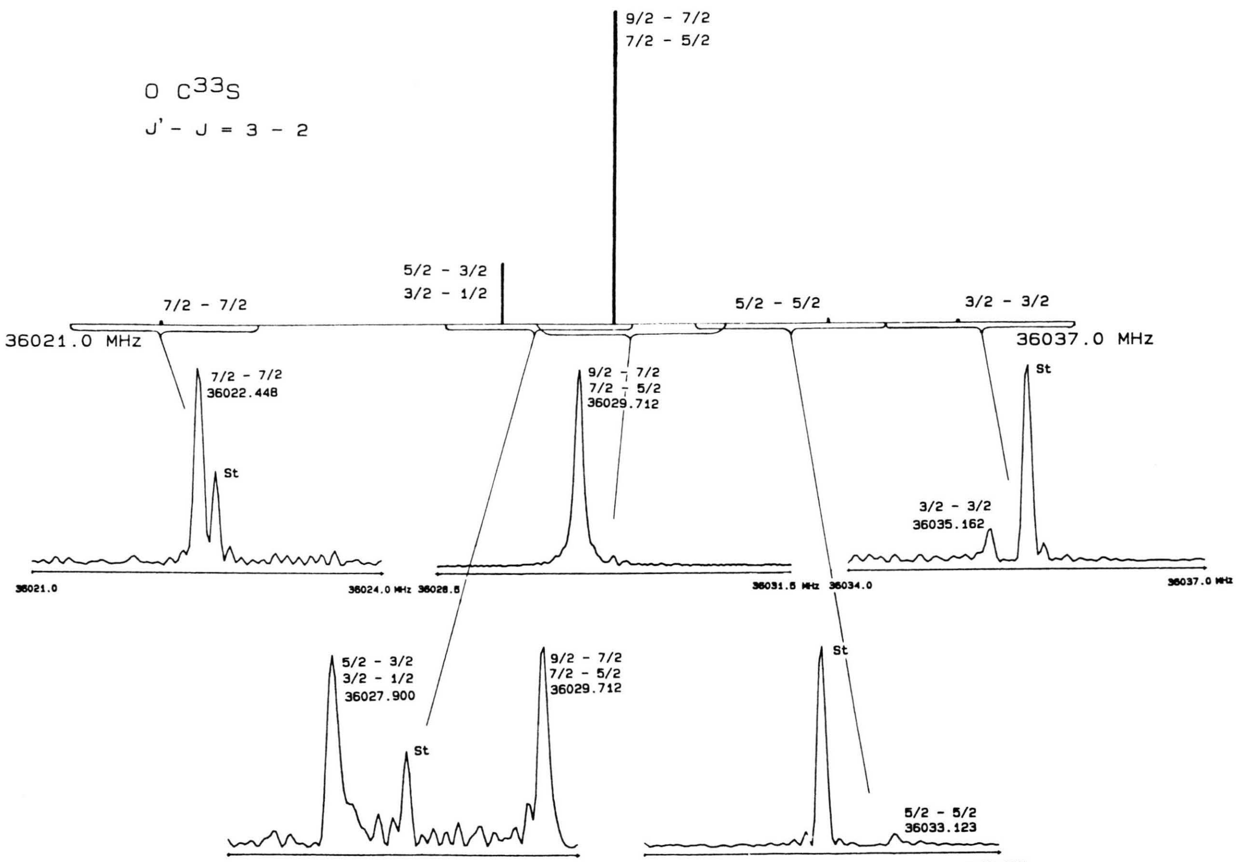

Fig. 3. Hyperfine structure of ^{33}S-carbonylsulfide in natural abundance. *Upper trace:* Theoretical pattern indicating the intensities in a power spectrum. *Lower traces:* Measured components and coherent perturbations (indicated by St). The lines were polarized with different polarizing frequencies because the small power of the signal source limited the polarized range. Sample interval 10 or 20 ns, 6000 to 30 000 k averaging cycles, pressure 2.5 mTorr, 0.3 Pa, temperature − 50 °C, 1024 data points of the transient decay supplemented by 3072 zeros prior to Fourier transformation.

Experimental Tests and Experience

The sensitivity was tested with isotopic species of carbonylsulfide in natural abundance. The $J = 2 - 3$ line of $O^{13}C^{34}S$ with an absorption coefficient of $8 \cdot 10^{-8}$ cm^{-1} was detected with 960 k averaging cycles.

In the course of these tests the hyperfine structure (hfs) of $OC^{33}S$ was measured. The recording is shown in Figure 3. The analysis is published elsewhere [9]. During the optimalization of the length of the polarizing MW pulse we noticed that the pulse length should be around 1.5 μs. In comparison to lower frequency bands, where 100 ns are sufficient, this indicates that the polarizing power is too low.

With cyanogen iodide, ICN, we tested the linewidth which can be obtained in favourable cases. Figure 4 shows the nitrogen hfs of the iodine hfs component $F_1 = 7/2 - 9/2$ of the transition $J = 4 - 5$ near 32 215 MHz.

The observed half width at half height is 20 kHz. The calculation also yields a width of 20 kHz consisting of a Doppler contribution of 14 kHz and a contribution due to wall collision broadening of 6 kHz. In this case the line-width has reached the limit of this type of spectrometer.

Further, the spectrometer was tested with perdeutero-methylamine, CD_3ND_2, 2-fluoropropane, $(CH_3)_2CHF$ [10] and other molecules. The common experience was that a larger number of averaging cycles is necessary to reach a quality of spectra comparable to those in lower frequency bands.

It should be mentioned that all those spectrometers have a MW-amplifier in front of the mixer (28) with a gain of about 30 dB. In addition the sample cells have a larger cross section and length.

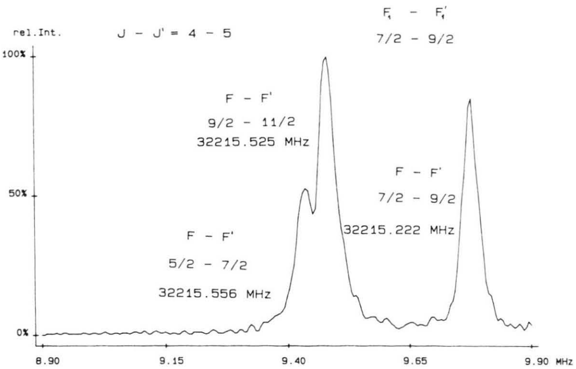

Fig. 4. A 1 MHz section out of a 10 MHz scan of the rotational power spectrum of cyanogen iodide, ICN. $J = 4 - 5$ transition, $F_1 = 7/2 - 9/2$ iodine hfs component. The nitrogen hfs is resolved. Sample interval 50 ns, 3520 k averaging cycles, pressure 0.3 mTorr, 0.04 Pa, temperature $-40\,^\circ$C, polarizing frequency 32 215 MHz, 1024 points of the transient decay supplemented by 3072 zeros prior to Fourier transformation, half width at half height of the single component 20 kHz.

We observed also switch transients of PIN switch (25) of some hundred ns, which we could not suppress with our present means. Therefore the delay between the MW pulse and the measurement was usual high in the order of 4 μs.

Summarizing the experience we can state that MWFT spectroscopy can be expanded above 26 GHz. To reach the performance of lower frequency spectrometers a travelling wave tube amplifier following the doubler (76) and a low noise amplifier in front of the mixer (28) will be useful.

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