Synthesis

Reviews and Full Papers in Chemical Synthesis

Supporting Information

for DOI: 10.1055/a-2042-3720



Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

Thieme

*Supporting Information*

# Synthesis of 1-(Trifluoromethyl)alkenes through Transition-Metal-Catalyzed Alkylation and Arylation of 1-Chloro-3,3,3-trifluoroprop-1-ene (HCFO-1233zd)

Wei Zhou[a], Qing-Wei Zhao[a], Yun-Cheng Luo[b], Xingang Zhang*[a,b]

[a]*College of Chemistry, Henan Institute of Advanced Technology, Zhengzhou University, Zhengzhou 450001, P. R. of China*

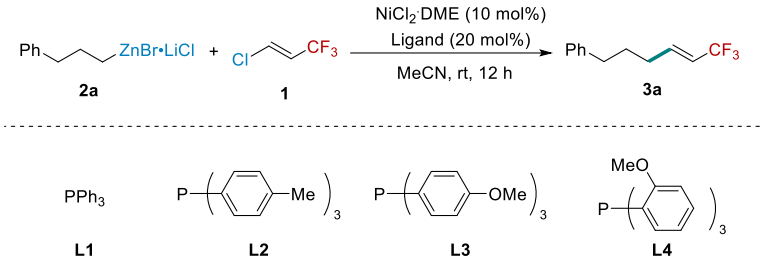
[b]*Key Laboratory of Organofluorine Chemistry, Center for Excellence in Molecular Synthesis, Shanghai Institute of Organic Chemistry, University of Chinese Academy of Sciences, Chinese Academy of Sciences, 345 Lingling Road, Shanghai, 200032, P. R. of China*

*xgzhang@mail.sioc.ac.cn*

**Table of Contents**

## 1. Optimization of the Reaction Conditions for the Alkylation of HCFO-1233zd 1

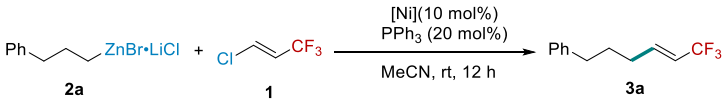
**Table S1. Screening of the ligand**[a]




| Entry | **Ligand** | **3a** (%)[b] |
|---|---|---|
| 1 | **No Ligand** | 42 |
| 2 | **L1** | 43 |
| 3 | **L2** | 32 |
| 4 | **L3** | 15 |
| 5 | **L4** | 18 |

[a]Reaction conditions (unless otherwise specified): **1** (4.0 equiv), **2a** (0.3 mmol, 1.0 equiv). [b]The yield was determined by $^{19}$F NMR using fluorobenzene as an internal standard.

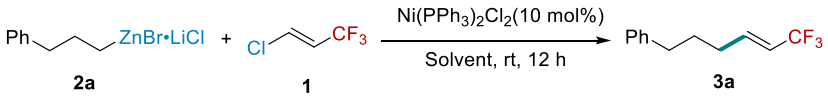
**Table S2. Screening of the nickel sources**[a]




| Entry | [Ni] | **3a** (%)[b] |
|---|---|---|
| 1 | $NiCl_2$·DME | 42 |
| 2 | $NiI_2$ | 40 |
| 3 | $Ni(OTf)_2$ | 41 |
| 4 | $Ni(ClO_4)_2·6H_2O$ | 35 |
| 5[c] | $Ni(PPh_3)_2Cl_2$ | **45** |
| 6 | $Ni(COD)_2$ | 43 |
| 7 | No Ni | nd |

[a]Reaction conditions (unless otherwise specified): **1** (4.0 equiv), **2a** (0.3 mmol, 1.0 equiv). [b]The yield was determined by $^{19}F$ NMR using fluorobenzene as an internal standard. [c]$PPh_3$ was not use. nd, not detected.

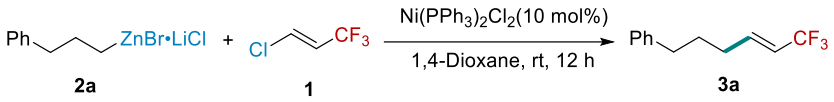
**Table S3. Screening of the solvents**[a]




| Entry | Solvent | **3a** (%)[b] |
|---|---|---|
| 1 | DMA | 80 |
| 2 | DMF | 53 |
| 3 | THF | 13 |
| 4 | 1,4-Dioxane | **92** |
| 5 | MeCN | 45 |
| 6 | NMP | 79 |
| 7 | DCM | 8 |
| 8 | Toluene | 21 |

[a]Reaction conditions (unless otherwise specified): **1** (4.0 equiv), **2a** (0.3 mmol, 1.0 equiv). [b]The yield was determined by $^{19}F$ NMR using fluorobenzene as an internal standard.

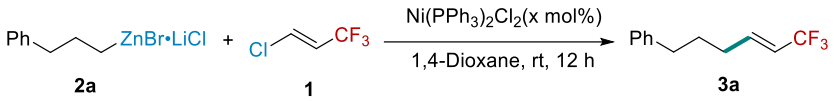
**Table S4. Screening of the loading amount of 1**[a]




| Entry | **1** (x equiv) | **3a** (%)[b] |
|---|---|---|
| 1 | 1 | 89 |
| 2 | 2 | **92** |
| 3 | 3 | 93 |
| 4 | 4 | 92 |
| 5 | 5 | 90 |
| 6 | 6 | 93 |

[a]Reaction conditions (unless otherwise specified): **1** (x equiv), **2a** (0.3 mmol, 1.0 equiv). [b]The yield was determined by $^{19}F$ NMR using fluorobenzene as an internal standard.

**Table S5. Screening of the loading amount of $Ni(PPh_3)_2Cl_2$[a]**

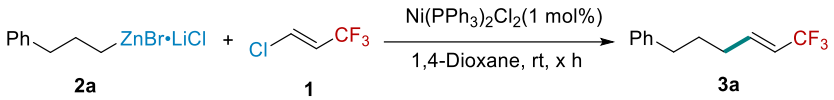



| Entry | $Ni(PPh_3)_2Cl_2$ (x) | **3a** (%)[b] |
|---|---|---|
| 1 | 0.1 | 67 |
| 2 | 0.5 | 91 |
| 3 | 1 | **92** |
| 4 | 2 | 93 |
| 5 | 5 | 90 |
| 6 | 10 | 92 |
| 7 | 20 | 90 |

[a]Reaction conditions (unless otherwise specified): **1** (2.0 equiv), **2a** (0.3 mmol, 1.0 equiv). [b]The yield was determined by $^{19}F$ NMR using fluorobenzene as an internal standard.

***Note:*** The use of 10 mol% or 20 mol% of $Ni(PPh_3)_2Cl_2$ led to comparable yields. This is probably because the Ni(0)-catalyzed cross-coupling is fast as demonstrated in Table S6. Once a small amount of Ni(0) species is generated by the reduction of $Ni(PPh_3)_2Cl_2$ with alkylzinc reagent, the Ni(0)-catalyzed cross-coupling between **2a** and **1** proceeds smoothly, which may suppress the further consumption of alkylzinc reagent by its reaction with $Ni(PPh_3)_2Cl_2$. However, the exact reason for this finding remains elusive at this stage.

**Table S6. Screening of the Reaction Time**[a]

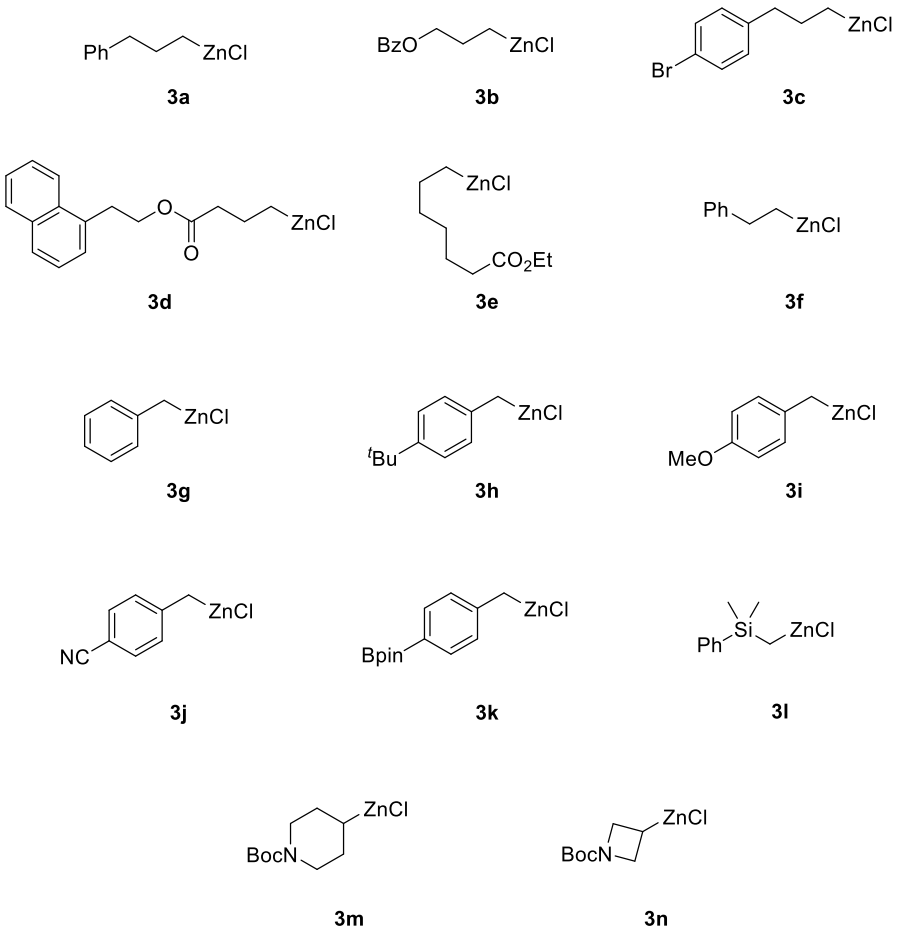



**2a** **1** **3a**

| Entry | **Time x (h)** | **3a** (%)[b] |
|---|---|---|
| 1 | 0.25 | 35 |
| 2 | 0.5 | 87 |
| 3 | 1 | 92 |
| 4 | 2 | **92 (87)** |
| 5 | 12 | 92 |

[a]Reaction conditions (unless otherwise specified): **1** (2 equiv), **2a** (0.3 mmol, 1.0 equiv). [b]The yield was determined by $^{19}F$ NMR using fluorobenzene as an internal standard, and the number in parentheses is the isolated yield

## 2. Preparation of the alkylzinc reagents

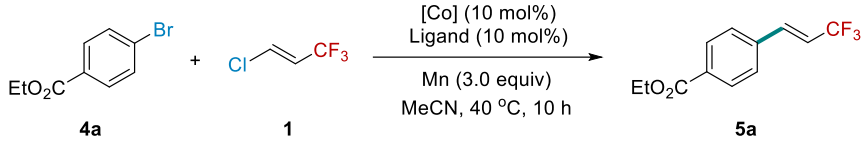


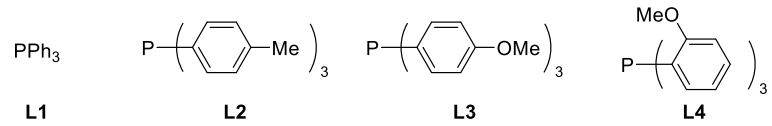

**Structures of trifluoromethylarenes**

***Note:*** Substrates **3g** are commercially available. Other substrates are prepared from commercially available alkyl halides.

## 3. Optimization of the Reaction Conditions for the arylation of HCFO-1233zd 1

**Table S7. Optimization of the reaction conditions**[a]



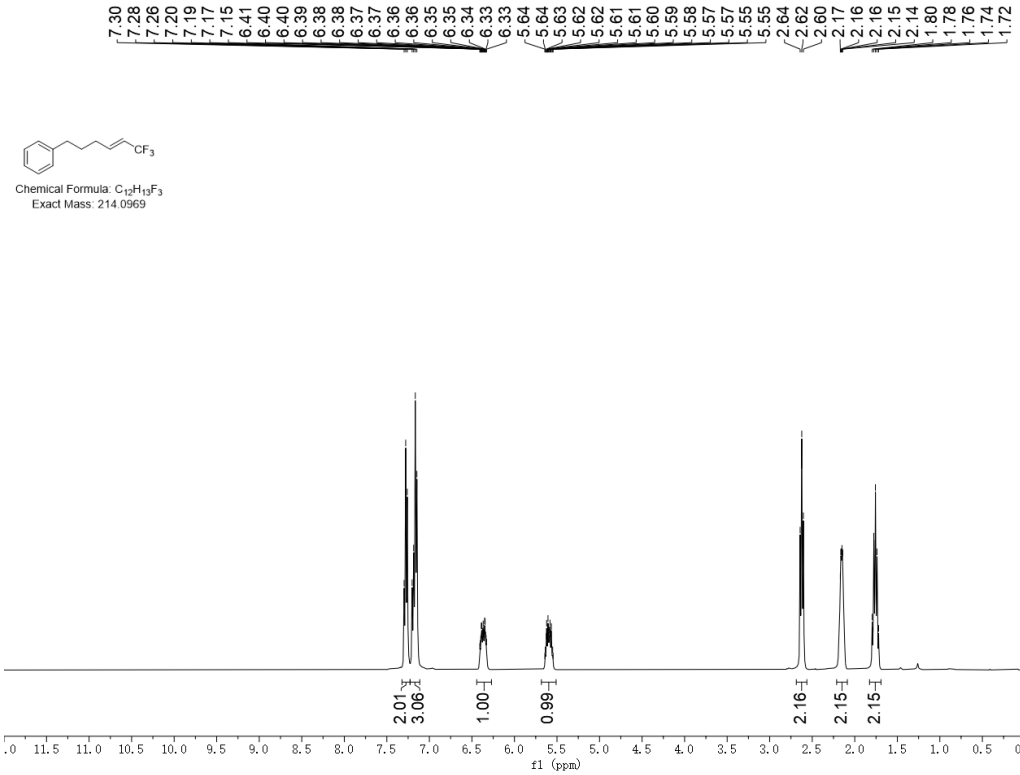

| Entry | [Co] | Ligand | Condition | Yield of **3a** (%)[b] |
|---|---|---|---|---|
| 1 | $CoCl_2$ | – | – | 35 |
| 2 | $CoCl_2$ | **L1** | – | 38 |
| 3 | $CoCl_2$ | **L2** | – | 40 |
| 4 | $CoCl_2$ | **L3** | – | 43 |
| 5 | $CoCl_2$ | **L4** | – | 58 |
| 6 | $CoBr_2$ | **L4** | – | 52 |
| 7 | $Co(OAc)_2$ | **L4** | – | ND |
| 8 | $Co(acac)_2$ | **L4** | – | ND |
| 9 | $CoCl_2$ | **L4** | rt instead of 40 °C | nd |
| 10 | $CoCl_2$ | **L4** | 60 °C instead of 40 °C | 39 |
| 11 | $CoCl_2$ | **L4** | Zn instead of Mn | 35 |
| 12 | $CoCl_2$ | **L4** | 1,4-dioxane instead of MeCN | ND |
| 13[c] | – | **L4** | – | ND |
| 14[c] | $CoCl_2$ | **L4** | – | 80 (80) |

[a]Reaction conditions (unless otherwise specified): **1** (0.6 mmol, 2.0 equiv), **4a** (0.3 mmol, 1.0 equiv), MeCN (3 mL). [b]Determined by $^{19}F$ NMR using fluorobenzene as an internal standard, and the number in parentheses is the isolated yield. [c]**1** (1.2 mmol, 4.0 equiv) was used. nd, not detected.

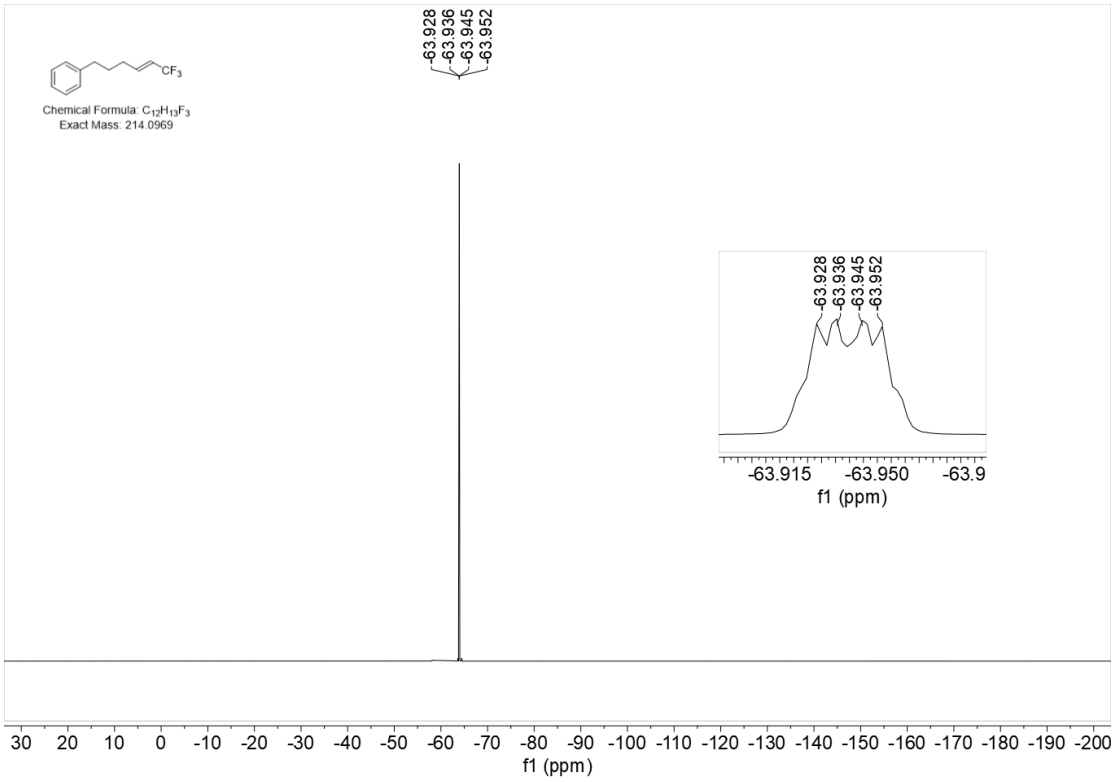
## 4. Copies of $^{1}$H NMR, $^{19}$F NMR and $^{13}$C NMR Spectra

### (*E*)-(6,6,6-Trifluorohex-4-en-1-yl)benzene (3a)

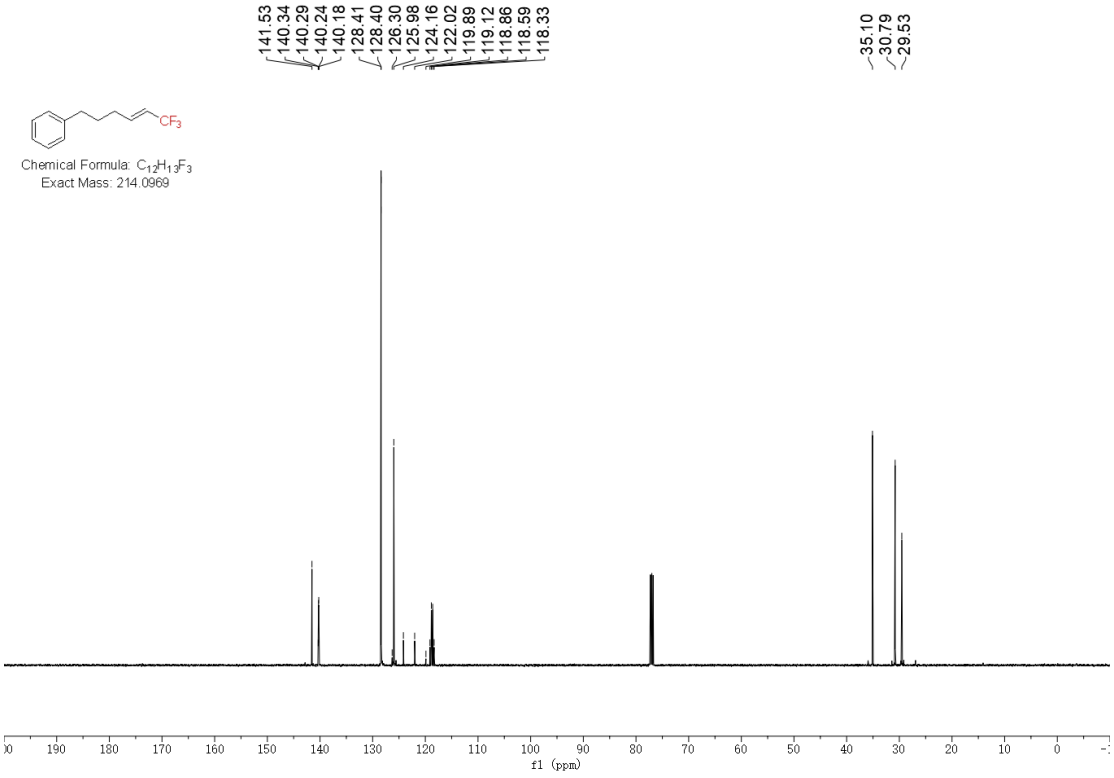
$^{1}$H NMR of **3a**




$^{19}$F NMR of **3a**

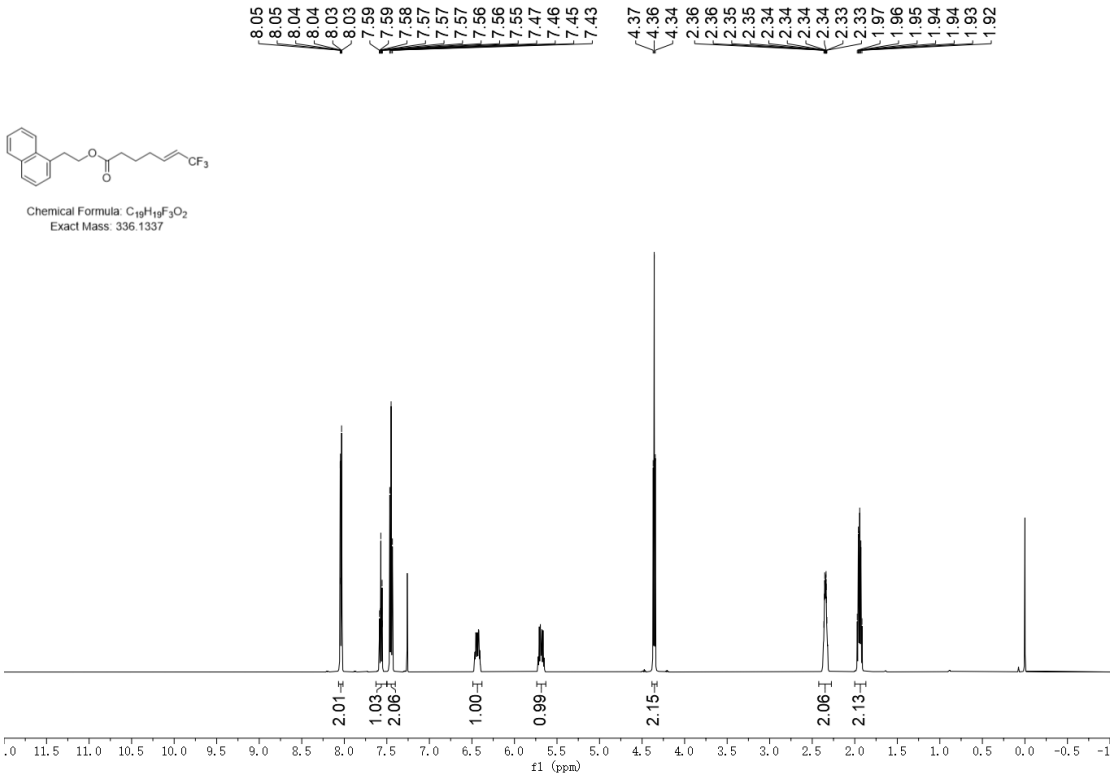


$^{13}$C NMR of **3a**

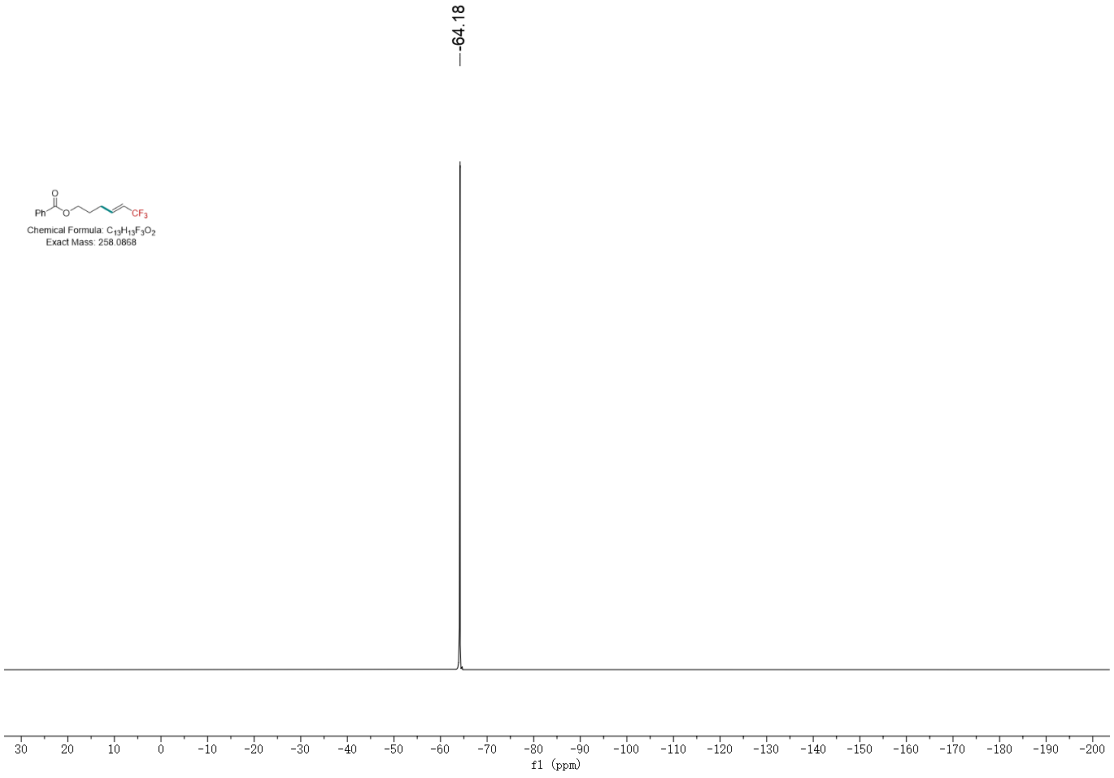



## (*E*)-6,6,6-Trifluorohex-4-en-1-yl benzoate (3b)

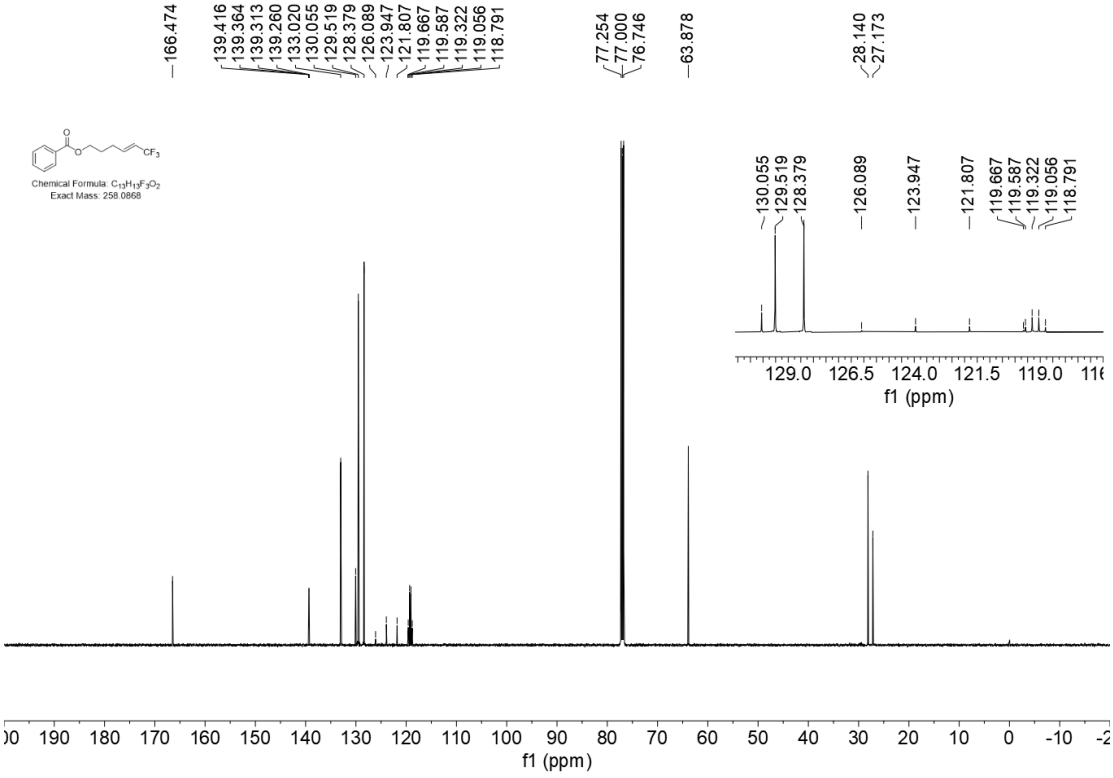
$^{1}$H spectra of **3b**



$^{19}$F spectra of **3b**

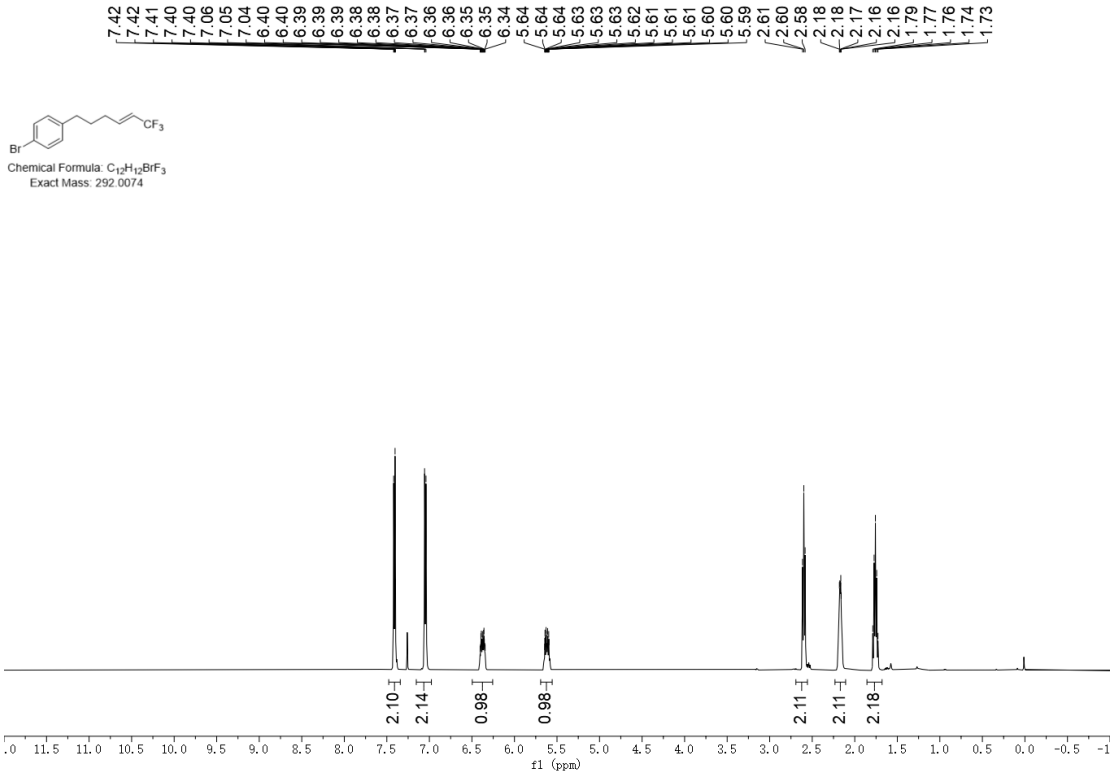



$^{13}$C spectra of **3b**

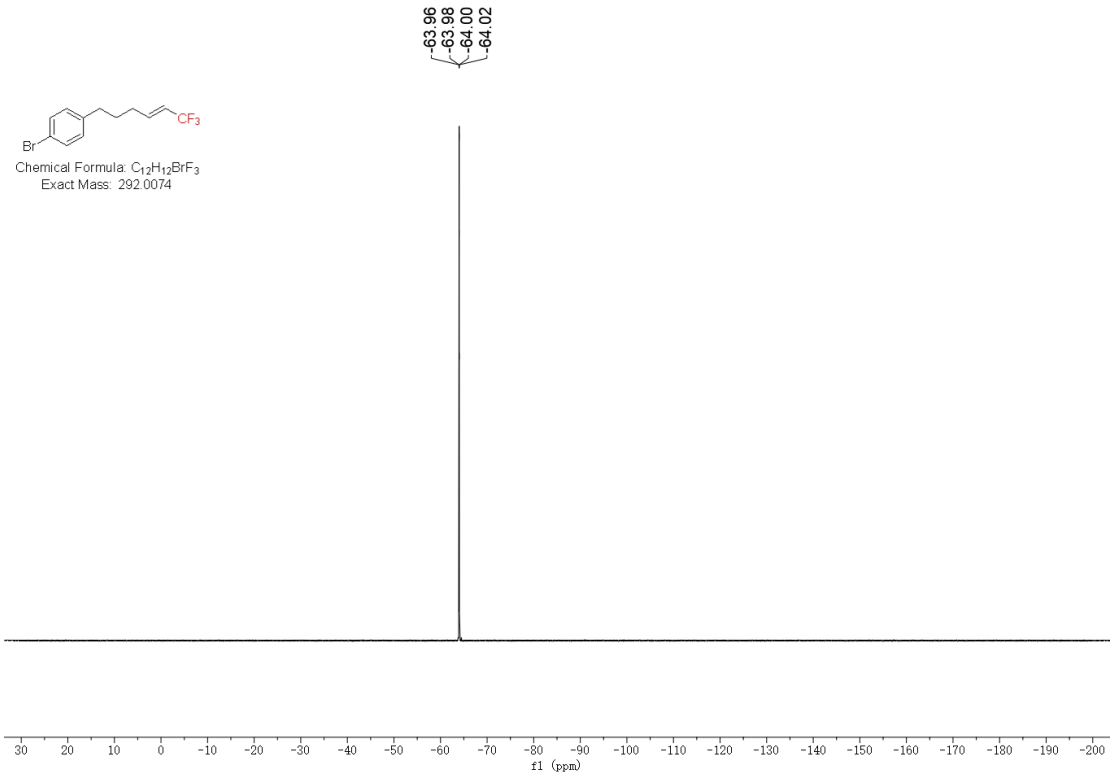


## (*E*)-1-Bromo-4-(6,6,6-trifluorohex-4-en-1-yl)benzene (3c)

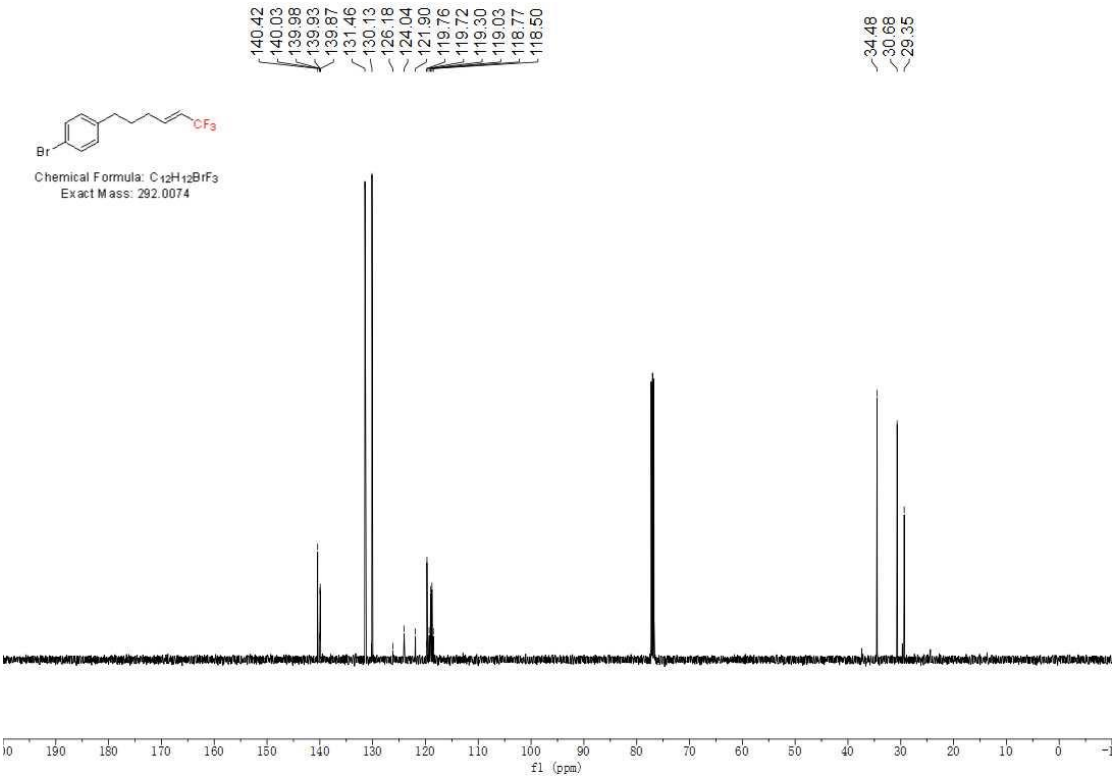
$^{1}$H NMR of 3**c**




$^{19}$F NMR of **3c**

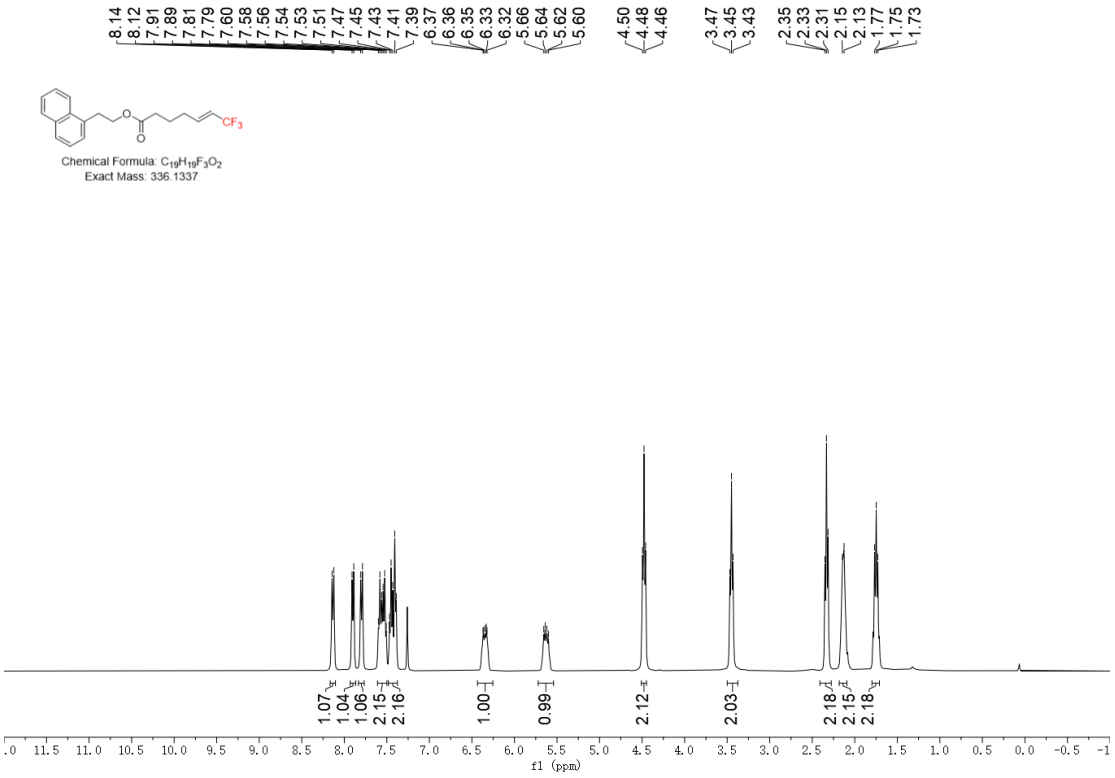


$^{13}$C NMR of **3c**

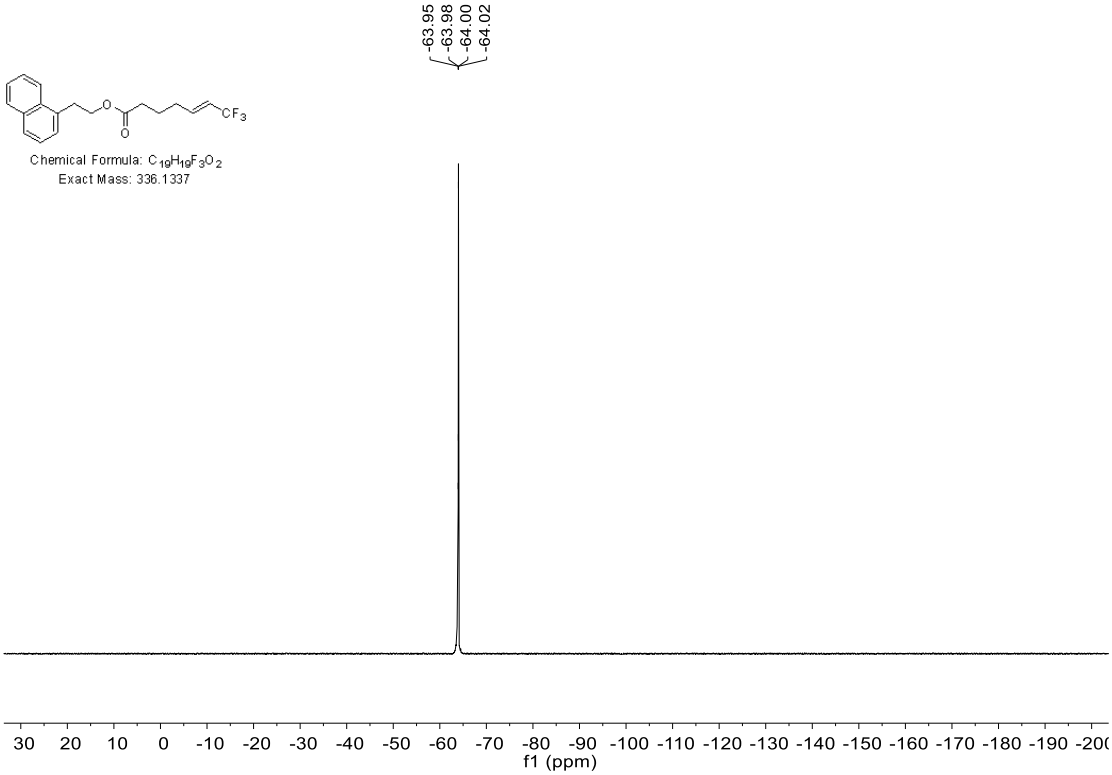



## 2-(Naphthalen-1-yl)ethyl (*E*)-7,7,7-trifluorohept-5-enoate (3d)

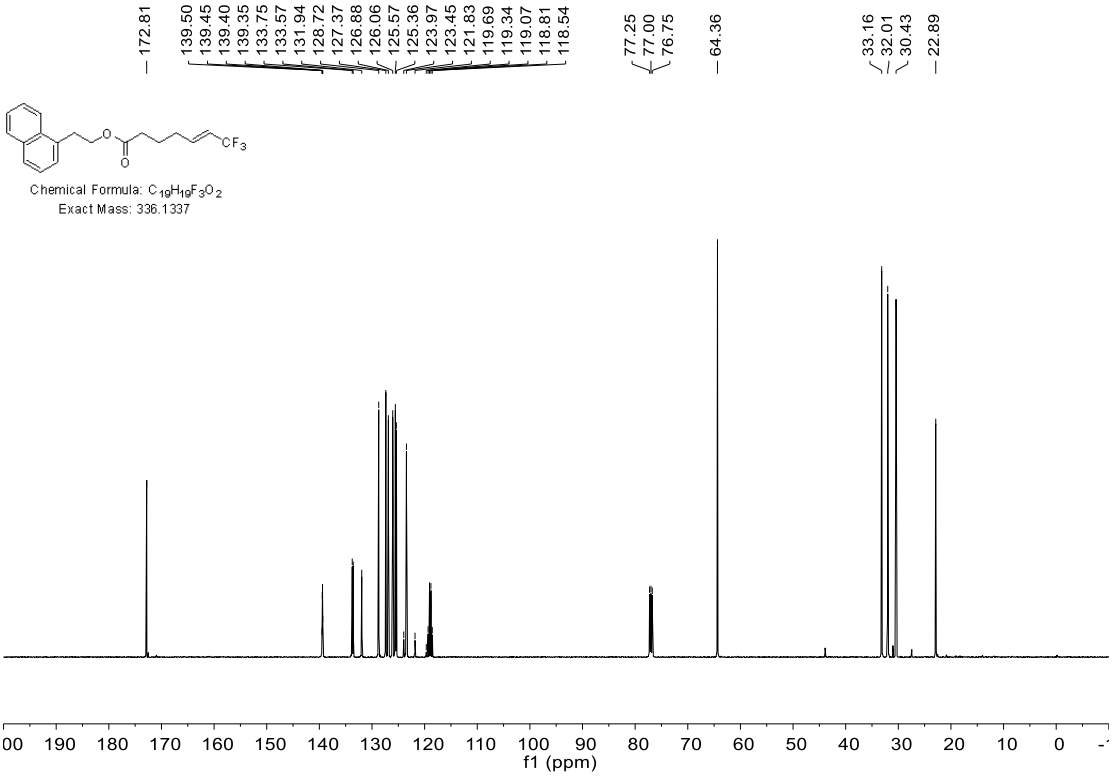
$^{1}$H NMR of **3d**



$^{19}$F NMR of **3d**

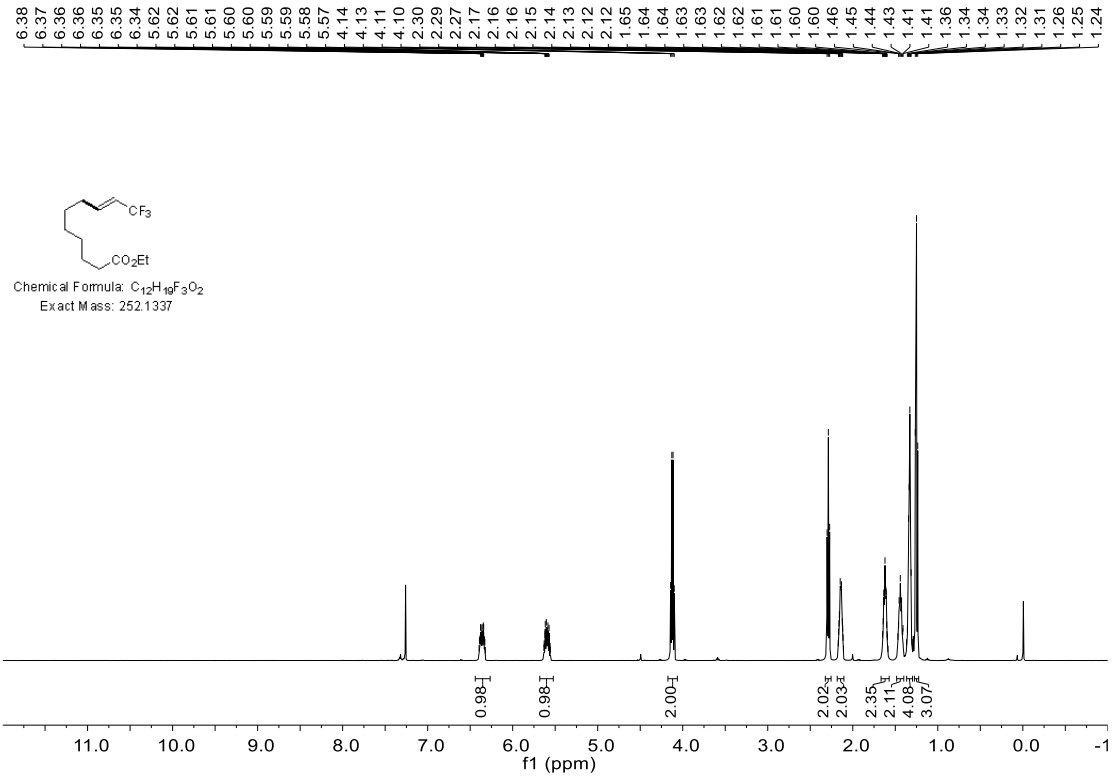



$^{13}$C NMR of **3d**

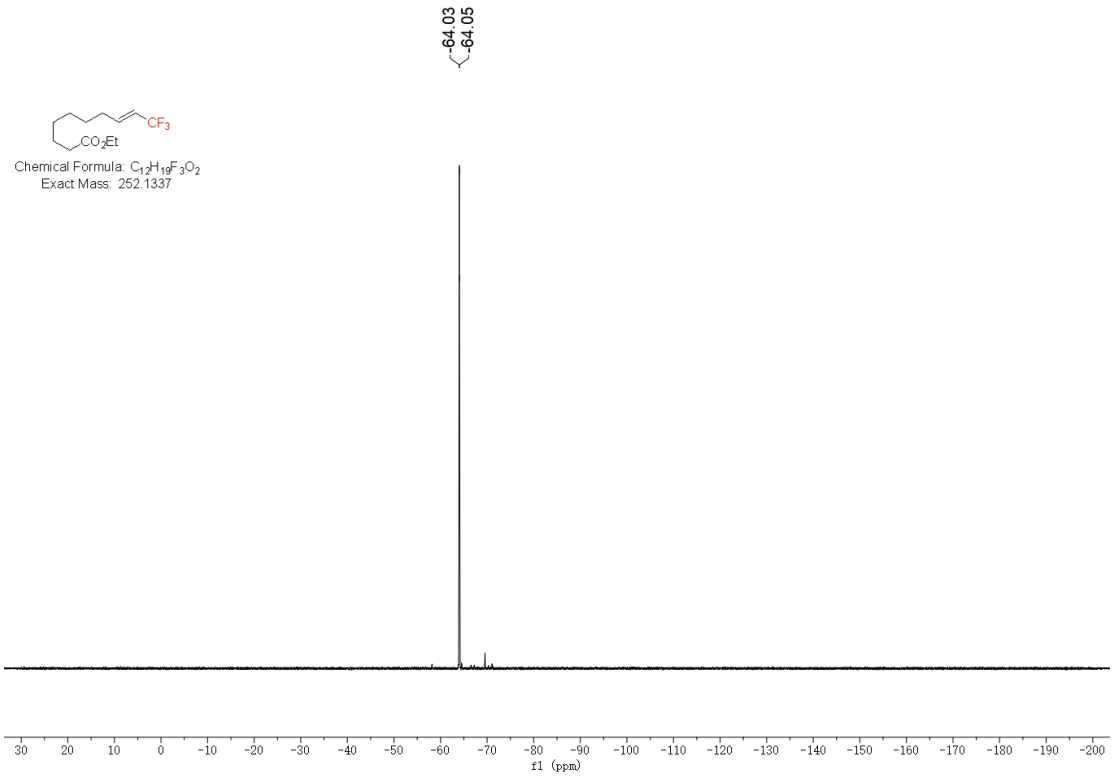


## Ethyl (*E*)-10,10,10-trifluorodec-8-enoate (3e)

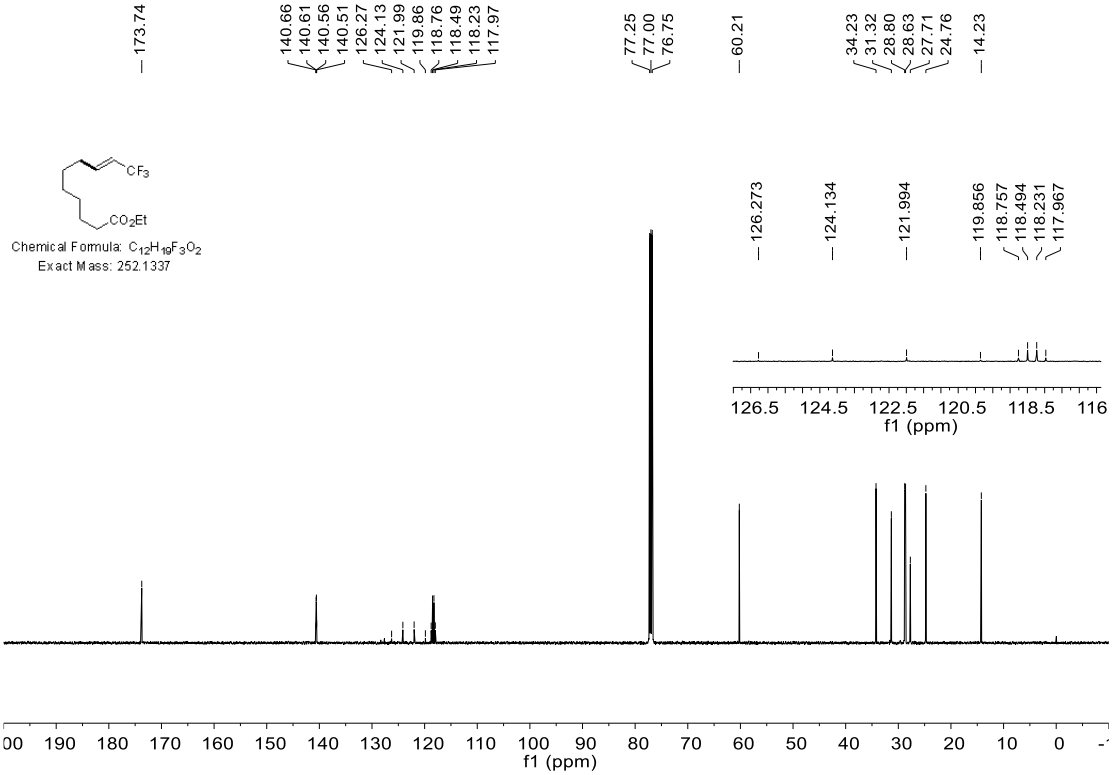
$^{1}$H NMR of **3e**




$^{19}$F NMR of **3e**

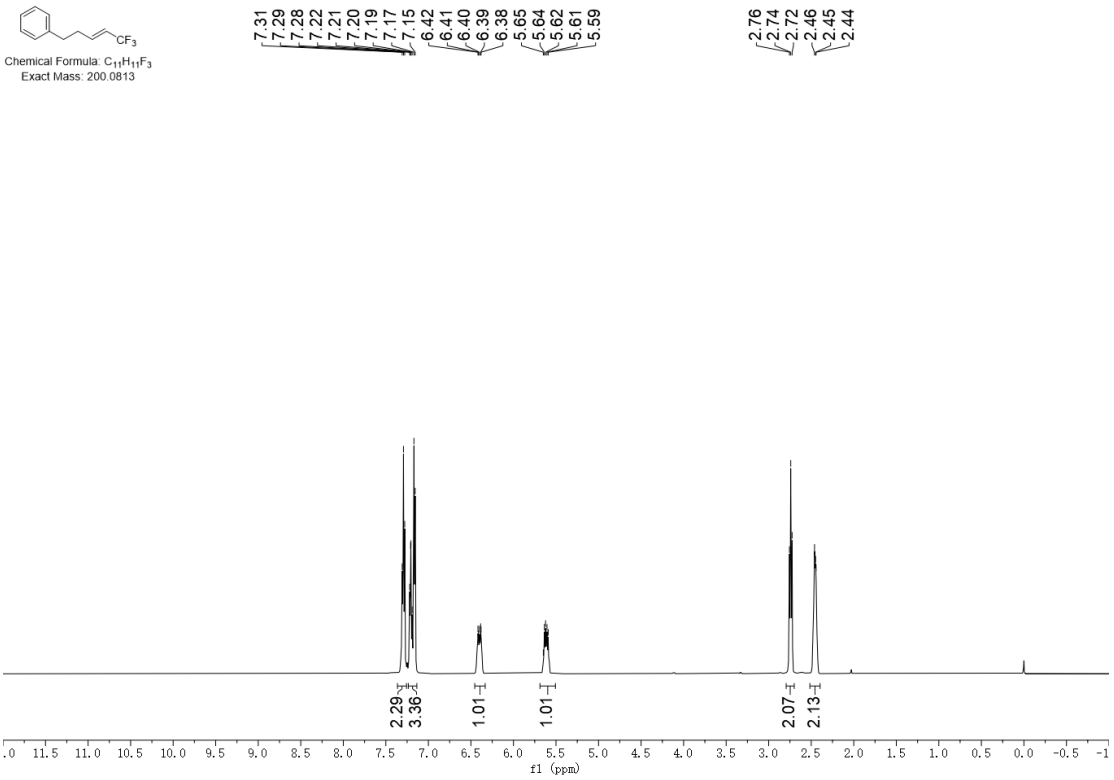


$^{13}$C NMR of **3e**

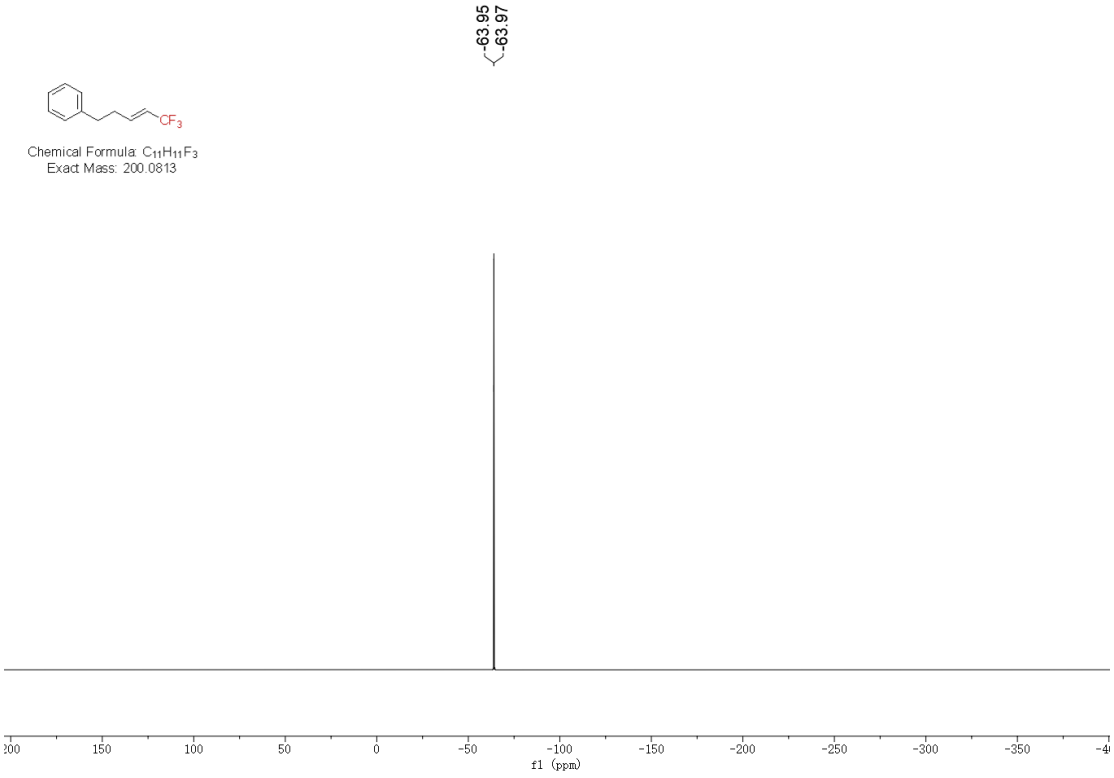



## (*E*)-(5,5,5-Trifluoropent-3-en-1-yl)benzene (3f)

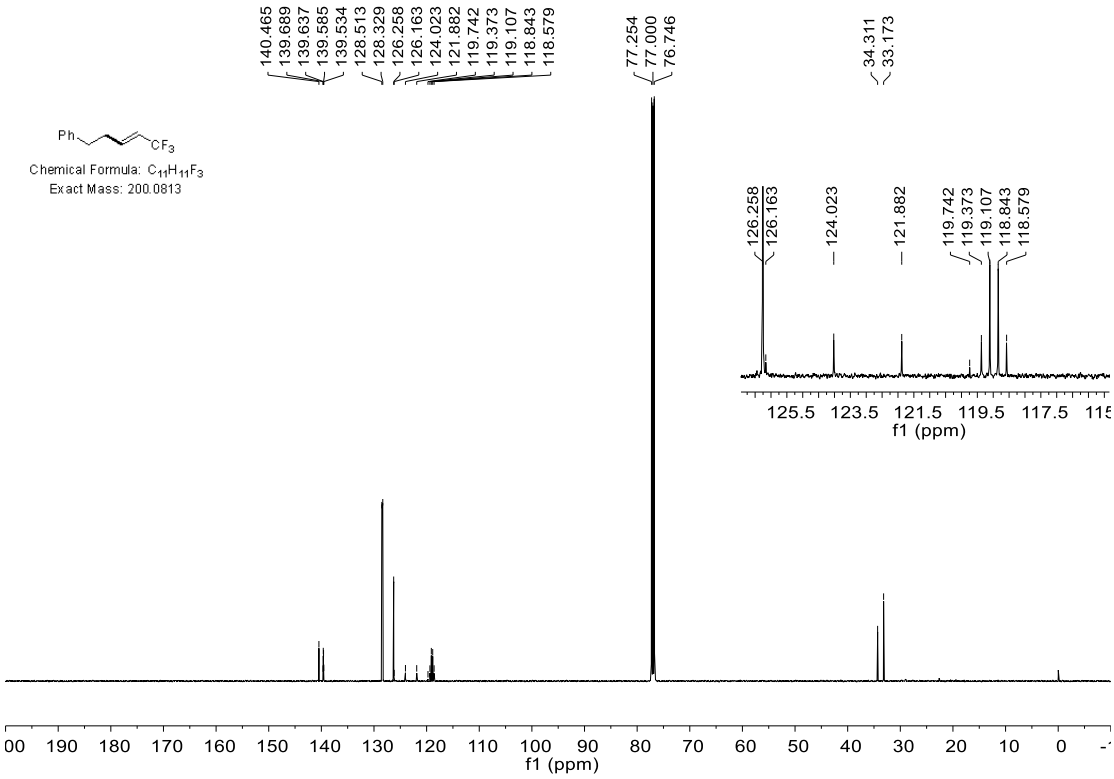
$^{1}$H NMR of **3f**



$^{19}$F NMR of **3f**

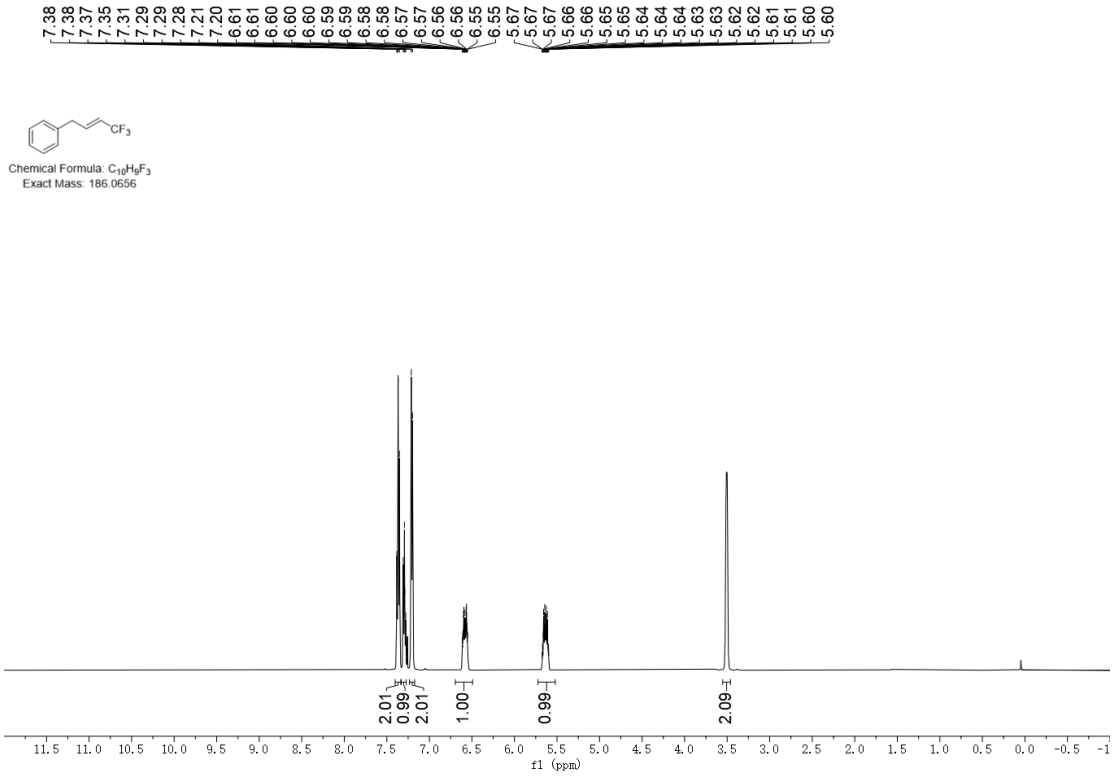



$^{13}$C NMR of **3f**

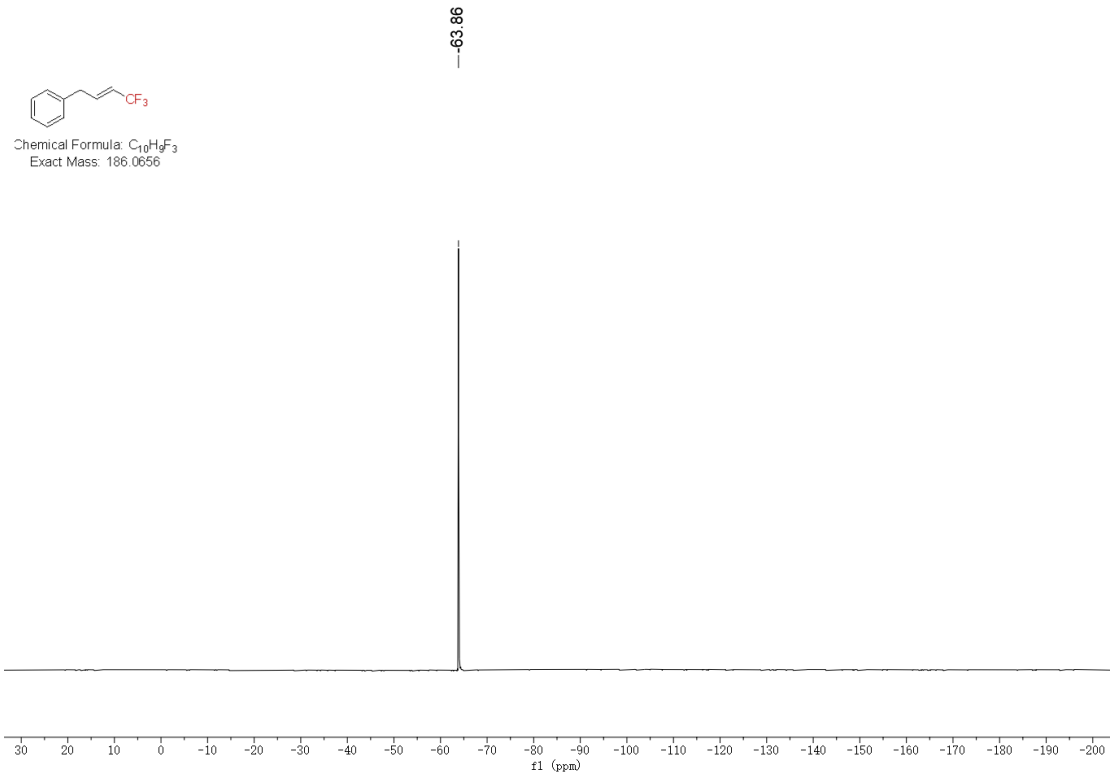


## (*E*)-(4,4,4-Trifluorobut-2-en-1-yl)benzene (3g)

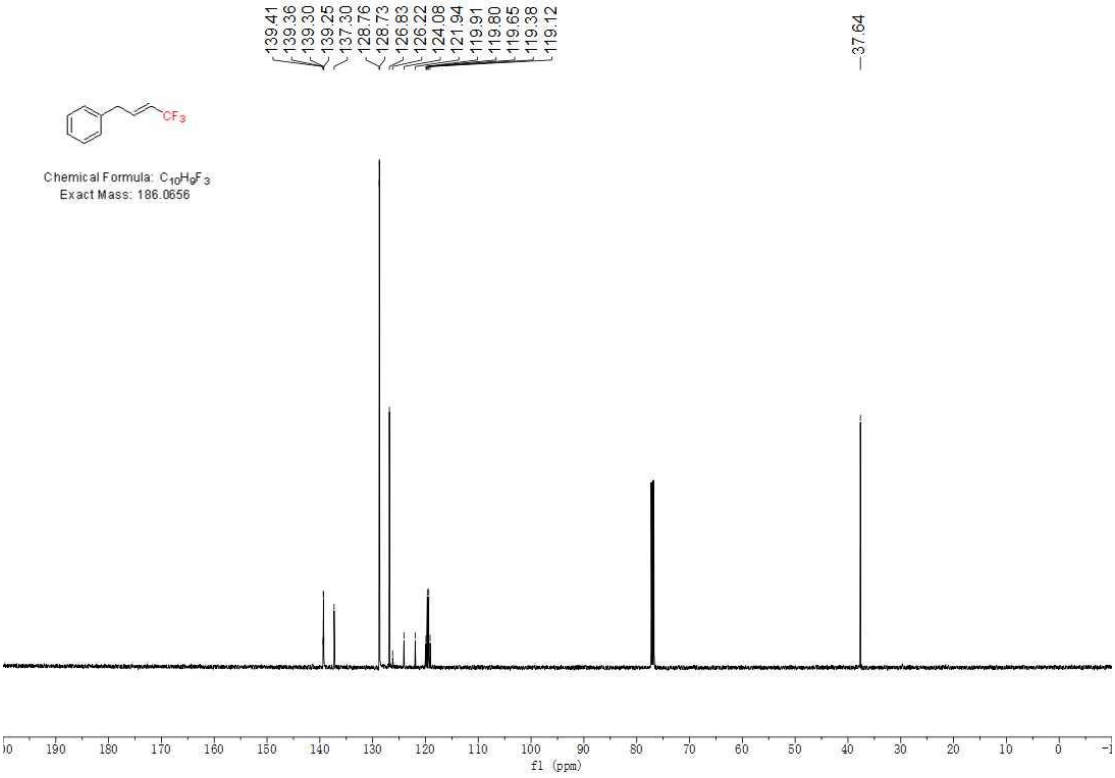
$^{1}$H NMR of **3g**




$^{19}$F NMR of **3g**

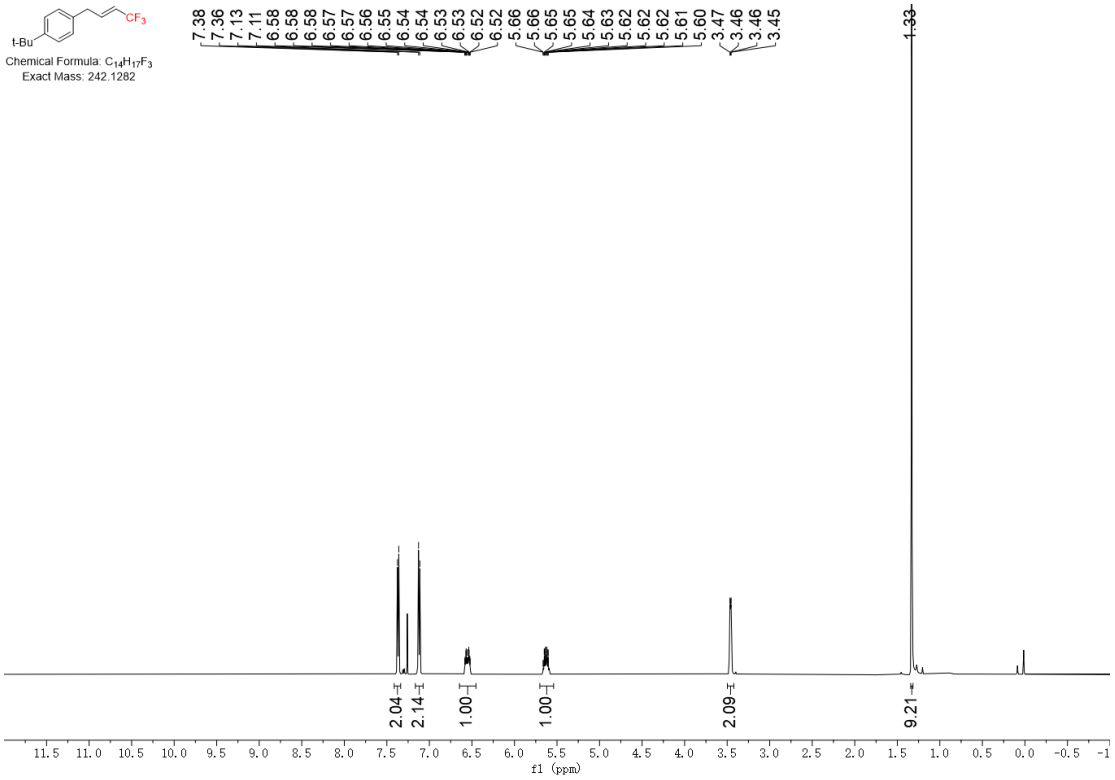


$^{13}$C NMR of **3g**

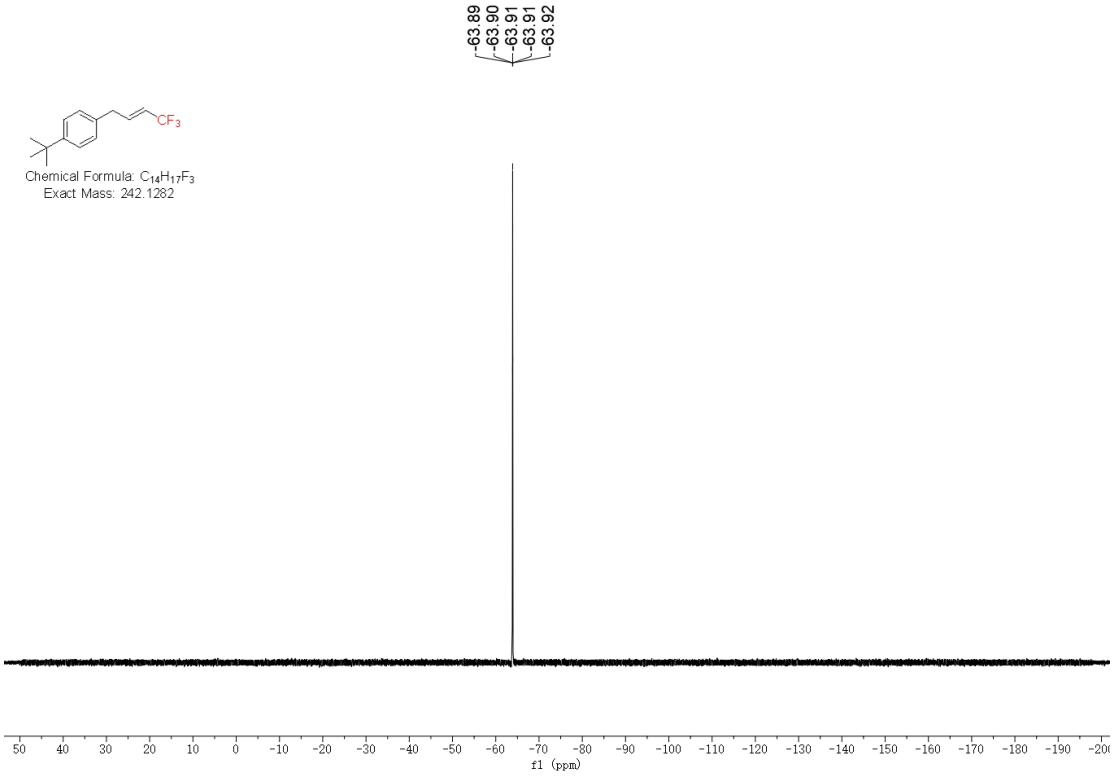



**(*E*)-1-(*tert*-Butyl)-4-(4,4,4-trifluorobut-2-en-1-yl)benzene (3h)**

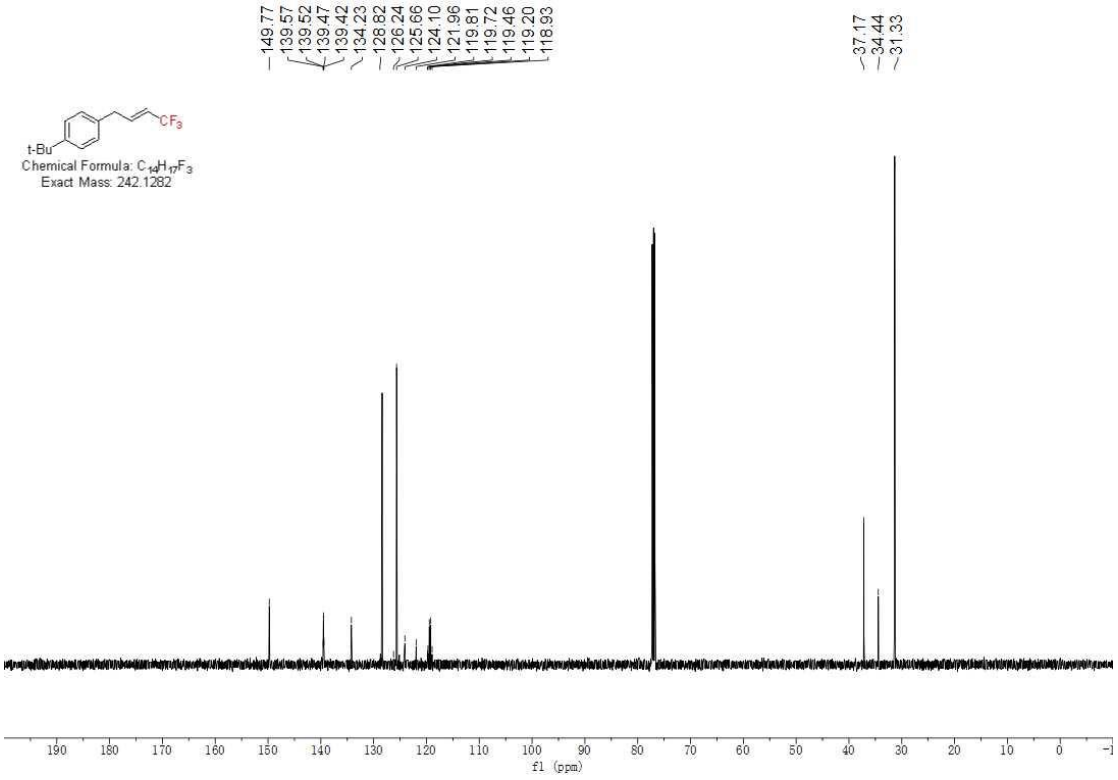
$^{1}$H NMR of **3h**



$^{19}$F NMR of **3h**

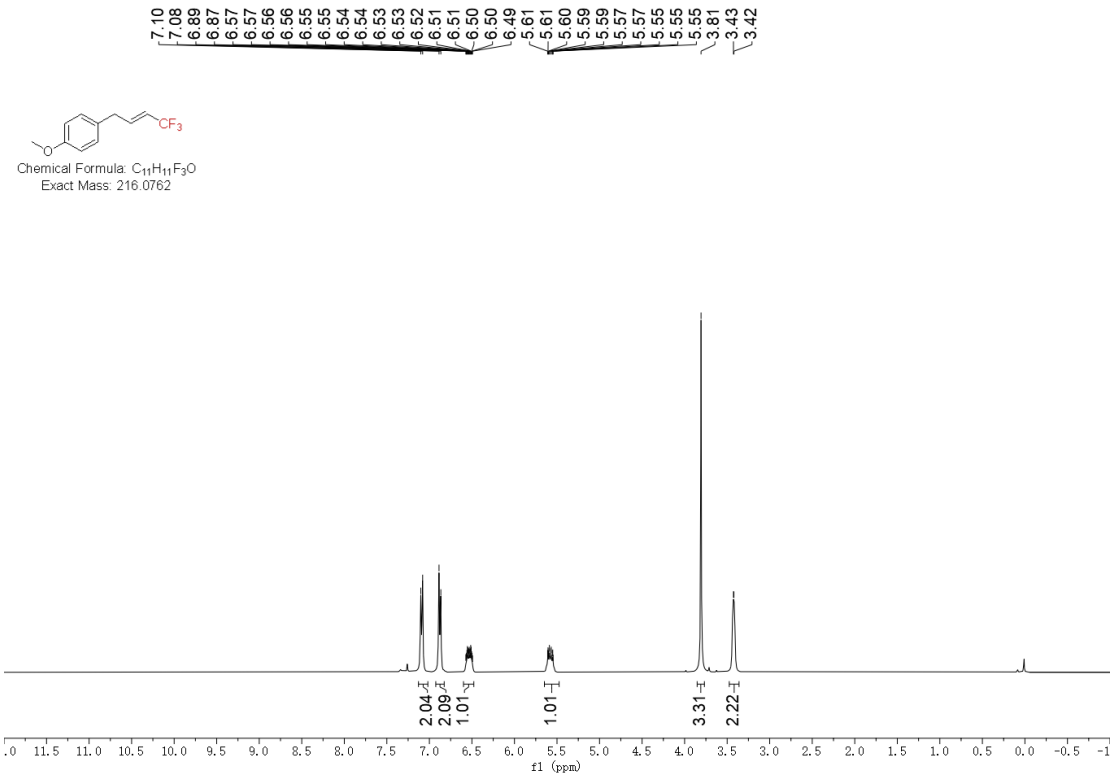



$^{13}$C NMR of **3h**

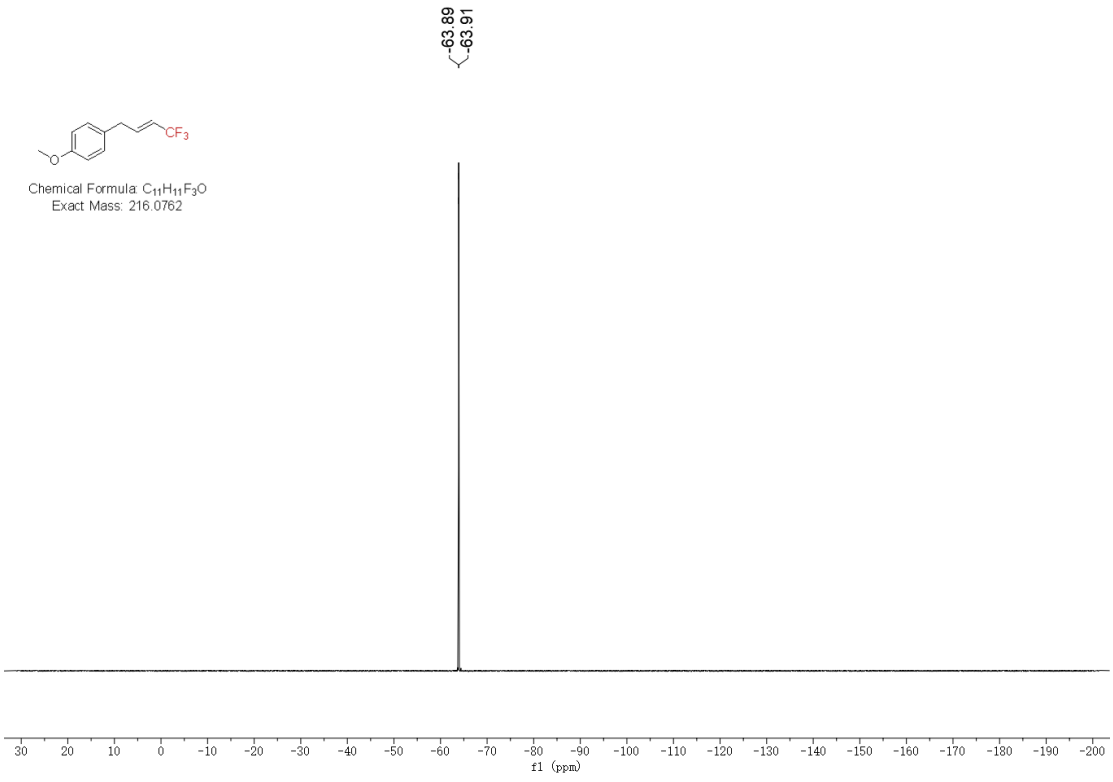


## (*E*)-1-Methoxy-4-(4,4,4-trifluorobut-2-en-1-yl)benzene (3i)

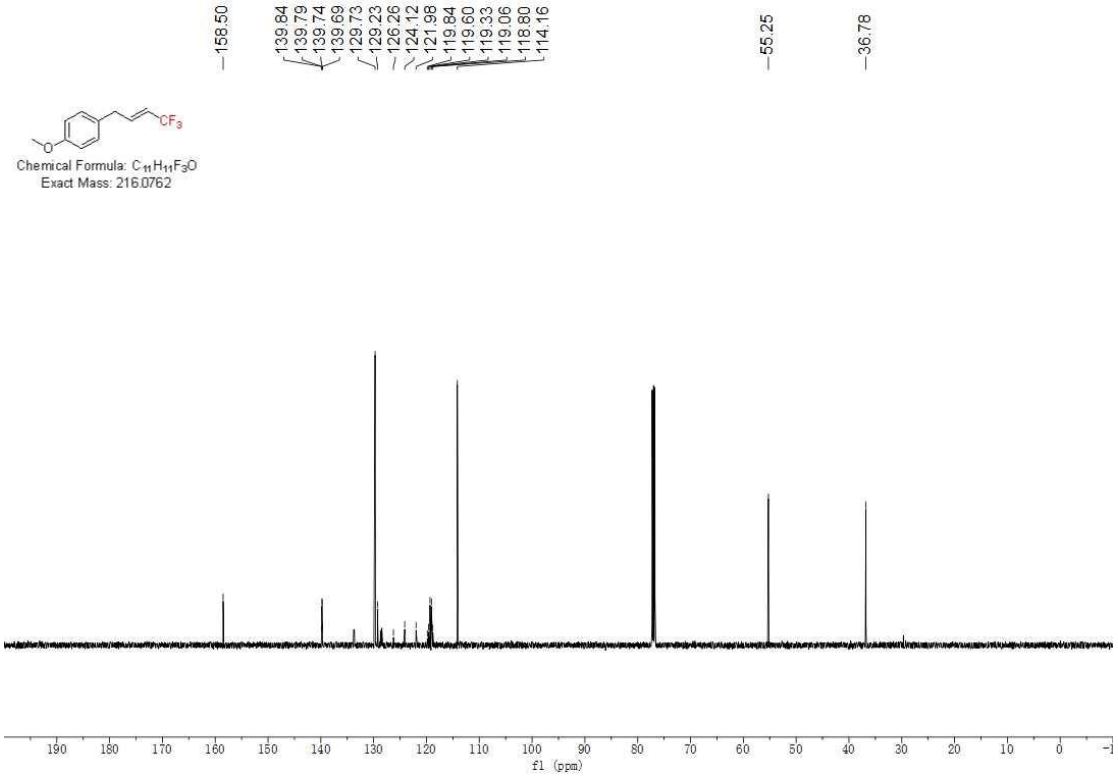
$^{1}$H NMR of **3i**




$^{19}$F NMR of **3i**

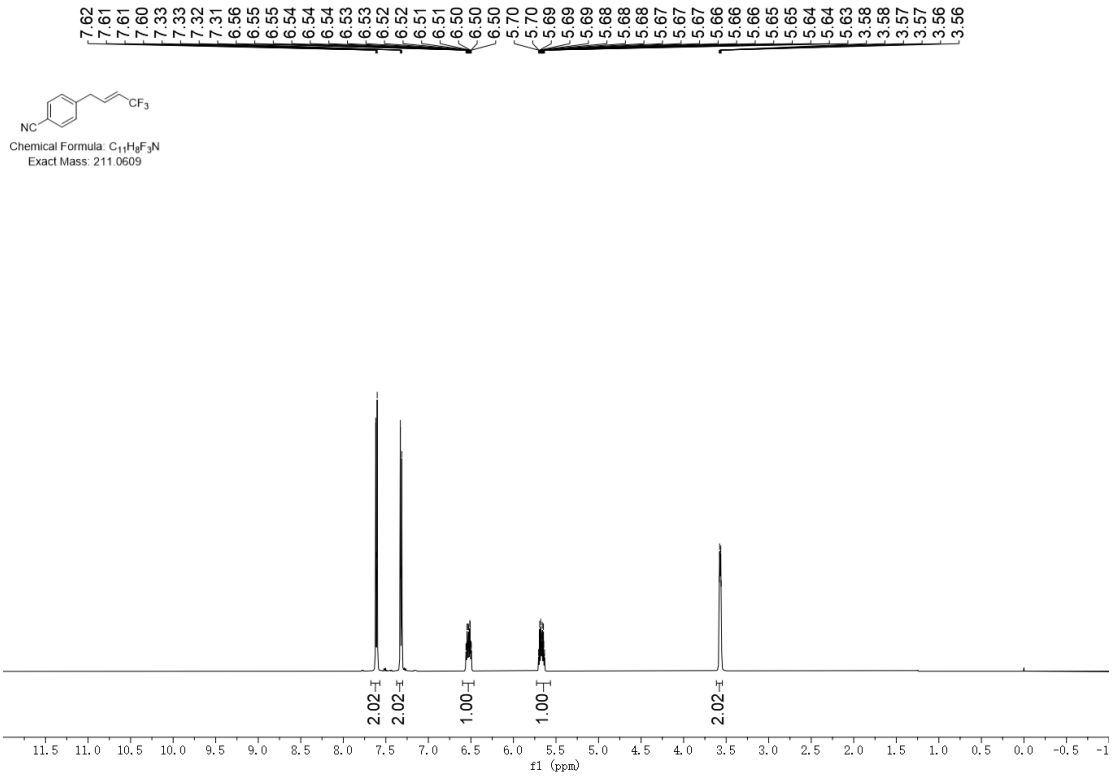


$^{13}$C NMR of **3i**

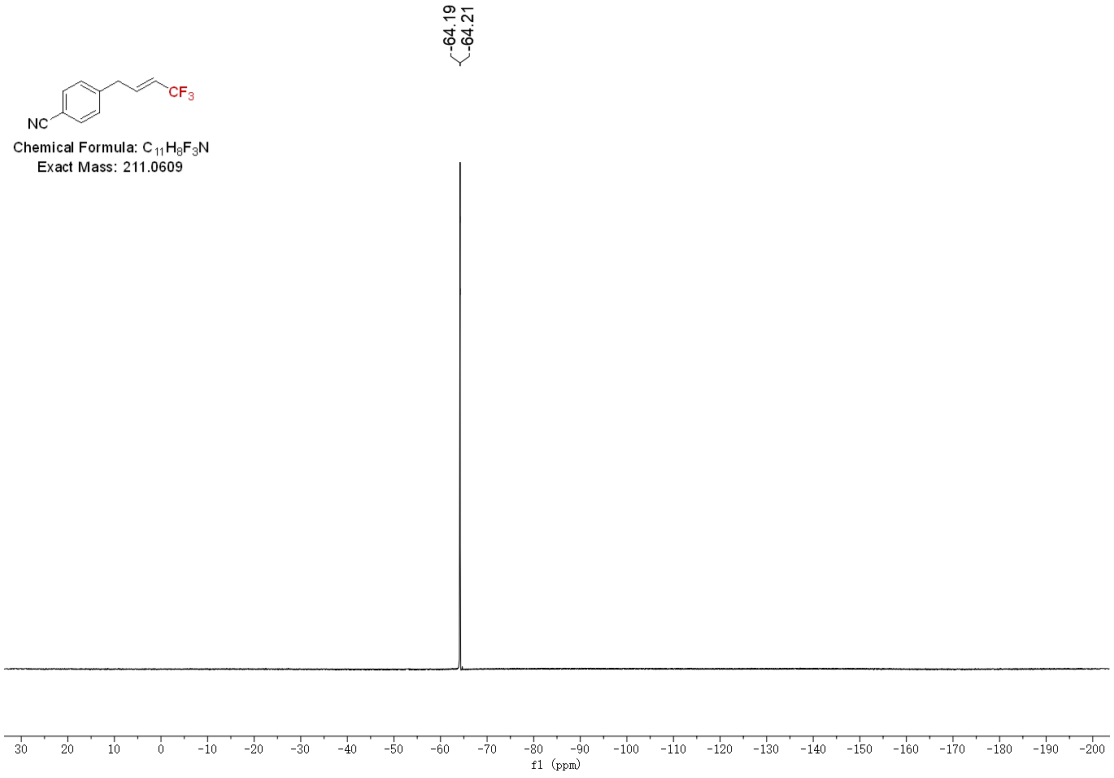



**(*E*)-4-(4,4,4-Trifluorobut-2-en-1-yl)benzonitrile (3j)**

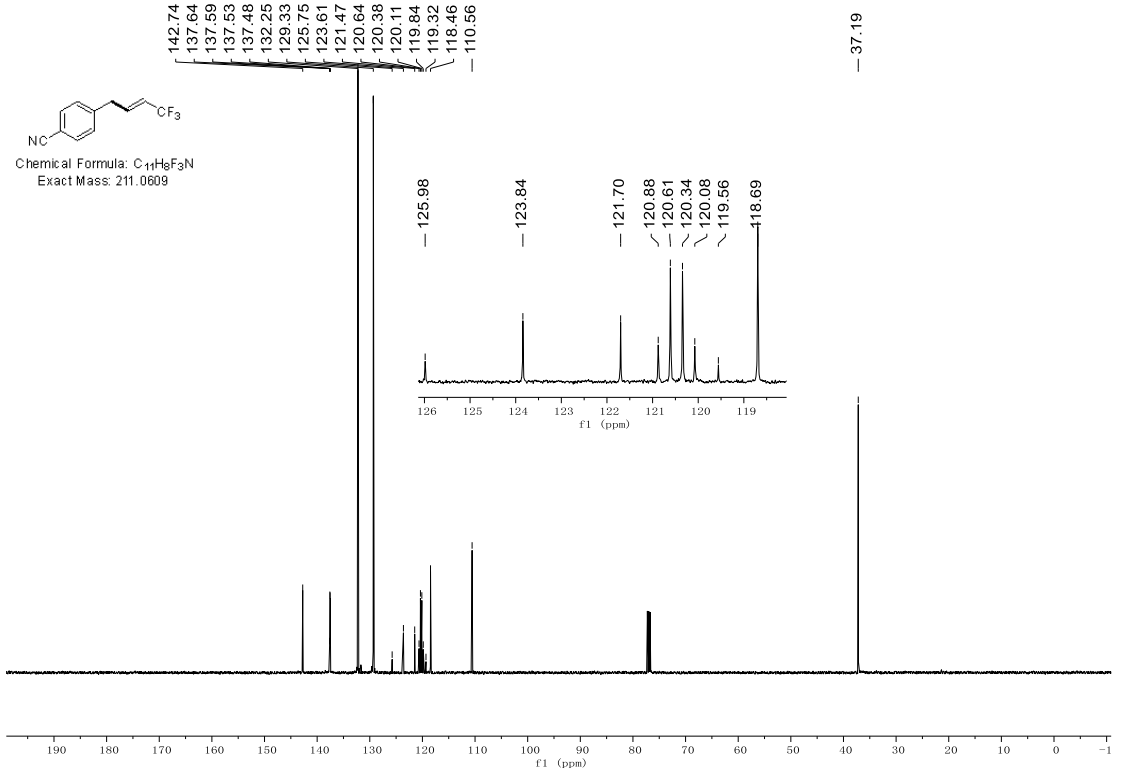
$^{1}$H NMR of **3j**



$^{19}$F NMR of **3j**

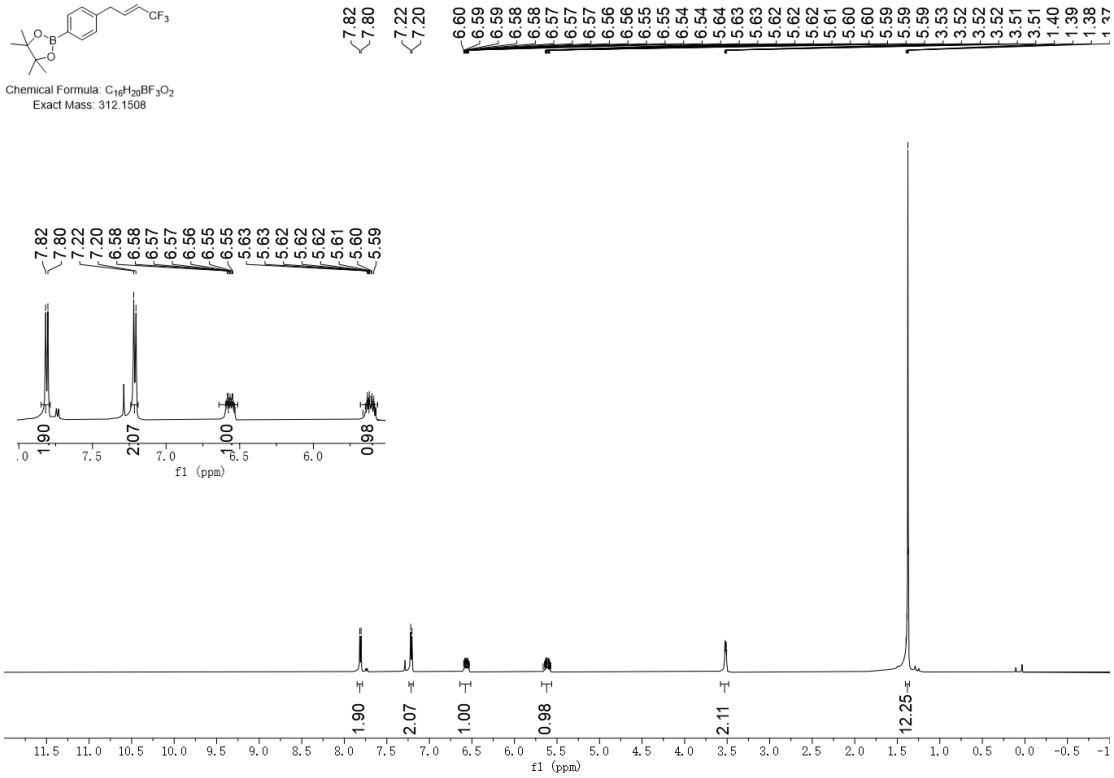



$^{13}$C NMR of **3j**

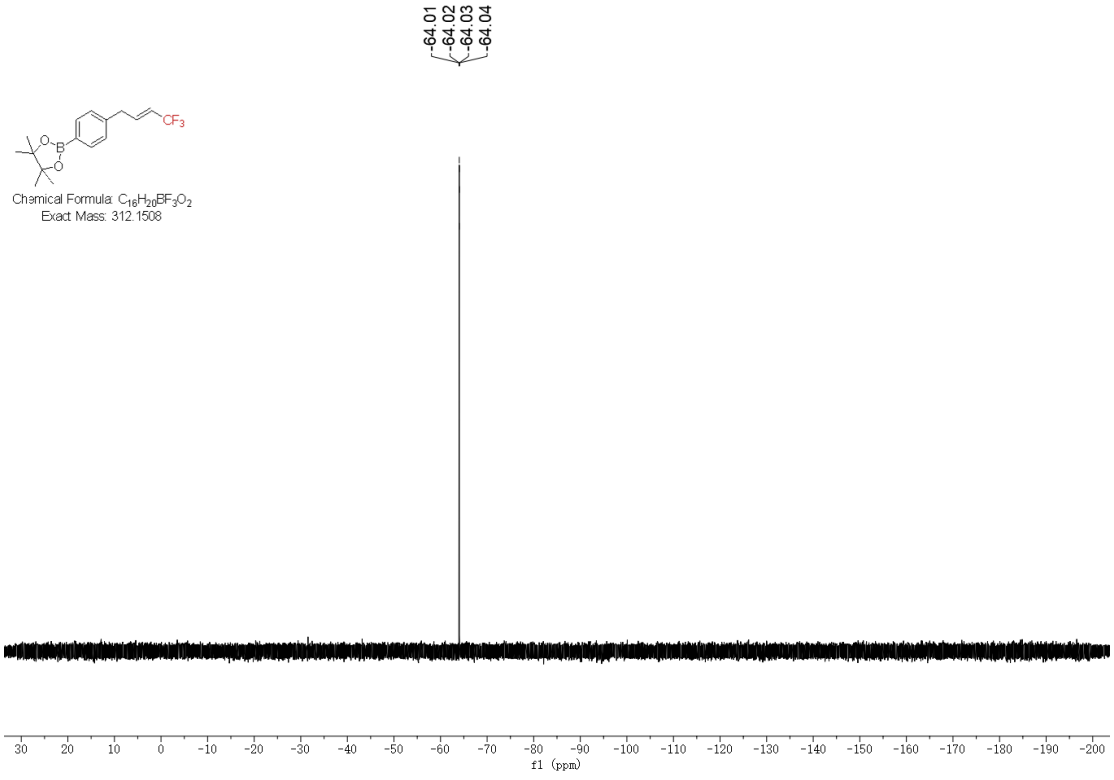


## (*E*)-4,4,5,5-Tetramethyl-2-(4-(4,4,4-trifluorobut-2-en-1-yl)phenyl)-1,3,2-dioxaborolane (3k)

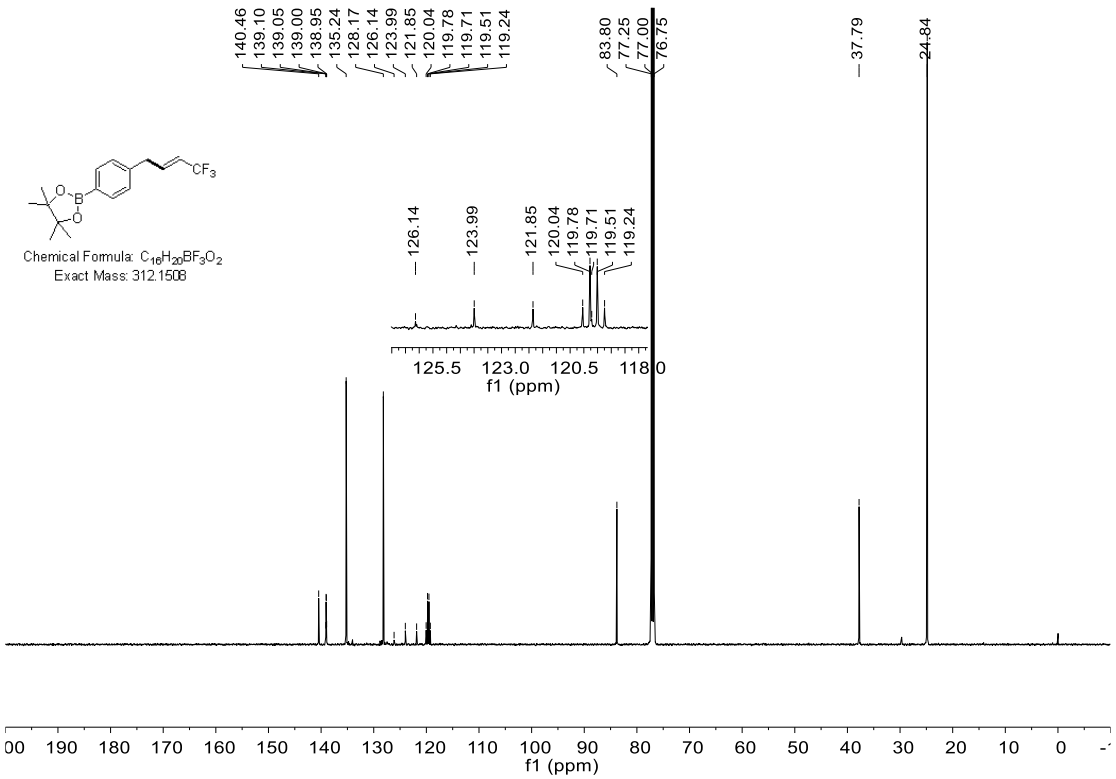
$^{1}$H NMR of **3k**




$^{19}$F NMR of **3k**

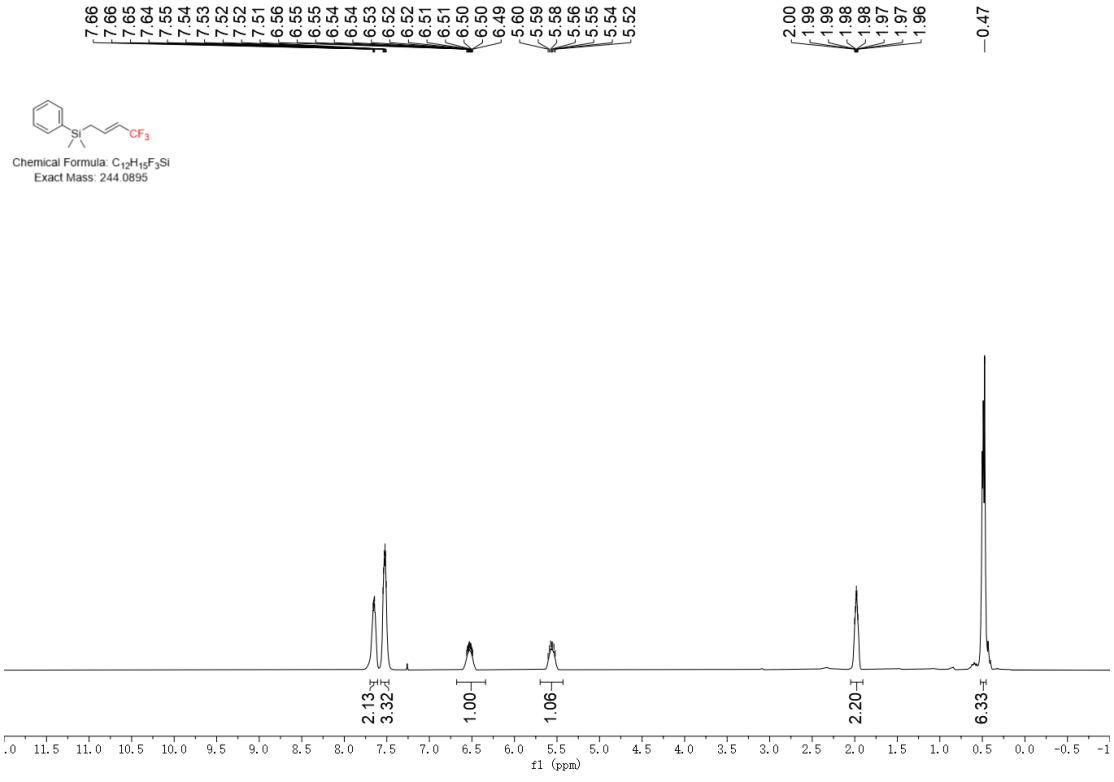


$^{13}$C NMR of **3k**

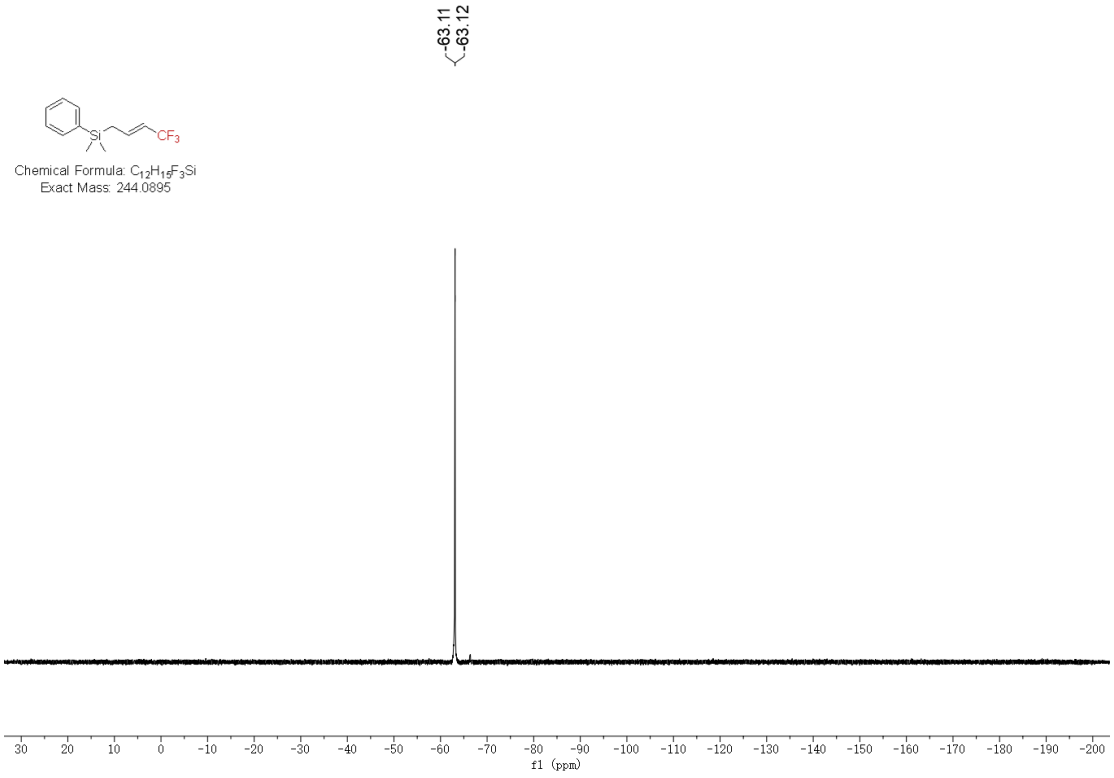



## (*E*)-Dimethyl(phenyl)(4,4,4-trifluorobut-2-en-1-yl)silane (3l)

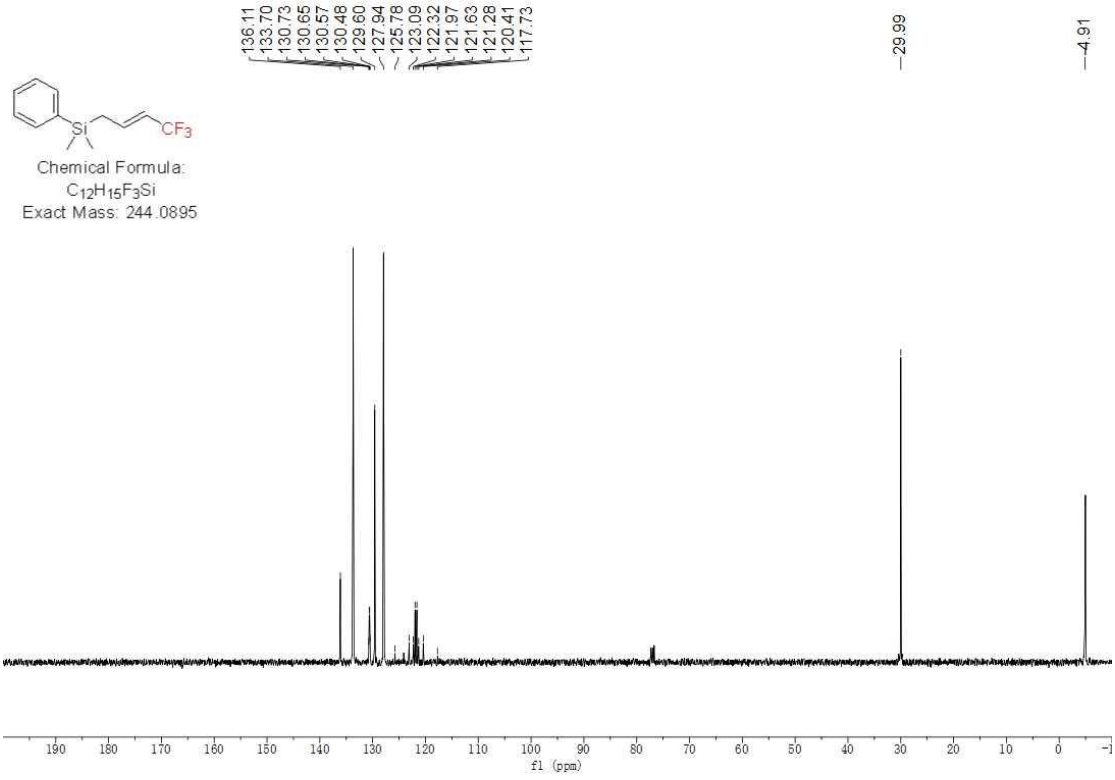
$^{1}$H NMR of **3l**



$^{19}$F NMR of **3l**

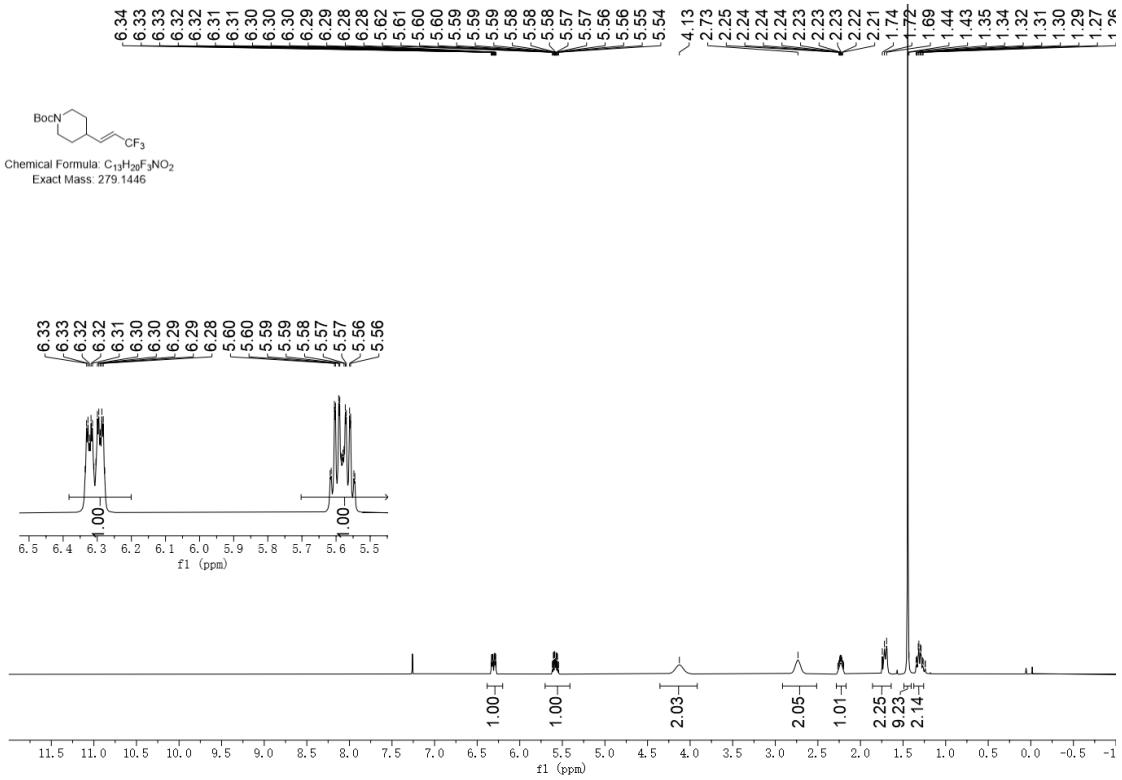



$^{13}$C NMR of **3l**

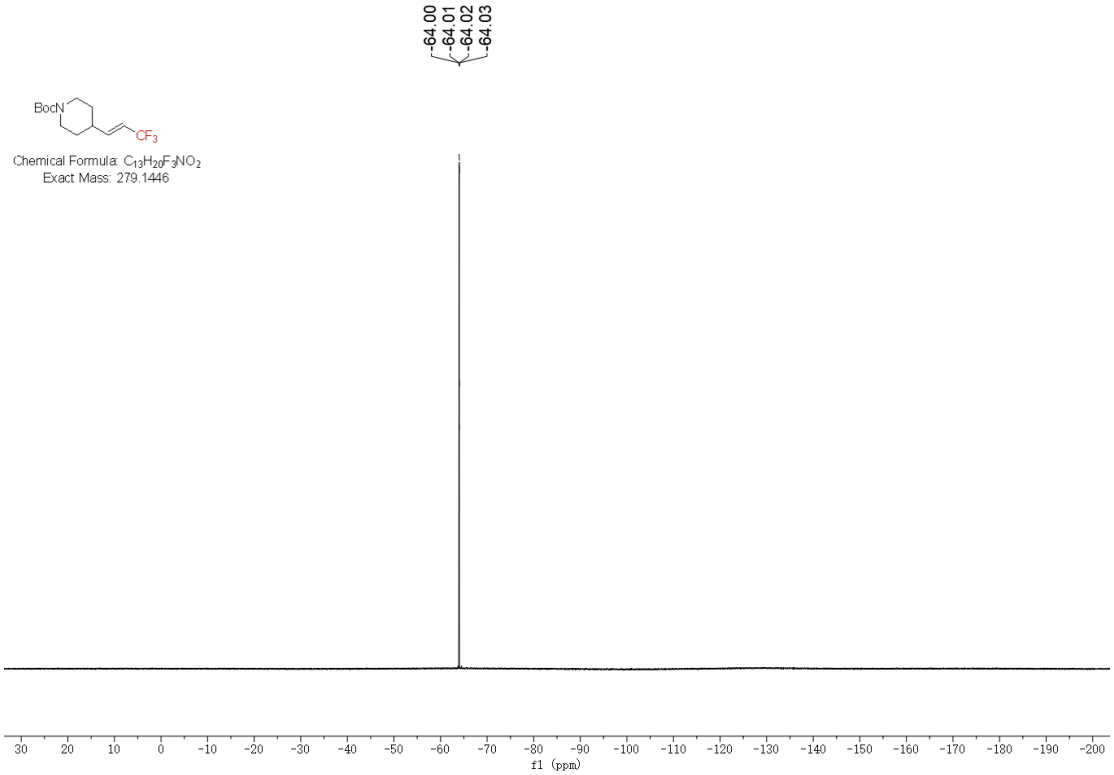


## *tert*-Butyl(*E*)-4-(3,3,3-trifluoroprop-1-en-1-yl)piperidine-1-carboxylate (3m)

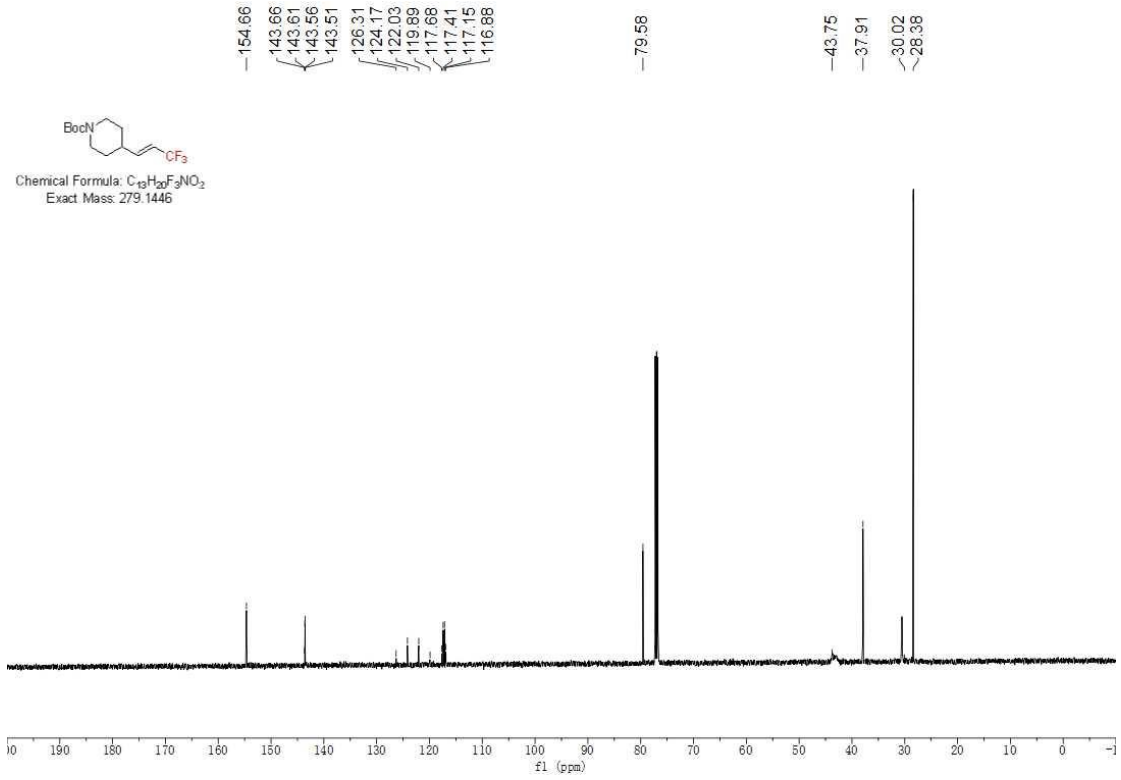
$^{1}$H NMR of **3m**




$^{19}$F NMR of **3m**

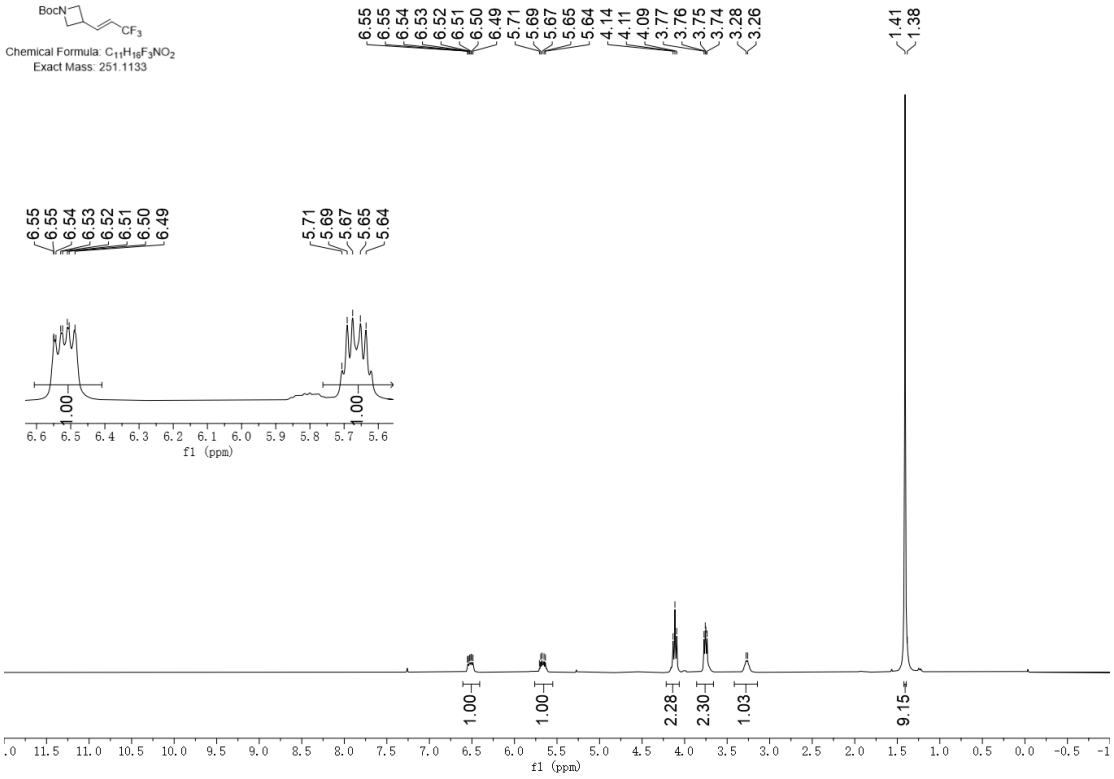


$^{13}$C NMR of **3m**

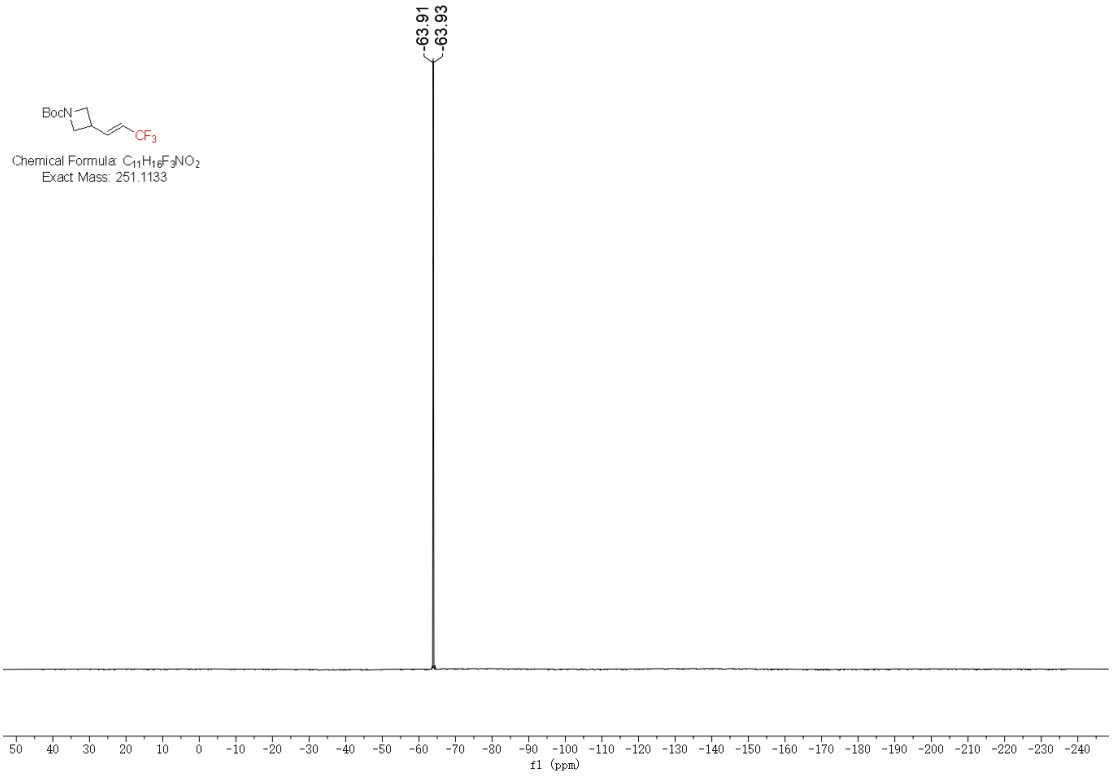



## *tert*-Butyl(*E*)-3-(3,3,3-trifluoroprop-1-en-1-yl)azetidine-1-carboxylate (3n)

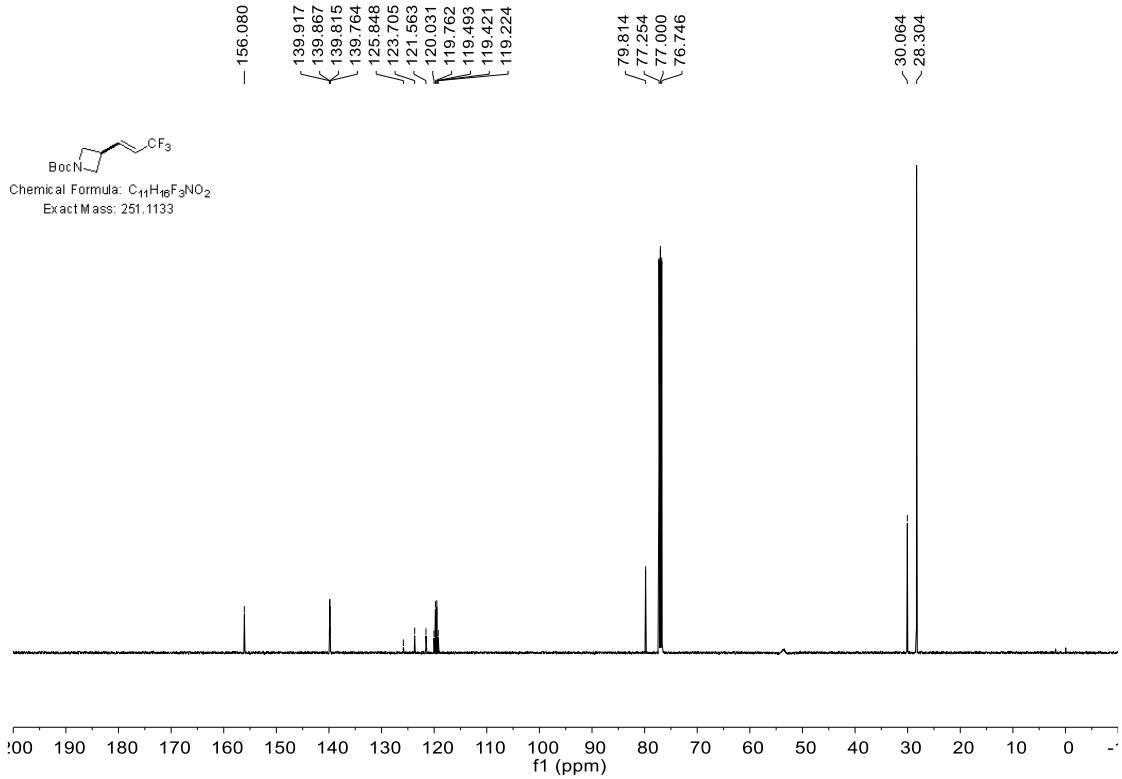
$^{1}$H NMR of **3n**



$^{19}$F NMR of **3n**

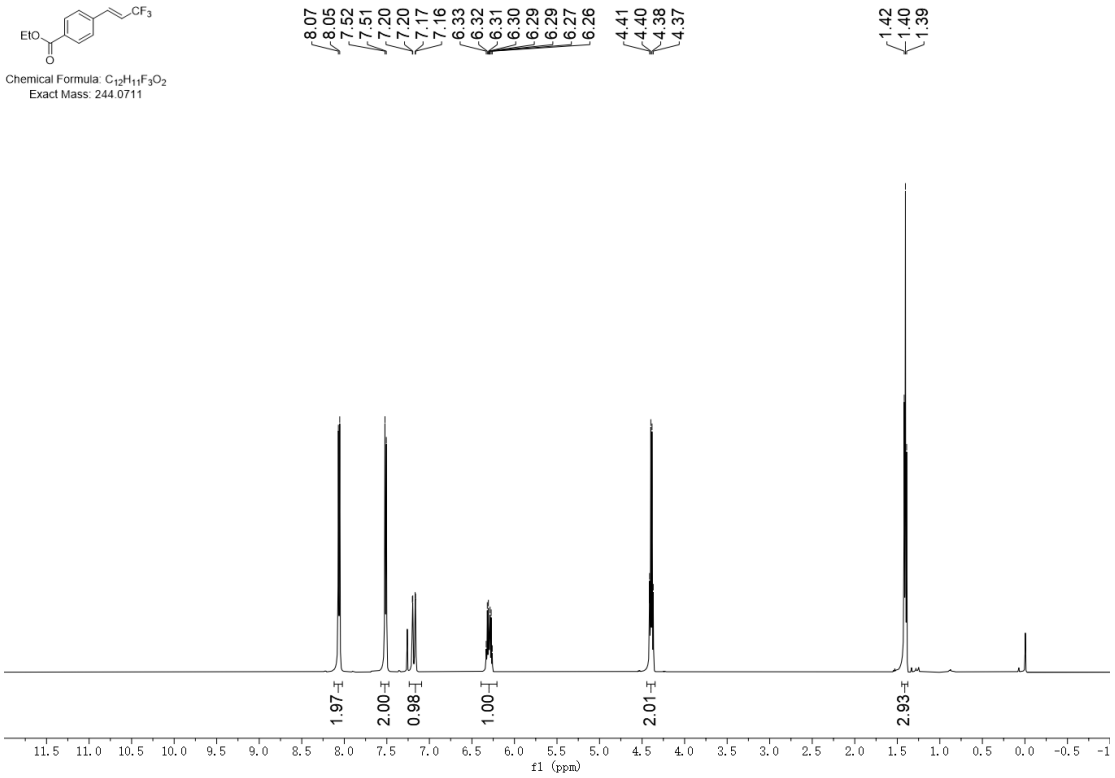



$^{13}$C NMR of **3n**

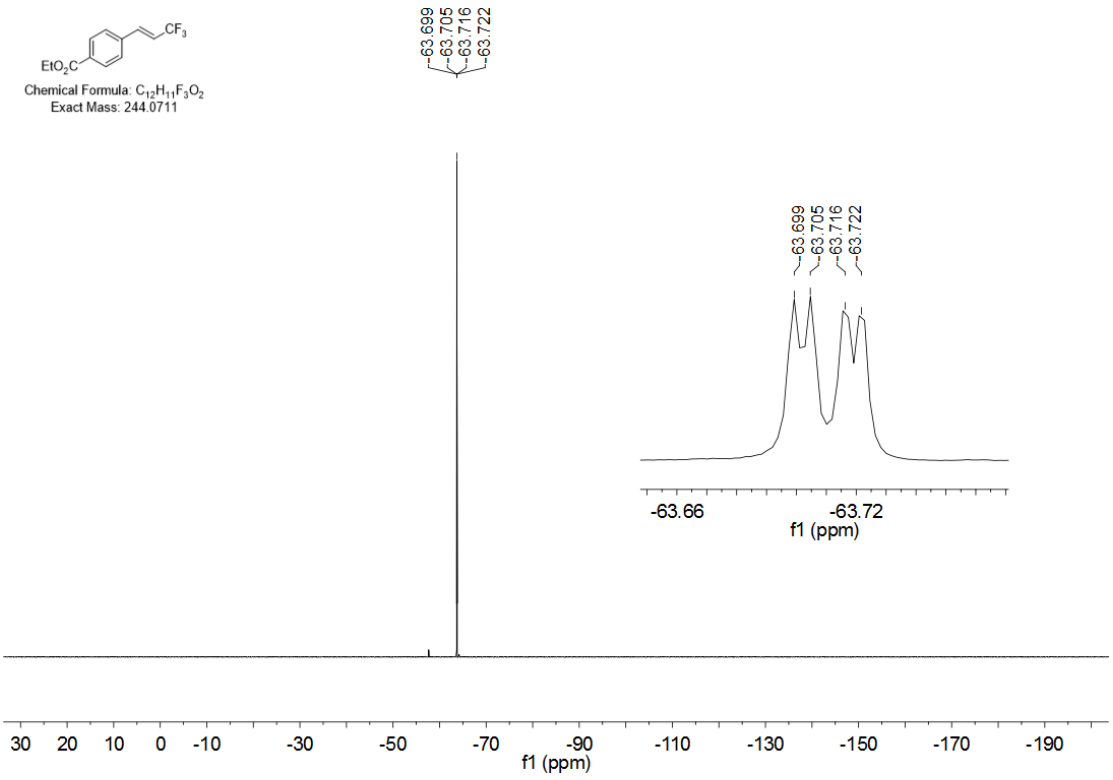


**(Ethyl (*E*)-4-(3,3,3-trifluoroprop-1-en-1-yl)benzoate (5a)**

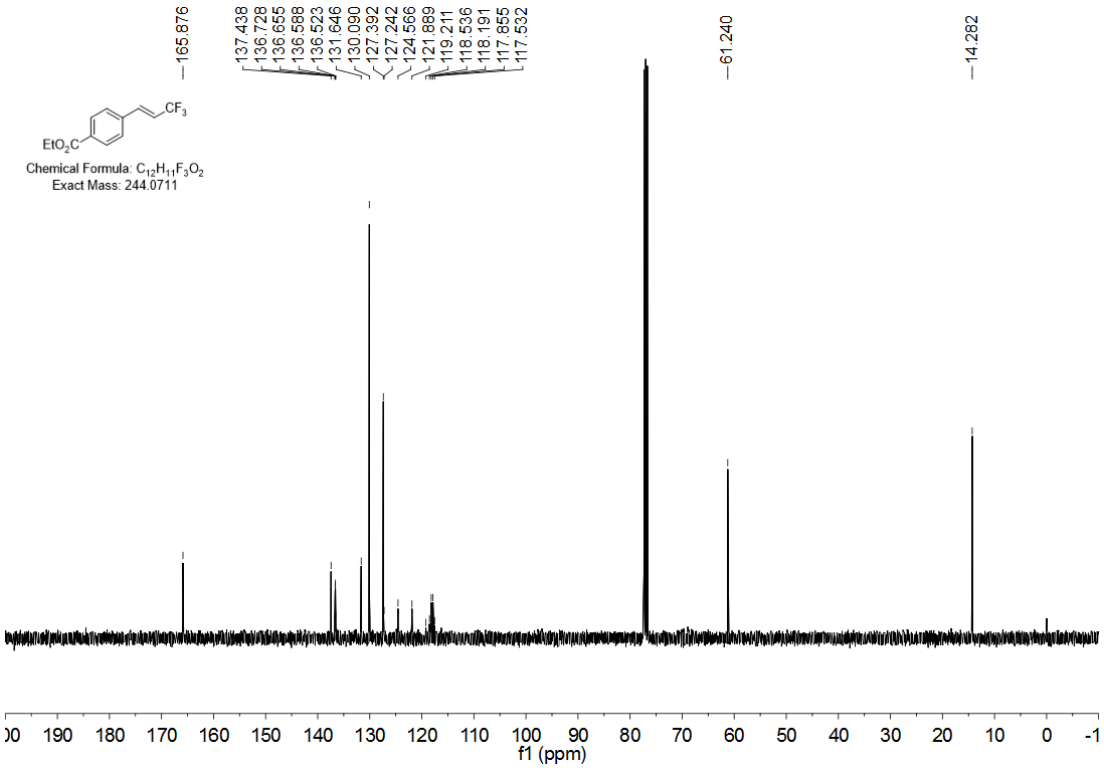
$^{1}$H NMR of **5a**




$^{19}$F NMR of **5a**

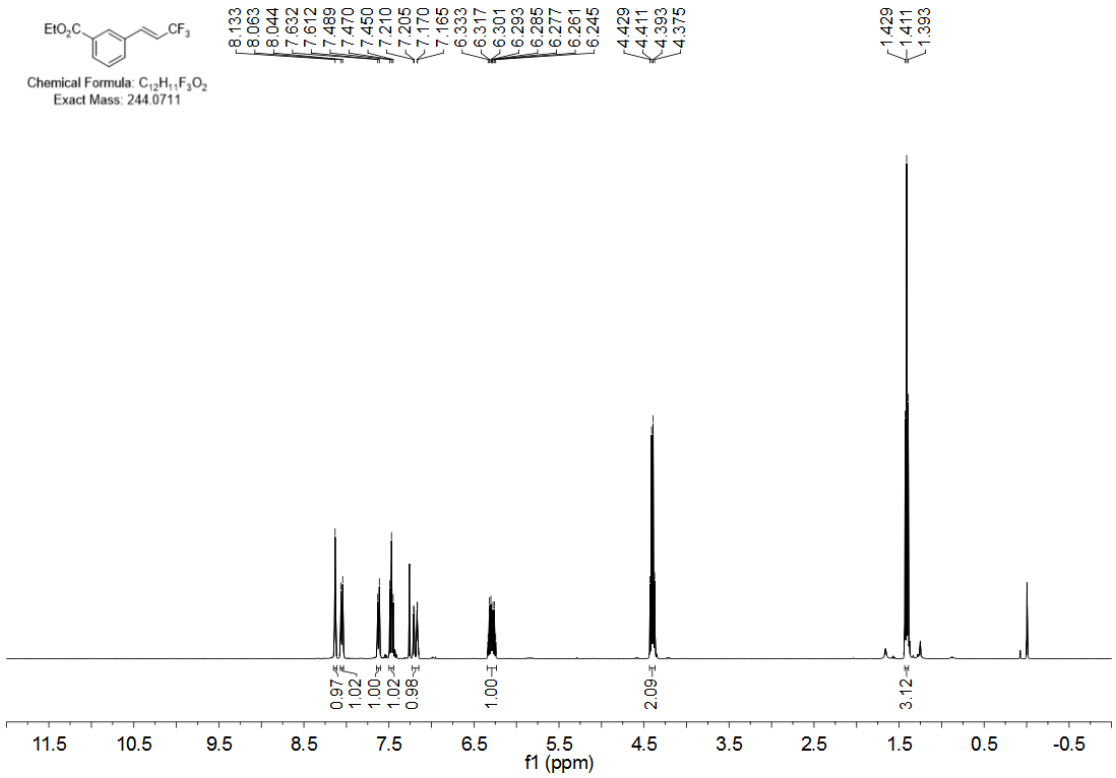


$^{13}$C NMR of **5a**

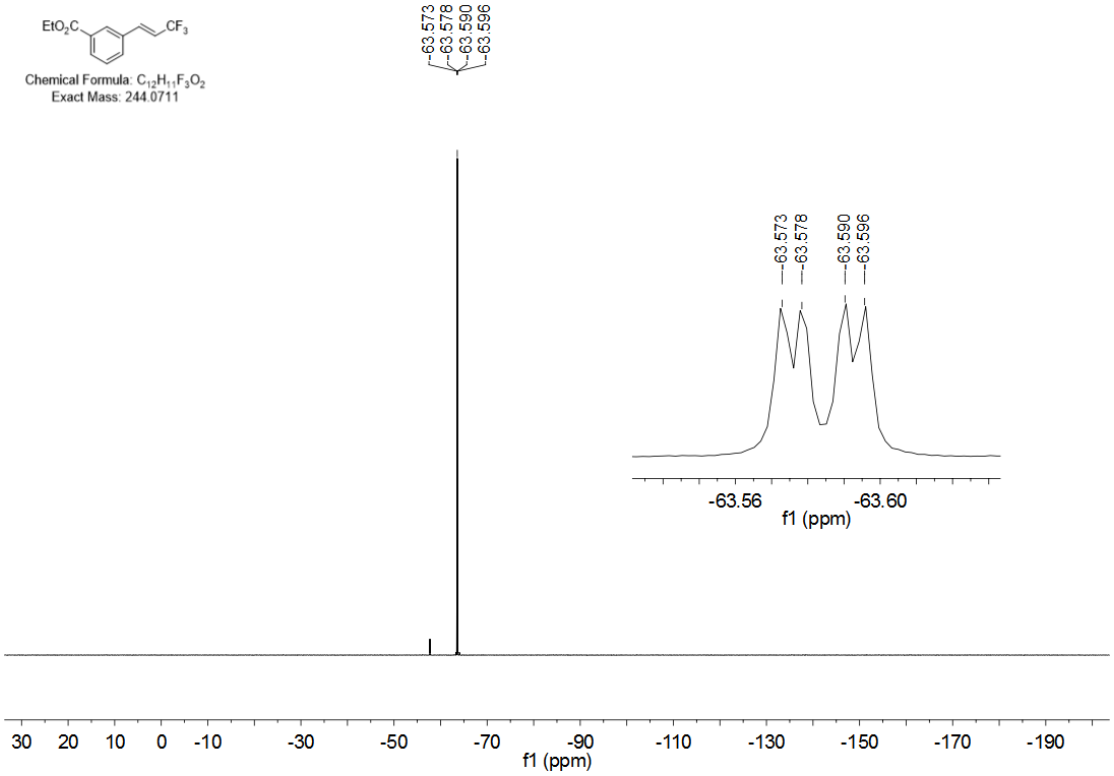



## Ethyl (*E*)-3-(3,3,3-trifluoroprop-1-en-1-yl)benzoate (5b)

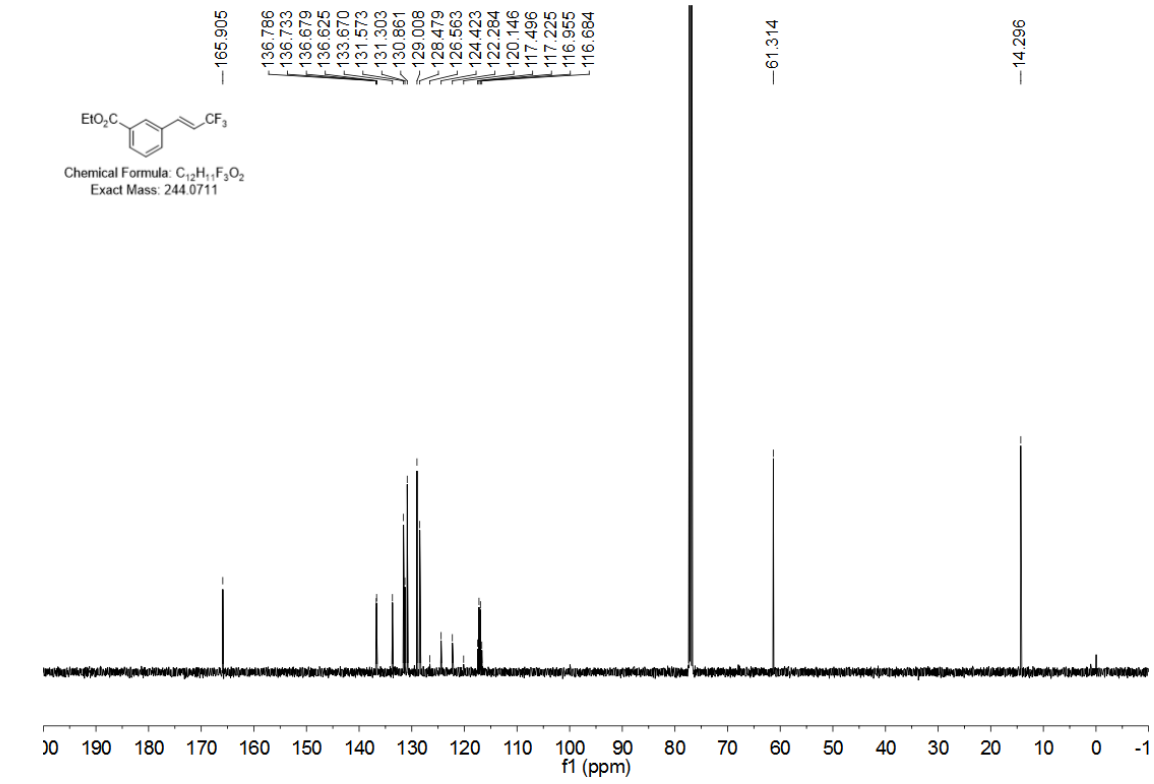
$^{1}$H NMR of **5b**



$^{19}$F NMR of **5b**

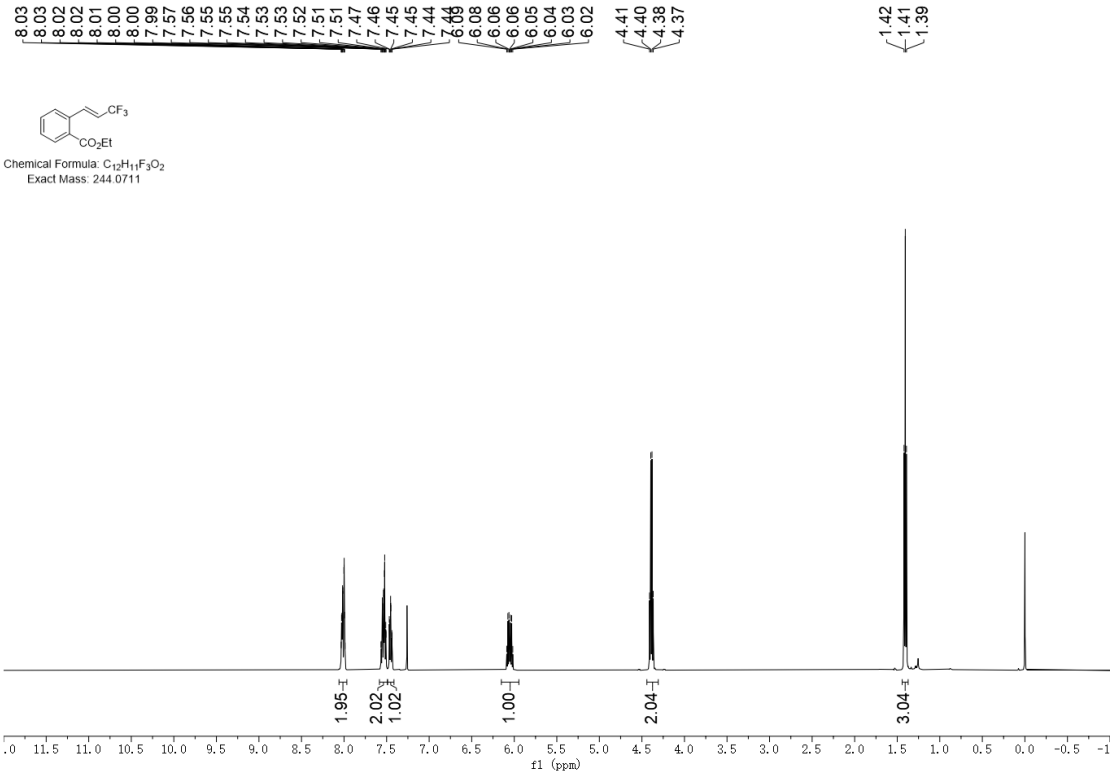



$^{13}$C NMR of **5b**

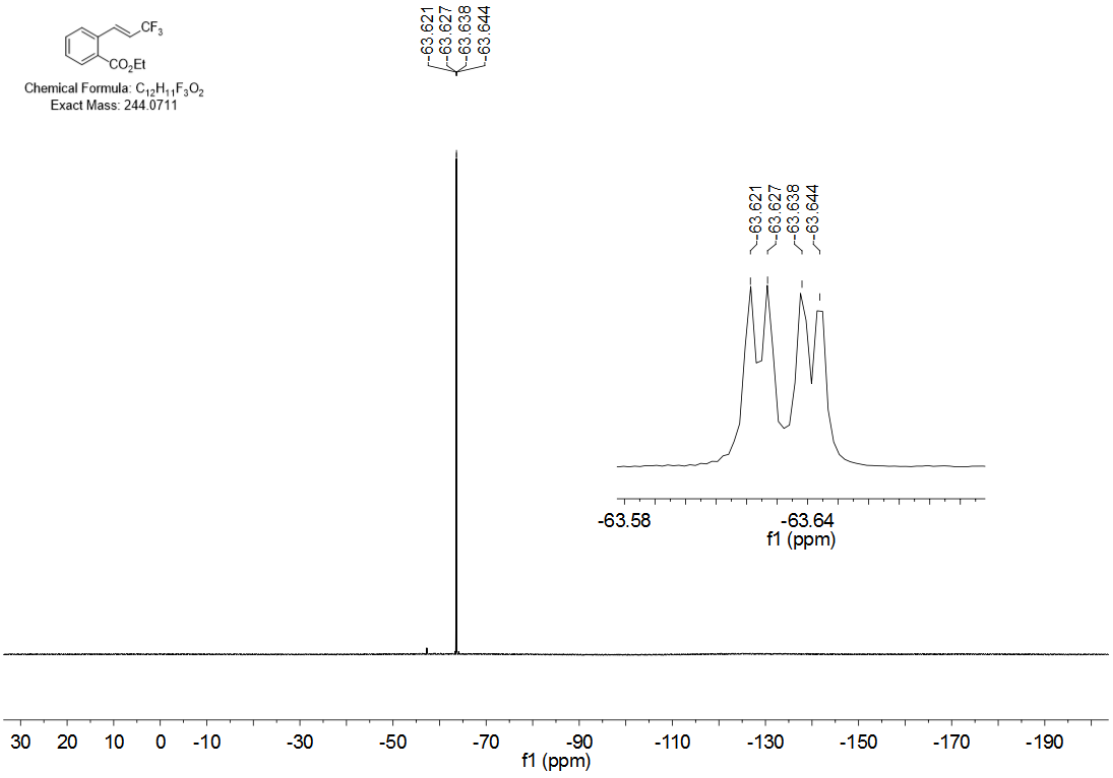


## Ethyl (*E*)-2-(3,3,3-trifluoroprop-1-en-1-yl)benzoate (5c)

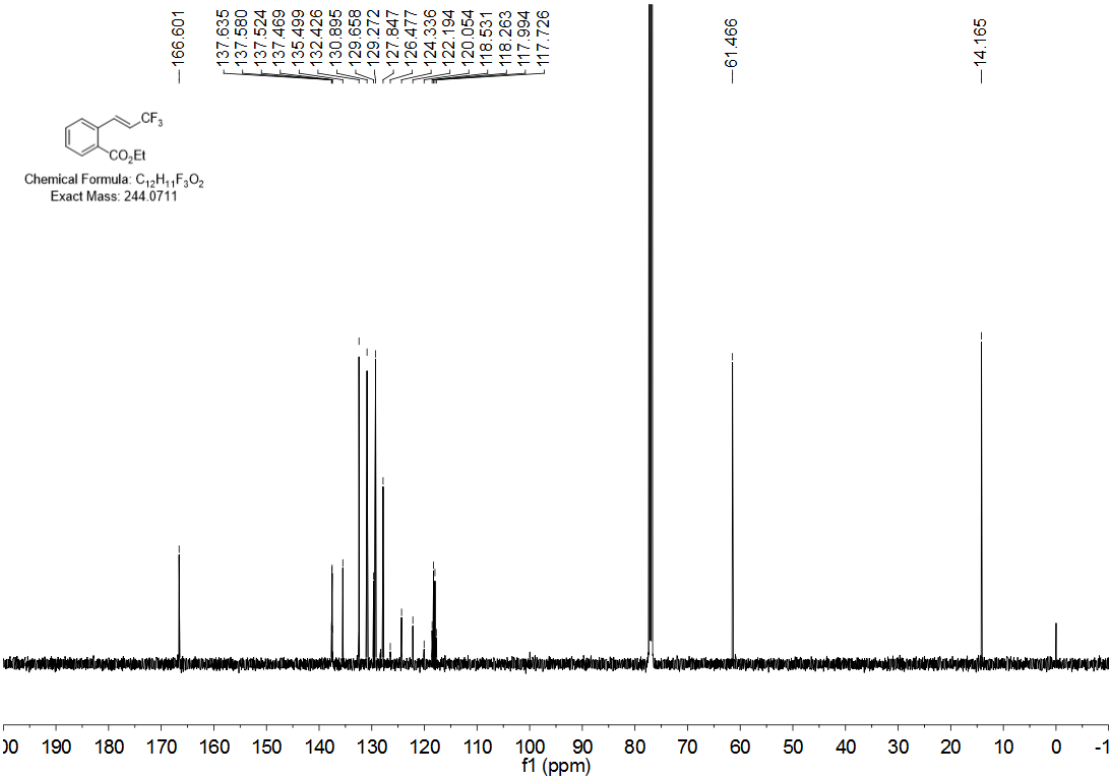
$^{1}$H NMR of **5c**




$^{19}$F NMR of **5c**

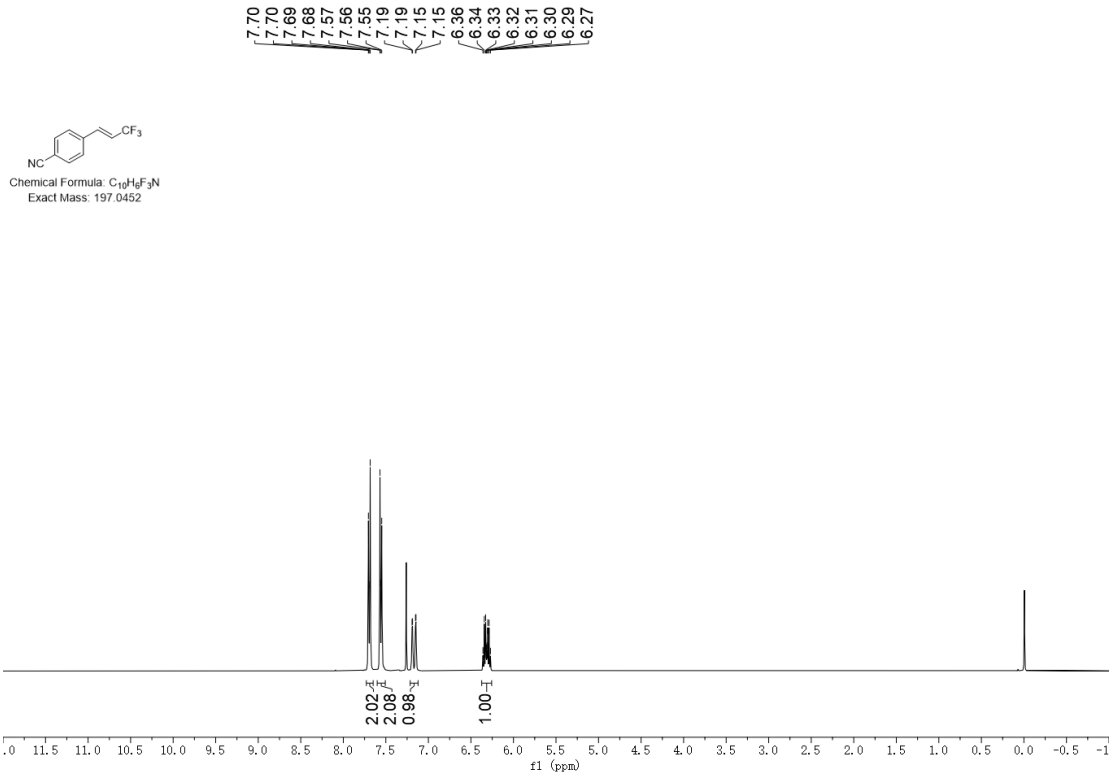


$^{13}$C NMR of **5c**

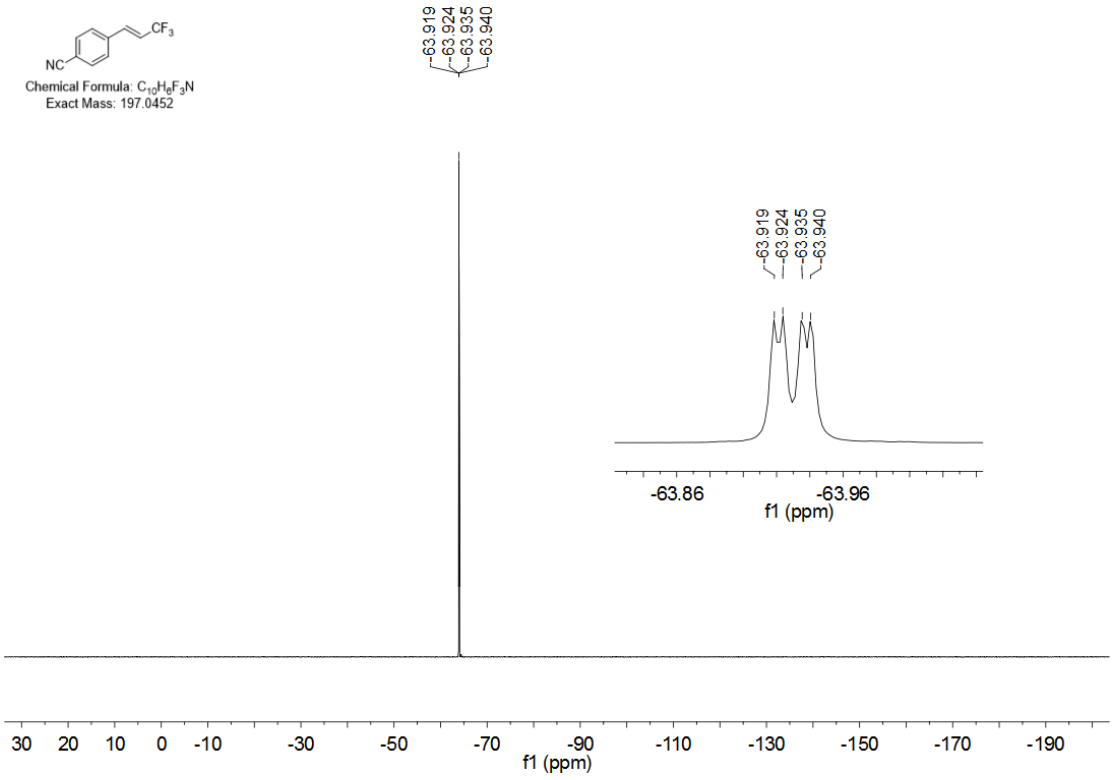



## (*E*)-4-(3,3,3-Trifluoroprop-1-en-1-yl)benzonitrile (5d)

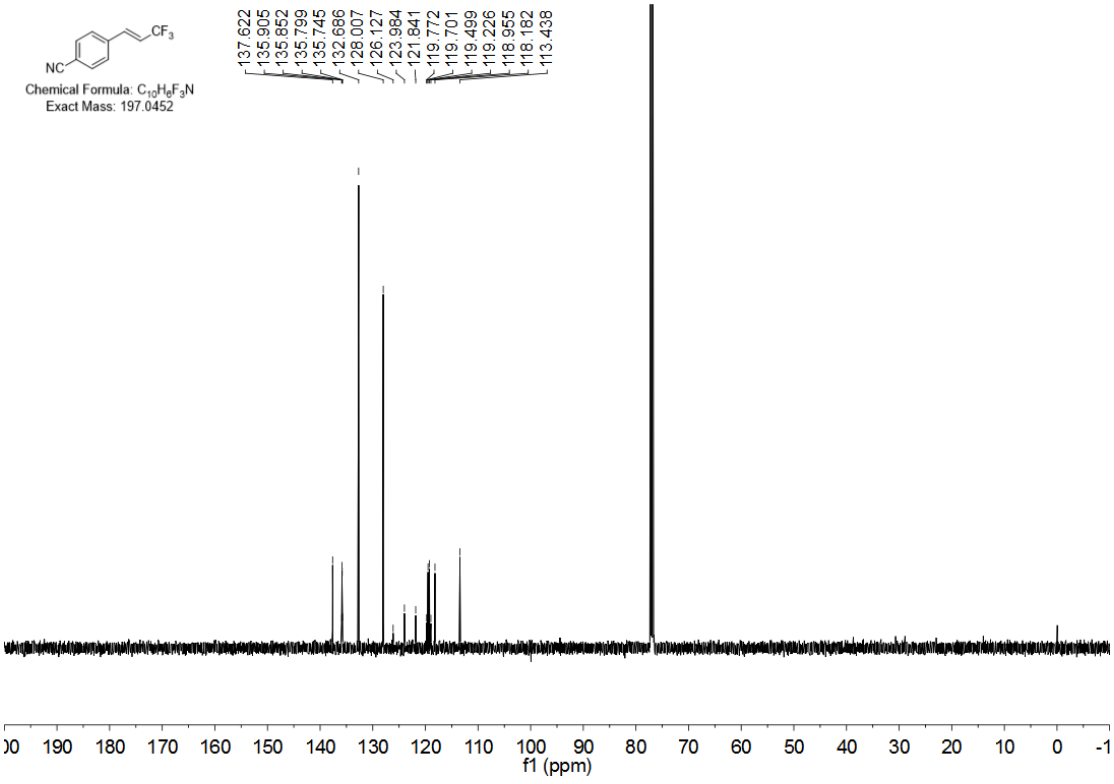
$^{1}$H NMR of **5d**



$^{19}$F NMR of **5d**

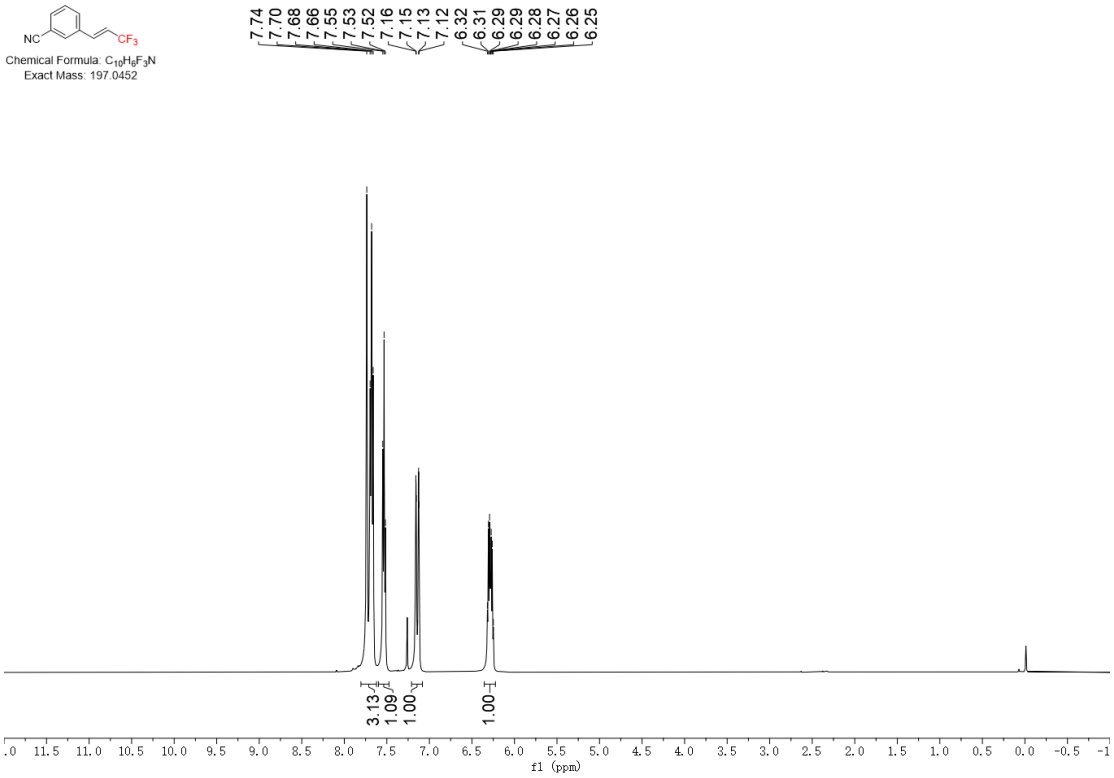



$^{13}$C NMR of **5d**

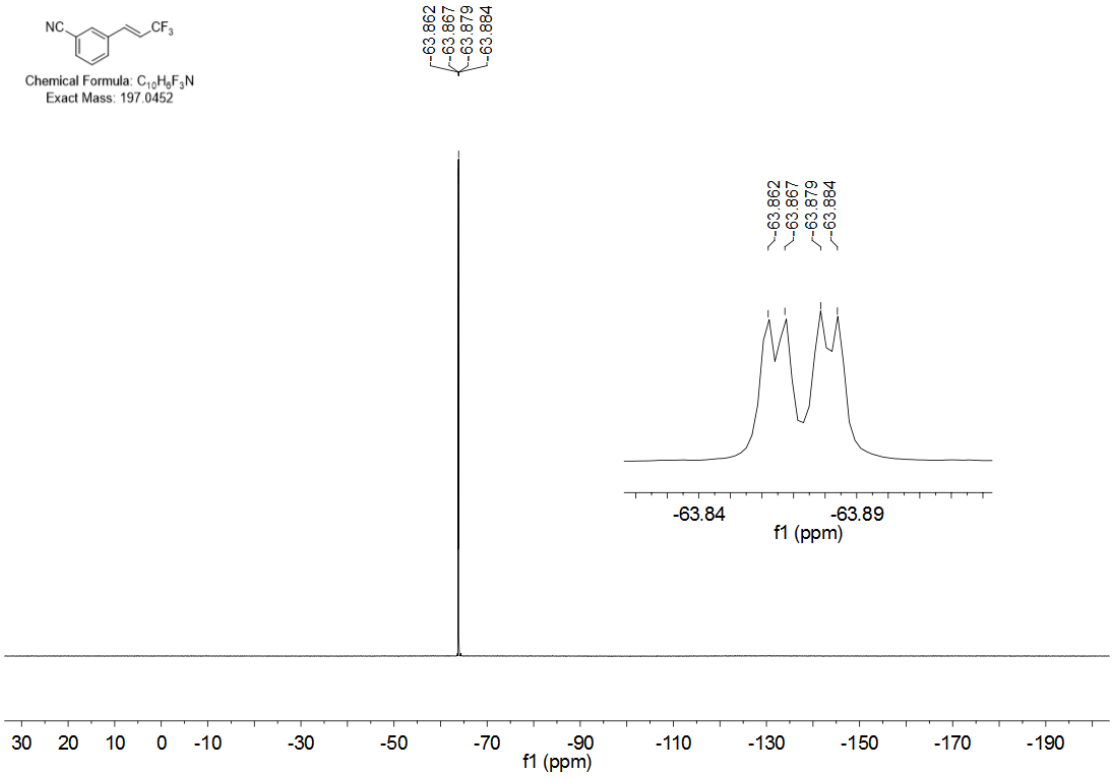


## (*E*)-3-(3,3,3-Trifluoroprop-1-en-1-yl)benzonitrile (5e)

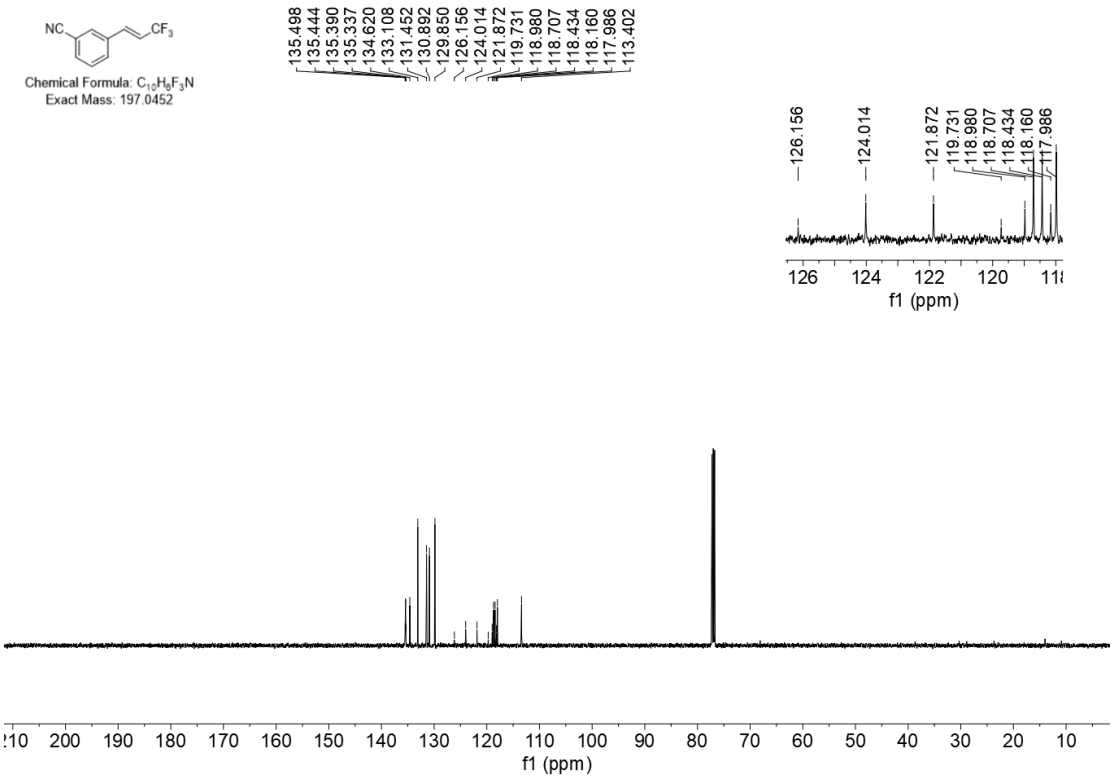
$^{1}$H NMR of **5e**




$^{19}$F NMR of **5e**

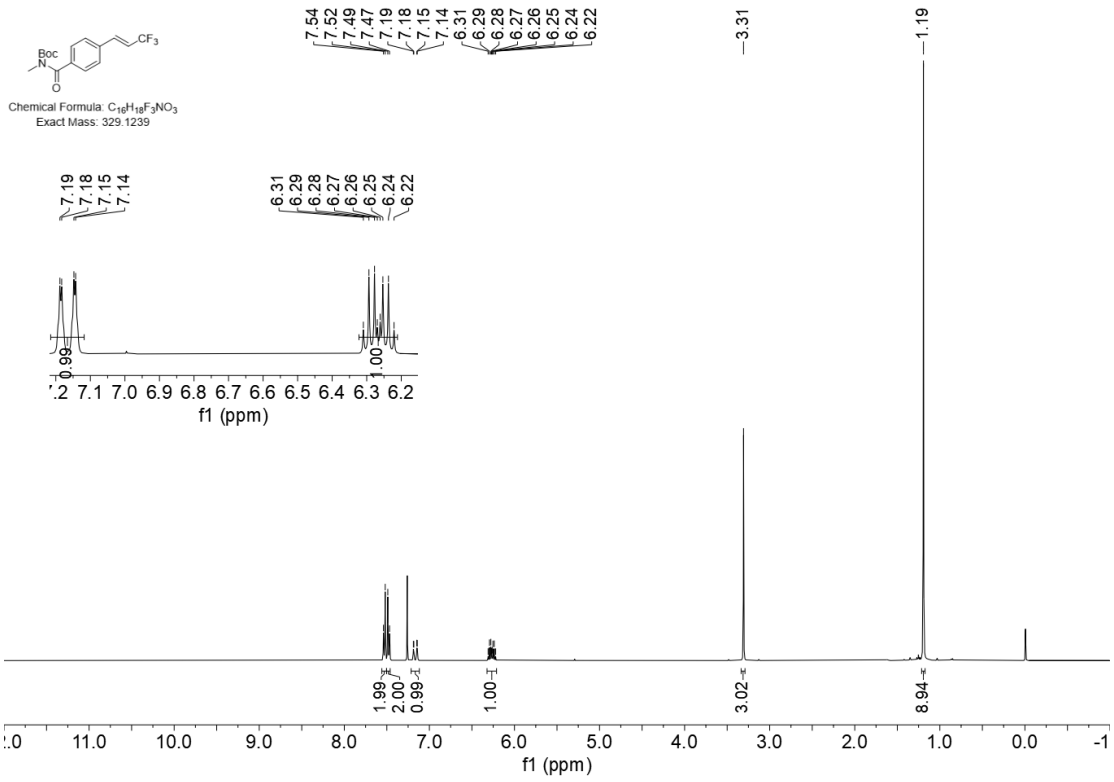


$^{13}$C NMR of **5e**

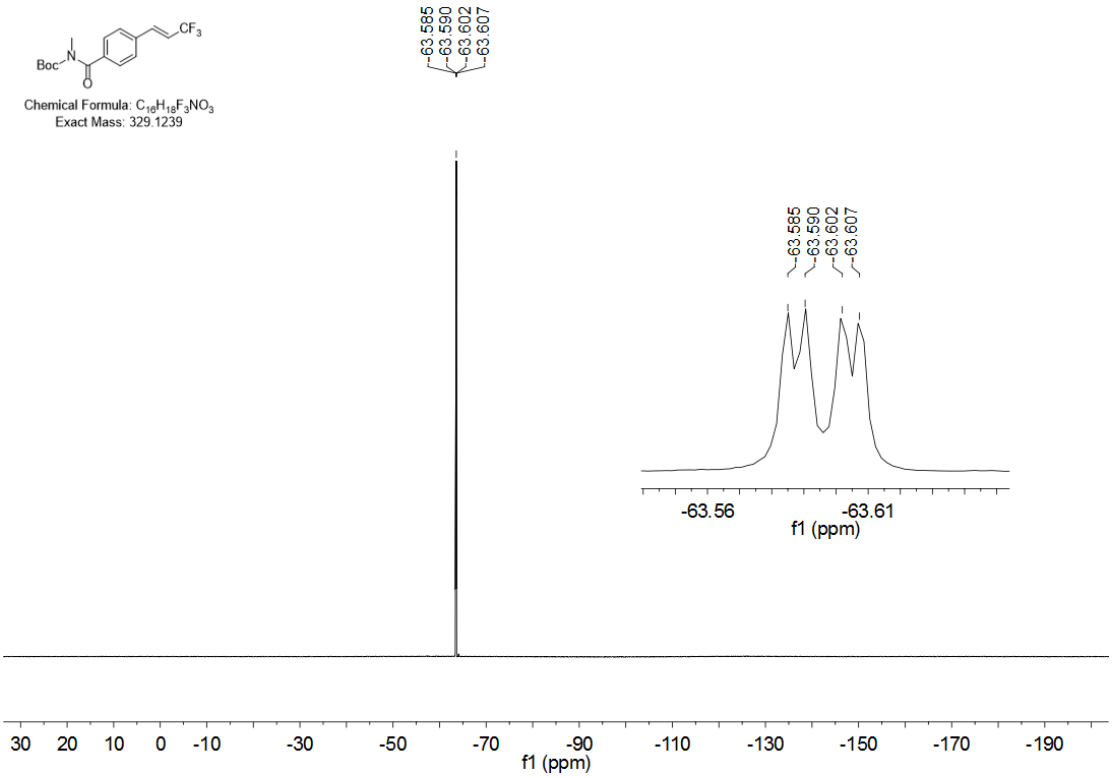



## *tert*-Butyl(*E*)-methyl(4-(3,3,3-trifluoroprop-1-en-1-yl)benzoyl)carbamate (5f)

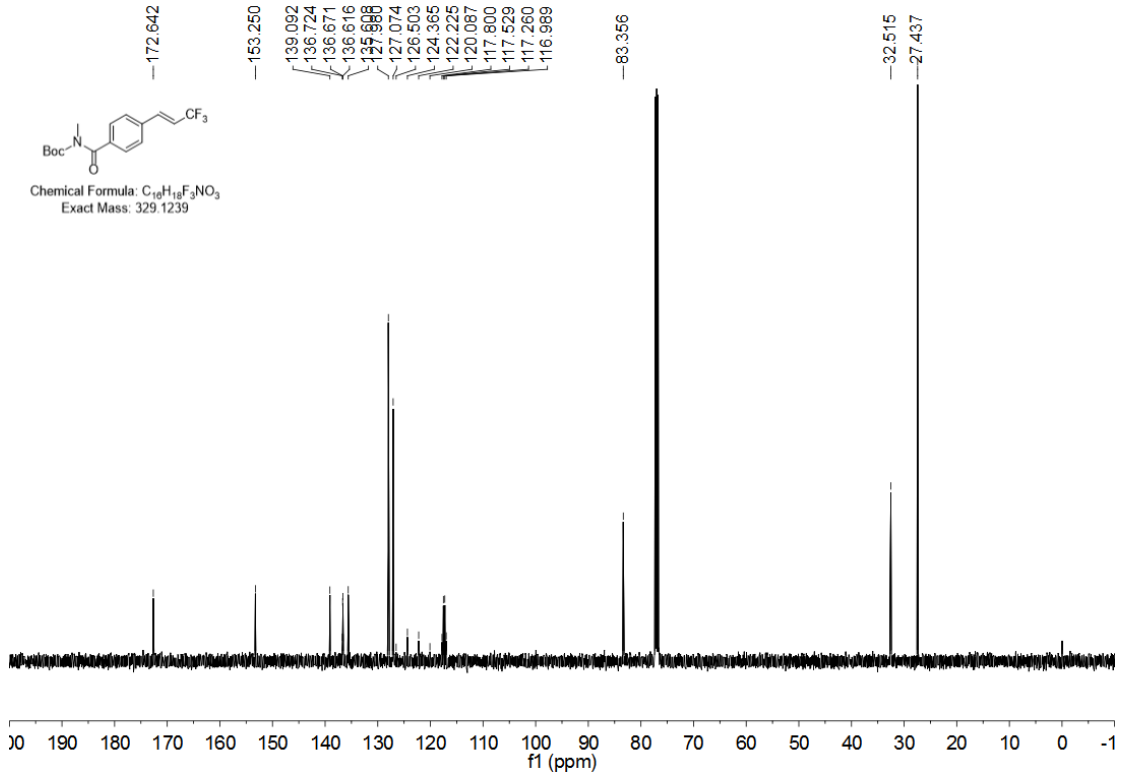
$^{1}$H NMR of **5f**



$^{19}$F NMR of **5f**

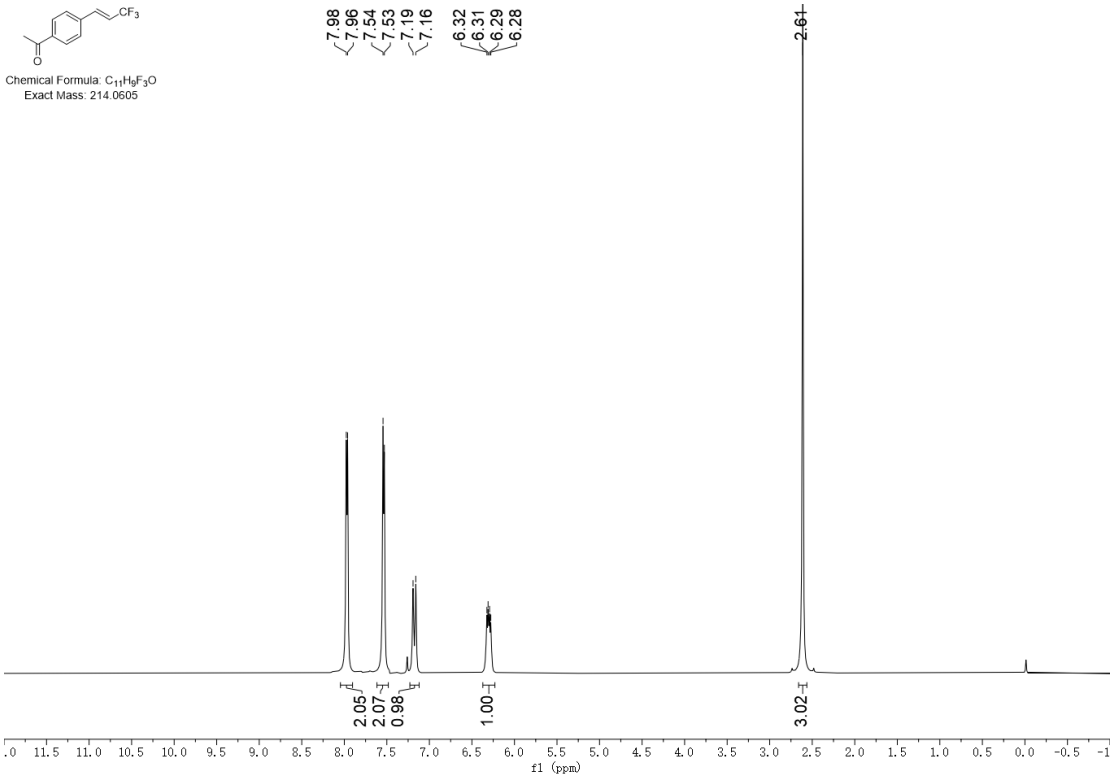



$^{13}$C NMR of **5f**

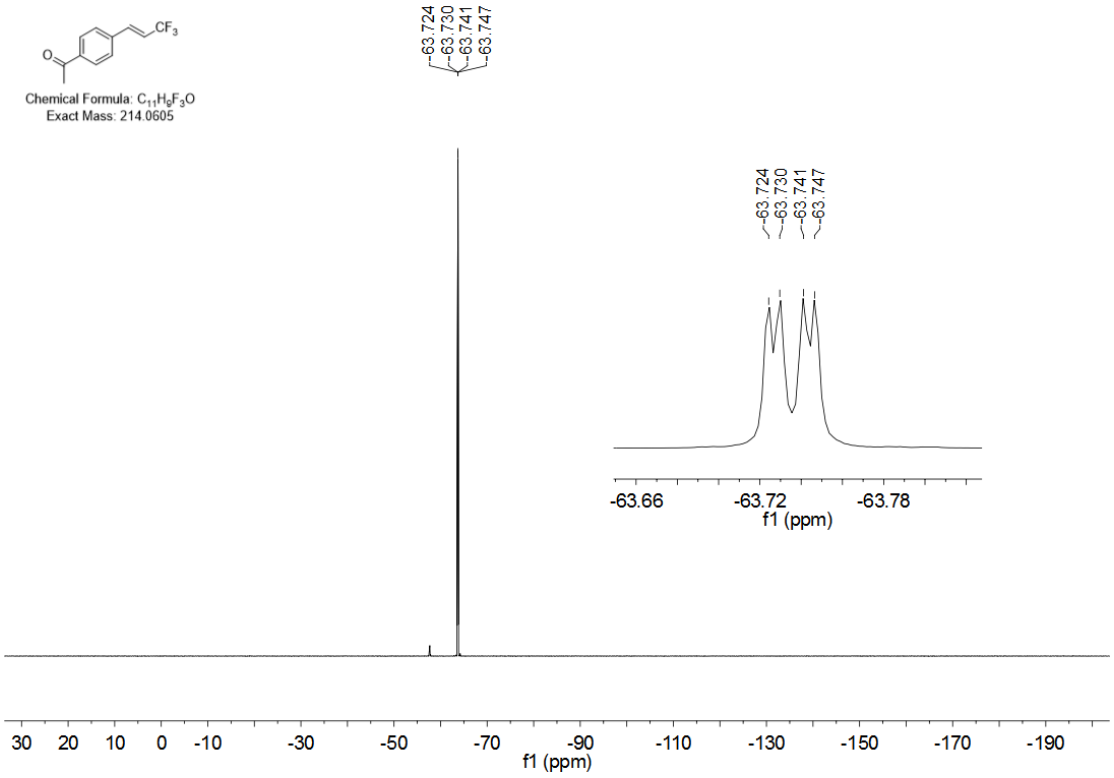


## (*E*)-1-(4-(3,3,3-Trifluoroprop-1-en-1-yl)phenyl)ethan-1-one (5g)

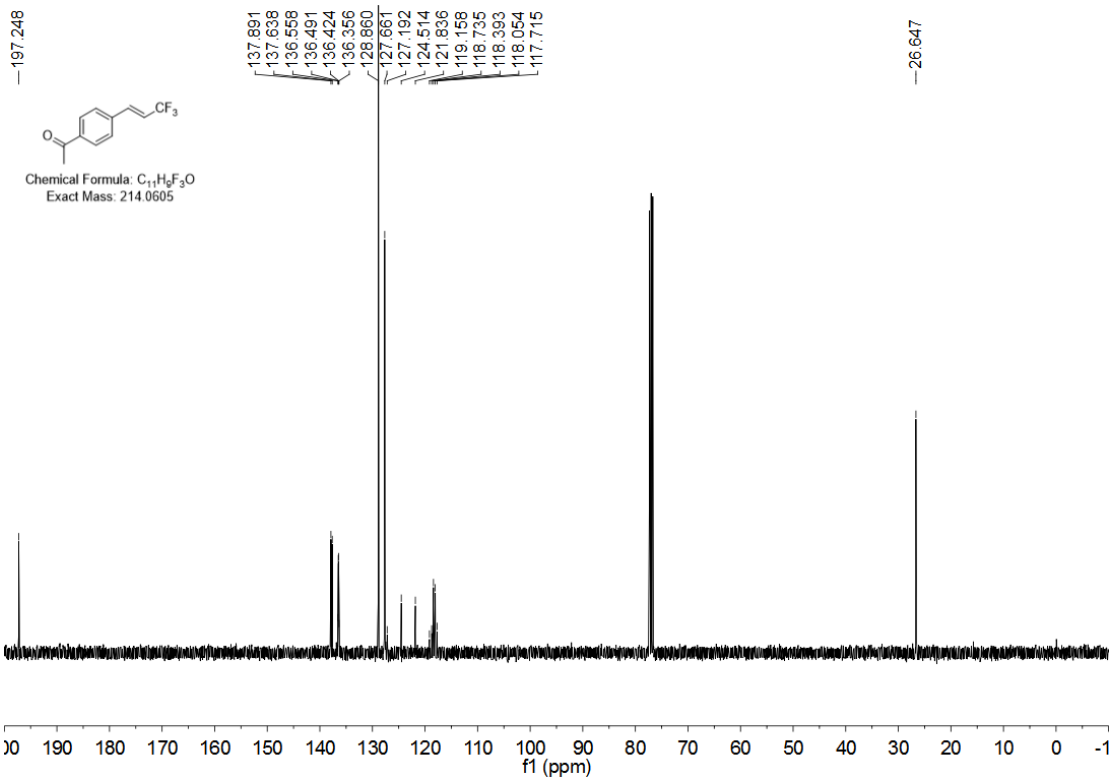
$^{1}$H NMR of **5g**




$^{19}$F NMR of **5g**

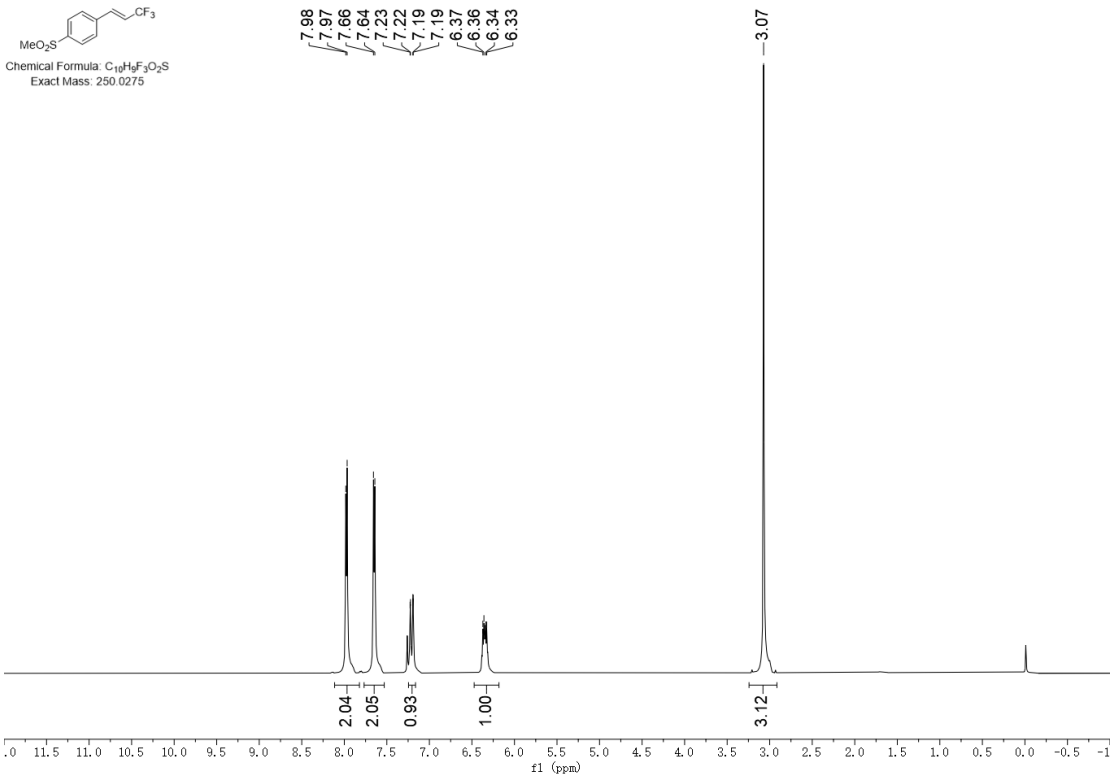


$^{13}$C NMR of **5g**

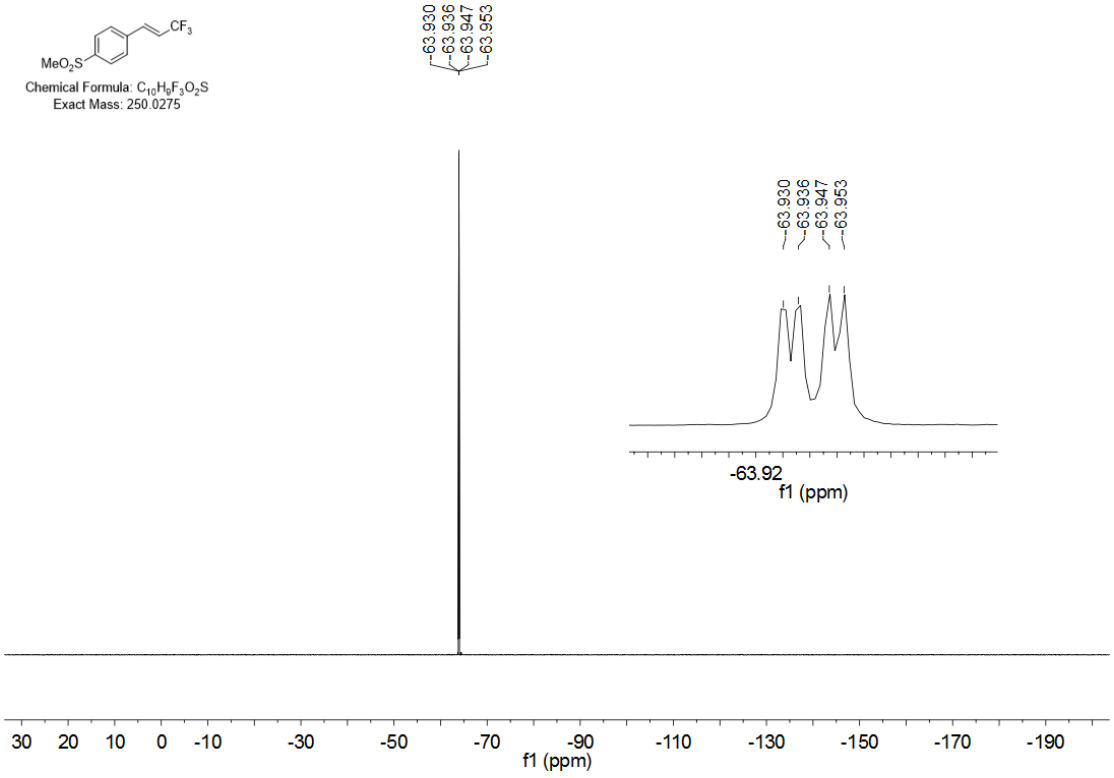



**(*E*)-1-(Methylsulfonyl)-4-(3,3,3-trifluoroprop-1-en-1-yl)benzene (5h)**

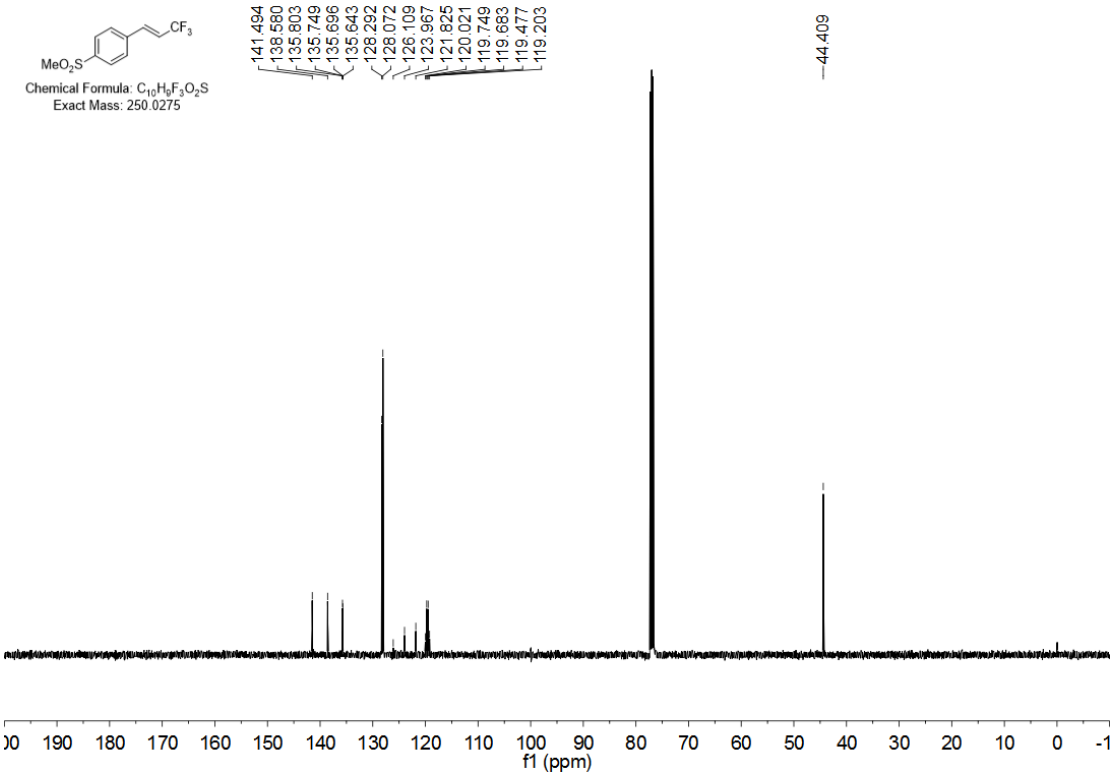
$^{1}$H NMR of **5h**



$^{19}$F NMR of **5h**

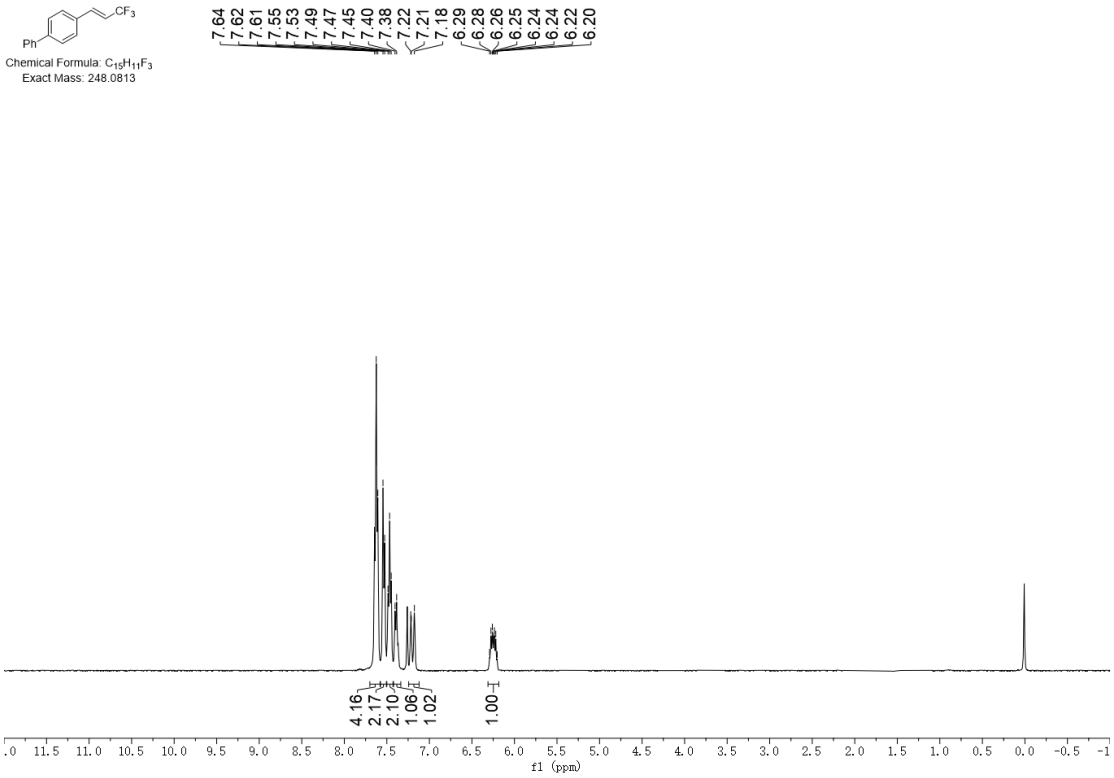



$^{13}$C NMR of **5h**

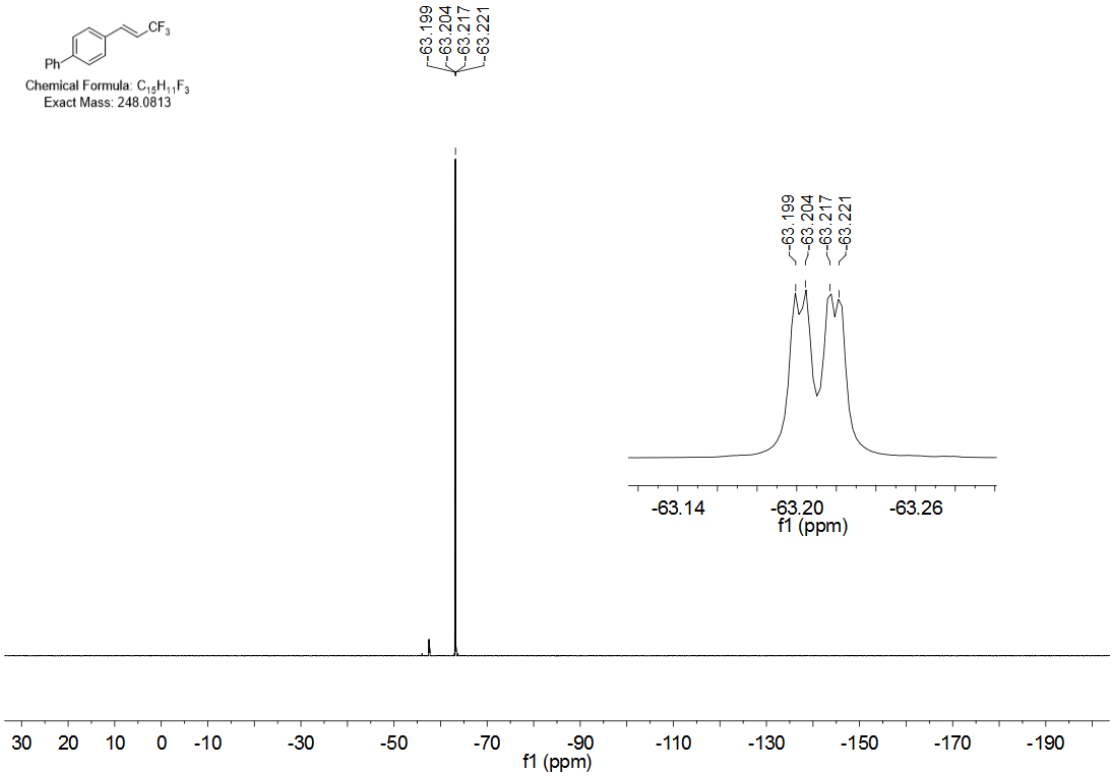


## (*E*)-4-(3,3,3-Trifluoroprop-1-en-1-yl)-1,1'-biphenyl (5i)

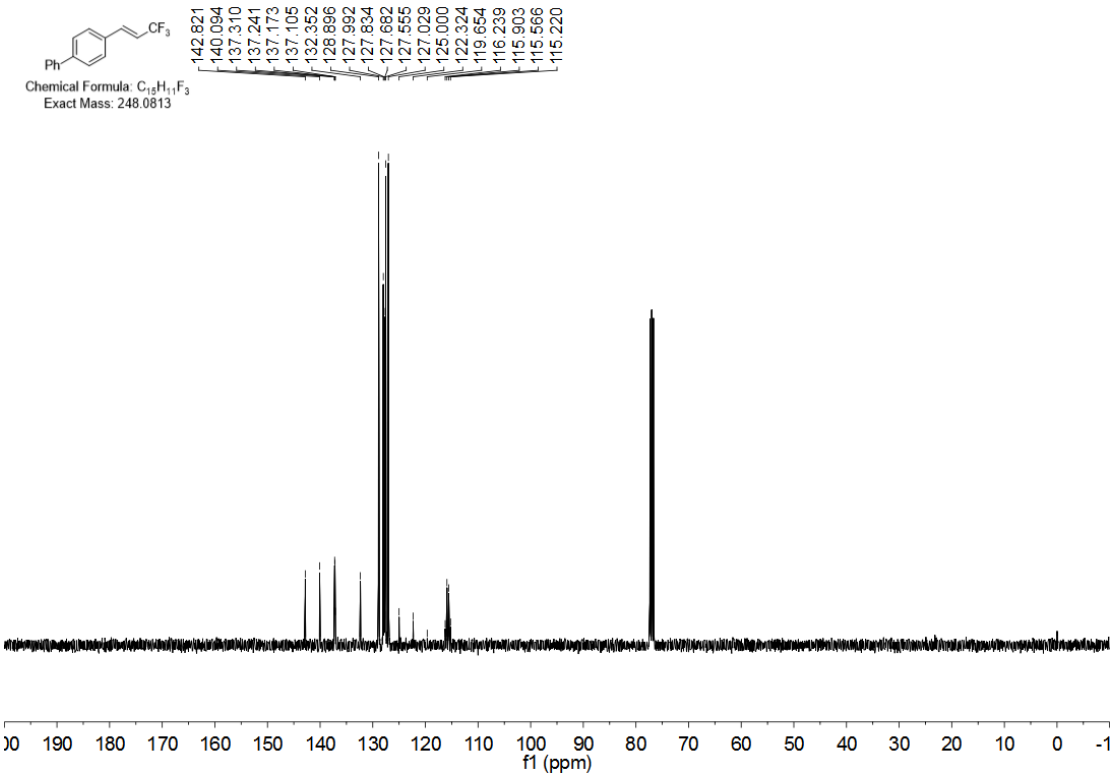
$^{1}$H NMR of **5i**




$^{19}$F NMR of **5i**

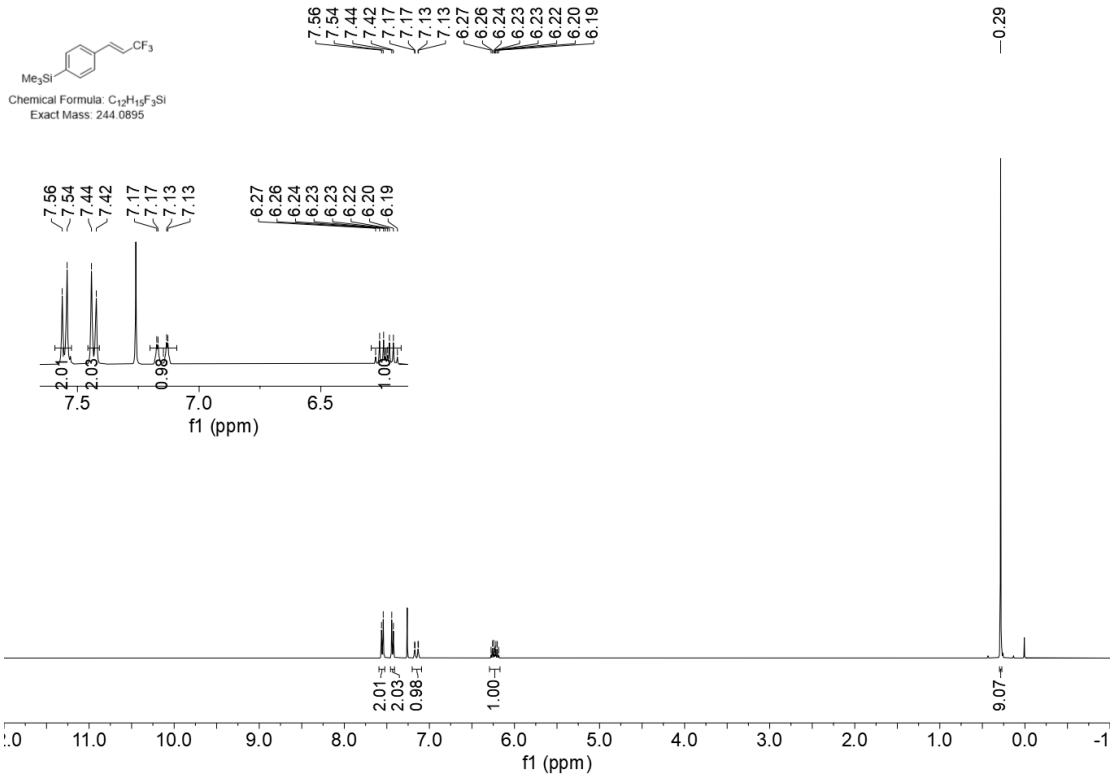


$^{13}$C NMR of **5i**

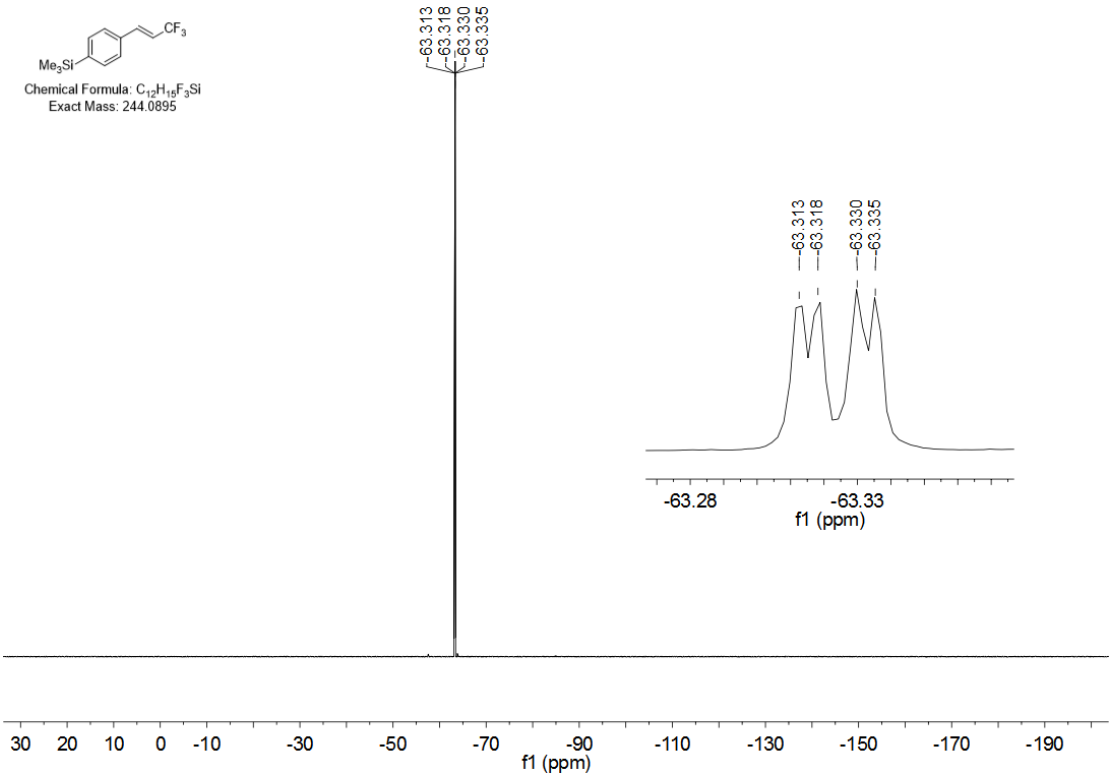



## (*E*)-Trimethyl(4-(3,3,3-trifluoroprop-1-en-1-yl)phenyl)silane (5j)

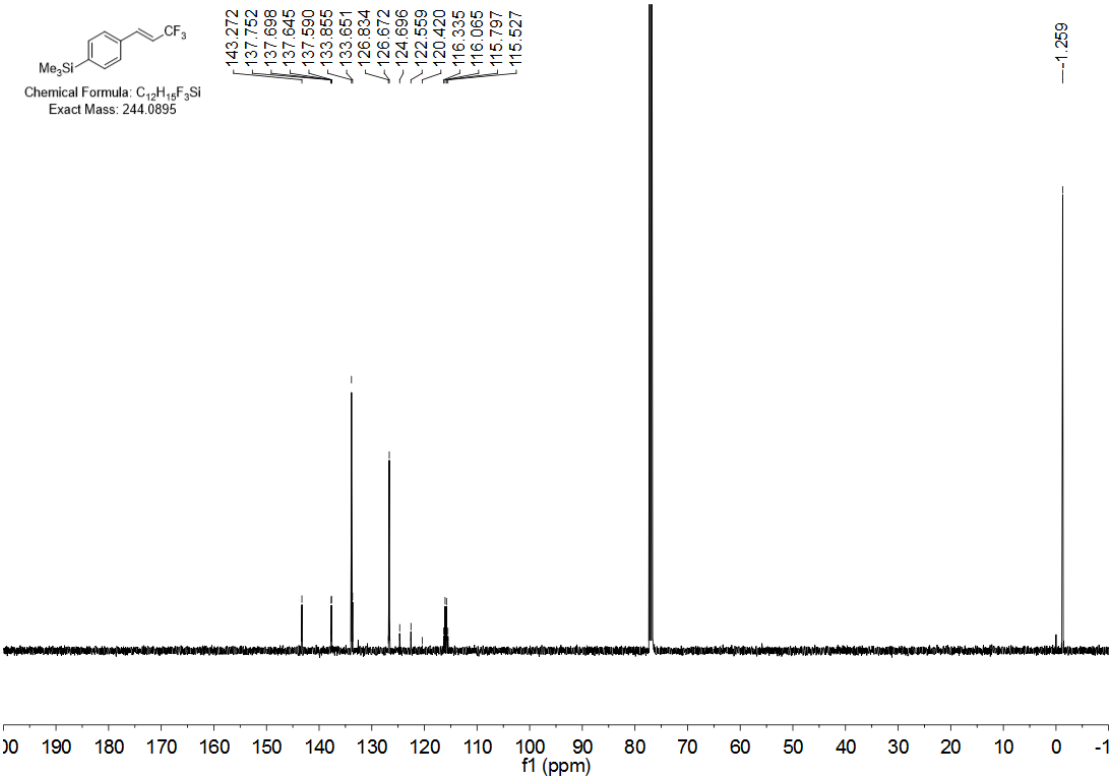
$^{1}$H NMR of **5j**



$^{19}$F NMR of **5j**

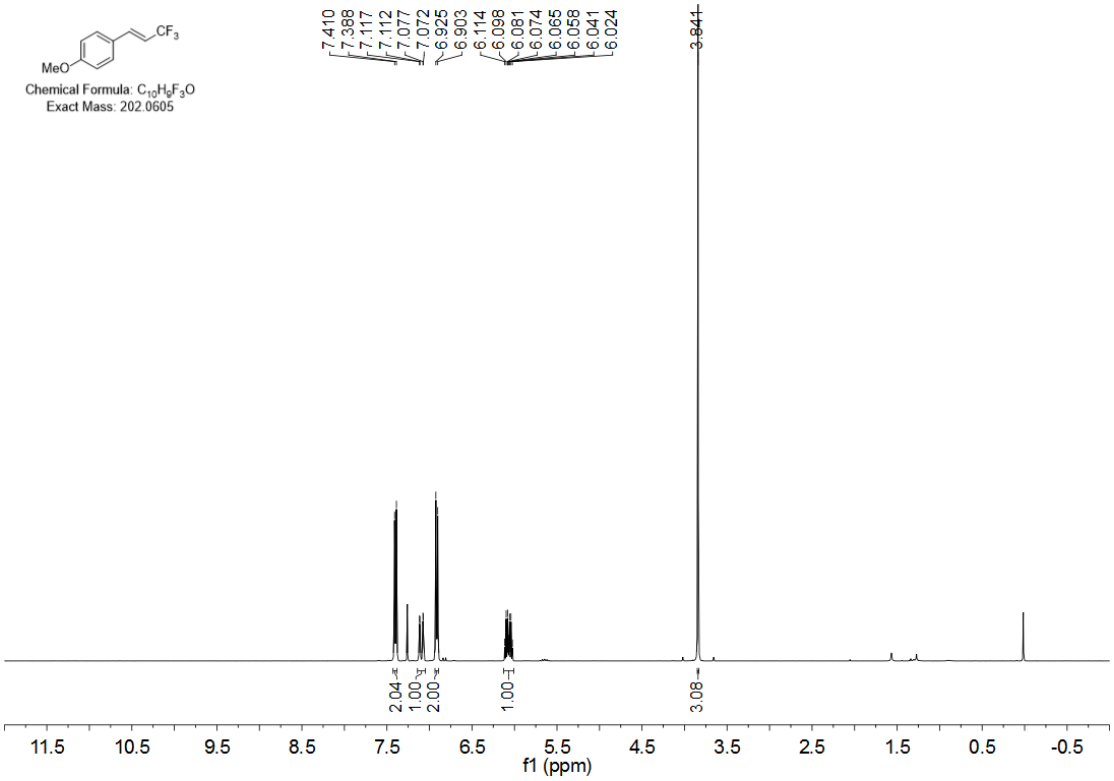



$^{13}$C NMR of **5j**

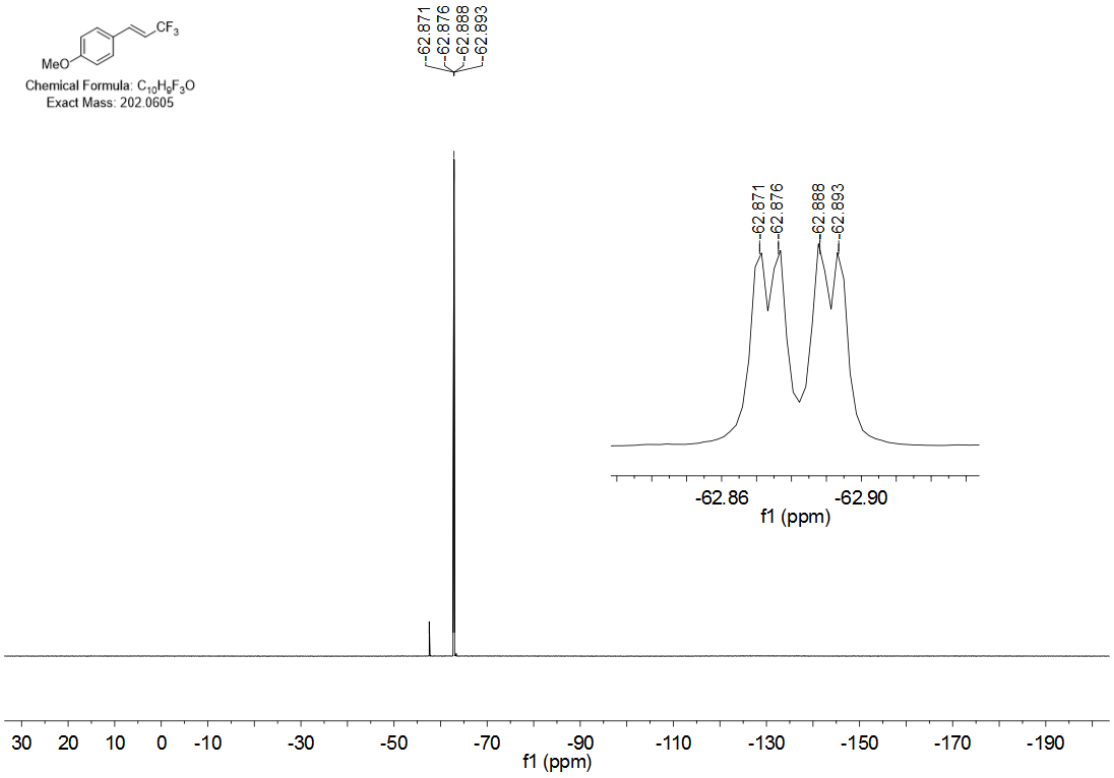


## (*E*)-1-Methoxy-4-(3,3,3-trifluoroprop-1-en-1-yl)benzene (5k)

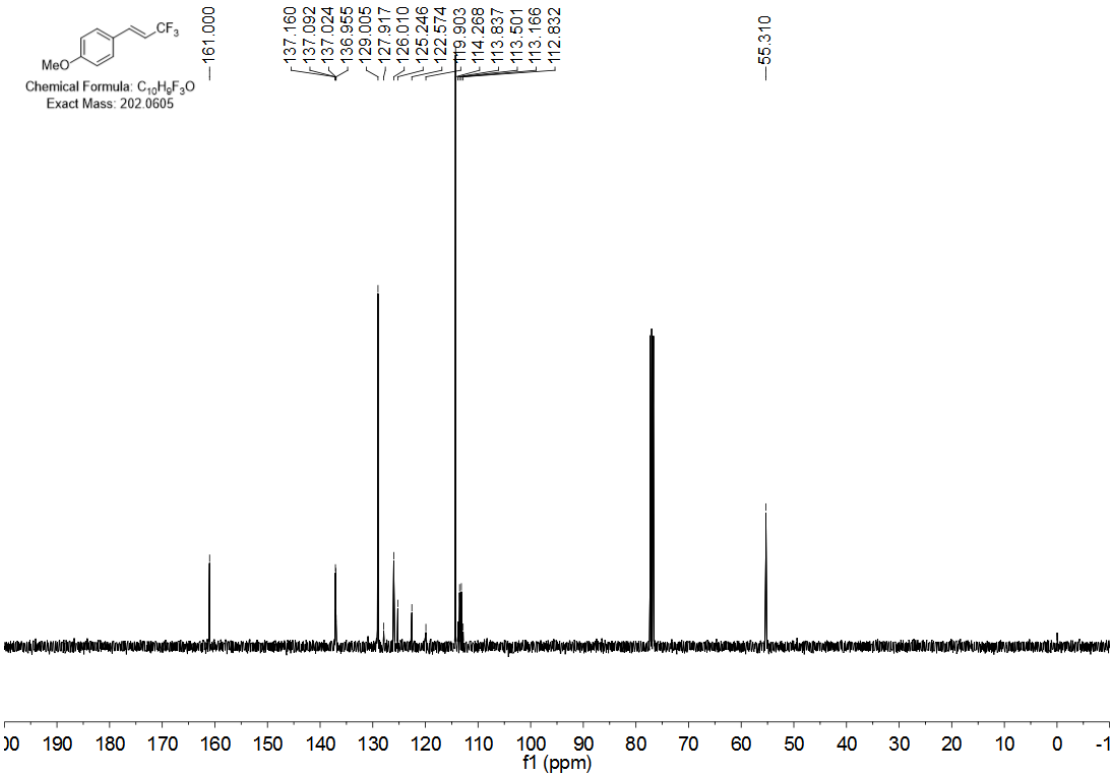
$^{1}$H NMR of **5k**




$^{19}$F NMR of **5k**

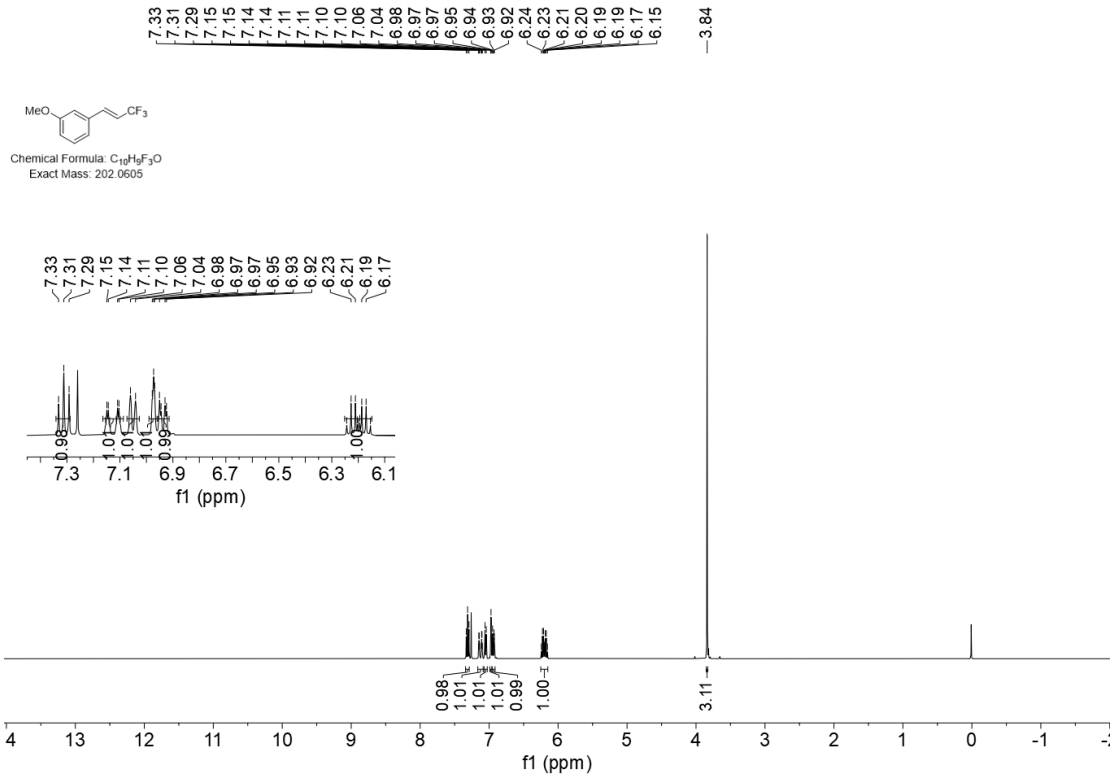


$^{13}$C NMR of **5k**

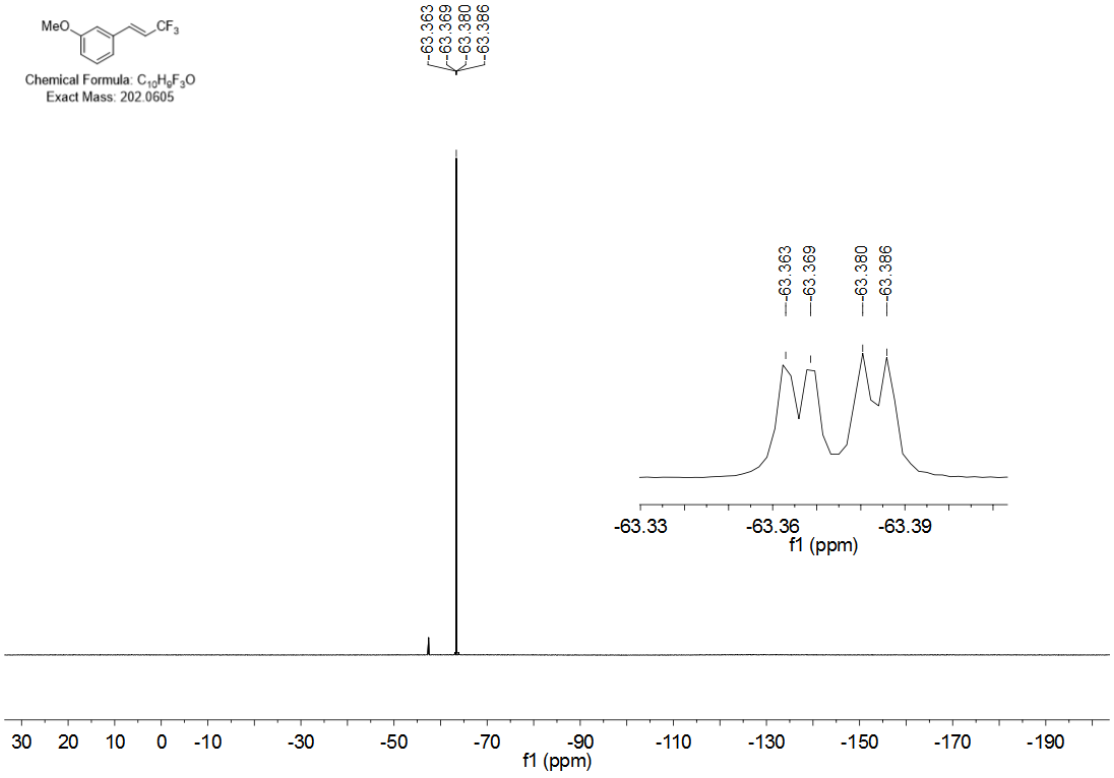



## (*E*)-1-Methoxy-3-(3,3,3-trifluoroprop-1-en-1-yl)benzene(5l)

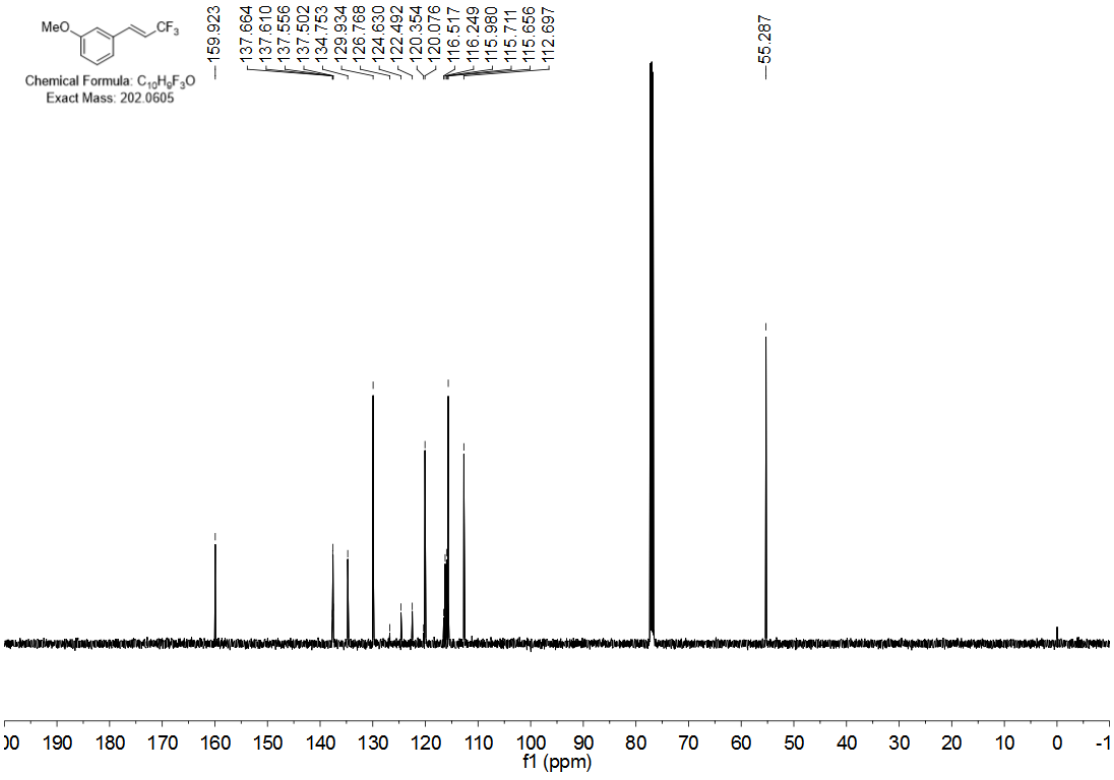
$^{1}$H NMR of **5l**



$^{19}$F NMR of **5l**

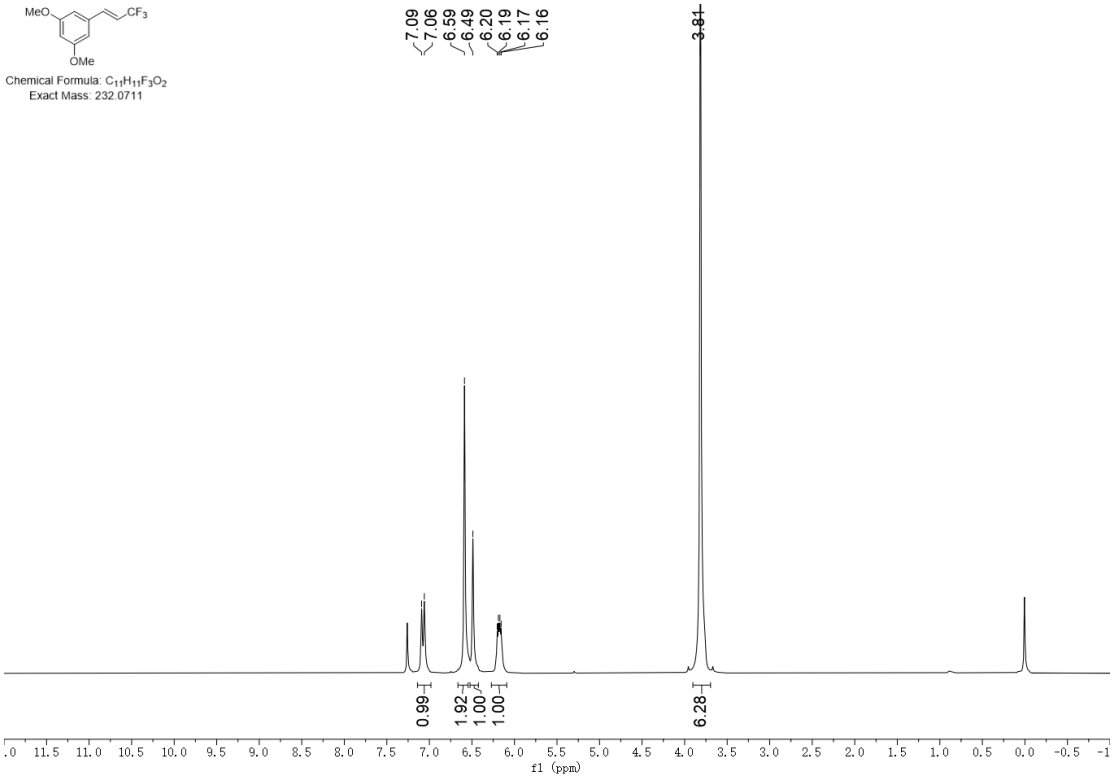



$^{13}$C NMR of **5l**

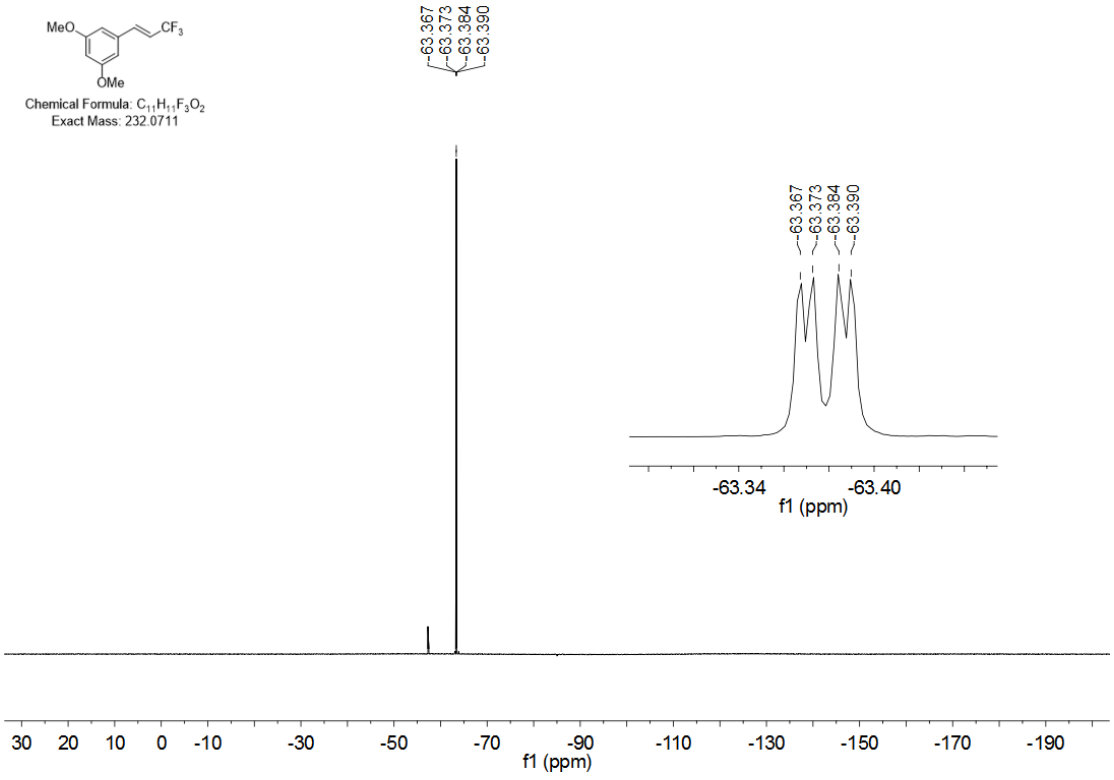


## (*E*)-1,3-Dimethoxy-5-(3,3,3-trifluoroprop-1-en-1-yl)benzene (5m)

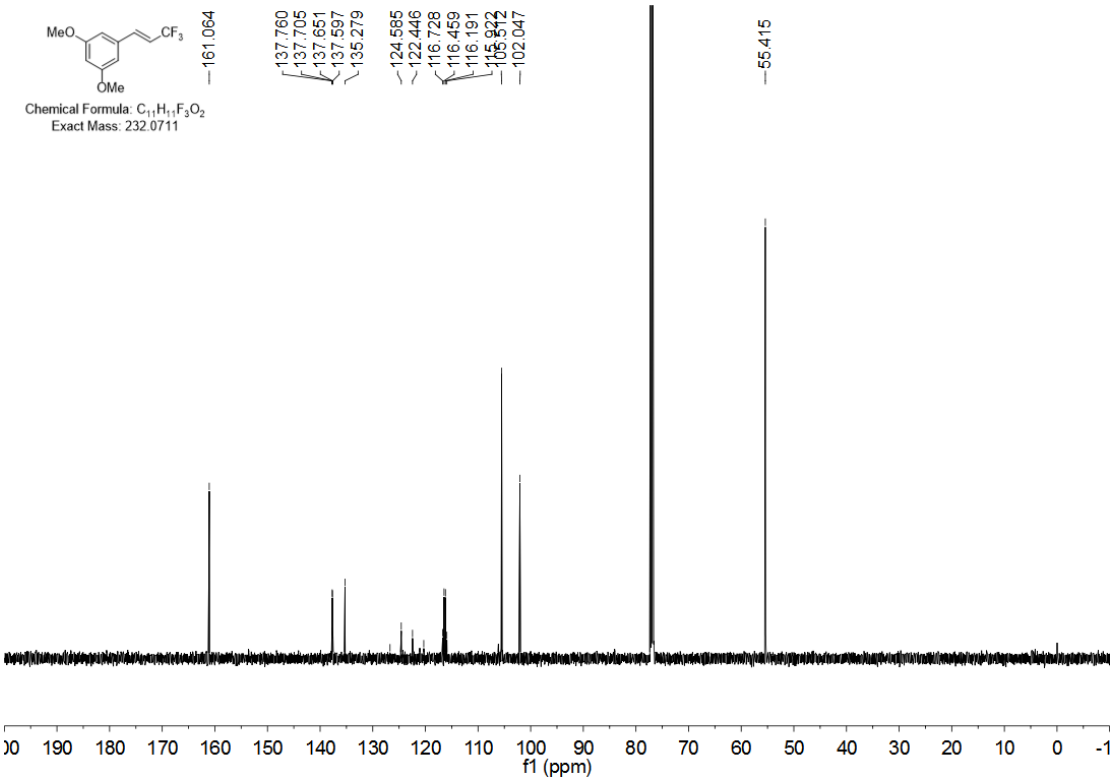
$^{1}$H NMR of **5m**




$^{19}$F NMR of **5m**

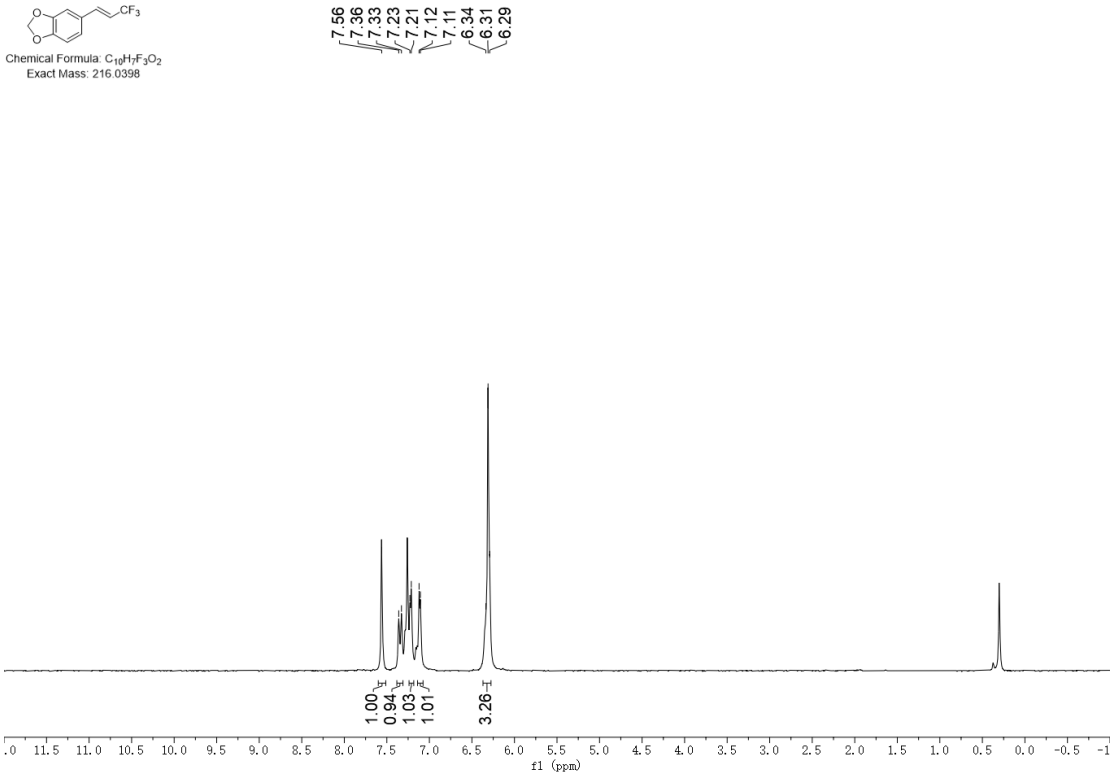


$^{13}$C NMR of **5m**

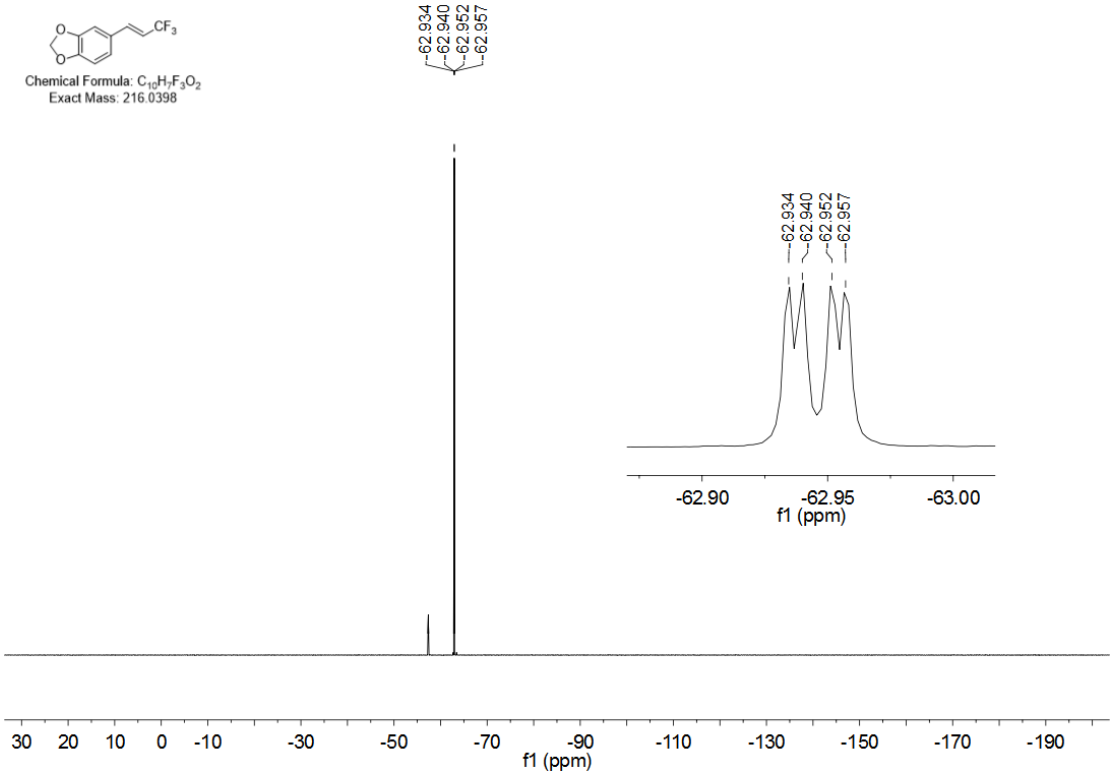



**(*E*)-5-(3,3,3-Trifluoroprop-1-en-1-yl)benzo[*d*][1,3]dioxole (5n)**

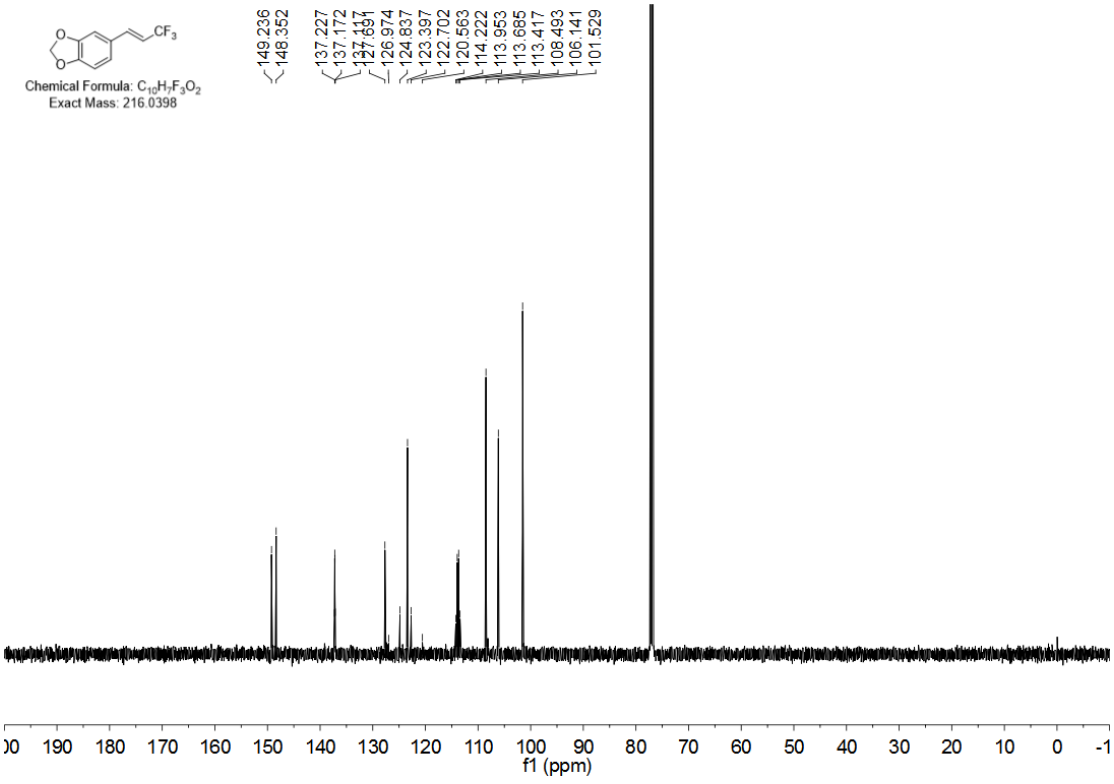
$^{1}$H NMR of **5n**



$^{19}$F NMR of **5n**

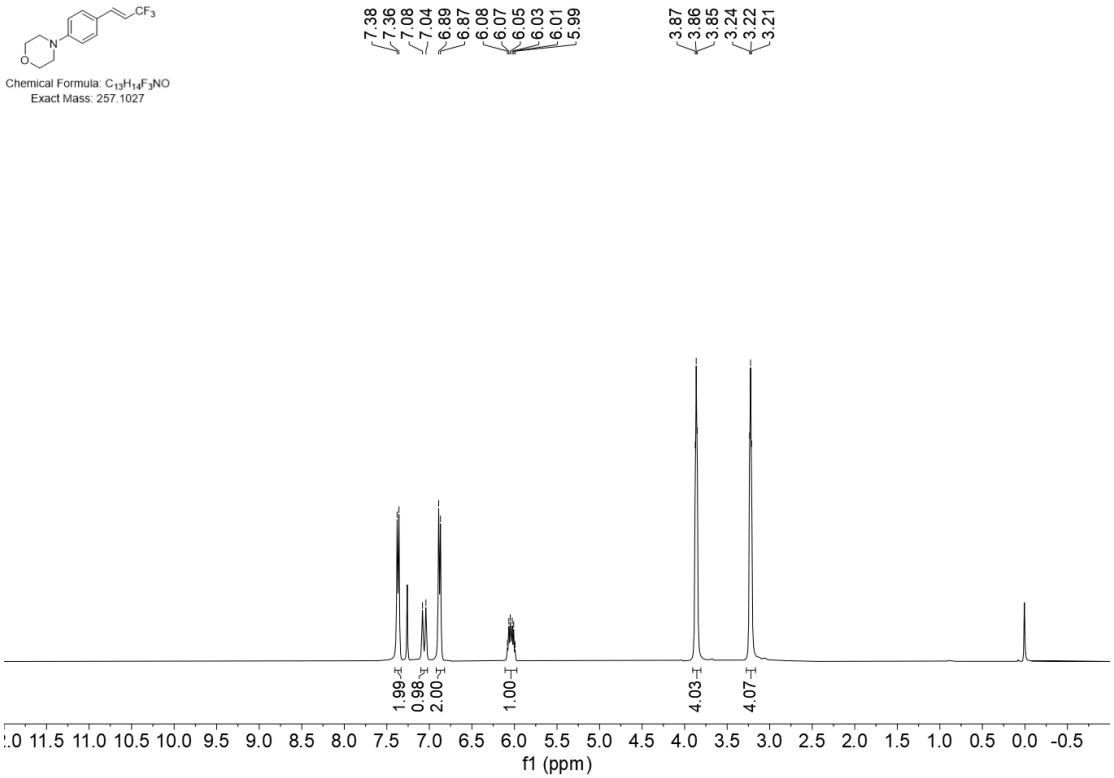



$^{13}$C NMR of **5n**

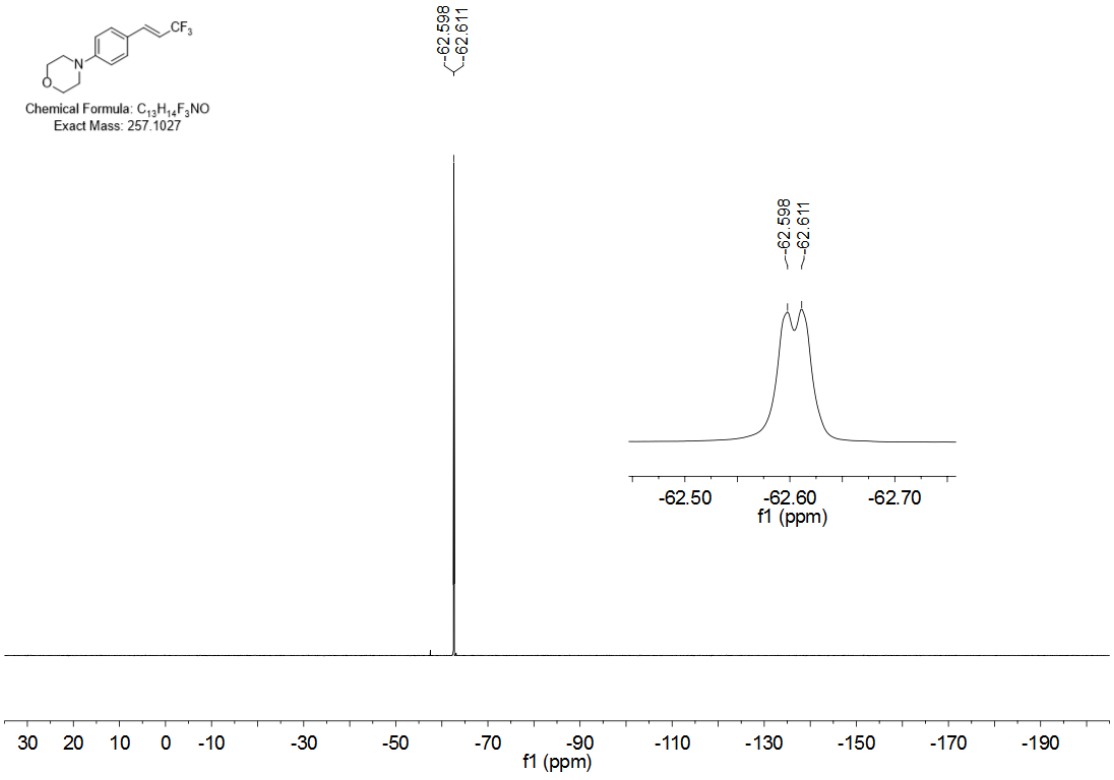


## (*E*)-4-(4-(3,3,3-Trifluoroprop-1-en-1-yl)phenyl)morpholine (5o)

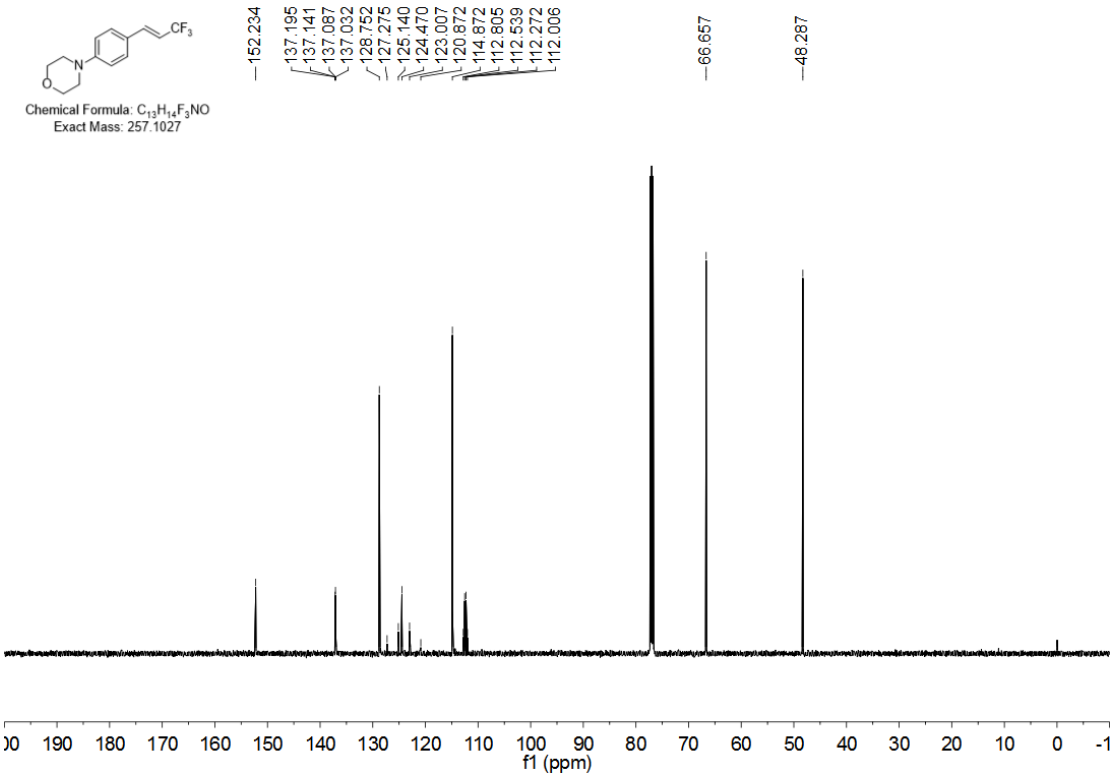
$^{1}$H NMR of **5o**




$^{19}$F NMR of **5o**

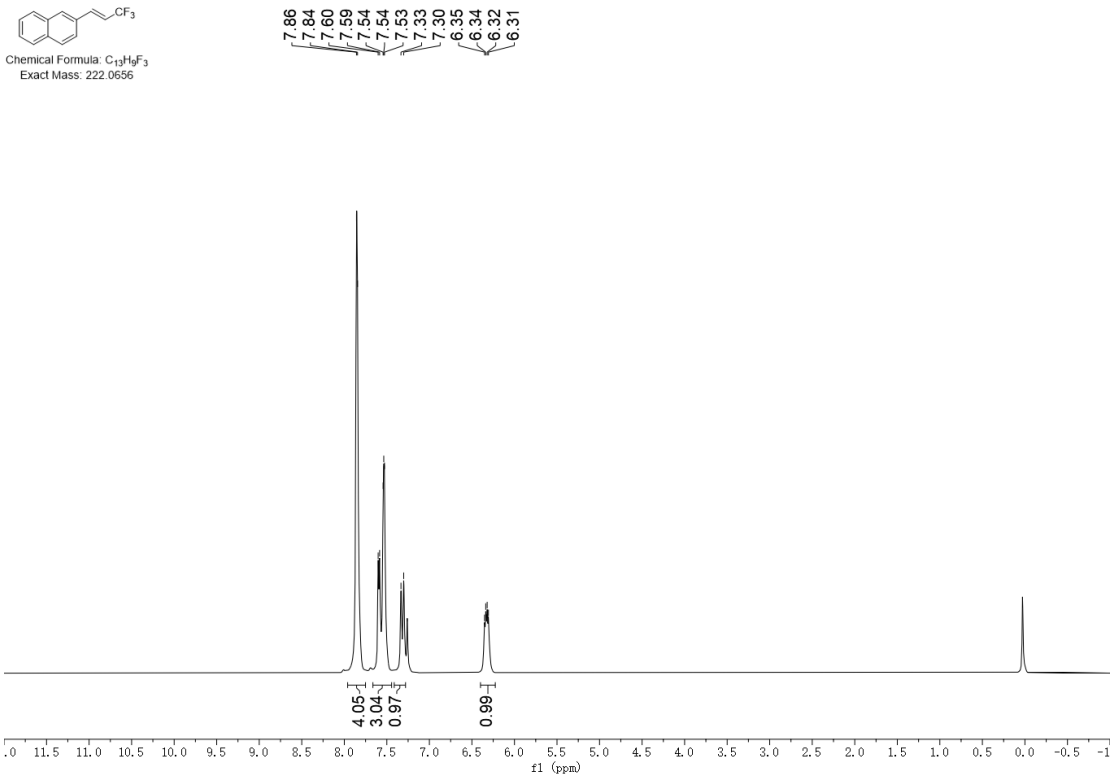


$^{13}$C NMR of **5o**

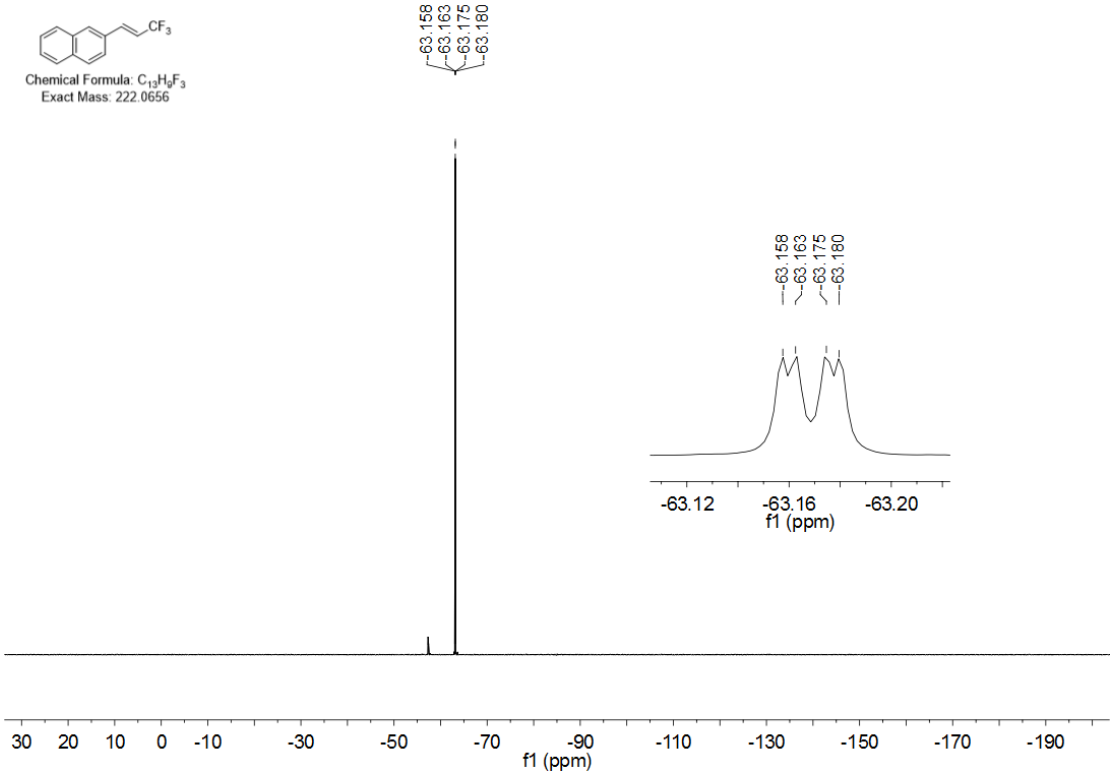



## (*E*)-2-(3,3,3-Trifluoroprop-1-en-1-yl)naphthalene (5p)

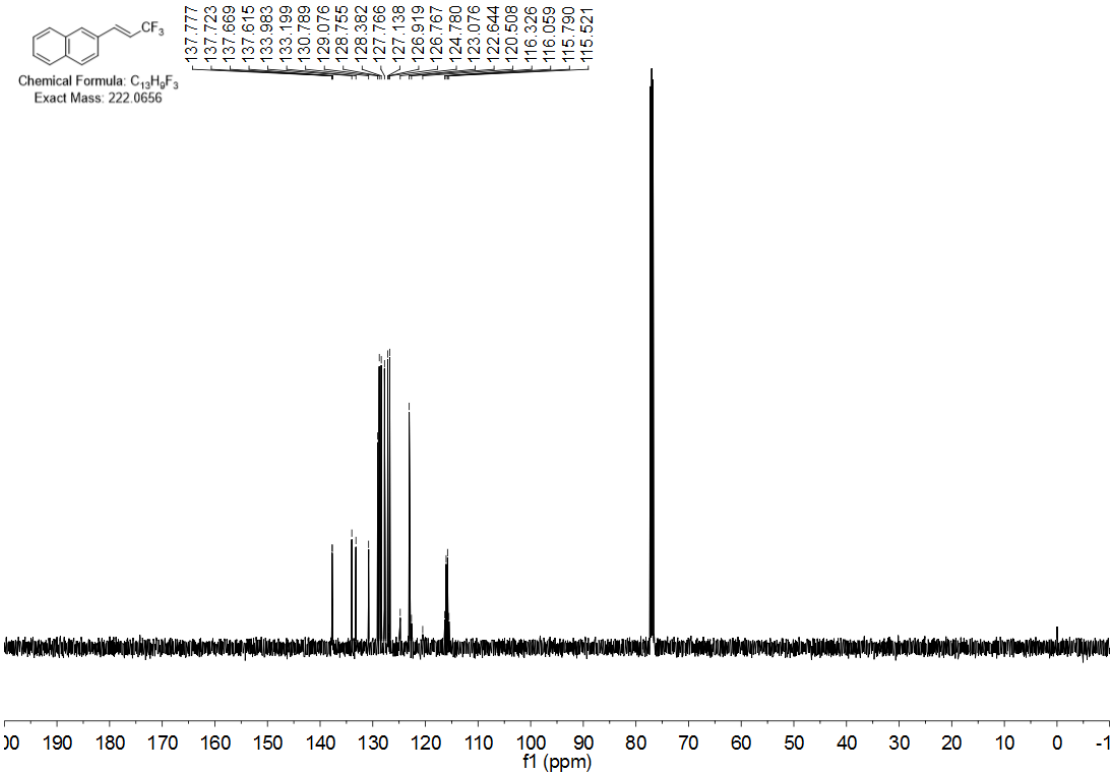
$^{1}$H NMR of **5p**



$^{19}$F NMR of **5p**

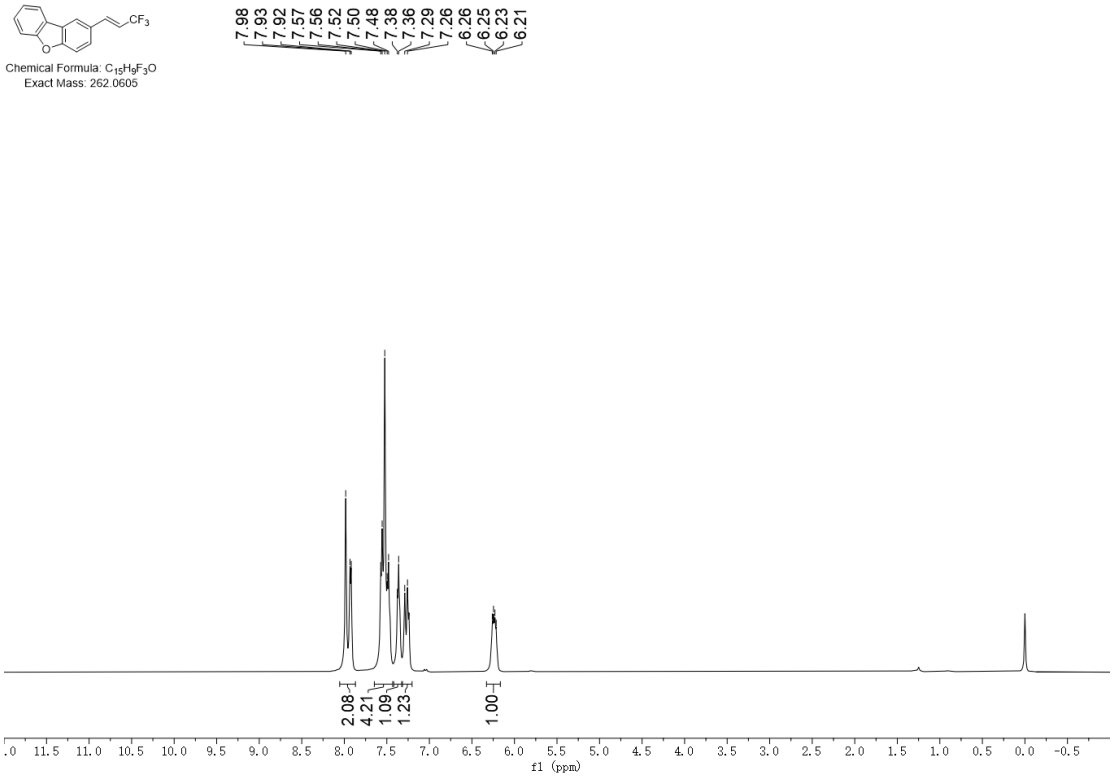



$^{13}$C NMR of **5p**

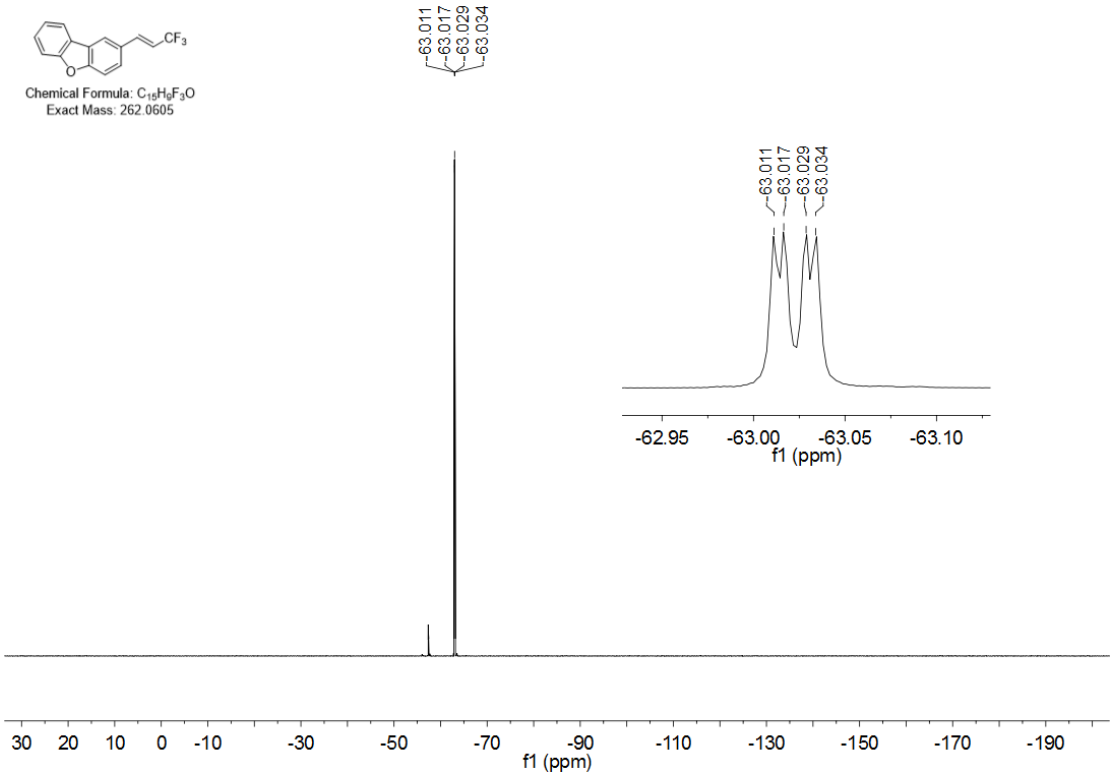


## (*E*)-2-(3,3,3-Trifluoroprop-1-en-1-yl)dibenzo[b,d]furan (5q)

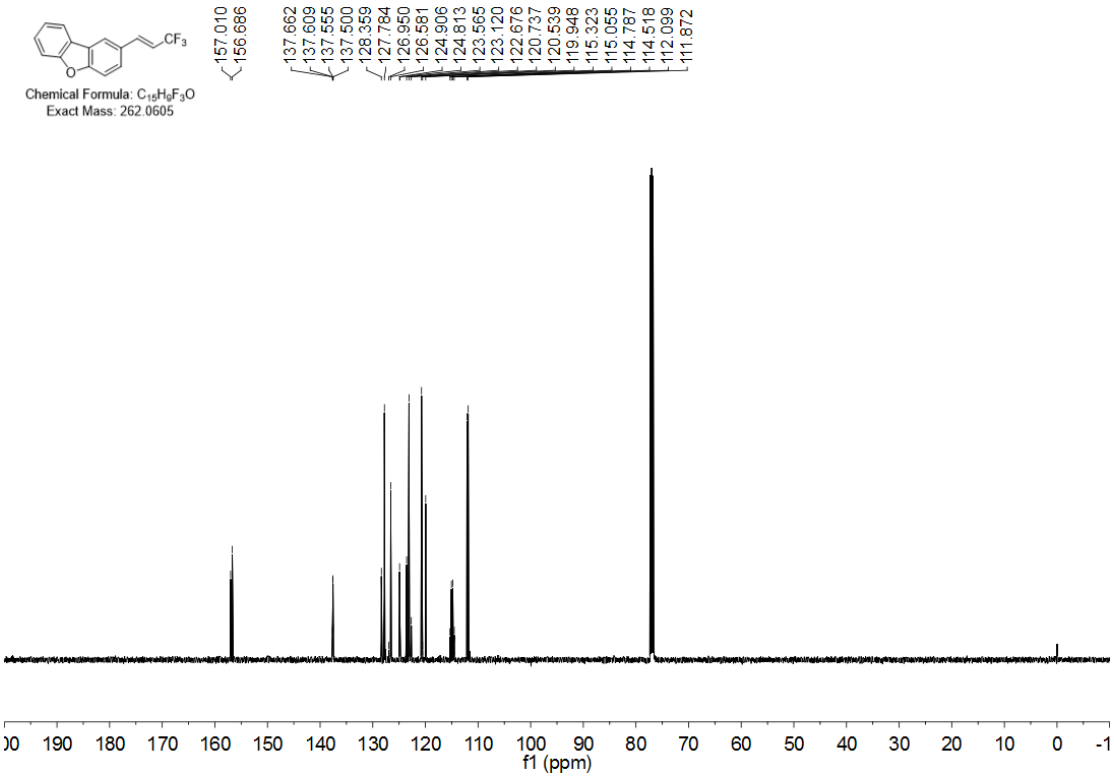
$^{1}$H NMR of **5q**




$^{19}$F NMR of **5q**

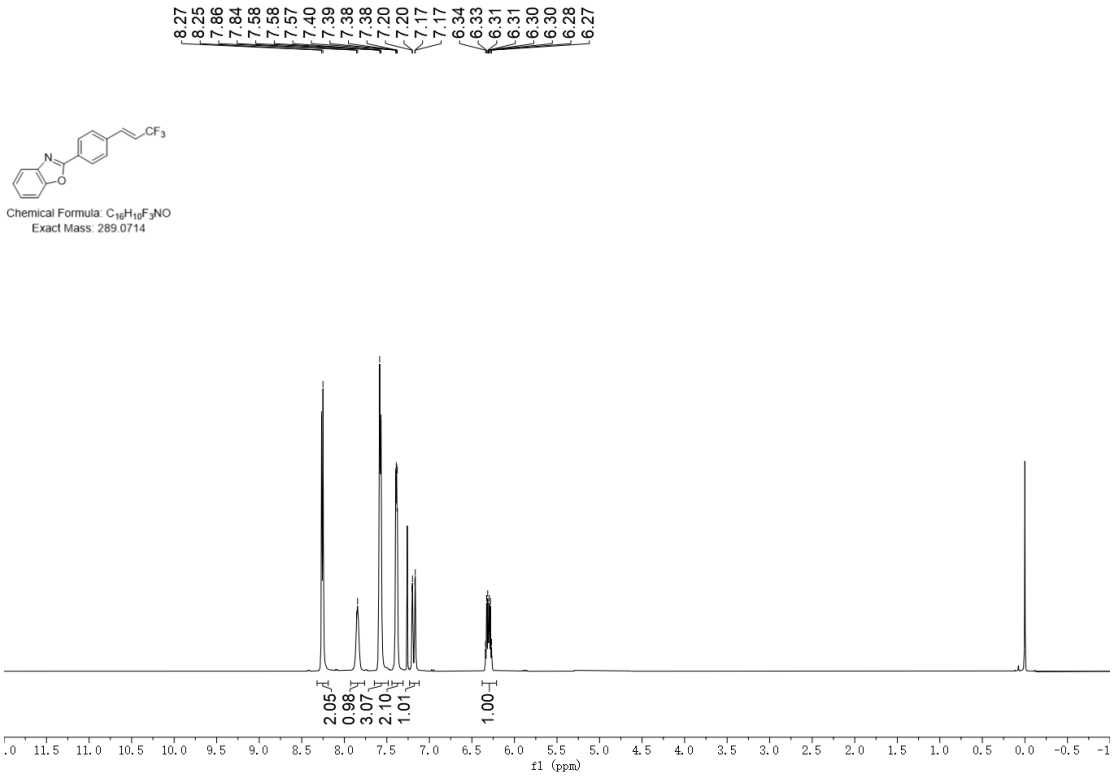


$^{13}$C NMR of **5q**

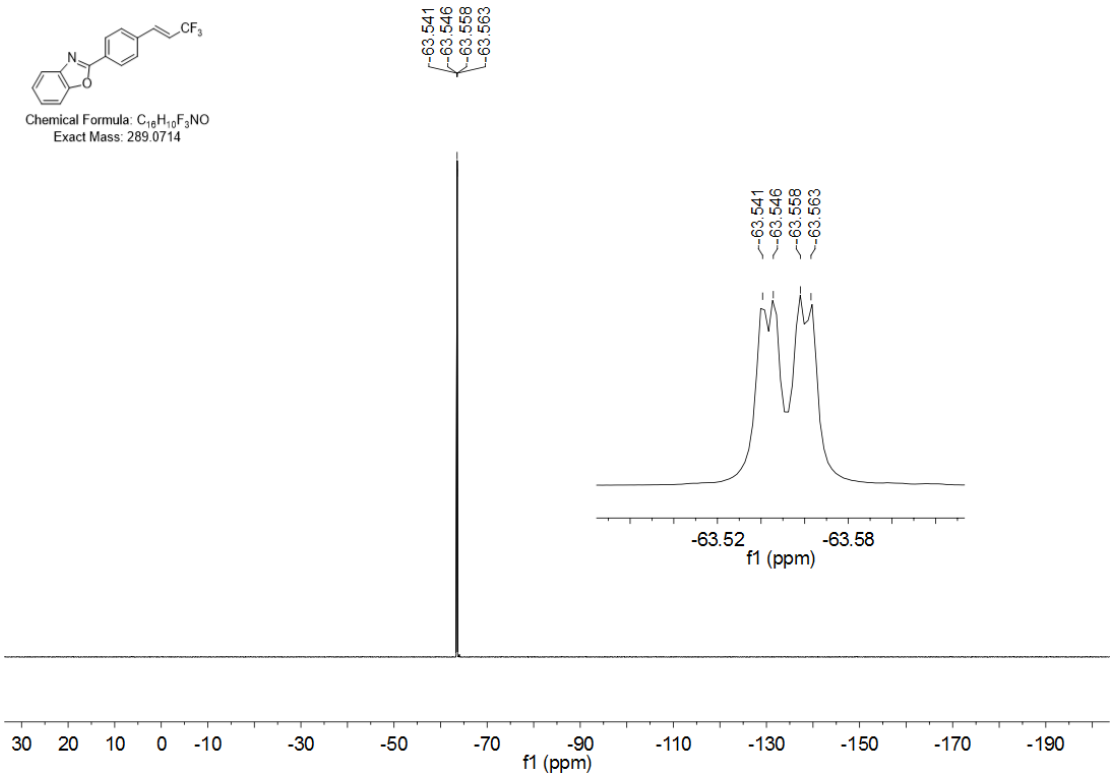



## (*E*)-2-(4-(3,3,3-Trifluoroprop-1-en-1-yl)phenyl)benzo[*d*]oxazole (5r)

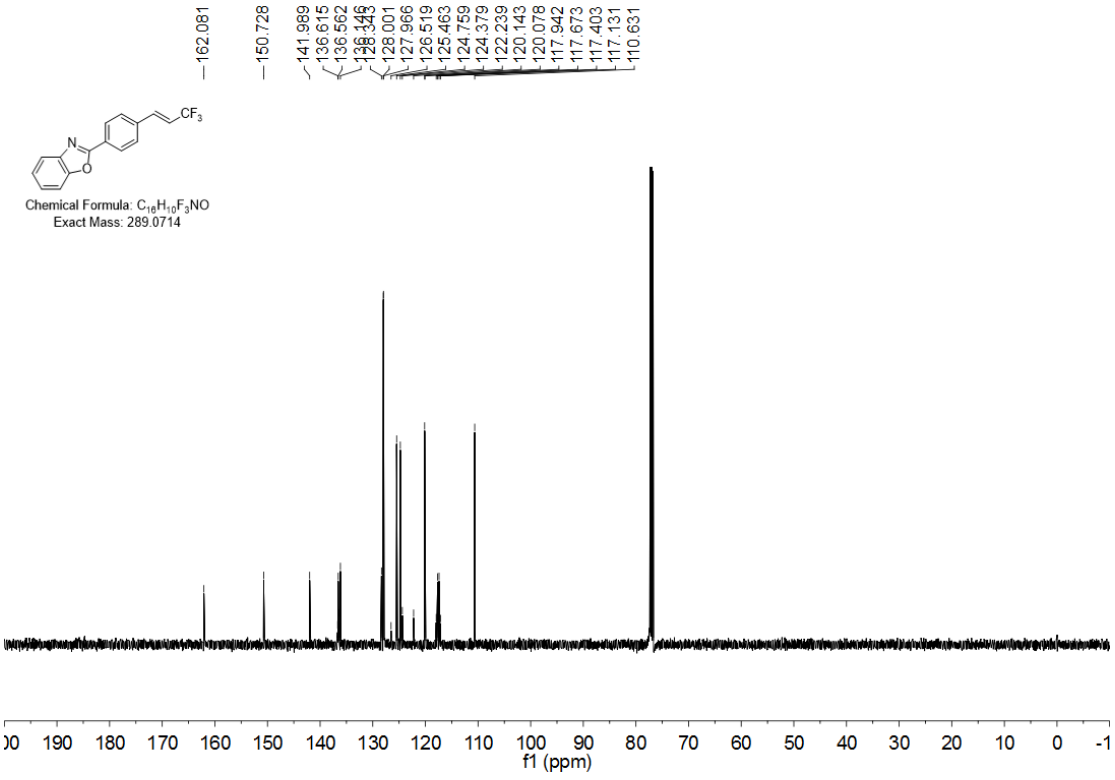
$^{1}$H NMR of **5r**



$^{19}$F NMR of **5r**

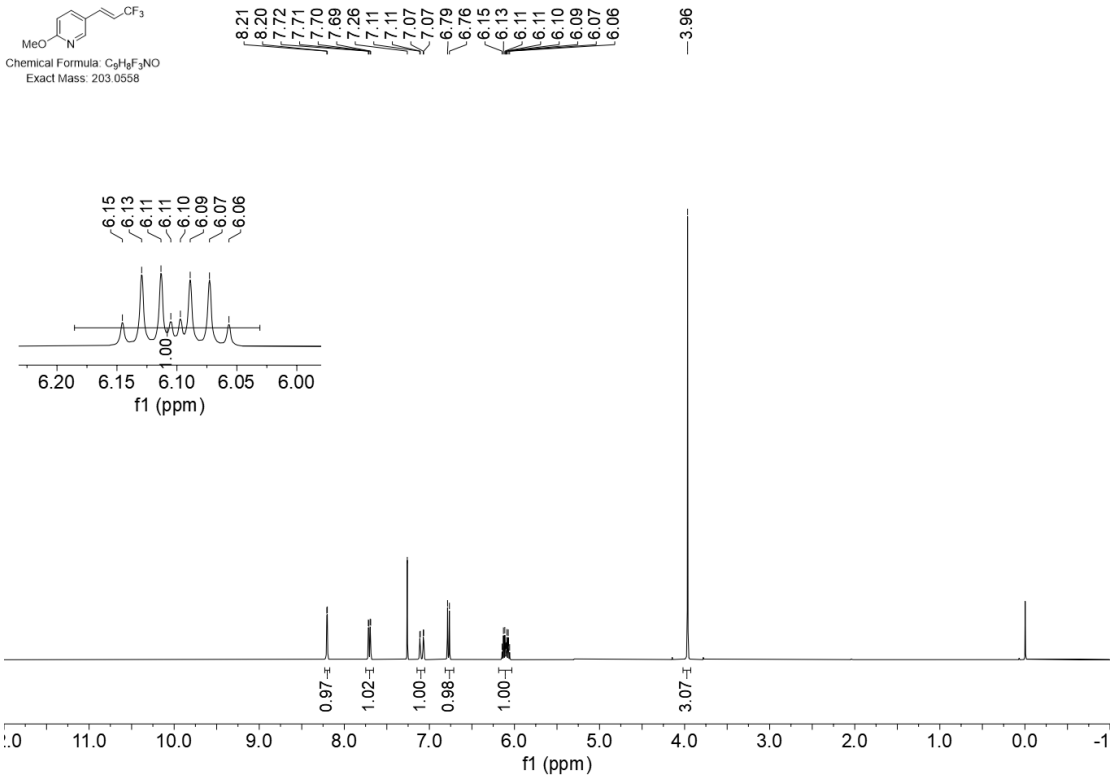



$^{13}$C NMR of **5r**

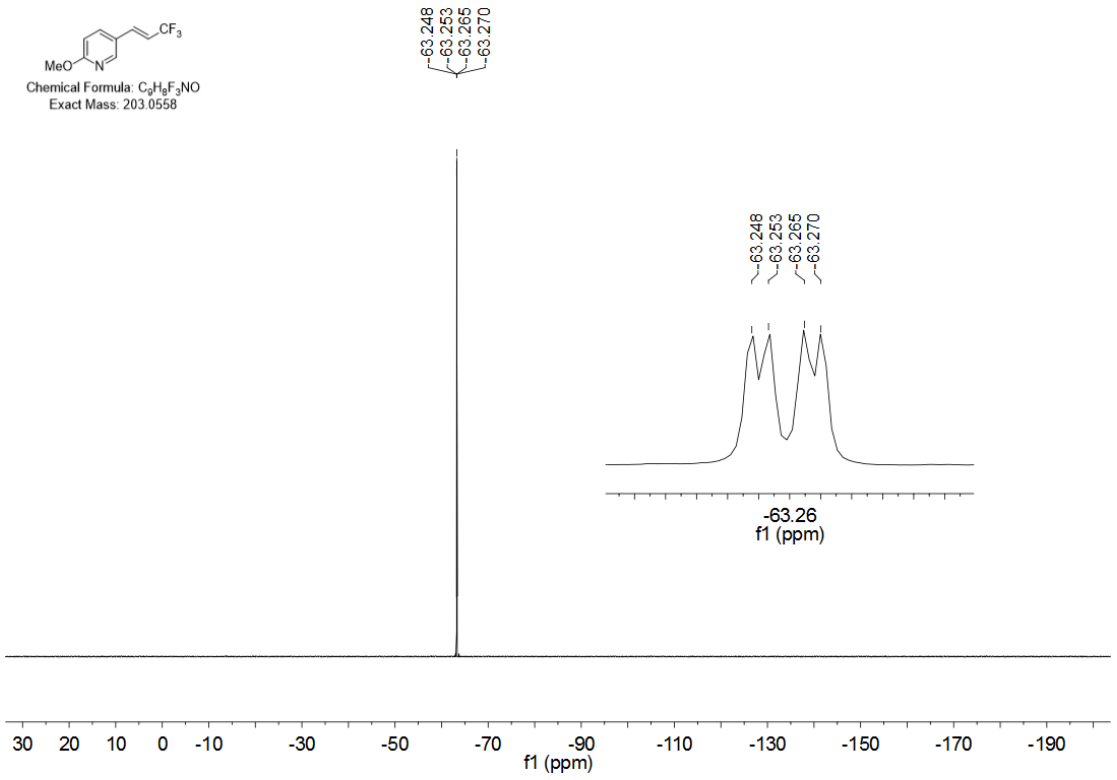


## (*E*)-2-Methoxy-5-(3,3,3-trifluoroprop-1-en-1-yl)pyridine (5s)

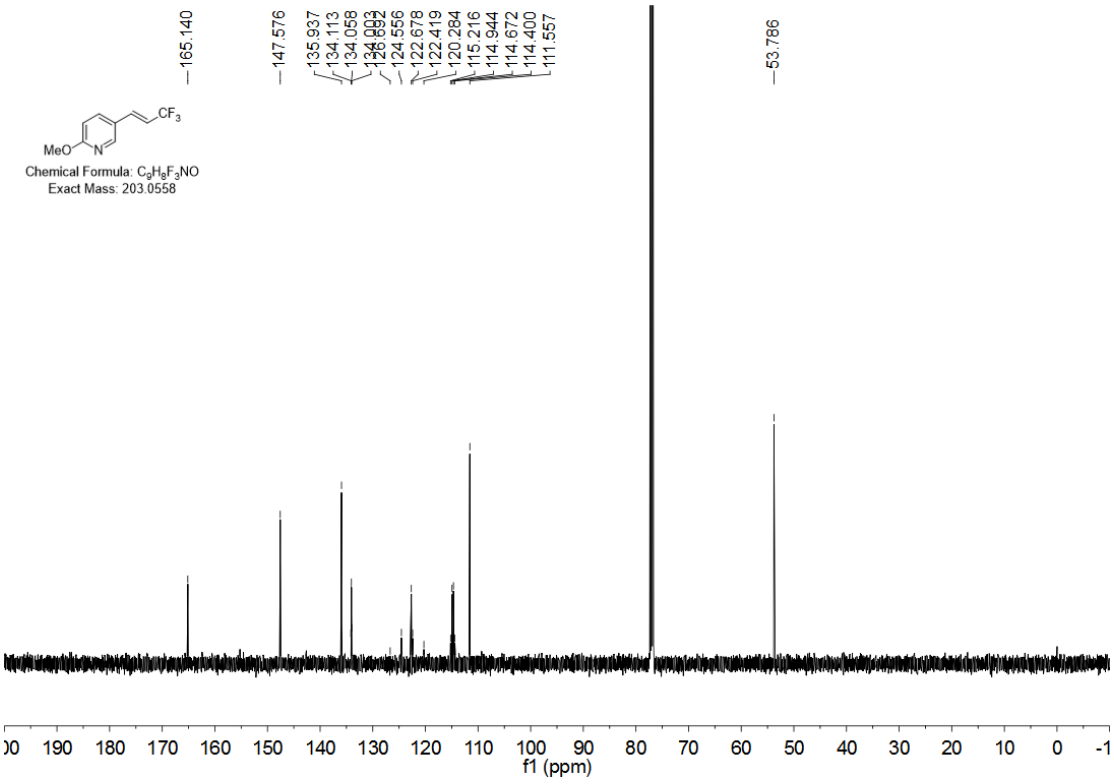
$^{1}$H NMR of **5s**




$^{19}$F NMR of **5s**

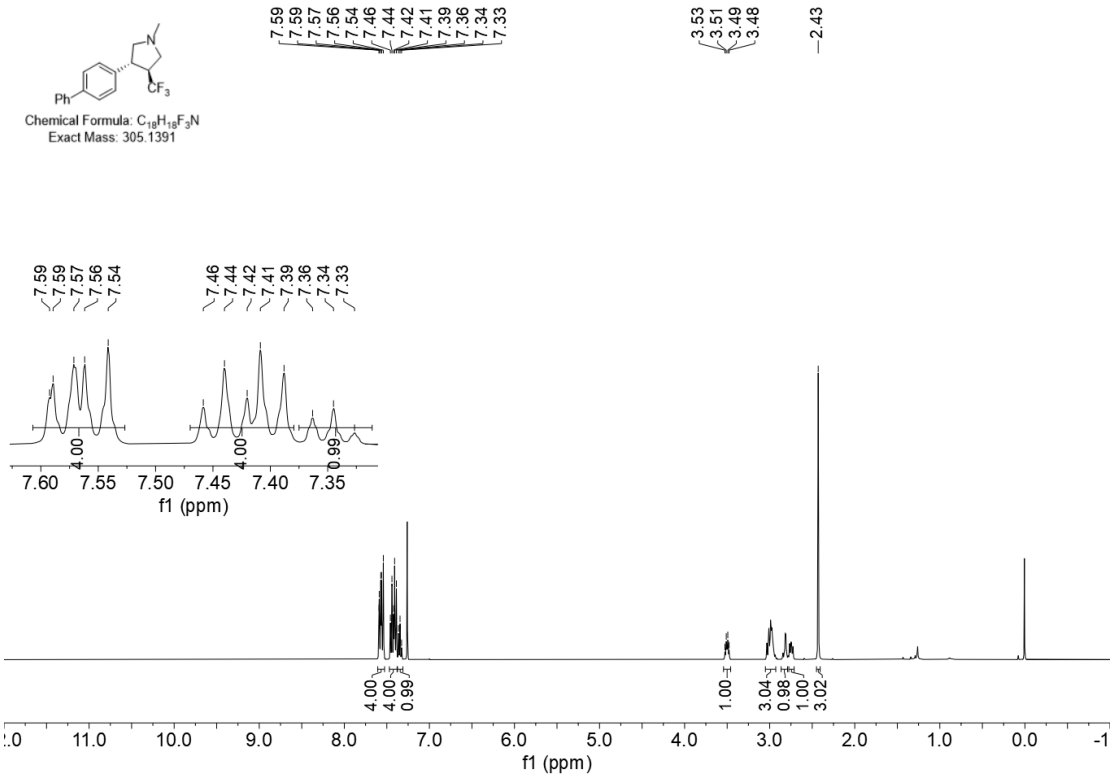


$^{13}$C NMR of **5s**

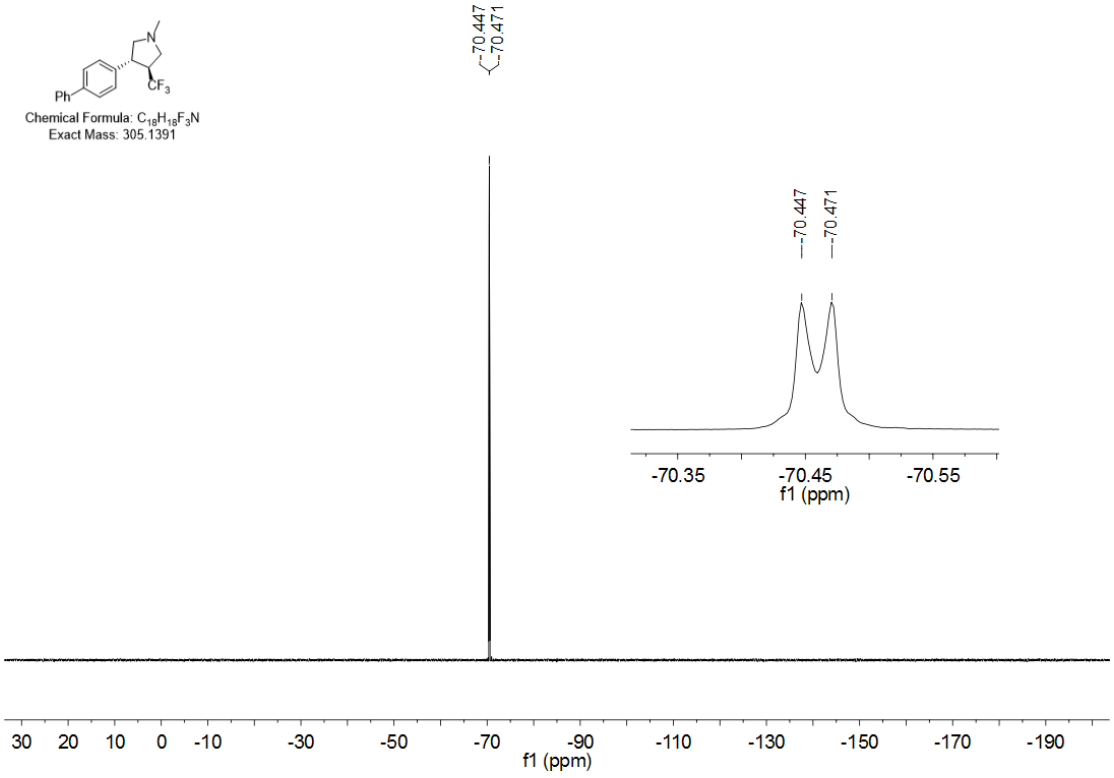



## 3-([1,1'-Biphenyl]-4-yl)-1-methyl-4-(trifluoromethyl)pyrrolidine (6)

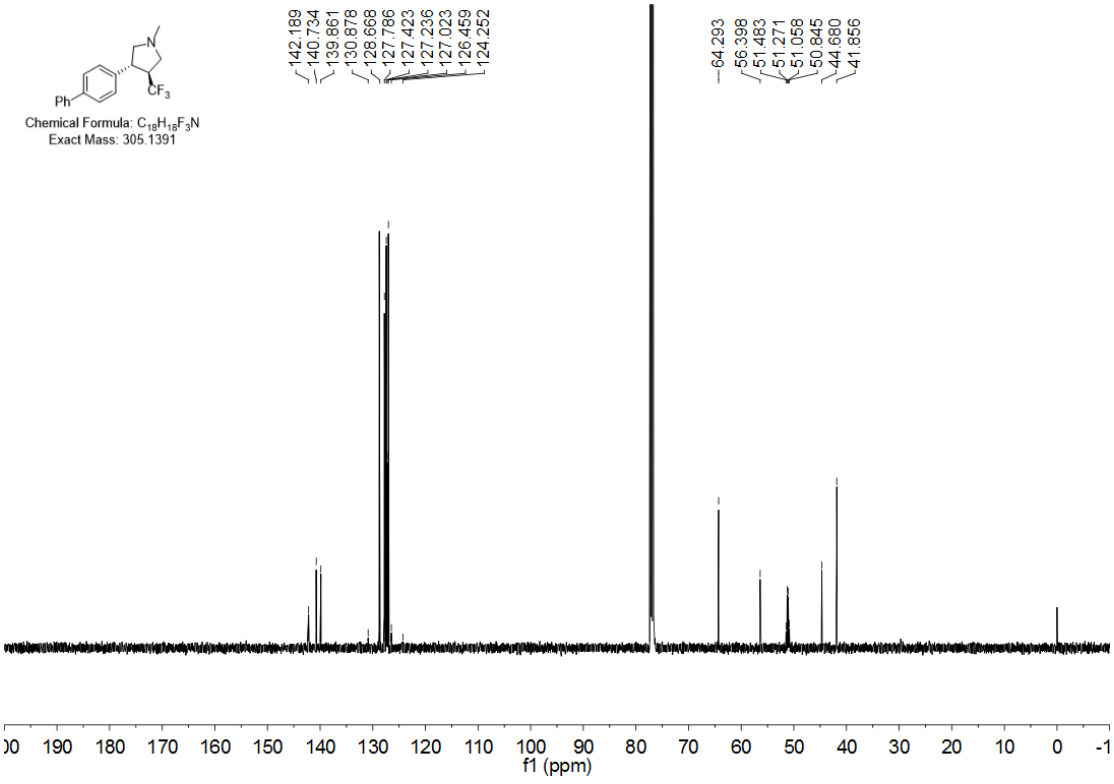
$^{1}$H NMR of **6**



$^{19}$F NMR of **6**

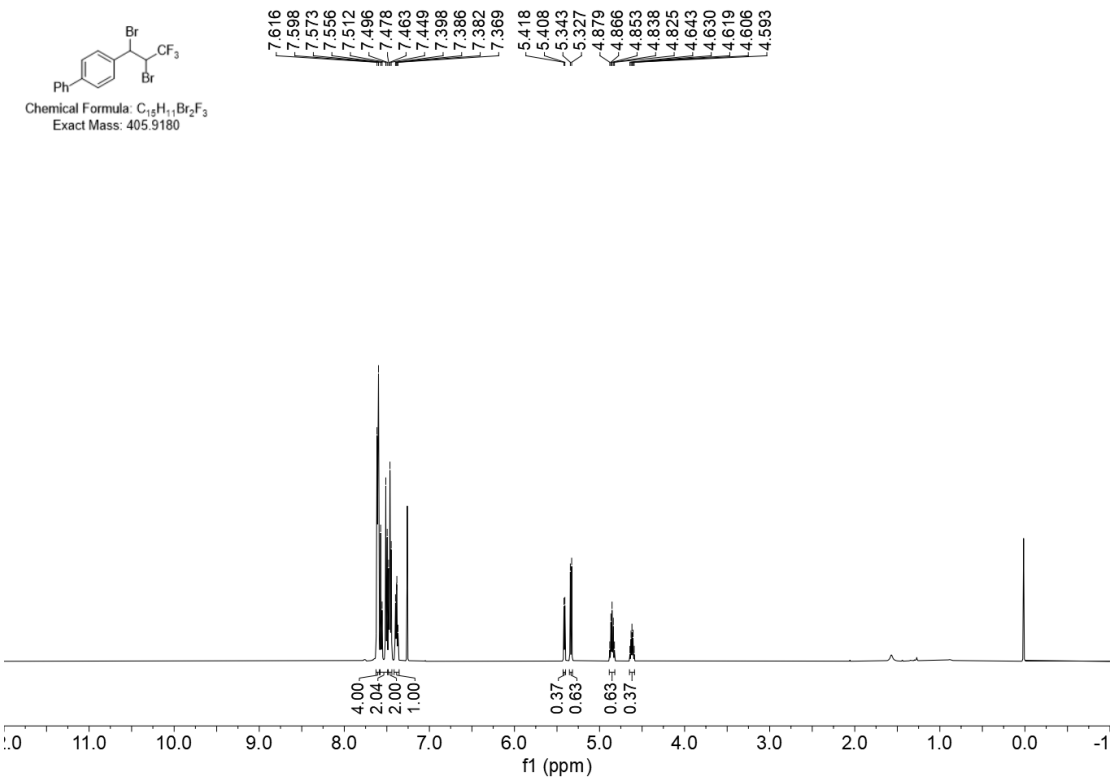



$^{13}$C NMR of **6**

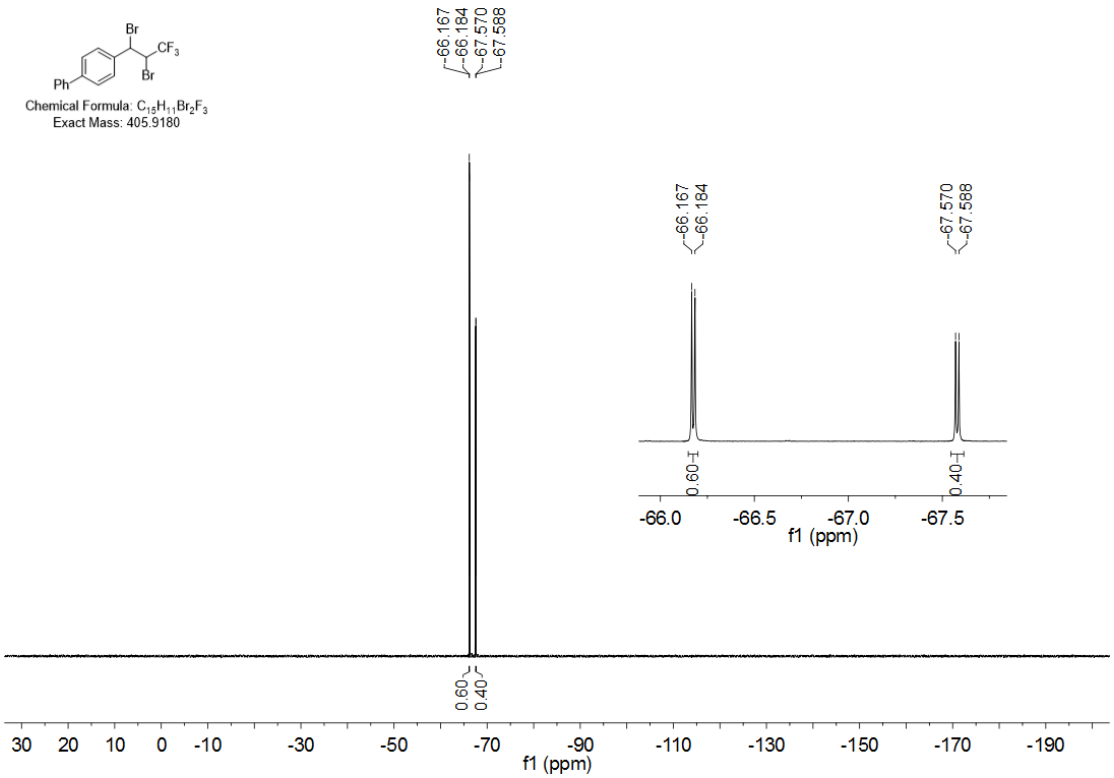


## 4-(1,2-Dibromo-3,3,3-trifluoropropyl)-1,1'-biphenyl (7)

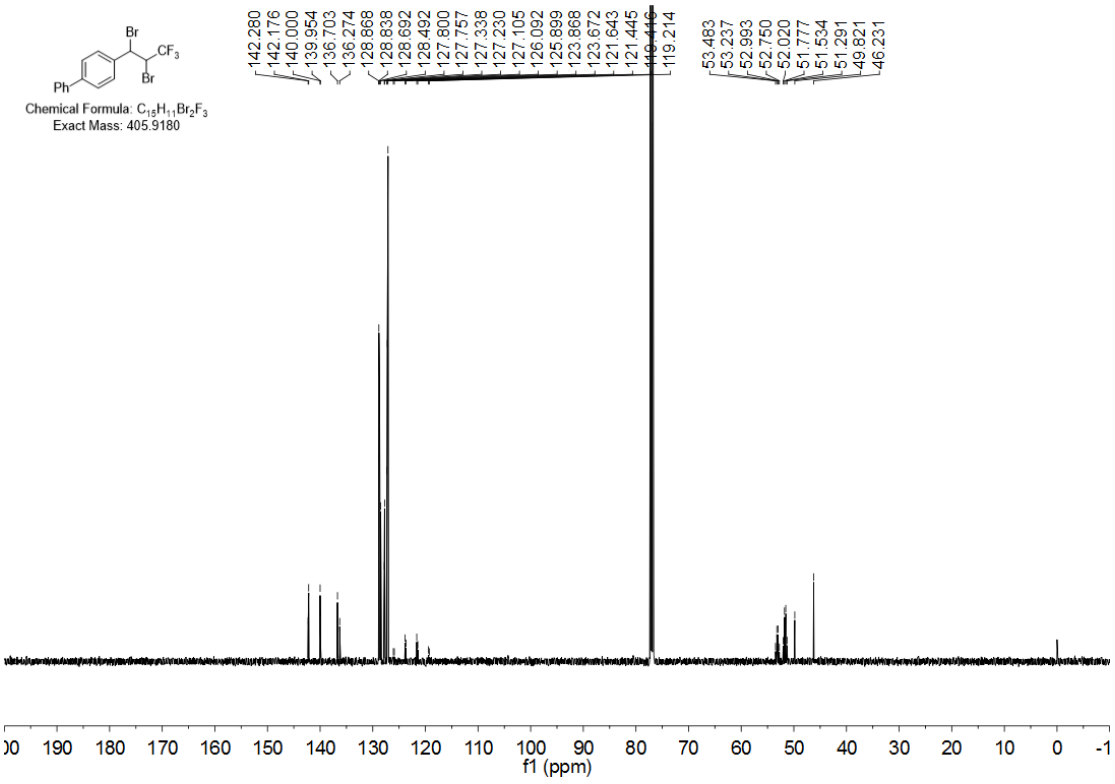
$^{1}$H NMR of **7**




$^{19}$F NMR of **7**

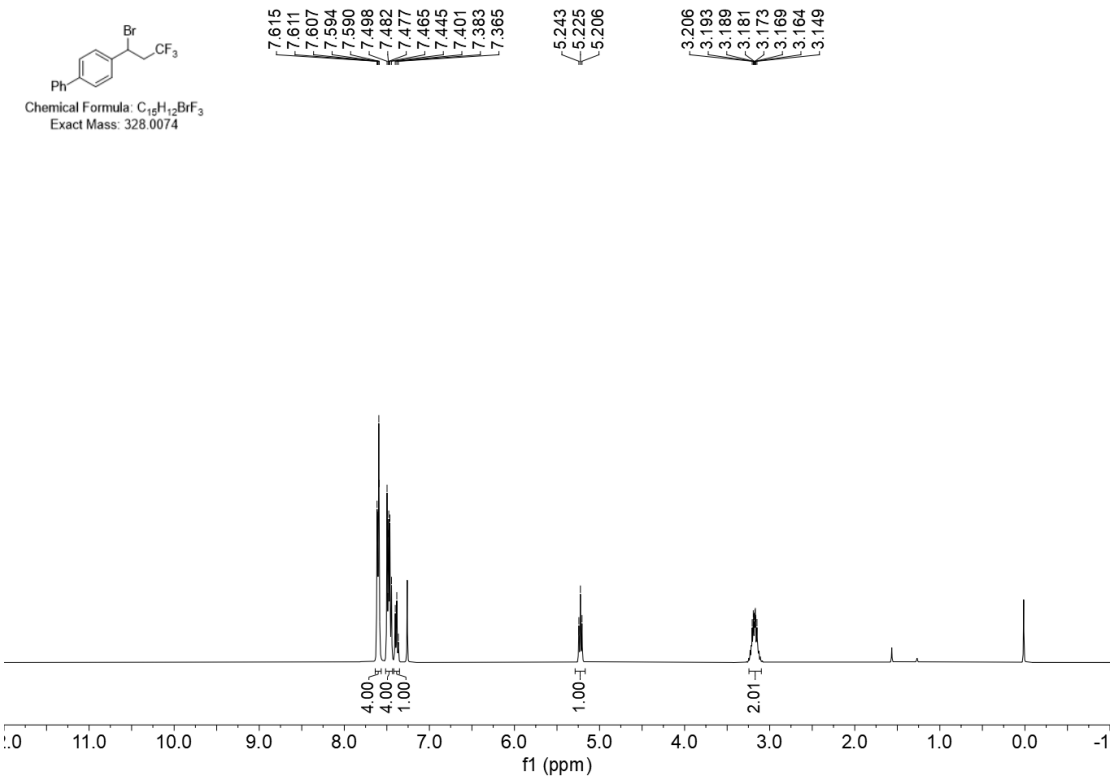


$^{13}$C NMR of **7**

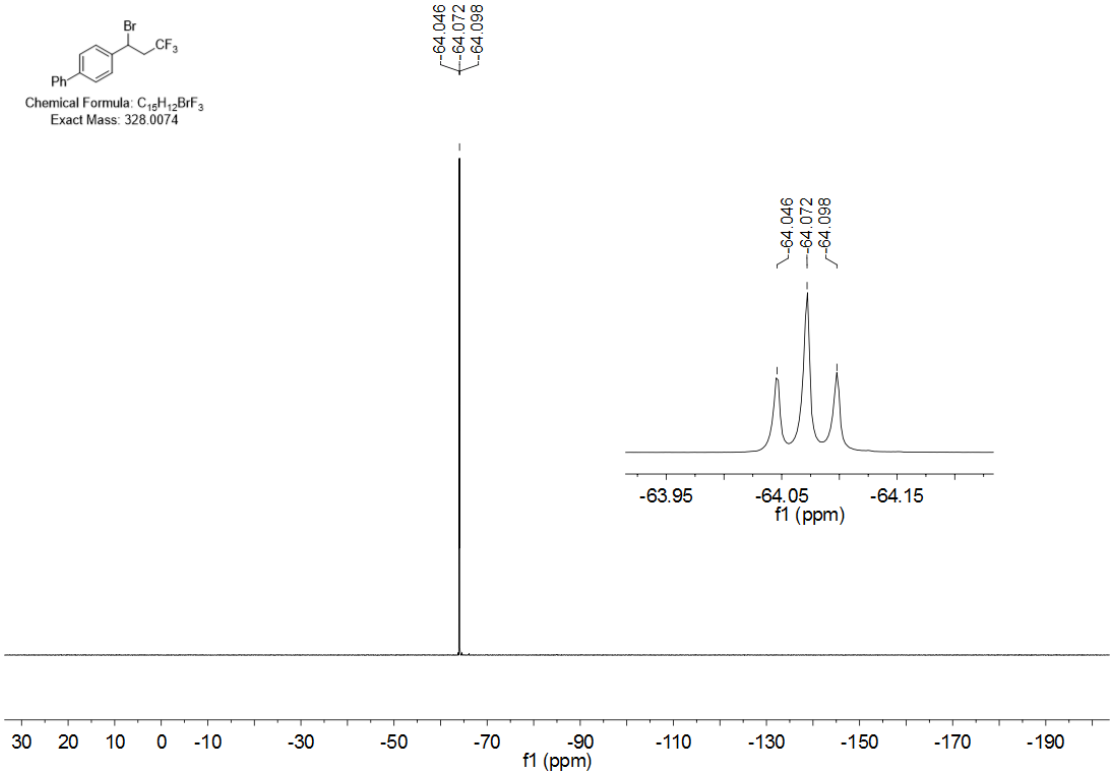



## 4-(1-Bromo-3,3,3-trifluoropropyl)-1,1'-biphenyl (8)

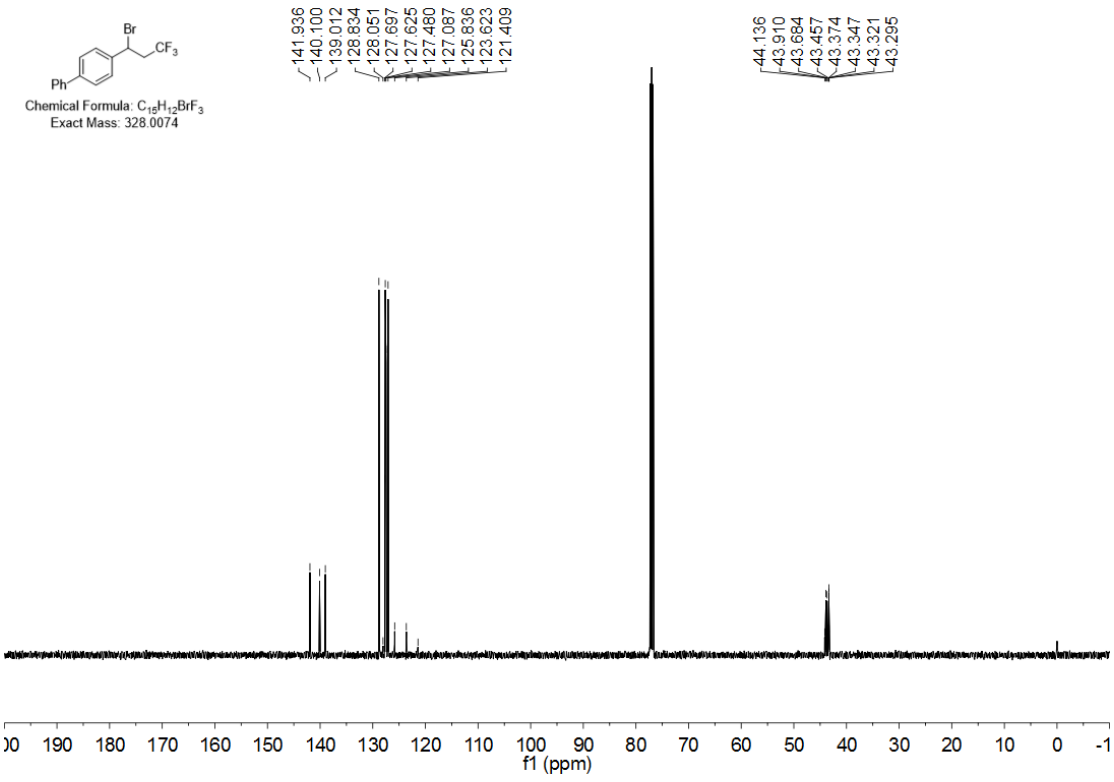
$^{1}$H NMR of **8**



$^{19}$F NMR of **8**

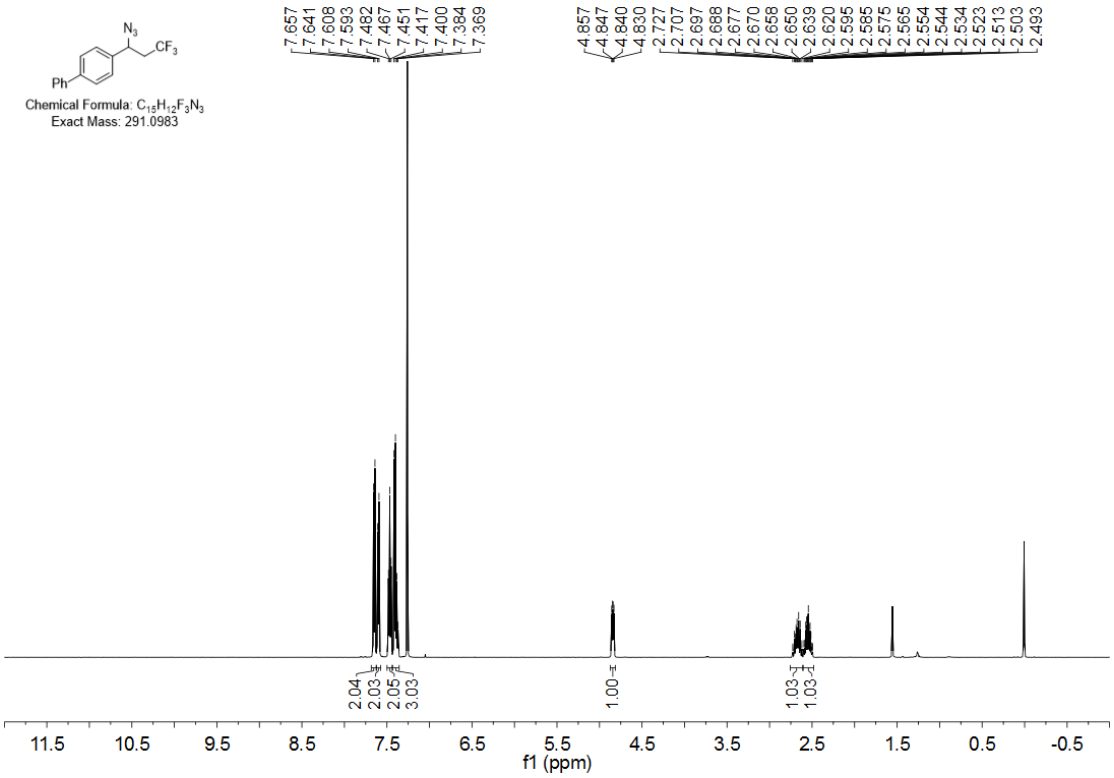



$^{13}$C NMR of **8**

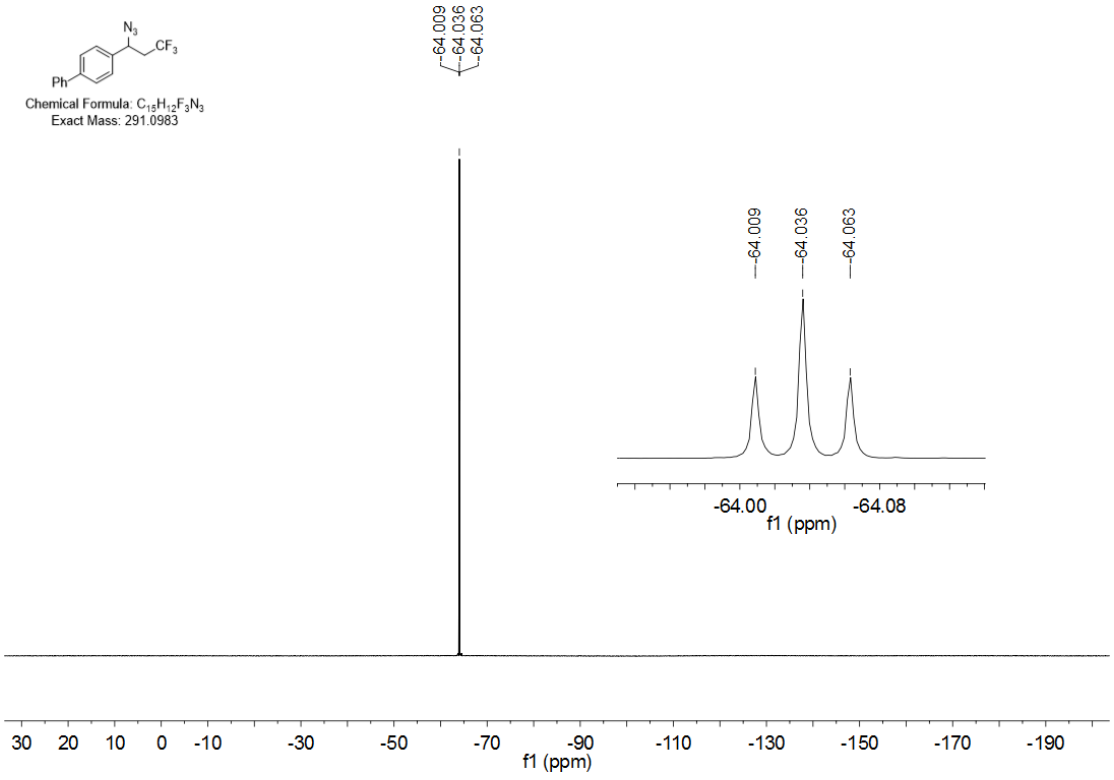


## 4-(1-Azido-3,3,3-trifluoropropyl)-1,1'-biphenyl (9)

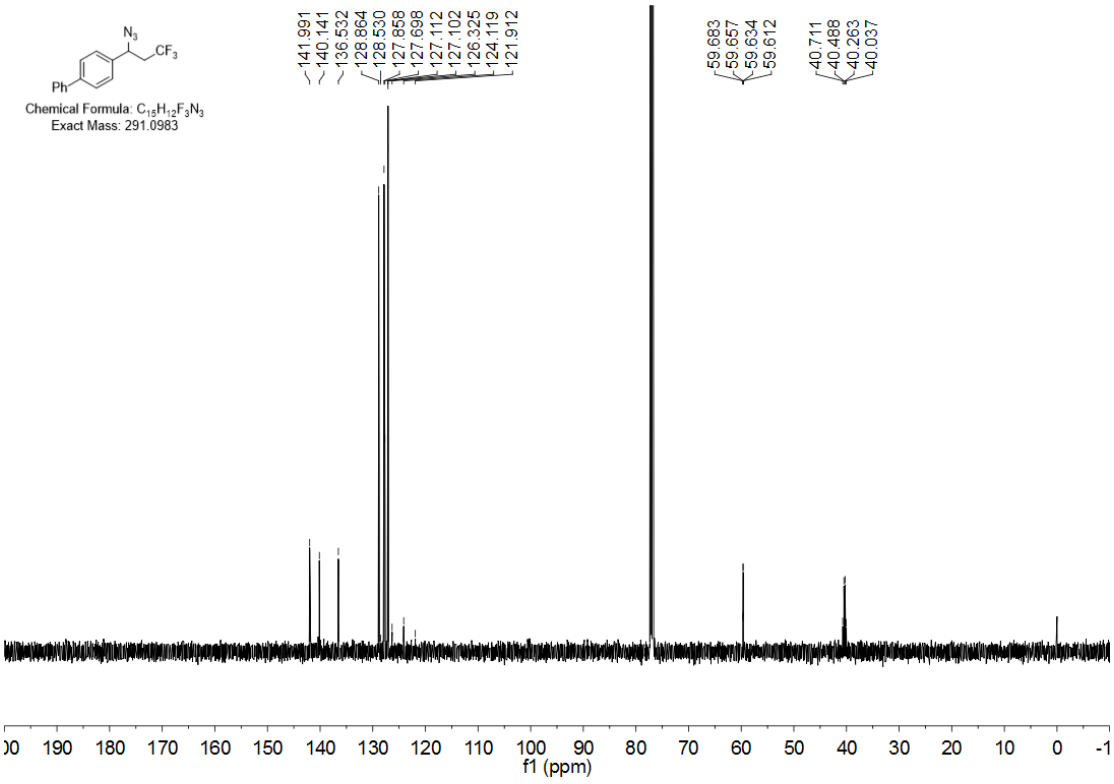
$^{1}$H NMR of **9**




$^{19}$F NMR of **9**

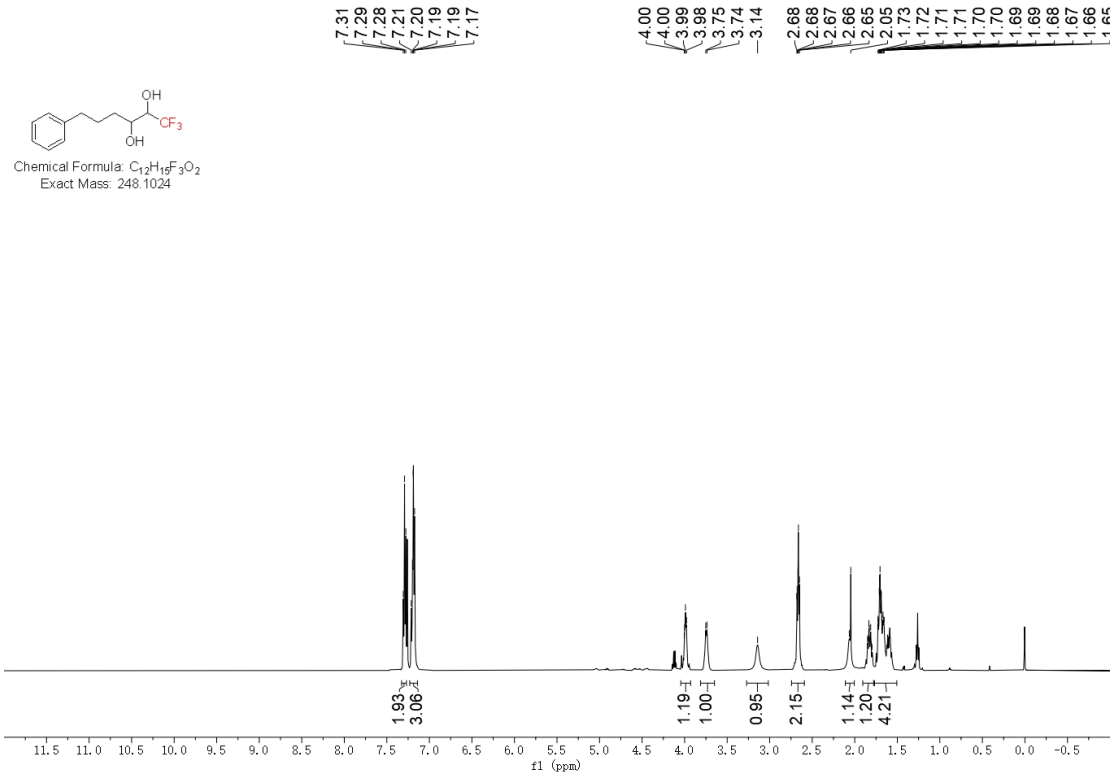


$^{13}$C NMR of **9**

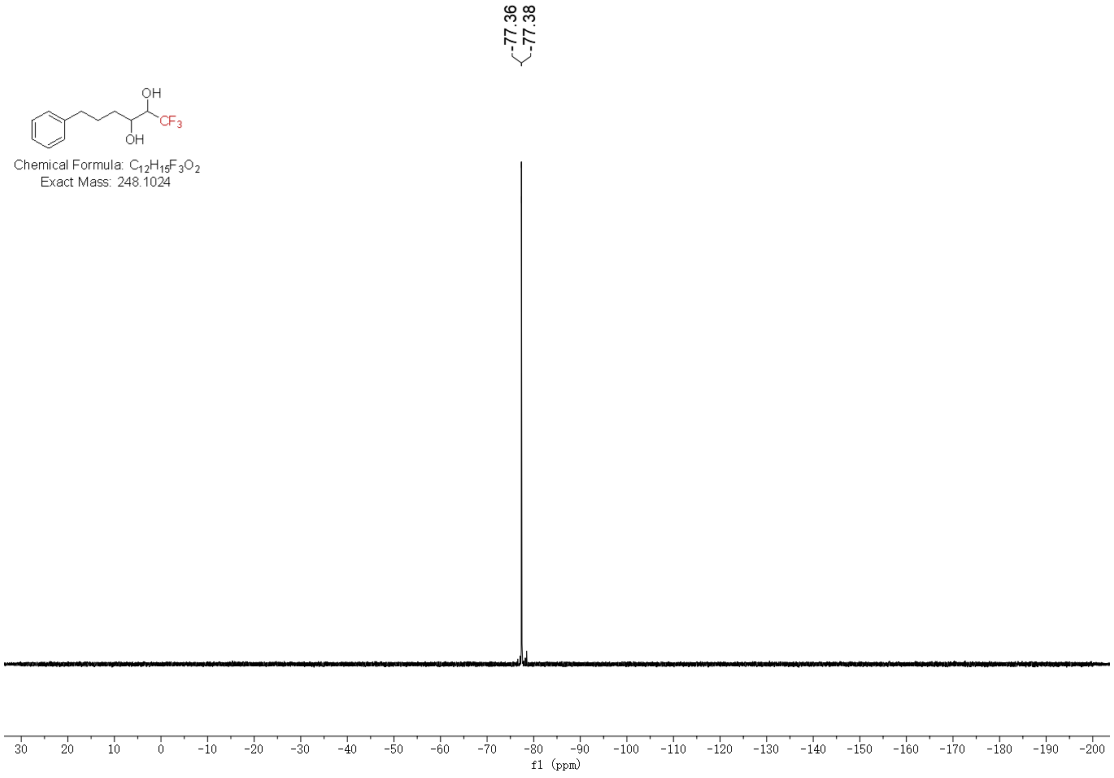



## 1,1,1-Trifluoro-6-phenylhexane-2,3-diol (10)

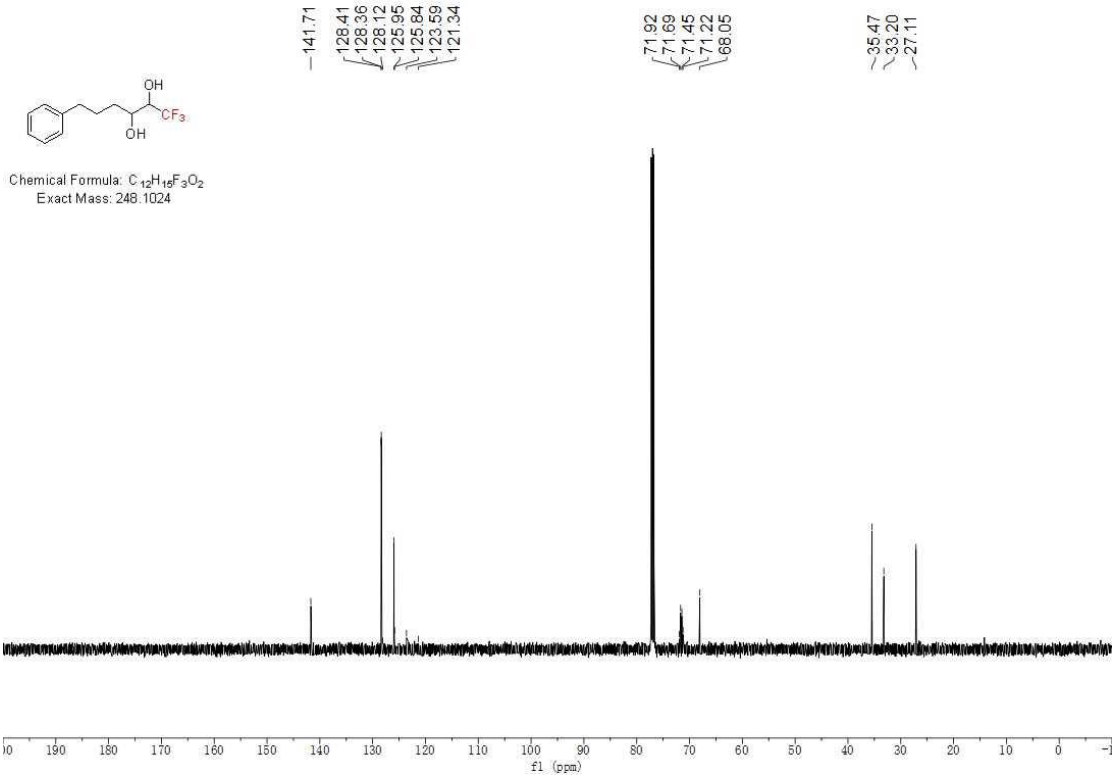
$^{1}$H NMR of **10**



$^{19}$F NMR of **10**

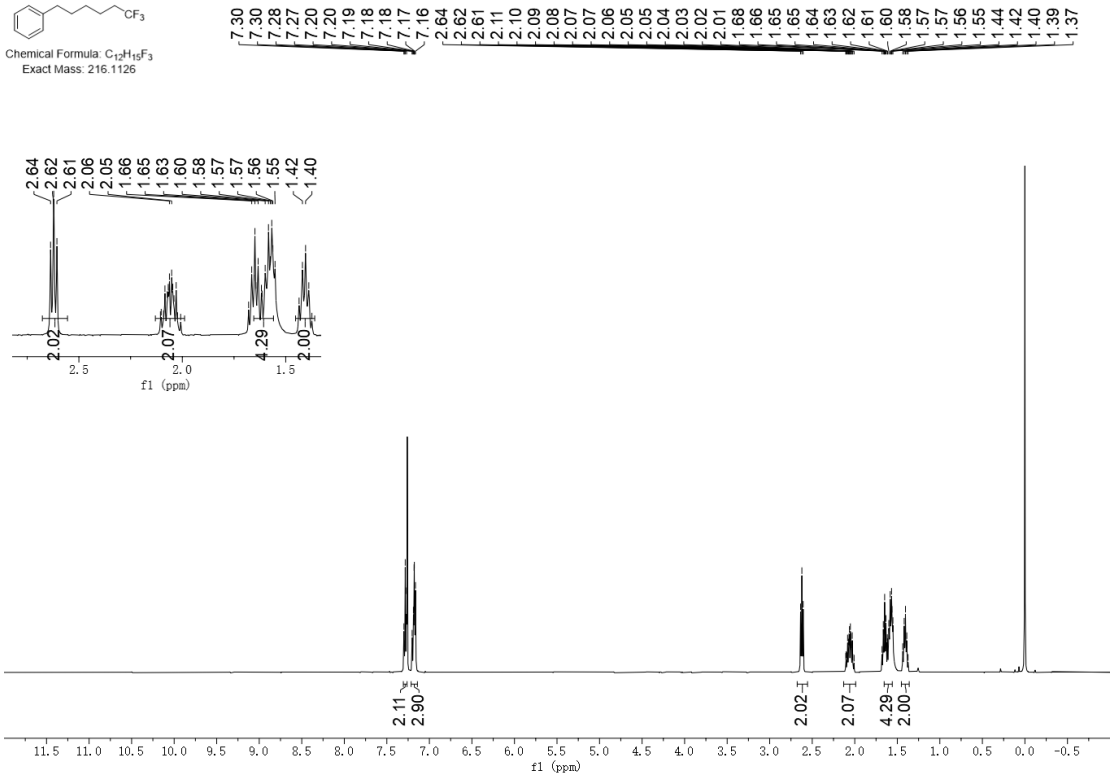



$^{13}$C NMR of **10**

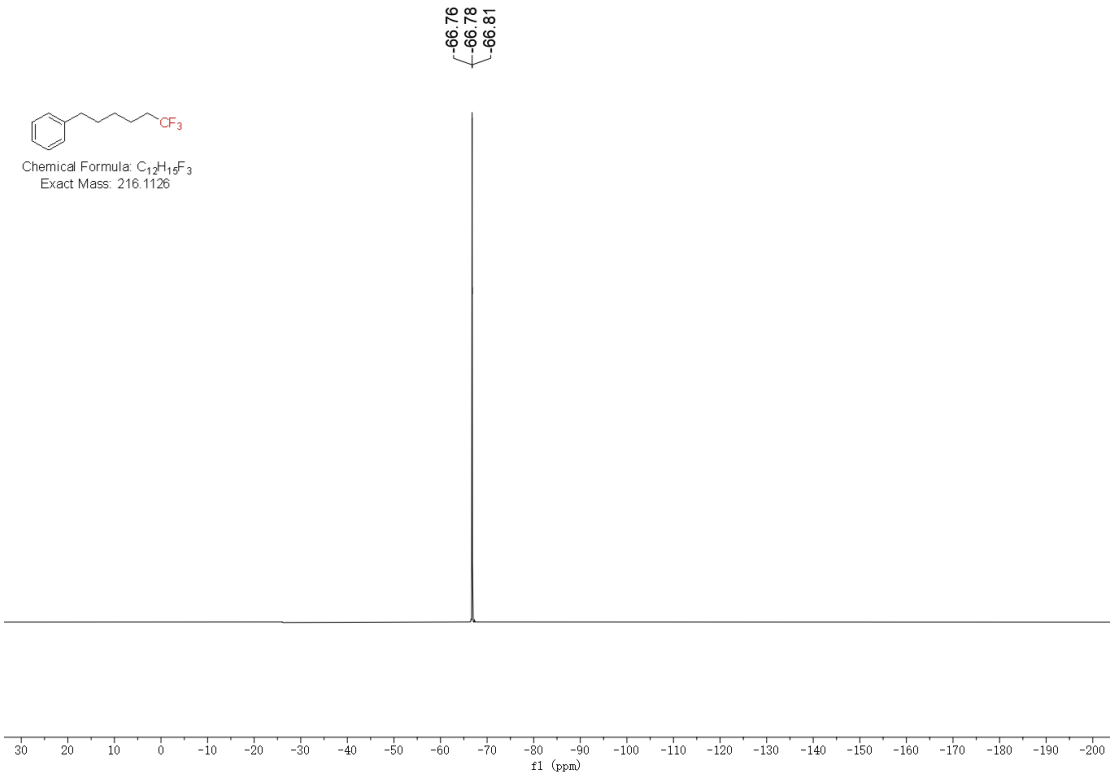


## (6,6,6-Trifluorohexyl)benzene (11)

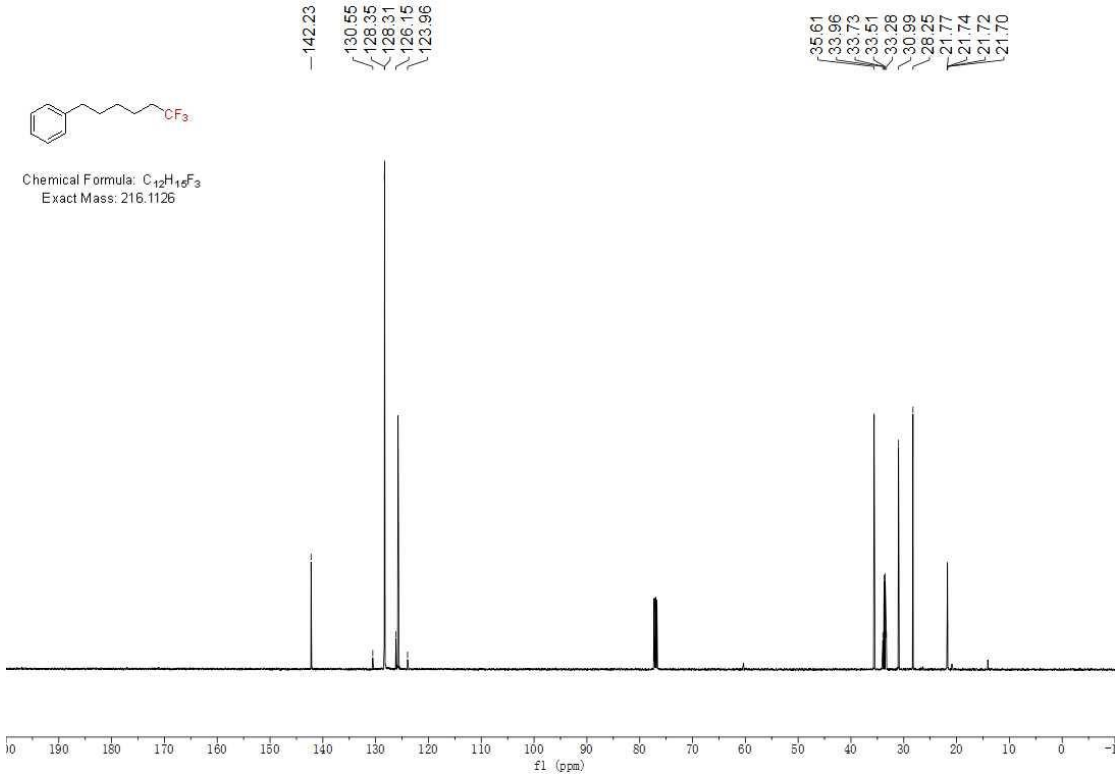
$^{1}$H NMR of **11**




$^{19}$F NMR of **11**



$^{13}$C NMR of **11**


142.23
130.55
128.35
128.31
126.15
123.96
35.61
33.96
33.73
33.51
33.28
30.99
28.25
21.77
21.74
21.72
21.70
CF3
Chemical Formula: C12H15F3
Exact Mass: 216.1126
f1 (ppm)