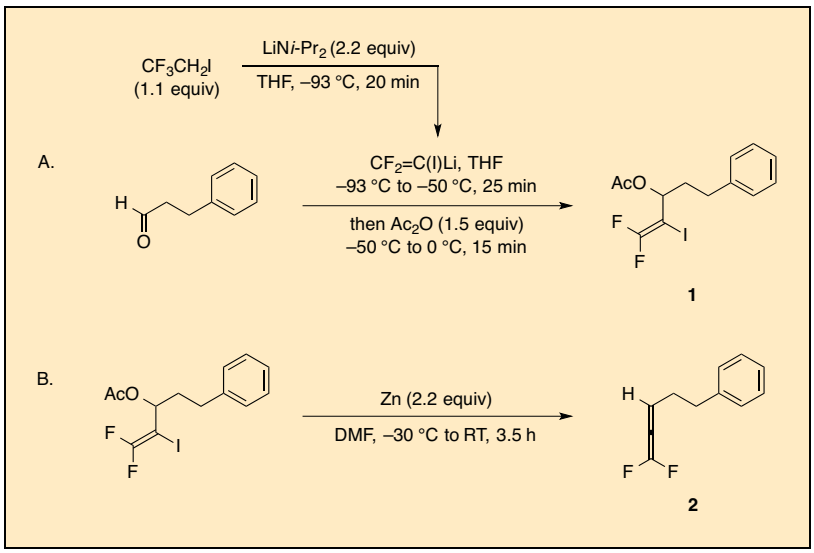
Organic Syntheses

Preparation of 1,1-Difluoroallenes by Difluorovinylidenation of Carbonyl Compounds

Kohei Fuchibe, Masashi Abe, Ken Oh, and Junji Ichikawa*[1]

Division of Chemistry, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8571, Japan

Checked by Shogo Sato, Keiichiro Sakata, and Keisuke Suzuki
Discussion Addendum: *Org. Synth.* **2022**, *99*, 113-124



Procedure

A. *1,1-Difluoro-2-iodo-5-phenylpent-1-en-3-yl acetate (**1**).* A flame-dried, 500-mL, three-necked, round-bottomed flask (Figure 1, a) is equipped with a Teflon-coated magnetic stirring bar (b), an internal thermometer (c), a dropping funnel (100 mL, d), and a three-way stopcock (e) fitted with an argon inlet. The probe of the thermometer is inserted to the round-bottomed flask through a septum (f1). A septum (f2) is placed on the dropping funnel.

DOI: 10.15227/orgyn.093.0352

The flask is charged with diisopropylamine (16.4 mL, 11.8 g, 117 mmol, 2.24 equiv) (Note 1) and THF (80 mL) (Note 2) via the dropping funnel, and the reaction mixture is chilled to 0 °C (bath temperature). Butyllithium (71.3 mL, 1.64 M in hexane, 117 mmol, 2.24 equiv) (Note 3) is added to the THF solution of diisopropylamine over 40 min via the dropping funnel at 0 °C. The inside of the dropping funnel is rinsed with THF (5 mL). The reaction mixture is stirred at 0 °C for an additional 10 min, and then chilled (internal temperature: –93 °C; bath temperature: –95 °C) using an ethanol/liq. N_2 bath (Note 4). 1,1,1-Trifluoro-2-iodoethane (5.66 mL, 12.1 g, 57.4 mmol, 1.1 equiv) (Note 5) is added to the THF solution of LDA over 15 min by a syringe through the septum (f1), during which the internal temperature is kept below –90 °C. The reaction mixture is stirred for 30 min. A THF (20 mL) solution of 3-phenylpropanal (6.87 mL, 7.00 g, 52.2 mmol) (Note 6) is added over 15 min via the dropping funnel. The inside of the dropping funnel is rinsed with THF (5 mL). After the addition of the aldehyde, the reaction temperature is raised (internal temperature: –60 to –50 °C; bath temperature: –50 °C) over 20 min, followed by an additional 15 min stirring. When complete consumption of the aldehyde is confirmed by TLC analysis (Note 7), acetic anhydride (7.54 mL, 8.14 g, 79.8 mmol, 1.53 equiv) (Note 8) is added by a syringe through the septum (f1) over 20 min, keeping the internal temperature below –50 °C. After the addition is finished, the ethanol/liq. N_2 bath is changed to an ice bath and the reaction mixture is stirred for an additional 15 min. A spot-to-spot formation of acetate (**1**) is confirmed by TLC analysis (Note 9). A saturated aq. NH_4Cl (350 mL) is added over 1 min at 0 °C (bath temperature). The products are extracted with ethyl acetate (3 × 20 mL) using a 500-mL separatory funnel. The combined organic layers are washed with brine (50 mL) and dried over anhydrous Na_2SO_4 (ca. 90 g). After removal of Na_2SO_4 by paper filtration, the solvent is removed by rotary evaporation (30 °C, 110 mmHg). The residue is kept under reduced pressure (room temp, 3 mmHg) to remove the solvent completely. A crude acetate (**1**) is obtained as a dark brown oil (approx. 20.9 g) in 91% purity (Note 10) and used for the next step without purification. Column chromatography (Note 11) is used when material of higher purity is required (Note 12).

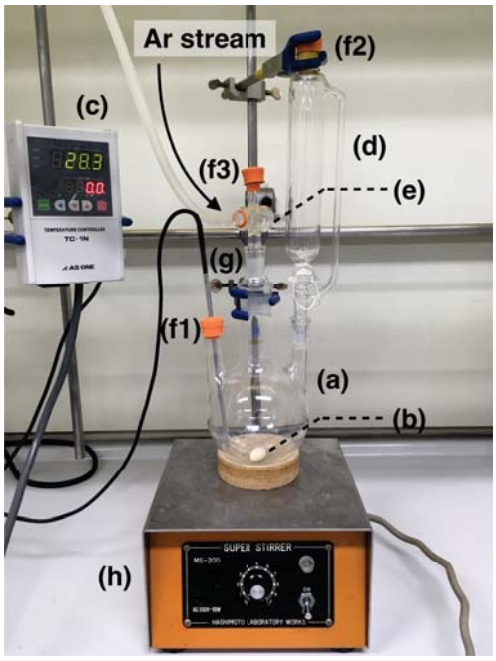


Figure 1. Set-up for Steps A and B (a: round-bottomed flask, 500 mL; b: magnetic stirring bar; c: thermometer; d: dropping funnel; e: three-way stopcock; f1–3: rubber septum; g: adaptor; h: magnetic stirrer)

Figure 2. After addition of CF_3CH_2I

Figure 3. After addition of Ac_2O

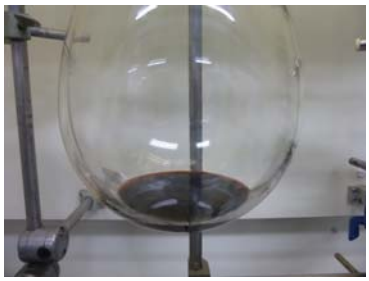


Figure 4. Crude acetate (1)

B. *1,1-Difluoro-5-phenylpenta-1,2-diene* (**2**). Zinc dust is activated by the following procedure. A 200-mL Erlenmeyer flask is charged with zinc dust (50 g) under air (Note 13). The zinc dust is washed with 2 M aq. HCl at room temperature (3 × 80 mL) (Note 14). The zinc dust is then washed with deionized water (8 × 60 mL) (Note 15) until the pH value of the water becomes 7 (Note 16). The zinc dust is further washed with methanol (8 × 60 mL) (Note 17) and ether (8 × 60 mL) (Note 18). The obtained active zinc dust is dried under reduced pressure (room temp, 6 mmHg) and stored under argon.

A flame-dried, 500-mL, three-necked, round-bottomed flask (Figure 1, a) is equipped with a Teflon-coated magnetic stirring bar (b), an internal thermometer (c), a dropping funnel (100 mL, d), and a three-way stopcock (e) fitted with an argon inlet. The probe of the thermometer is inserted to the round-bottomed flask through a septum (f1). A septum (f2) is placed on the dropping funnel.

The flask is charged with zinc dust (6.84 g, 105 mmol, 2.2 equiv) (Note 19). Dimethylformamide (DMF) (153 mL) (Note 20) is added via the dropping funnel and the suspension is chilled to –20 °C (bath temperature). A DMF (26 mL) solution of the crude acetate (**1**, 20.9 g) is added over 10 min via the dropping funnel. The inside of the dropping funnel is rinsed with DMF (5 mL). The reaction mixture is warmed to room temperature and stirred for 70 min (Note 21). A spot-to-spot formation of 1,1-difluoroallene (**2**) (Note 22) is confirmed by TLC analysis. Unreacted zinc dust is removed by passing through a small pad of celite (7 cm × 1 cm) (Note 23) and the celite is washed with ether (50 mL). Saturated aq. NH_4Cl (50 mL) and water (20 mL) are added and the products are extracted with ether (3 × 20 mL) using a 500-mL separatory funnel. The combined organic layers are washed with brine (50 mL) and dried over anhydrous Na_2SO_4 (ca. 30 g). After

removal of Na_2SO_4 by paper filtration, the solvent is removed by rotary evaporation (30 °C, 260 mmHg).

The residue (14.0 g) is charged on a column (5 cm × 30 cm) of silica gel (100 g), and eluted with pentane (60 mL fractions collected in test tubes) (Note 24). Product (**2**) is obtained in fractions 4–9. These fractions are combined and the solvent is removed by rotary evaporation (30 °C, 290 mmHg) (Note 25). The obtained oil is kept under reduced pressure for a short period of time (room temp, 3 mmHg, 3 min) to remove the solvent completely. 1,1-Difluoroallene (**2**) is obtained as a colorless oil (6.18 g, 72% yield based on crude acetate (**1**) and 66% yield based on 3-phenypropanal) (Notes 26, 27 and 28).

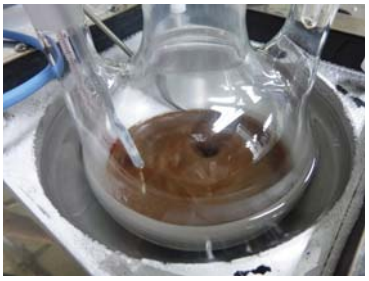


Figure 5. After addition of crude acetate

Figure 6. Product (2)

Notes

1. Diisopropylamine (99.0+%) was purchased from Tokyo Chemical Industry Co., Ltd. and was used after distillation from NaOH.
2. THF (anhydrous; Kanto Chemical Co., Inc.) was purified under argon using a solvent purification unit (Wako Pure Chemical Co., Inc.)
3. Butyllithium (hexane solution, 1.6 M) was purchased from Nakalai Tesque, Inc. and titrated with diphenylacetic acid in THF at room temperature.
4. During the preparation of CF_2=C(I)Li and the addition of aldehyde, the internal temperature must be kept below –90 °C to prevent the decomposition of the vinyllithium through elimination of LiF.
5. 1,1,1-Trifluoro-2-iodoethane (95+%) was purchased from Kanto Chemical Co., Inc. and used after distillation from CaH_2.

6. 3-Phenylpropanal (90+%) was purchased from Kanto Chemical Co., Inc. and used after distillation from $CaSO_4$.
7. TLC analysis is performed on silica gel with 20:1 hexane-AcOEt eluent (1 cm × 5 cm, glass-backed, Merck KGaA, TLC silica gel 60 F_{254}, 1.05715.0001). 3-Phenylpropanal has Rf = 0.31 and 1,1-difluoro-2-iodo-5-phenylpent-1-en-3-ol has Rf = 0.19.
8. Acetic anhydride (97+%) was purchased from Kanto Chemical Co., Inc. and used after distillation from *N*,*N*-diethylaniline.
9. TLC analysis is performed on silica gel with 20:1 hexane-AcOEt eluent. 1,1-Difluoro-2-iodo-5-phenylpent-1-en-3-yl acetate (**1**) has $R_f = 0.41$.
10. ^{19}F NMR analysis of an aliquot (55.0 mg) of the crude acetate (**1**, 20.9 g) using α,α,α-trifluorotoluene (19.6 mg) as internal reference indicates that acetate (**1**) is obtained in 91% yield. α,α,α-Trifluorotoluene (98+%) was purchased from Tokyo Chemical Industry Co., Ltd.
11. If necessary, acetate (**1**) can be purified by column chromatography. For example, the crude acetate (**1**, 21.0 g) obtained in another run from 3-phenylpropanal (6.87 mL, 7.00 g, 52.2 mmol) is dissolved in 20:1 hexane–AcOEt (ca. 30 mL) and charged on a column (5 cm × 45 cm) of silica gel (120 g) and eluted with 20:1 hexane-AcOEt (60 mL fractions collected in test tubes). Acetate (**1**) is obtained in fractions 3–15. These fractions are combined and the solvent is removed by evaporation (40 °C, 40 mmHg; RT, 4 mmHg), which affords pure acetate (**1**) as a colorless oil (15.74 g, 82% yield) in 97.1% purity (Note 10).
12. 1,1-Difluoro-2-iodo-5-phenylpent-1-en-3-yl acetate (**1**) is bench-stable but should be stocked in a refrigerator (0 °C). The purified compound has the following spectroscopic properties: ^1H NMR (600 MHz, $CDCl_3$, $SiMe_4$) δ: 1.86–1.92 (m, 1H), 2.05–2.11 (m, 1H), 2.07 (s, 3H), 2.56–2.61 (m, 2H), 4.96–4.99 (m, 1H), 7.17–7.22 (m, 3H), 7.29 (dd, *J* = 7.4, 7.6 Hz, 2H); ^{13}C NMR (151 MHz, $CDCl_3$, $SiMe_4$) δ: 20.9, 31.0, 36.1, 53.9 (dd, *J* = 25, 26 Hz), 68.9 (d, *J* = 3 Hz), 126.3, 128.3, 128.6, 140.3, 154.1 (dd, *J* = 286, 286 Hz), 169.6; ^{19}F NMR (565 MHz, $CDCl_3$, C_6F_6) δ: 89.2 (d, *J* = 22 Hz, 1F), 90.2 (d, *J* = 22 Hz, 1F); IR (ATR): 3028, 2934, 1747, 1717, 1269, 1225, 1027, 699 cm^{-1}; HRMS (ESI-TOF): $[M+Na]^+$ calcd. for $C_{13}H_{13}F_2IO_2Na$: 388.9826, found: 388.9821.
13. Zinc dust (96+%) was purchased from Tokyo Chemical Industry Co., Ltd.
14. In the first wash, zinc dust is stirred for 15 min in 2 M aq. HCl and the aq. HCl is then removed by decantation. In the second and third

washes, zinc dust is stirred for 30 sec. Conc. HCl was purchased from Kishida Chemical Co., Ltd.

15. Zinc dust is stirred for 30 sec in deionized water and the water is then removed by decantation.
16. The test paper was purchased from Advantec Toyo Kaisha, Ltd. (UNIV, pH 1–11).
17. Zinc dust is stirred for 30 sec in methanol. Methanol (99%) was purchased from Nakalai Tesque, Inc. and used as received.
18. Zinc dust is stirred for 30 sec in diethyl ether. Diethyl ether (anhydrous; Kanto Chemical Co., Inc.) was purified under argon using a solvent purification unit (Wako Pure Chemical Co., Inc.)
19. Active zinc dust is weighed under air and quickly put into the reaction vessel.
20. DMF (99%) was purchased from Nakalai Tesque, Inc. and used after distillation from CaH_2.
21. After removing the cold bath, the internal temperature slowly rises to about 26 °C and then declines to room temperature.
22. TLC analysis is performed on silica gel with 20:1 hexane–AcOEt eluent. 1,1-Difluoro-5-phenylpenta-1,2-diene (**2**) has $R_f = 0.97$.
23. Celite was purchased from Wako Pure Chemical Industries Ltd. (No. 500).
24. Pentane was purchased from Nacalai Tesque, Inc. and used as received.
25. Removal of the solvent by rotary evaporation should be stopped when condensation of the solvent is not observed. Otherwise, yield of the product (**2**) decreases by evaporation.
26. The reaction was checked two additional times on identical scale and provided 5.95 g (63%) and 6.20 g (66%) of the product with the yield based on 3-phenypropanal.
27. Isolated difluoroallene (**2**) was analyzed by ^{1}H NMR spectroscopy as 98.9 wt% using ethylene carbonate as an internal standard. The submitters report that difluoroallene was observed as a single peak by GC analysis (GC-14B instrument, Shimadzu Corporation), but this analysis was not attempted by the Checkers. The submitter's GC instrument was equipped with Rtx-5 (Restek Corporation) column (30 m × 0.25 mm, film thickness 0.25 μm). Retention time (**2**): t = 7.40 min with N_2 flow rate of 1.9 mL/min. Temperature profile: T = 60 °C/2 min, 60–280 °C/11 min, then 280 °C/30 min.
28. 1,1-Difluoro-5-phenylpenta-1,2-diene (**2**) undergoes slow decomposition at room temperature, which therefore should be stored

in a refrigerator (–19 °C). This compound has the following spectroscopic properties: ^{1}H NMR (600 MHz, $CDCl_3$, $SiMe_4$) δ: 2.54–2.60 (m, 2H), 2.81 (t, *J* = 7.6 Hz, 2H), 6.47 (tt, *J* = 6.1, 2.4 Hz, 1H), 7.18–7.22 (m, 3H), 7.30 (dd, *J* = 7.3, 7.3 Hz, 2H); ^{13}C NMR (151 MHz, $CDCl_3$, $SiMe_4$) δ: 33.85, 33.86, 121.5 (t, *J* = 5.5 Hz), 126.3, 128.4, 128.5, 140.7, 152.9 (t, *J* = 259.2 Hz), 170.2 (t, *J* = 36.0 Hz); ^{19}F NMR (565 MHz, $CDCl_3$, C_6F_6) δ: 60.027 (s), 60.035 (s); IR (ATR): 3029, 2930, 2861, 2014, 1463, 1197, 747, 699 cm^{-1}.

Working with Hazardous Chemicals

The procedures in *Organic Syntheses* are intended for use only by persons with proper training in experimental organic chemistry. All hazardous materials should be handled using the standard procedures for work with chemicals described in references such as "Prudent Practices in the Laboratory" (The National Academies Press, Washington, D.C., 2011; the full text can be accessed free of charge at http://www.nap.edu/catalog.php?record_id=12654). All chemical waste should be disposed of in accordance with local regulations. For general guidelines for the management of chemical waste, see Chapter 8 of Prudent Practices.

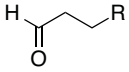
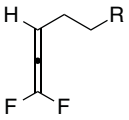
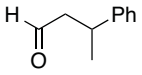
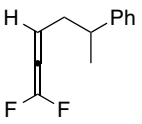
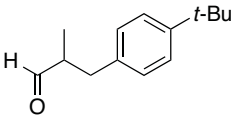
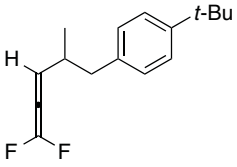
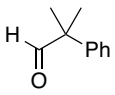
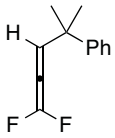
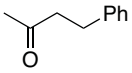
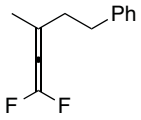
In some articles in *Organic Syntheses*, chemical-specific hazards are highlighted in red “Caution Notes” within a procedure. It is important to recognize that the absence of a caution note does not imply that no significant hazards are associated with the chemicals involved in that procedure. Prior to performing a reaction, a thorough risk assessment should be carried out that includes a review of the potential hazards associated with each chemical and experimental operation on the scale that is planned for the procedure. Guidelines for carrying out a risk assessment and for analyzing the hazards associated with chemicals can be found in Chapter 4 of Prudent Practices.

The procedures described in *Organic Syntheses* are provided as published and are conducted at one's own risk. *Organic Syntheses, Inc.*, its Editors, and its Board of Directors do not warrant or guarantee the safety of individuals using these procedures and hereby disclaim any liability for any injuries or damages claimed to have resulted from or related in any way to the procedures herein.

Discussion

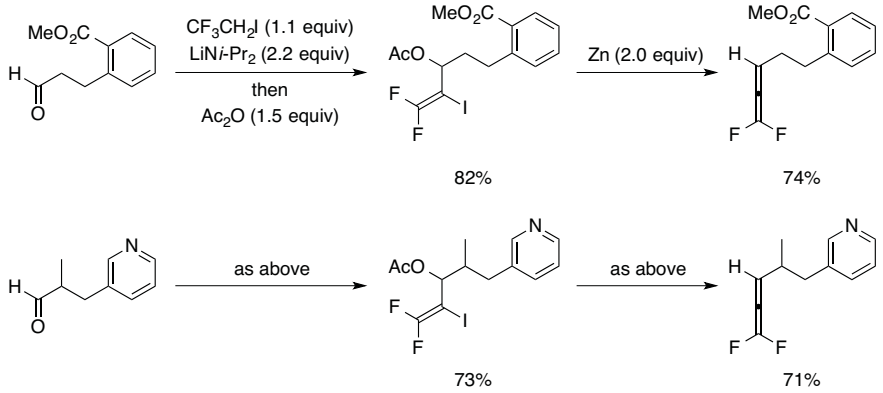
1,1-Difluoroallenes have been synthesized via either the formation of the second C–C double bond in fluorinated alkenes or the rearrangement of the C–C triple bonds in fluorinated alkynes.[2] The former involves elimination reactions of (i) trifluoromethylalkenes and (ii) difluoroalkenes, while the latter involves substitution reactions of difluoropropargyl bromides. The substitution reactions are further classified into two types, wherein the propargyl moieties serve as (iii) nucleophiles or (iv) electrophiles.

Table 1. Synthesis of 1,1-Difluoroallenes

Entry	Carbonyl compound	1,1-Difluoroallene 2	1, 2 / %
1			82, 86 (R = Ph)
2			83, 82 (R = 1-Naph)
3			84, 87 (R = n-C_7H_{15})
4			81, 95
5			87, 92
6			83, 93
7			80,[a] 86

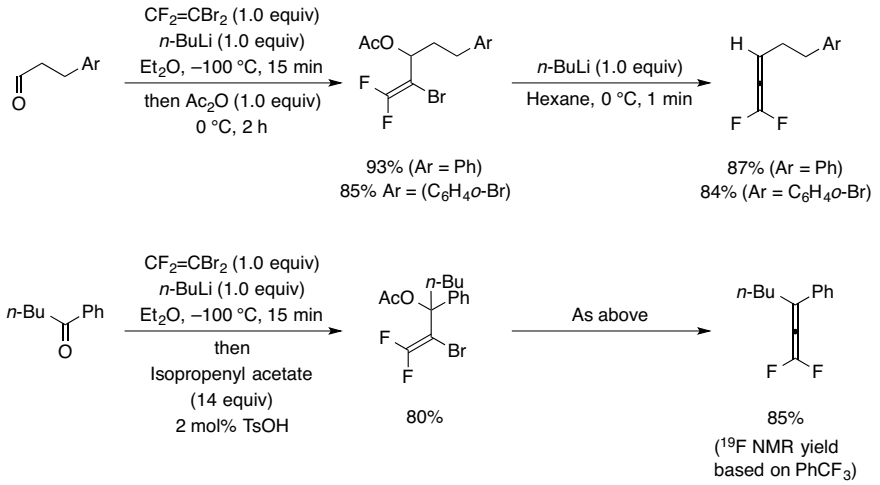
[a] Acetylation was performed with isopropenyl acetate (14 equiv)/2 mol%

The present 1,1-difluoroallene synthesis is classified as the type (ii) synthesis and provides a highly general route to the variously substituted 1,1-difluoroallenes because of the wide availability of starting aldehydes and ketones (Table 1).[3] Not only linear aldehydes (Entries 1–3) but also branched aldehydes (Entries 4 and 5), including tertiary alkanals (Entry 6), afford the corresponding 1,1-difluoroallenes in high yields. Ketones are also efficiently converted to the corresponding 1,1-difluoroallenes (Entry 7). It is noteworthy that both ester and pyridine moieties are tolerant to the reaction conditions and the corresponding difluoroallenes are obtained in high yields (Scheme 1).



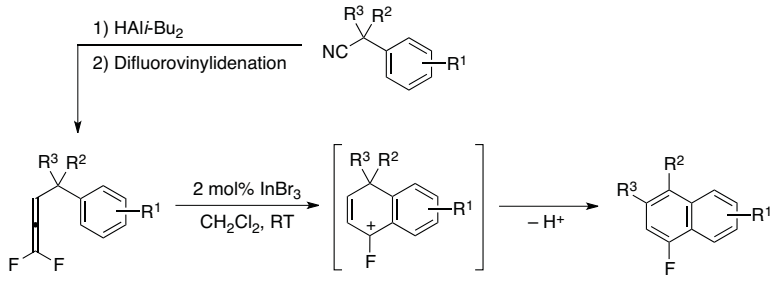
Scheme 1. Synthesis of 1,1-Difluoroallenes Bearing Ester and Pyridine Moieties

This difluoroallene synthesis is a modification of our former 1,1-dibromo-2,2-difluoroethene-based protocol (Scheme 2).[4] Since there is a short supply of dibromodifluoroethene because of its ozone depletion property, trifluoroiodoethane is adopted instead as a starting material.



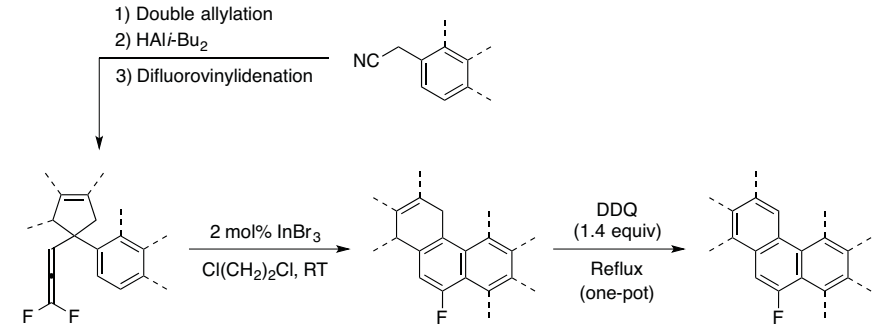
Scheme 2. Dibromodifluoroethene-Based Synthesis of 1,1-Difluoroallenes

1,1-Difluoroallenes are versatile intermediates that undergo nucleophilic additions, substitutions, and cycloadditions.[1] In addition, difluoroallenes serve as an appropriate platform for the synthesis of polycyclic aromatic hydrocarbons (PAHs).[5] 1,1-Difluoroallenes, bearing an aryl group and an alkyl substituent adjacent to the difluoroallene moiety, are readily prepared from arylacetonitriles by half-reduction followed by difluorovinylidenation (Scheme 3). Treatment of the 1,1-difluoroallenes with 2 mol% of $InBr_3$ facilitates the domino Friedel–Crafts-type cyclization/1,2-alkyl migration (or deprotonation) to afford regioselectively fluorinated naphthalenes in high yields. Difluoroallenes bearing an aryl group and a cyclopentene moiety similarly undergo the domino Friedel–Crafts-type cyclization/alkyl migration sequence, resulting in ring formation and ring expansion. Subsequent one-pot dehydrogenation with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone (DDQ) efficiently provides pinpoint-fluorinated higher-order PAHs (Scheme 4), which are promising organic materials for printable electronic devices.[6]

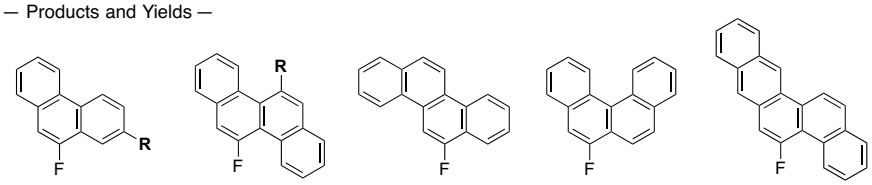


R^1 = *p*-Me, R^2 = R^3 = Me, 0.5 h 85%
R^1 = *m*-Br, R^2 = R^3 = Me, 1.5 h 74%
R^1 = H, R^2 $(CH_2)_2Ph$, R^3 = H, 2.0 h 83%

Scheme 3. Domino Synthesis of Pinpoint-Fluorinated Naphthalenes



— Products and Yields —



93% (R = Me)
66% (R = OMe)

85% (R = H)
98% (R = Me)

88%

60%

84%

Scheme 4. Domino Synthesis of Pinpoint-Fluorinated PAHs

References

1. Division of Chemistry, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Ibaraki 305–8571, Japan. E-mail: junji@chem.tsukuba.ac.jp. This work was partially supported by Tosoh F-Tech, Inc.
2. Fuchibe, K.; Ichikawa, J. *1,1-Dihaloallenes* in Web of Science Knowledge Updates 2014/2, Thieme, Stuttgart, **2014**, pp. 217–231.
3. (a) Oh, K.; Fuchibe, K.; Ichikawa, J. *Synthesis* **2011**, 881–886. (b) Oh, K.; Fuchibe, K.; Yokota, M.; Ichikawa, J. *Synthesis* **2012**, *44*, 857–861.
4. Yokota, M.; Fuchibe, K.; Ueda, M.; Mayumi, Y.; Ichikawa, J. *Org. Lett.* **2009**, *11*, 3994–3997.
5. (a) Fuchibe, K.; Mayumi, Y.; Zhao, N.; Watanabe, S.; Yokota, M.; Ichikawa, J. *Angew. Chem. Int. Ed.* **2013**, *52*, 7825–7828. (b) Fuchibe, K.; Mayumi, Y.; Yokota, M.; Aihara, H.; Ichikawa, J. *Bull. Chem. Soc. Jpn.* **2014**, *87*, 942–949.
6. Fuchibe, K.; Morikawa, T.; Shigeno, K.; Fujita, T.; Ichikawa, J. *Org. Lett.* **2015**, *17*, 1126–1129.

Appendix
Chemical Abstracts Nomenclature (Registry Number)

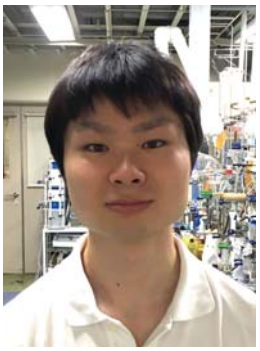
1,1-Difluoro-2-iodo-5-phenylpent-1-en-3-yl acetate: Benzenepropanol, α-(2,2-difluoro-1-iodoethenyl)-, 1-acetate; (**1**) (1309570-95-3)
Diisopropylamine: 2-Propanamine, *N*-(1-methylethyl)-; (108-18-9)
Butyllithium: Lithium, butyl-; (109-72-8)
1,1,1-Trifluoro-2-iodoethane: Ethane, 1,1,1-trifluoro-2-iodo-; (353-83-3)
3-Phenylpropanal: Benzenepropanal; (104-53-0)
Acetic anhydride: Acetic acid, 1,1'-anhydride; (108-24-7)
1,1-Difluoro-5-phenylpenta-1,2-diene: Benzene, (5,5-difluoro-3,4-pentadien-1-yl)-; (**2**) (1186222-29-6)
Zinc; (7440-66-6)

Kohei Fuchibe was born in Fukui, Japan in 1974. He received his B.Sc. in 1999 and Ph.D. in 2002 from the University of Tokyo (Prof. K. Narasaka). He joined Gakushuin University as a Research Associate in 2002 and was shifted to an Assistant Professor in 2007. He moved to University of Tsukuba as a Lecturer in 2007 and was promoted to an Associate Professor in 2011. His research interests involve organic synthetic reactions catalyzed by transition metals or organic small molecules.

Masashi Abe was born in the state of New Hampshire, USA in 1991. He received his B.Sc. in 2014 from University of Tsukuba and is pursuing a master's degree at the same university (Prof. J. Ichikawa). He is majoring in synthetic organic chemistry and now working on the development of synthetic methods for polycyclic aromatic hydrocarbons.

Ken Oh (Jian Wang) was born in Shandong, China in 1970, graduated from Wuhan University in 1991, moved to Japan as a research student in 1998, received his M.Sc. in 2001 from the University of Tokyo (Prof. K. Kitazawa) and Ph.D. in 2012 from University of Tsukuba (Prof. J. Ichikawa). He joined Shandong Non-metallic Materials Institute in 1991. He worked as a Senior Chemist for DuPont-Mitsui Fluorochemicals Co., Ltd. during 2005-2012. From 2012, he worked as a Chief Senior Researcher in Zeon Corporation. His research interests involve organic synthesis of functional molecules (from small to macro), especially organofluorine compounds.

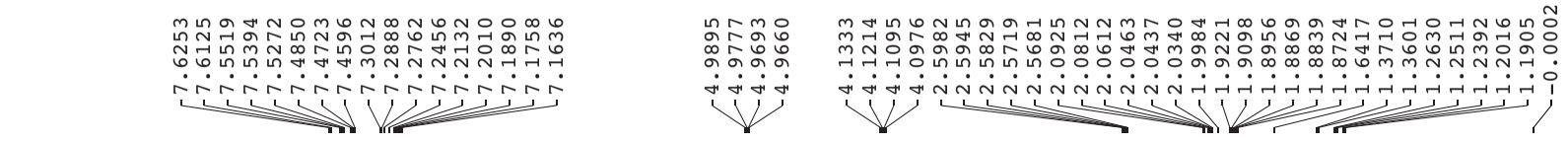
Junji Ichikawa was born in Tokyo, Japan in 1958. He received his B.Sc. in 1981 and Ph.D. in 1986 from the University of Tokyo (Prof. T. Mukaiyama). He joined Kyushu University as an Assistant Professor in 1985. In 1989, he was a postdoctoral research associate in Harvard University (Prof. E. J. Corey) and then worked in Kyushu Institute of Technology as a Lecturer and an Associate Professor. In 1999, he moved to the University of Tokyo, as an Associate Professor. He was appointed Professor in University of Tsukuba in 2007. His research interests lie in the area of synthetic methodology based on the properties of metals and fluorine.

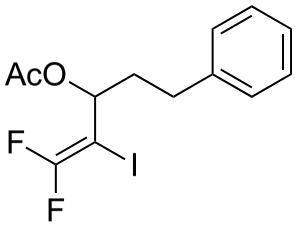


Shogo Sato was born in Kanagawa, Japan in 1990. He received his B.Sc. degree from Aoyama Gakuin University (Prof. H. Sugimura) in 2013. In the same year, he joined the research group of Prof. Keisuke Suzuki at Tokyo Institute of Technology. His research focuses on the synthesis of natural products.

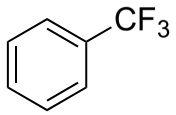
Keiichiro Sakata was born in Tokyo, Japan in 1992. He received his B.S. degree in 2015 from Waseda University (Prof. S. Hosokawa) and pursing a master's degree at Tokyo Institute of Technology (Prof. K. Suzuki). He is majoring in synthetic organic chemistry and now focuses on synthetic methods of natural products.

Crude 1,1-difluoro-2-iodo-5-phenylpent-1-en-3-yl acetate, 1H NMR



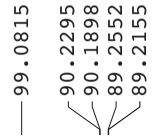


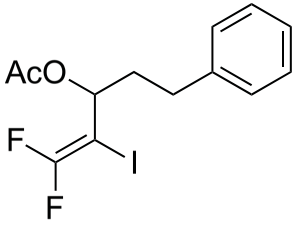
(Internal Standard)

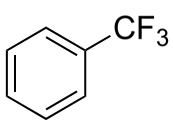



```
Current Data Parameters
NAME          SS2-743-cr
EXPNO                 20
PROCNO                 1

F2 - Acquisition Parameters
Date_           20160328
Time              20.38
INSTRUM           spect
PROBHD   5 mm CPPBBO BB
PULPROG            zg30
TD                65536
SOLVENT           CDCl3
NS                   16
DS                    2
SWH           12019.230 Hz
FIDRES         0.183399 Hz
AQ             2.7262976 sec
RG                15.79
DW               41.600 usec
DE               10.00 usec
TE               300.0 K
D1            1.00000000 sec
TD0                   1

======== CHANNEL f1 ========
SFO1         600.1337060 MHz
NUC1                1H
P1                12.00 usec
PLW1         23.00000000 W

F2 - Processing parameters
SI                65536
SF           600.1300244 MHz
WDW                 EM
SSB       0
LB                0.30 Hz
GB        0
PC                1.00
```

Crude 1,1-difluoro-2-iodo-5-phenylpent-1-en-3-yl acetate, 19F NMR



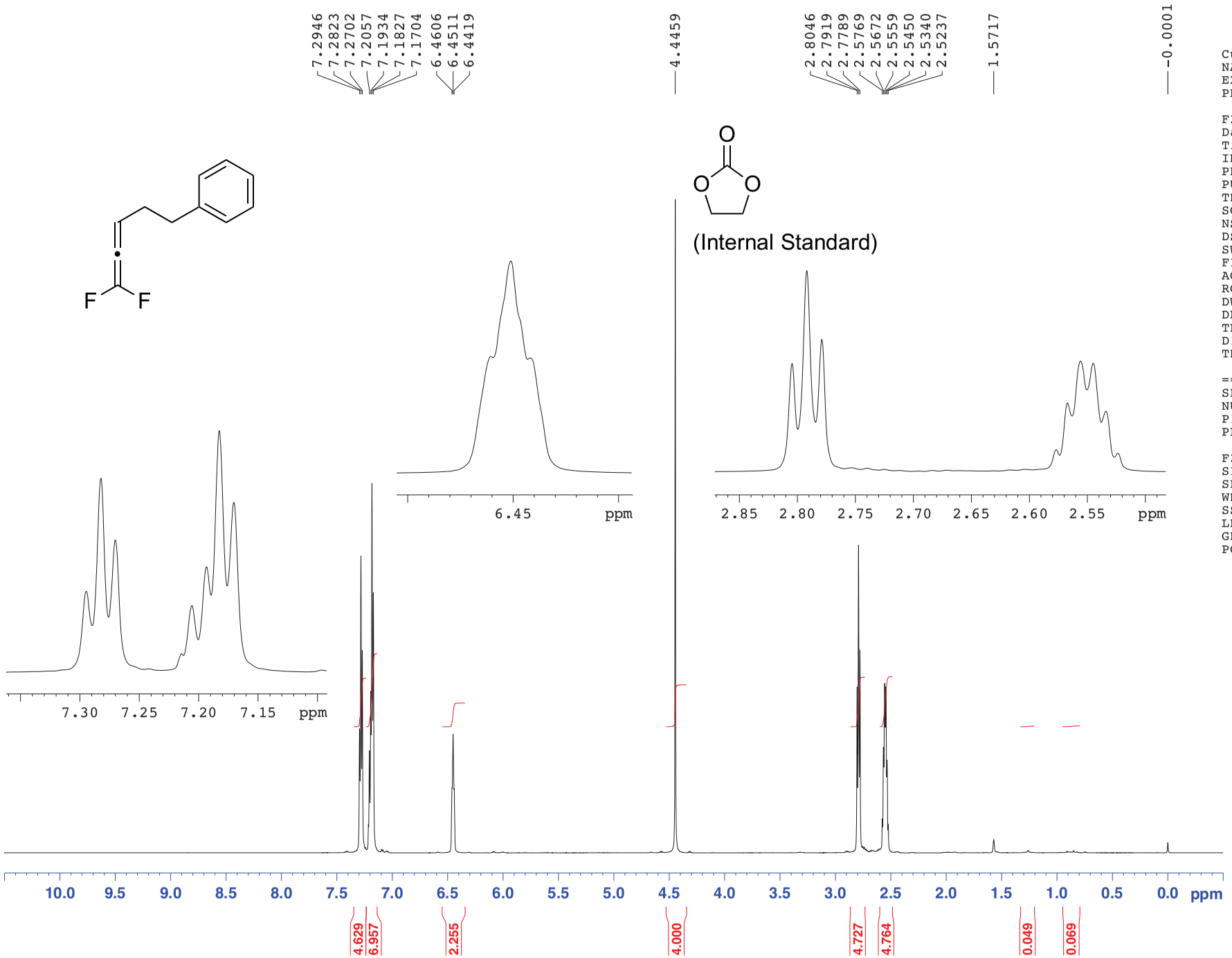




(Internal Standard)

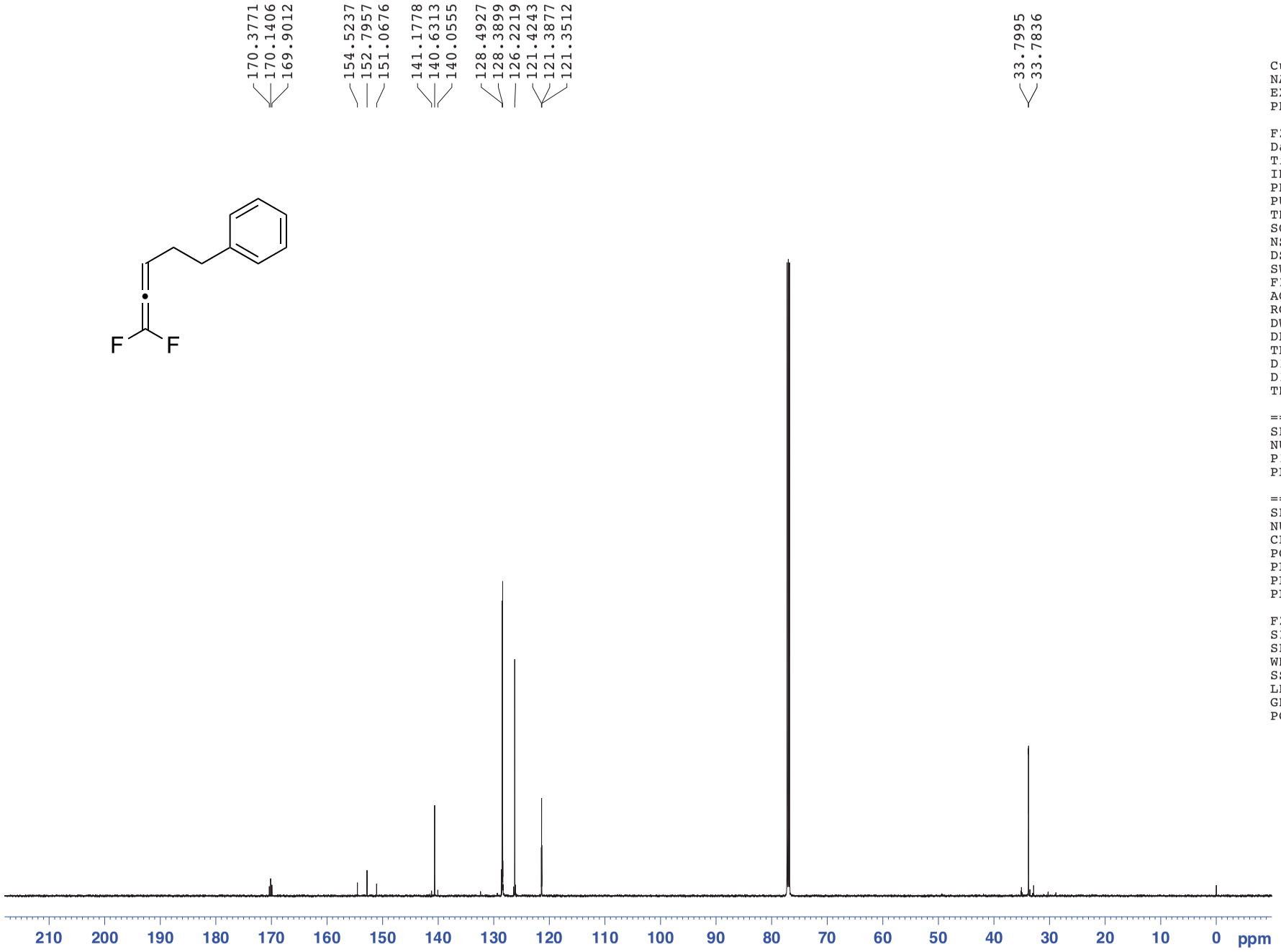

```
Current Data Parameters
NAME          SS2-821-cr
EXPNO                 12
PROCNO                 1

F2 - Acquisition Parameters
Date_           20160829
Time               11.20
INSTRUM            spect
PROBHD   5 mm CPPBBO BB
PULPROG          zgflqn
TD                131072
SOLVENT            CDCl3
NS                    16
DS                     4
SWH           133928.578 Hz
FIDRES          1.021794 Hz
AQ              0.4893355 sec
RG                175.56
DW                 3.733 usec
DE                18.00 usec
TE                298.0 K
D1           1.00000000 sec
TD0                    1

======== CHANNEL f1 ========
SFO1         564.6299196 MHz
NUC1                19F
P1                15.00 usec
PLW1         15.50000000 W

F2 - Processing parameters
SI                 65536
SF           564.5949998 MHz
WDW                   EM
SSB       0
LB                 0.30 Hz
GB        0
PC                 1.00
```

1,1-Difluoro-5-phenylpenta-1,2-diene, 1H NMR



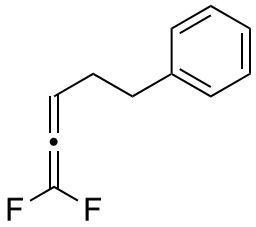

```
Current Data Parameters
NAME                  SS2-OS1
EXPNO                      10
PROCNO                      1

F2 - Acquisition Parameters
Date_                20160615
Time                    12.27
INSTRUM                 spect
PROBHD    5 mm CPPBBO BB
PULPROG                 zg30
TD                     65536
SOLVENT                CDC13
NS                        16
DS                         2
SWH                12019.230 Hz
FIDRES             0.183399 Hz
AQ                 2.7262976 sec
RG                      14.24
DW                    41.600 usec
DE                    10.00 usec
TE                    300.0 K
D1                 1.00000000 sec
TD0                        1

======== CHANNEL f1 ========
SFO1            600.1337060 MHz
NUC1                       1H
P1                    12.00 usec
PLW1           23.00000000 W

F2 - Processing parameters
SI                     65536
SF              600.1300447 MHz
WDW                       EM
SSB          0
LB                     0.30 Hz
GB           0
PC                     1.00
```

1,1-Difluoro-5-phenylpenta-1,2-diene, 13C NMR



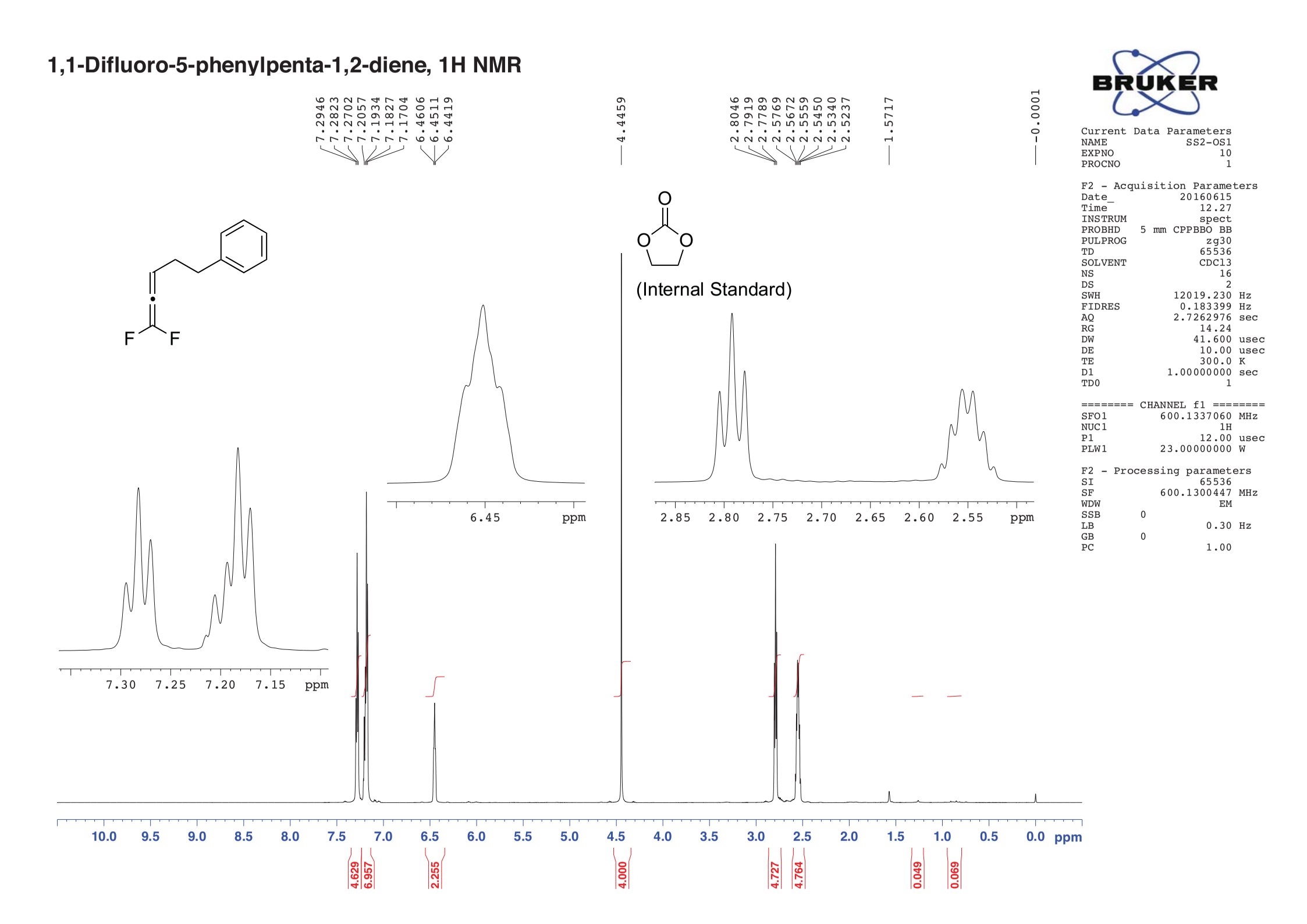

```
Current Data Parameters
NAME         KS1-221-c12
EXPNO                 21
PROCNO                 1

F2 - Acquisition Parameters
Date_           20160415
Time               23.08
INSTRUM            spect
PROBHD   5 mm CPPBBO BB
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                  512
DS                    4
SWH           36057.691 Hz
FIDRES         0.550197 Hz
AQ            0.9087659 sec
RG               175.56
DW               13.867 usec
DE                18.00 usec
TE                300.0 K
D1           2.00000000 sec
D11          0.03000000 sec
TD0                   1

======== CHANNEL f1 ========
SFO1        150.9178981 MHz
NUC1                13C
P1                10.00 usec
PLW1         70.00000000 W

======== CHANNEL f2 ========
SFO2        600.1324005 MHz
NUC2                1H
CPDPRG[2         waltz16
PCPD2             70.00 usec
PLW2         26.00000000 W
PLW12         0.76407999 W
PLW13         0.37439999 W

F2 - Processing parameters
SI                 32768
SF          150.9028095 MHz
WDW                   EM
SSB       0
LB                 1.00 Hz
GB        0
PC                 1.40
```

1,1-Difluoro-5-phenylpenta-1,2-diene, 19F NMR



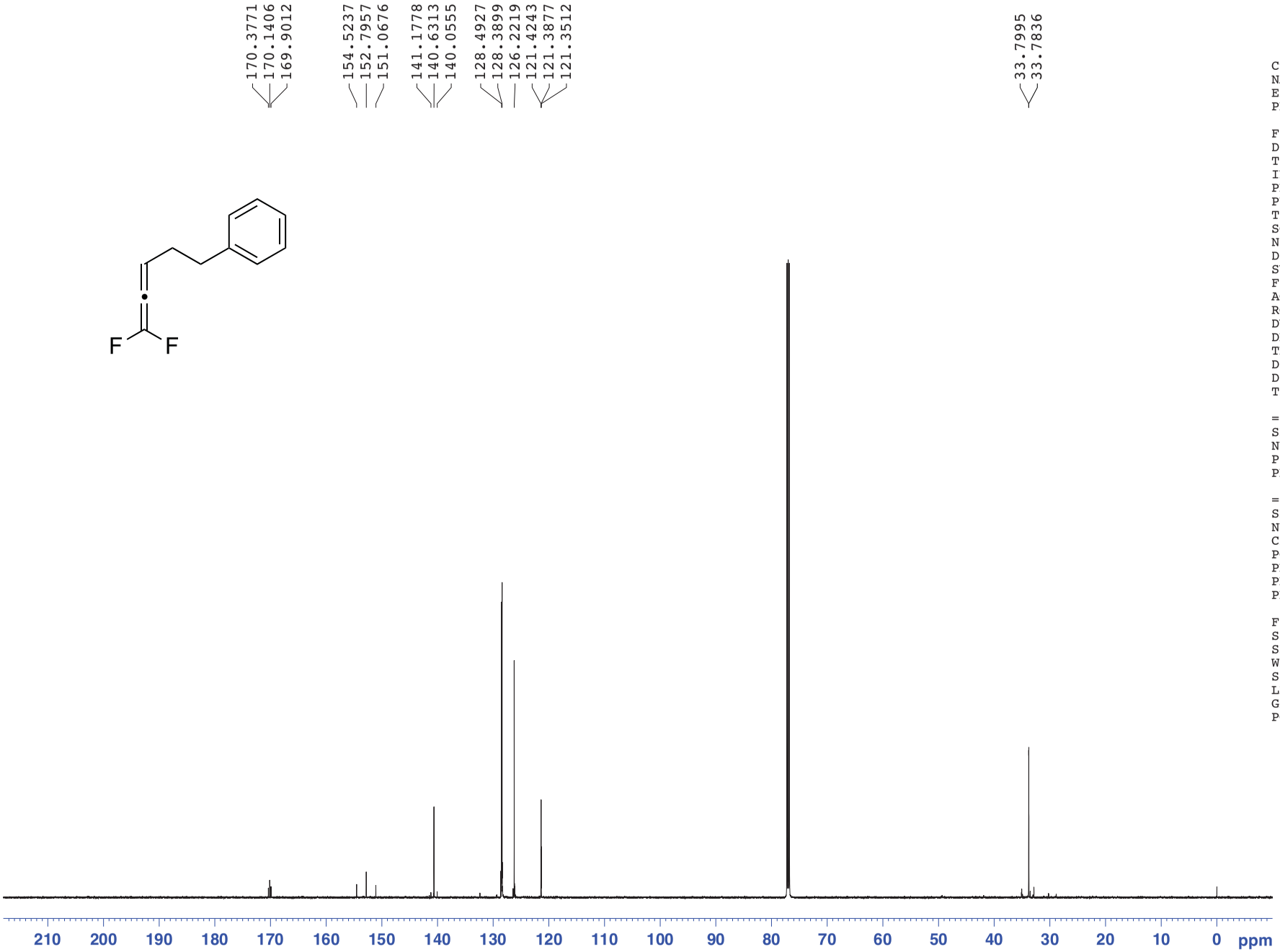

```
Current Data Parameters
NAME                  SS2-OS1
EXPNO                      20
PROCNO                      1

F2 - Acquisition Parameters
Date_                20160615
Time                    13.02
INSTRUM                 spect
PROBHD    5 mm CPPBBO BB
PULPROG                 zgflqn
TD                      131072
SOLVENT                 CDCl3
NS                         16
DS                          4
SWH                133928.578 Hz
FIDRES               1.021794 Hz
AQ                 0.4893355 sec
RG                    175.56
DW                     3.733 usec
DE                    18.00 usec
TE                    300.0 K
D1                 1.00000000 sec
TD0                         1

======== CHANNEL f1 ========
SFO1             564.6299196 MHz
NUC1                    19F
P1                    15.00 usec
PLW1            15.50000000 W

F2 - Processing parameters
SI                      65536
SF               564.5947769 MHz
WDW                        EM
SSB       0
LB                     0.30 Hz
GB        0
PC                     1.00
```

1,1-Difluoro-5-phenylpenta-1,2-diene, 1H NMR



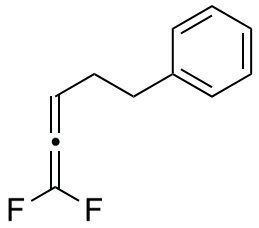

```
Current Data Parameters
NAME                  SS2-OS1
EXPNO                      10
PROCNO                      1

F2 - Acquisition Parameters
Date_                20160615
Time                    12.27
INSTRUM                 spect
PROBHD    5 mm CPPBBO BB
PULPROG                 zg30
TD                     65536
SOLVENT                CDCl3
NS                        16
DS                         2
SWH                12019.230 Hz
FIDRES             0.183399 Hz
AQ                 2.7262976 sec
RG                     14.24
DW                    41.600 usec
DE                    10.00 usec
TE                    300.0 K
D1                 1.00000000 sec
TD0                        1

======== CHANNEL f1 ========
SFO1           600.1337060 MHz
NUC1                      1H
P1                     12.00 usec
PLW1           23.00000000 W

F2 - Processing parameters
SI                     65536
SF             600.1300447 MHz
WDW                       EM
SSB          0
LB                     0.30 Hz
GB           0
PC                     1.00
```

1,1-Difluoro-5-phenylpenta-1,2-diene, 13C NMR




```
Current Data Parameters
NAME         KS1-221-c12
EXPNO                 21
PROCNO                 1

F2 - Acquisition Parameters
Date_           20160415
Time               23.08
INSTRUM            spect
PROBHD   5 mm CPPBBO BB
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                  512
DS                    4
SWH           36057.691 Hz
FIDRES         0.550197 Hz
AQ            0.9087659 sec
RG               175.56
DW               13.867 usec
DE                18.00 usec
TE                300.0 K
D1           2.00000000 sec
D11          0.03000000 sec
TD0                   1

======== CHANNEL f1 ========
SFO1        150.9178981 MHz
NUC1                13C
P1                10.00 usec
PLW1        70.00000000 W

======== CHANNEL f2 ========
SFO2        600.1324005 MHz
NUC2                1H
CPDPRG[2         waltz16
PCPD2             70.00 usec
PLW2        26.00000000 W
PLW12        0.76407999 W
PLW13        0.37439999 W

F2 - Processing parameters
SI                 32768
SF          150.9028095 MHz
WDW                   EM
SSB       0
LB                 1.00 Hz
GB        0
PC                 1.40
```

1,1-Difluoro-5-phenylpenta-1,2-diene, 19F NMR




```
Current Data Parameters
NAME                  SS2-OS1
EXPNO                      20
PROCNO                      1

F2 - Acquisition Parameters
Date_                20160615
Time                    13.02
INSTRUM                 spect
PROBHD    5 mm CPPBBO BB
PULPROG                zgflqn
TD                     131072
SOLVENT                 CDCl3
NS                         16
DS                          4
SWH                133928.578 Hz
FIDRES               1.021794 Hz
AQ                   0.4893355 sec
RG                      175.56
DW                       3.733 usec
DE                      18.00 usec
TE                      300.0 K
D1                 1.00000000 sec
TD0                         1

======== CHANNEL f1 ========
SFO1               564.6299196 MHz
NUC1                       19F
P1                       15.00 usec
PLW1               15.50000000 W

F2 - Processing parameters
SI                         65536
SF                 564.5947769 MHz
WDW                        EM
SSB       0
LB                       0.30 Hz
GB        0
PC                       1.00
```