Exploring Radio Frequency Attacks in Outer Space

Dr. James Pavur
DOD Chief Digital and AI Office: Directorate for Digital Services*

* Opinions expressed are solely my own and do not express the views or opinions of my employer.

CDAO

KA-SAT Coverage: European Spot Beams

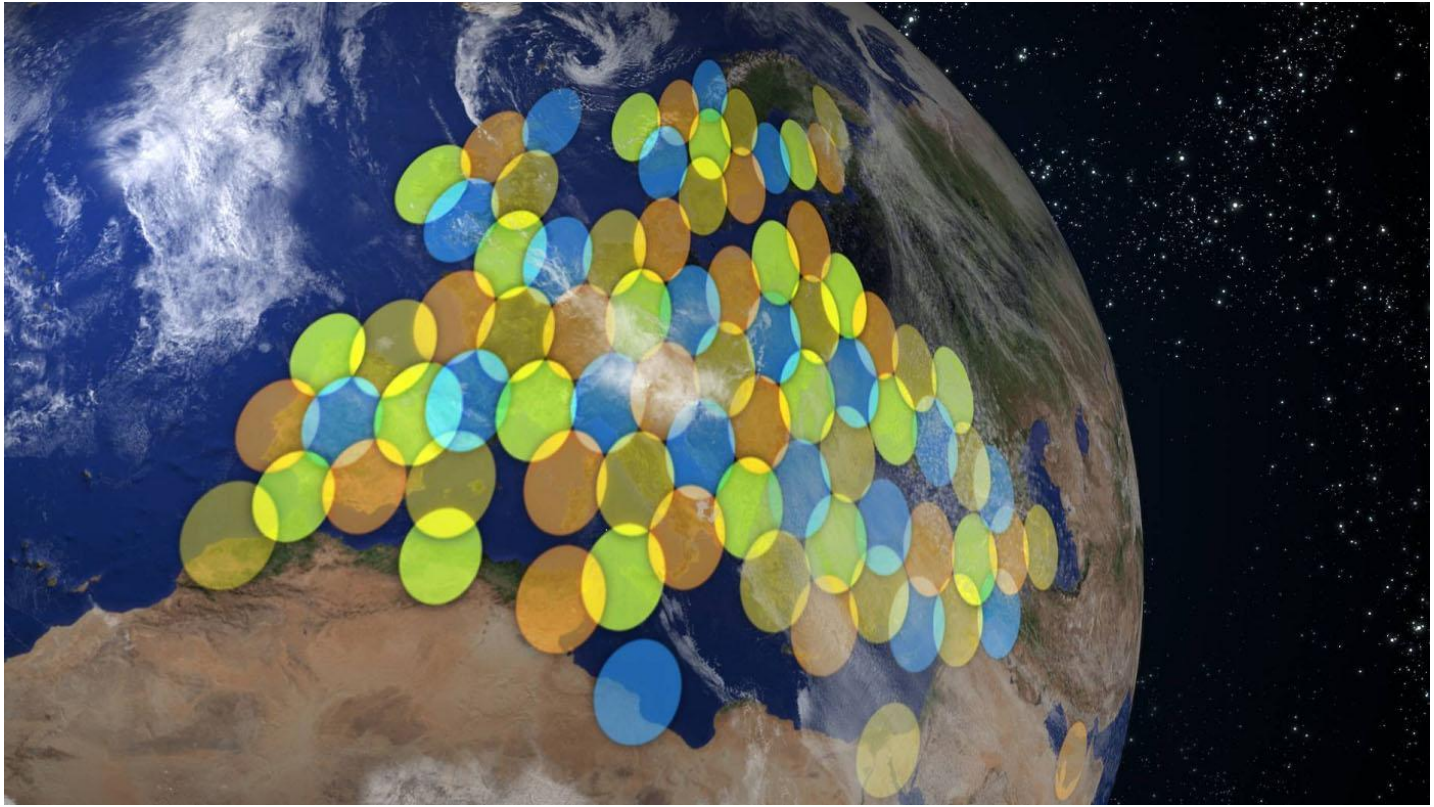

Image: *KA-SAT spot beams coverage*. Axisite. Wikimedia Commons. CC-BY-SA-3.0.

February 24, 2022 - 3:02 am UTC

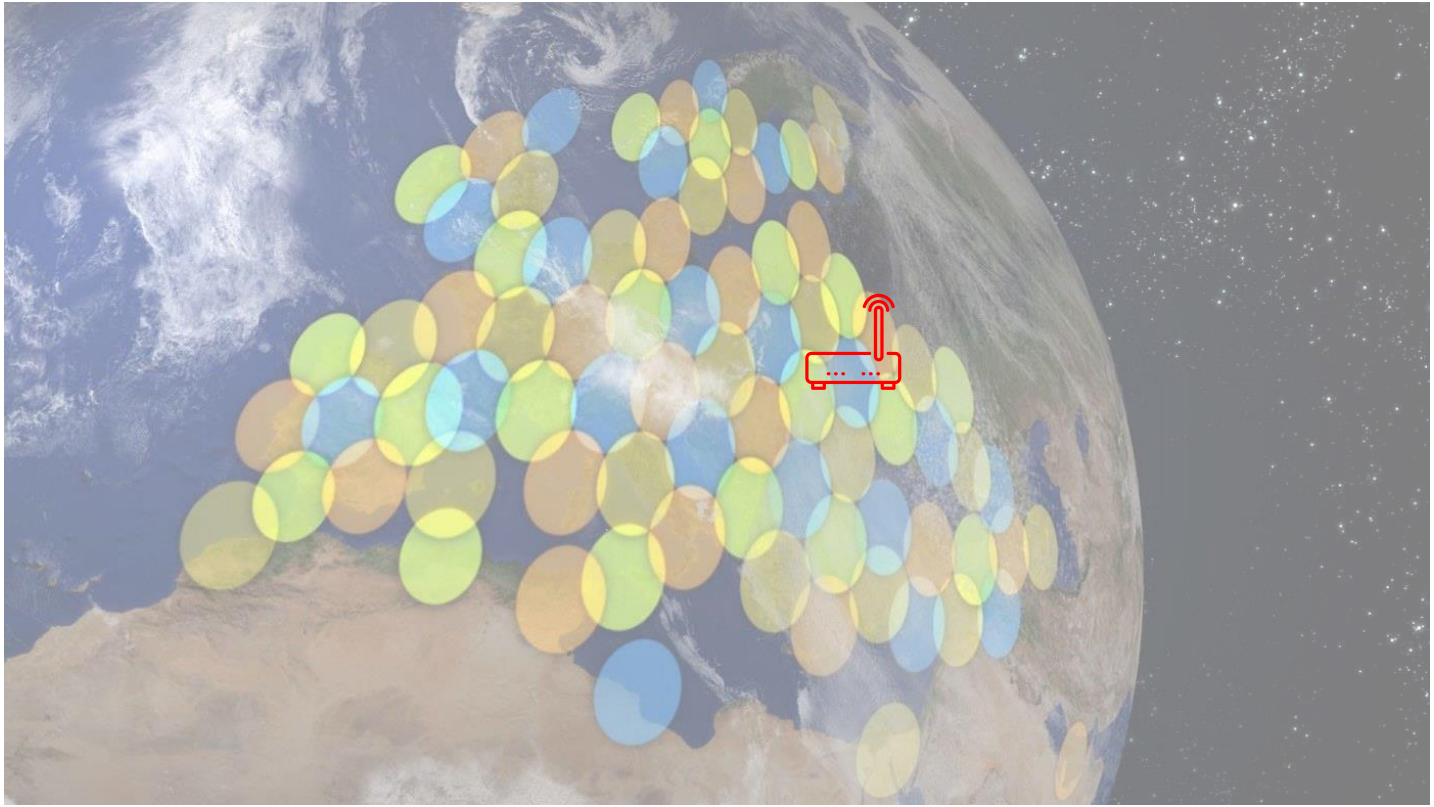

Image: *KA-SAT spot beams coverage*. Axisite. Wikimedia Commons. CC-BY-SA-3.0.

February 24, 2022 - 4:15 am UTC

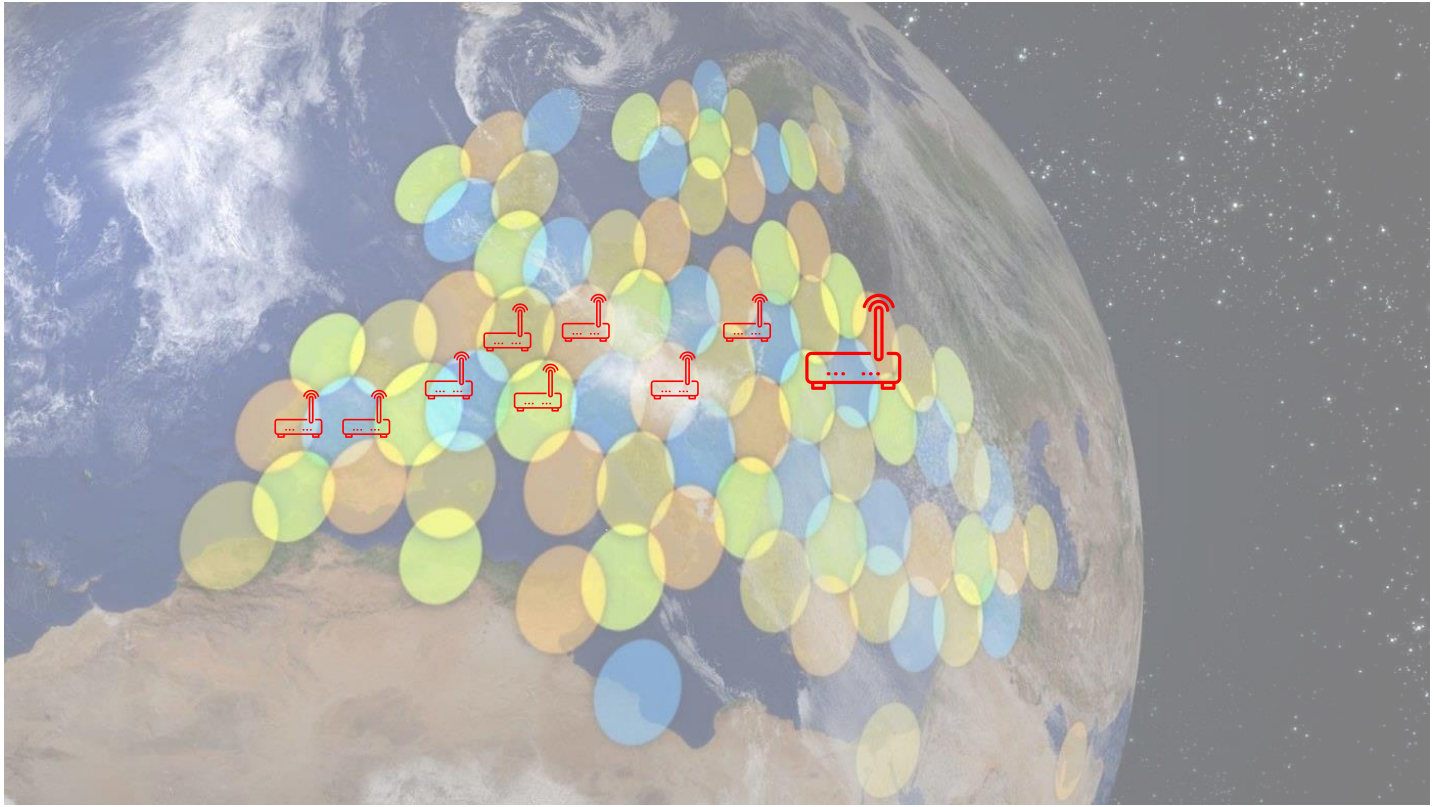

Image: *KA-SAT spot beams coverage*. Axisite. Wikimedia Commons. CC-BY-SA-3.0.

February 24, 2022 - 5:00 am UTC

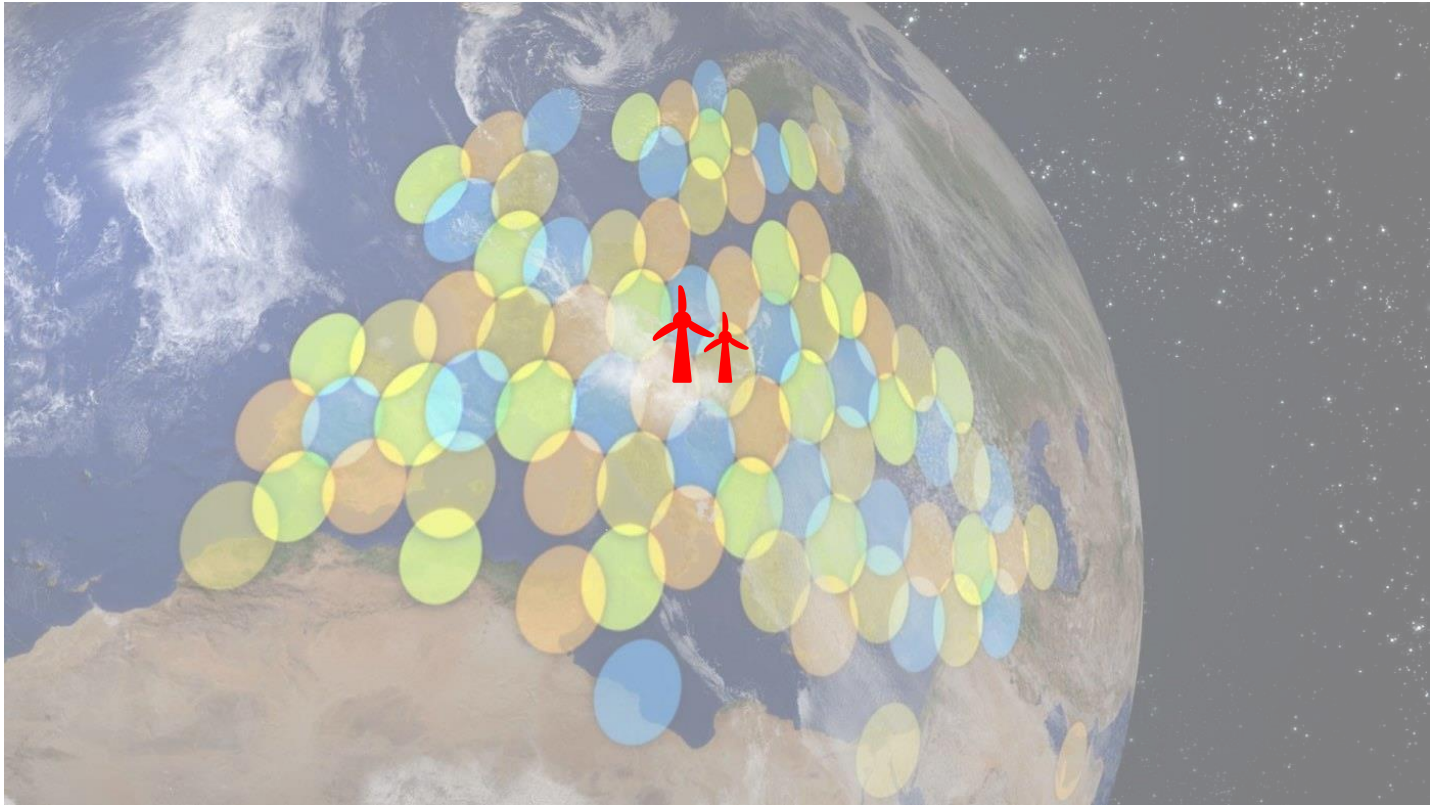

Image: *KA-SAT spot beams coverage*. Axisite. Wikimedia Commons. CC-BY-SA-3.0.

Space Cyber’s Escalatory Future…

Civil Infrastructure
as Wartime Target

Space Cyber's Escalatory Future…

Collateral /
Spillover Damage

Civil Infrastructure
as Wartime Target

Space Cyber's Escalatory Future…

Cross-Border Disruption

Collateral / Spillover Damage

Civil Infrastructure as Wartime Target

Looking to the Past…

60 Years of Satellite Exploitation

Countries involved in satellite exploitation by year of first entry

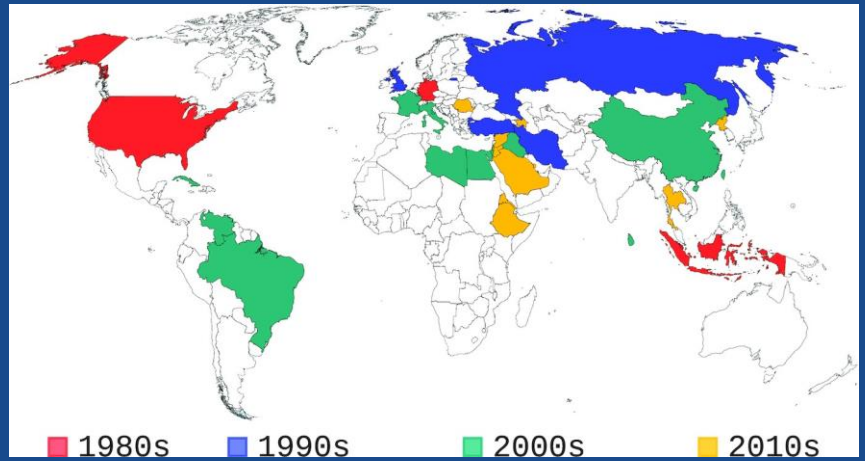

Figure: Pavur & Martinovic, Building a launchpad for satellite cyber-security research: lessons from 60 years of spaceflight, *Journal of Cybersecurity*, https://doi.org/10.1093/cybsec/tyac008

Signal Exploitation: >2/3 of Historical Satellite Attacks

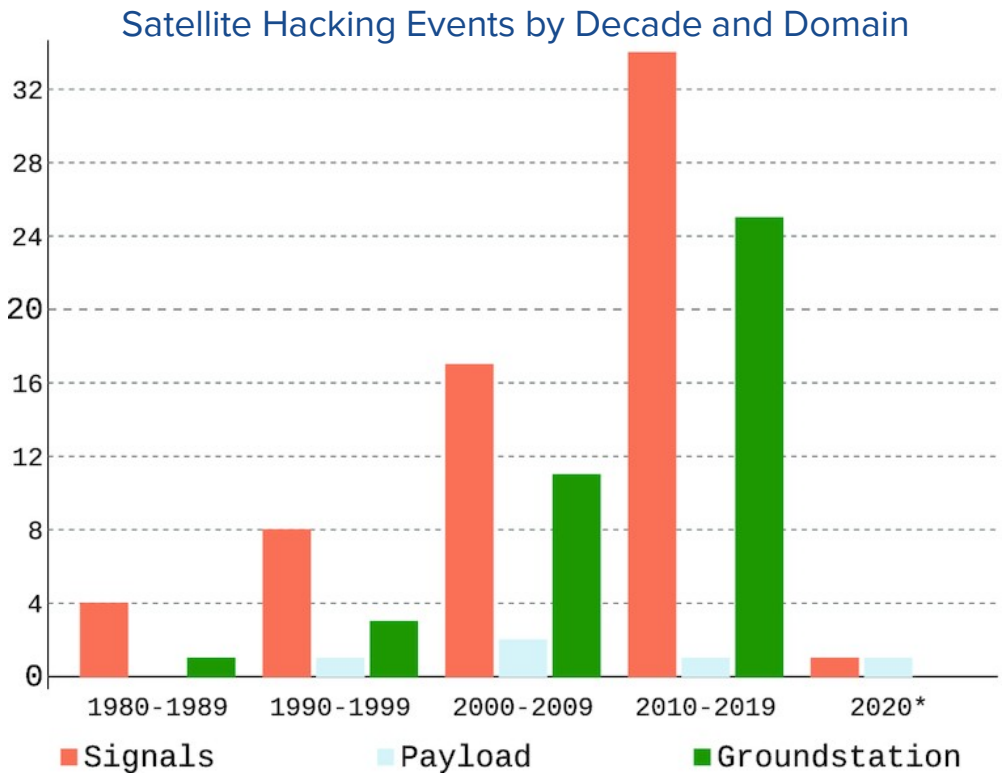

Figure: Pavur & Martinovic, Building a launchpad for satellite cyber-security research: lessons from 60 years of spaceflight, *Journal of Cybersecurity*, https://doi.org/10.1093/cybsec/tyac008

1972: The Right to Jam

Soviet Asks U.N. to Bar Intrusion by Satellite TV

By HEDRICK SMITH

Special to The New York Times

MOSCOW, Aug. 10—The Soviet Union today proposed an international convention to prevent nations from directing television broadcasts from satellites to private homes in other countries without the countries' express consent.

The Soviet press agency,

banned. In case of violations, the Soviet proposal would grant the aggrieved nation the right of unspecified countermeasures.

The Soviet proposal was seen as an effort to head off future use by such ideological rivals as the United States or China

"One article appeared to give countries the right to jam electronically satellite relay transmissions - which would be relatively easy to do" - NYT; Aug 11, 1972

April 27, 1986: Captain Midnight Incident

SEC. 303. INTERFERENCE WITH THE OPERATION OF A SATELLITE.

(a) OFFENSE.—Chapter 65 of title 18, United States Code, is amended by inserting at the end the following:

18 USC 1367.

"§ 1367. Interference with the operation of a satellite

"(a) Whoever, without the authority of the satellite operator, intentionally or maliciously interferes with the authorized operation of a communications or weather satellite or obstructs or hinders any satellite transmission shall be fined in accordance with this title or imprisoned not more than ten years or both.

"(b) This section does not prohibit any lawfully authorized investigative, protective, or intelligence activity of a law enforcement agency or of an intelligence agency of the United States."

October 21, 1986

Captain Midnight Attack
Early instance of satellite signal hijacking by an individual hacker.

1986

And so it begins…

Captain Midnight Attack
Early instance of satellite signal hijacking by an individual hacker.

1986

2002

Falun Gong Piracy Incidents
Early example of non-state actor engaged in satellite signal piracy.

Banned Falun Gong Movement Jammed Chinese Satellite Signal

By Philip P. Pan
Washington Post Foreign Service

BEIJING, July 8—The banned Falun Gong spiritual movement jammed one of China's main television satellites for eight days and briefly beamed a video into millions of homes during last month's World Cup soccer finals, the government said today.

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Chinese officials declined to say how many people were affected, but Sinosat-1 is central to a project launched in 1998 to expand TV access to the nation's most remote regions. More than 70 million people in 100,000 villages rely on it, according to the government.

The government said frequent interference with its broadcasts continued until June 30, but

And so it begins...

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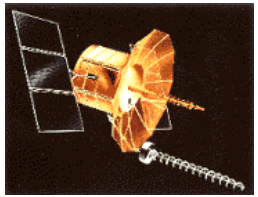
Early instance of satellite signal hijacking by an individual hacker.



“Bolinha” Piracy Incident
Brazil cracks down on truckers hijacking US military FLTSAT-8 transponders for long-range comms.

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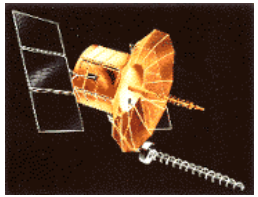

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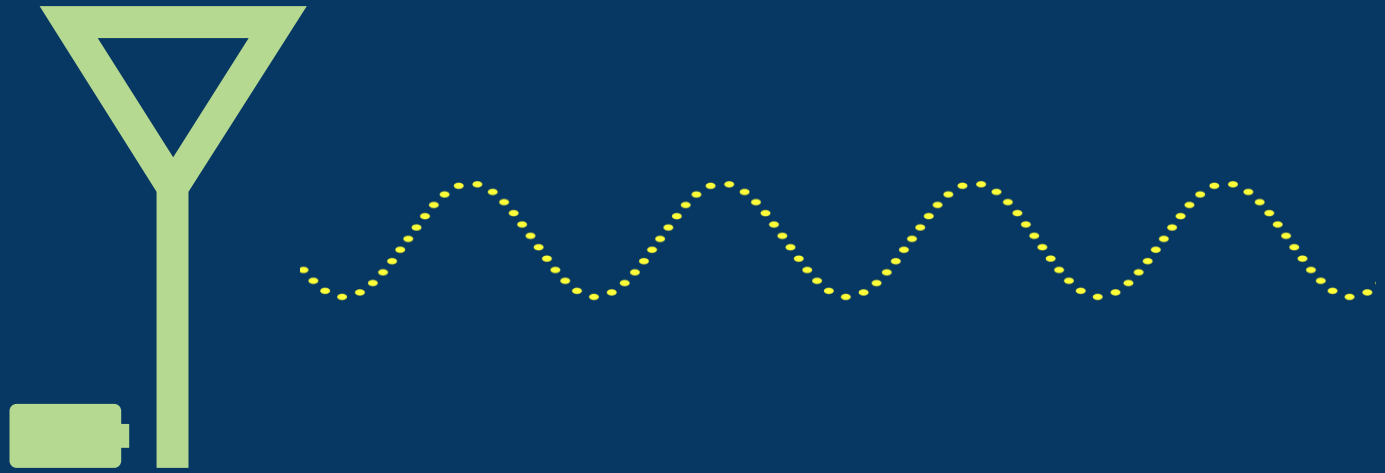
***Trident Juncture* GPS Interference**
Norway and Finland accuse Russia of emitting GPS jamming signals from Kola Peninsula during joint military exercises.

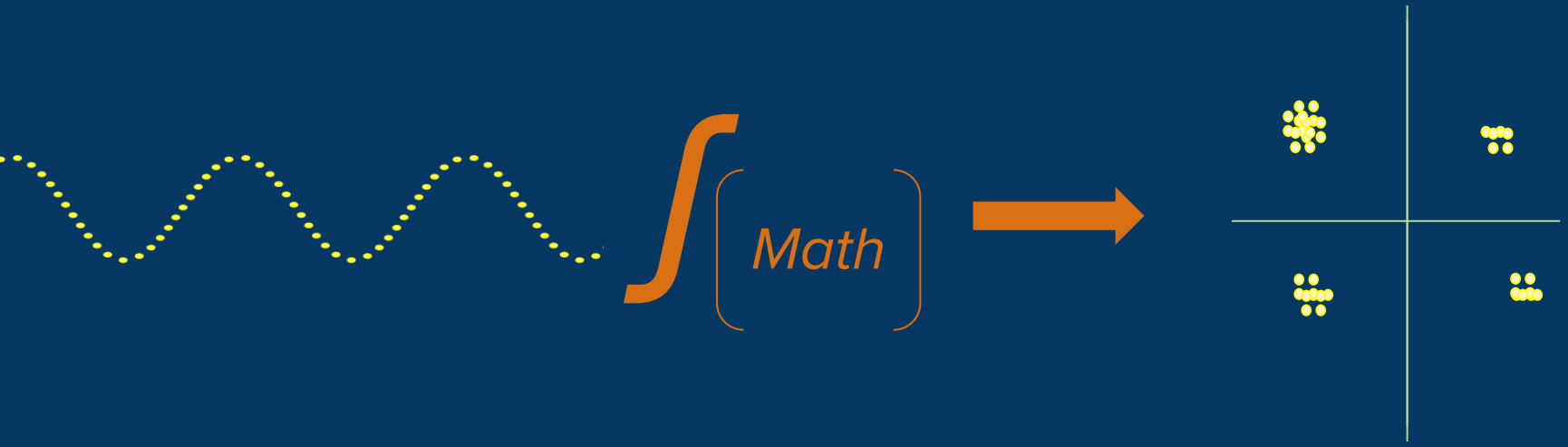
And so it begins…

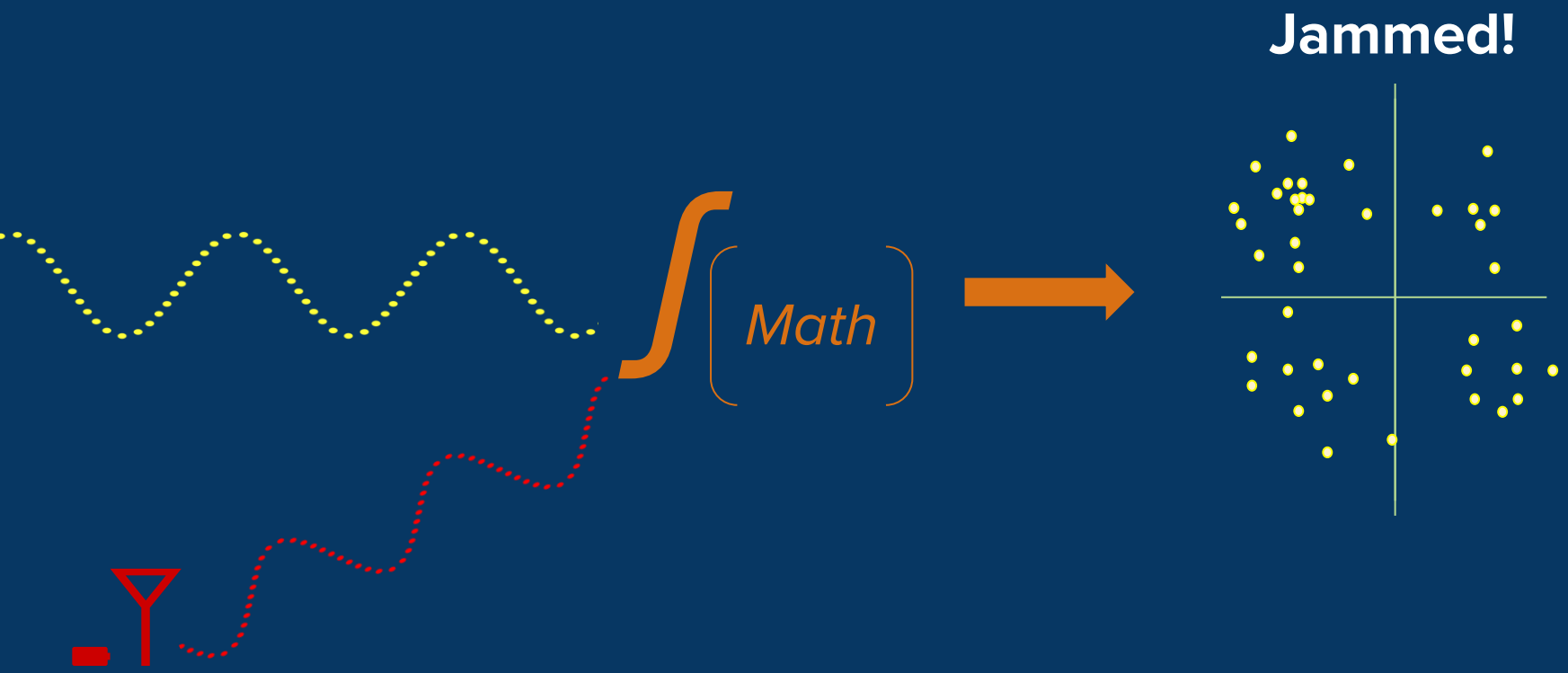
How?

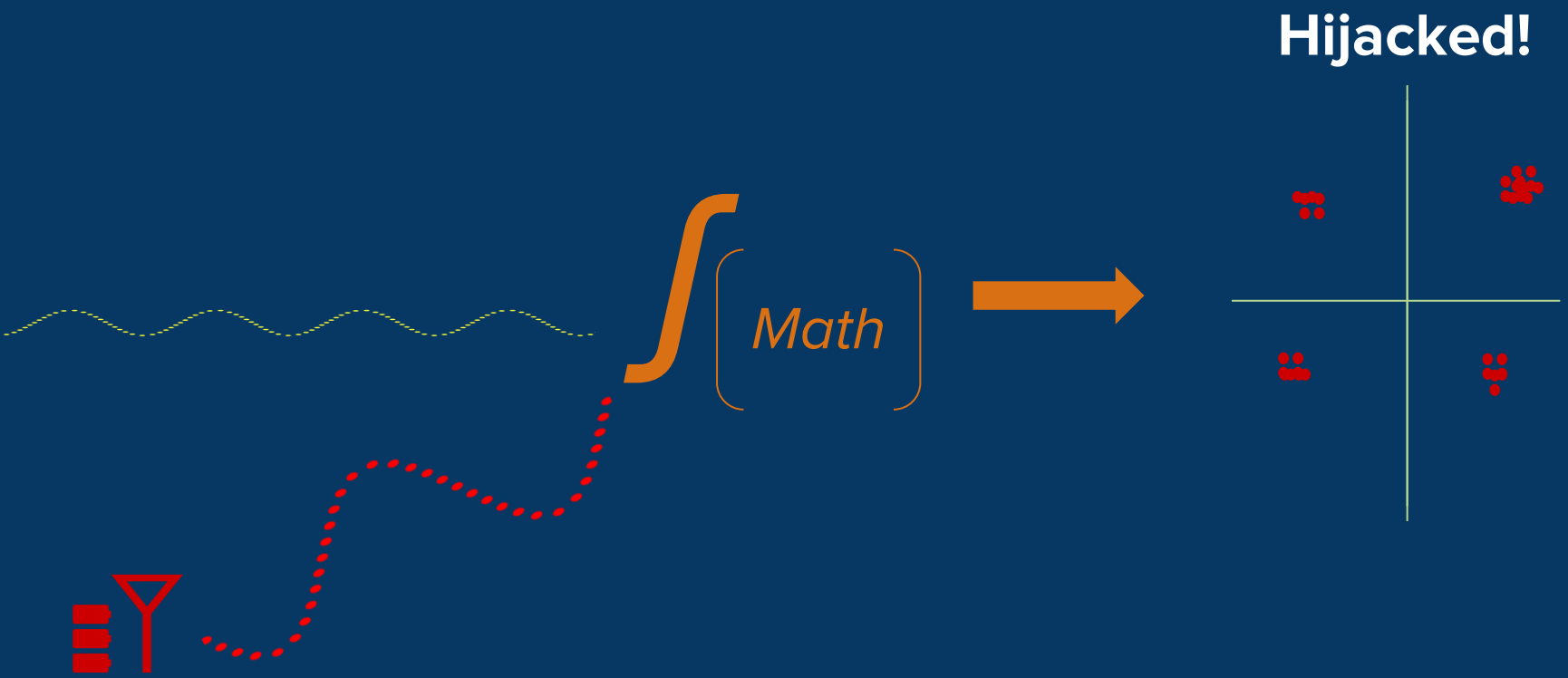
A *Very* Short Introduction to Radio Interference



Math


Math


Jammed!
Math


Hijacked!
Math

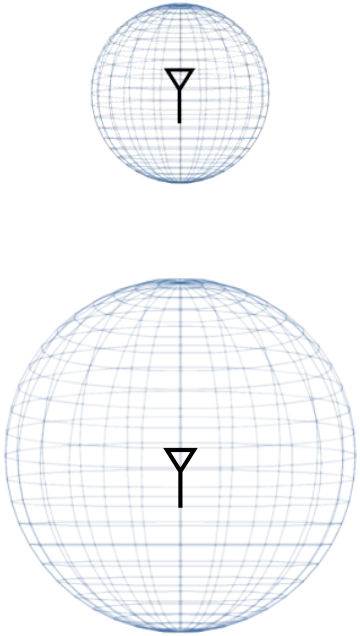
What’s Special About Satellites?

Free Space Path Loss

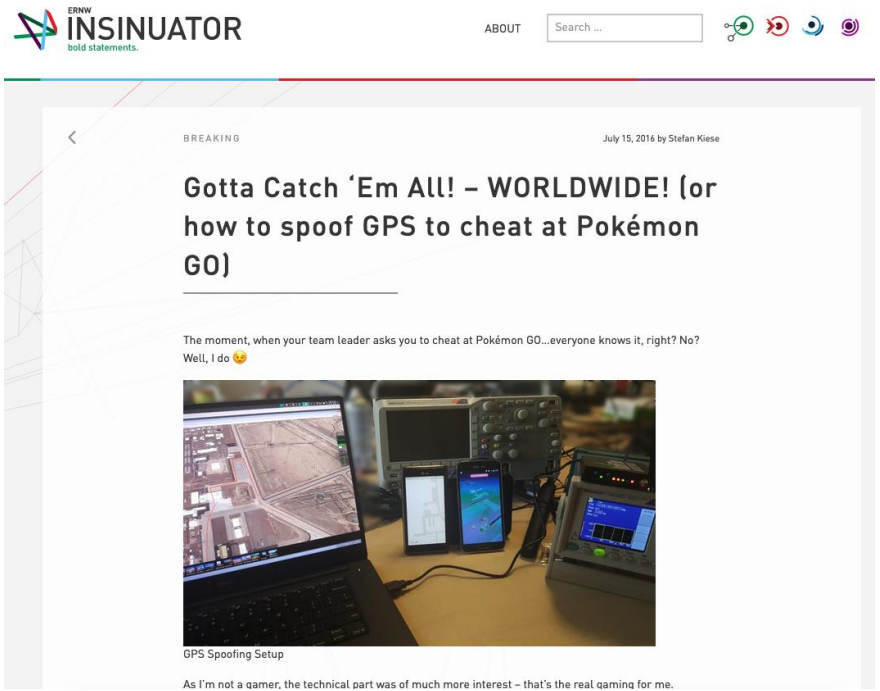
$$\left(\frac{4 * \pi * distance}{wavelength}\right)^2$$

Free Space Path Loss

$$\left(\frac{4 * \pi * distance}{wavelength}\right)^{2}$$



How is this possible?



ERNW INSINUATOR bold statements.

ABOUT Search ...

BREAKING

July 15, 2016 by Stefan Kiese

Gotta Catch 'Em All! – WORLDWIDE! (or how to spoof GPS to cheat at Pokémon GO)

The moment, when your team leader asks you to cheat at Pokémon GO…everyone knows it, right? No? Well, I do 😉

GPS Spoofing Setup

As I'm not a gamer, the technical part was of much more interest – that's the real gaming for me.

https://insinuator.net/2016/07/gotta-catch-em-all-worldwide-or-how-to-spoof-gps-to-cheat-at-pokemon-go/

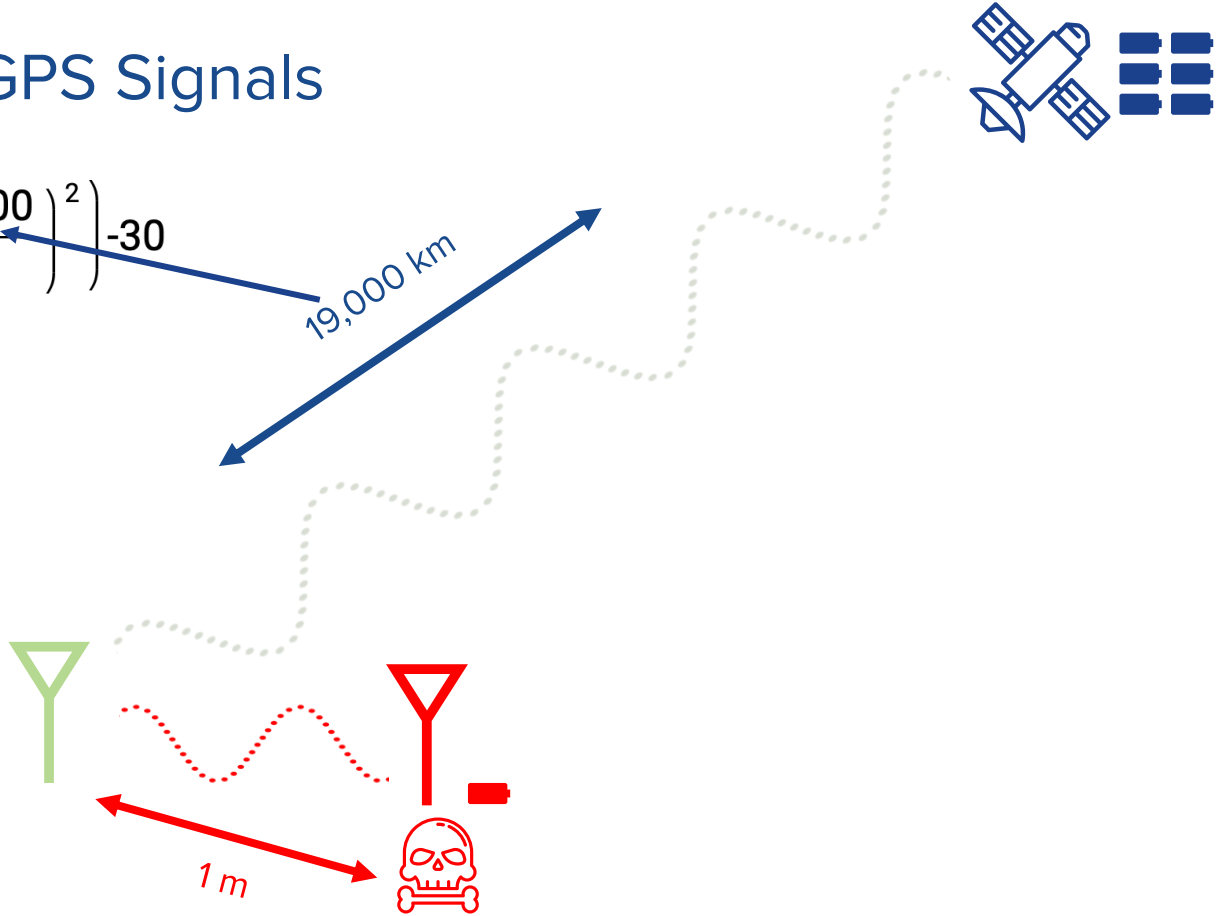
FSPL -> Weak GPS Signals

$$26.5-10*\log_{10}\left(\left(\frac{4*\pi*19000}{0.19}\right)^2\right)-30$$

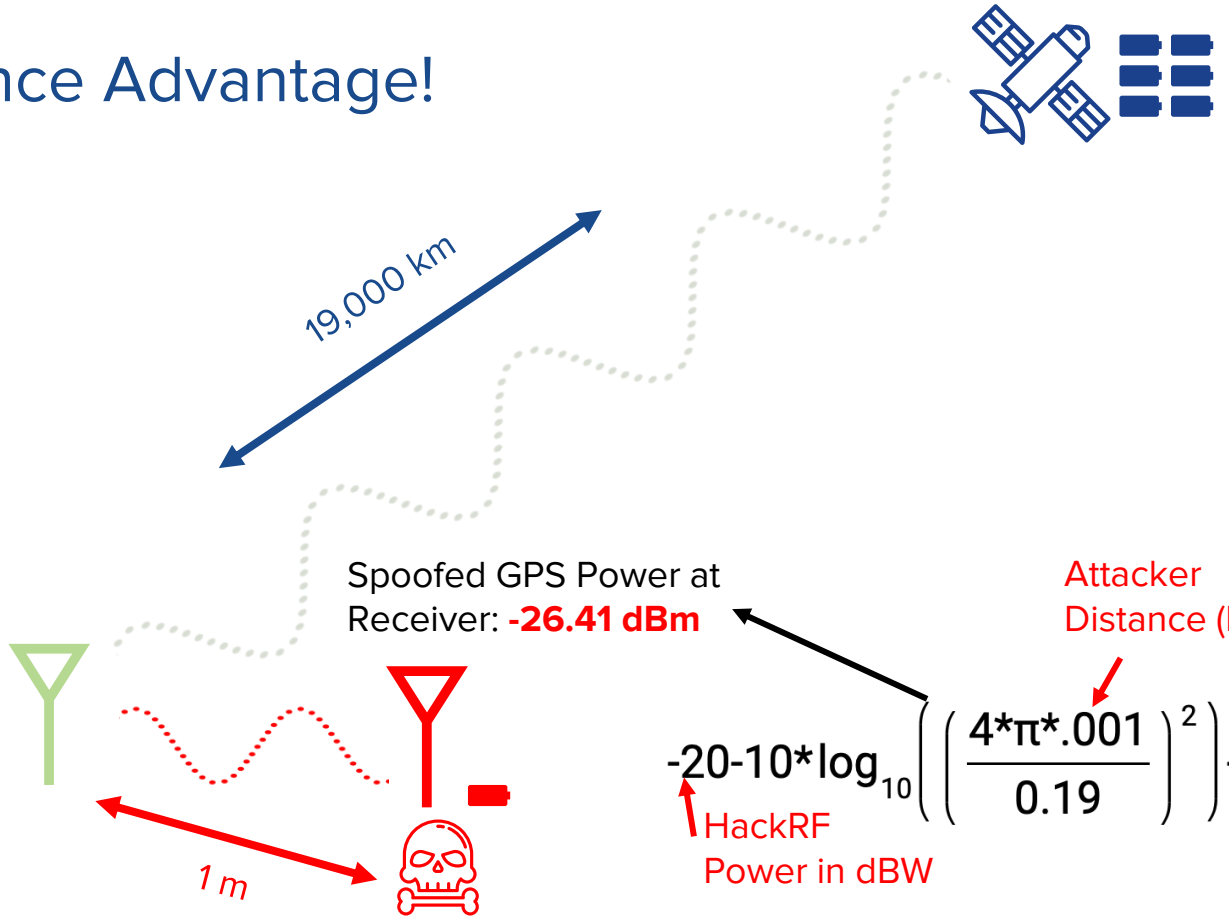
GPS Satellite
Power in dBW

19,000 km

Legit GPS Power at
Receiver: **-125.48 dBm**



Use That Distance Advantage!



Legit GPS Power at Receiver: **-125.48 dBm**

Spoofed GPS Power at Receiver: **-26.41 dBm**

Attacker Distance (km)

$$-20-10*\log_{10}\left(\left(\frac{4*\pi*.001}{0.19}\right)^2\right)-30$$

HackRF Power in dBW

Example: GPS Interference

Example: GPS Interference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Université Grenoble Alpes
НИИЯФ МГУ
SPACEPHARMA
simply microgravity
TALLINN UNIVERSITY OF TECHNOLOGY
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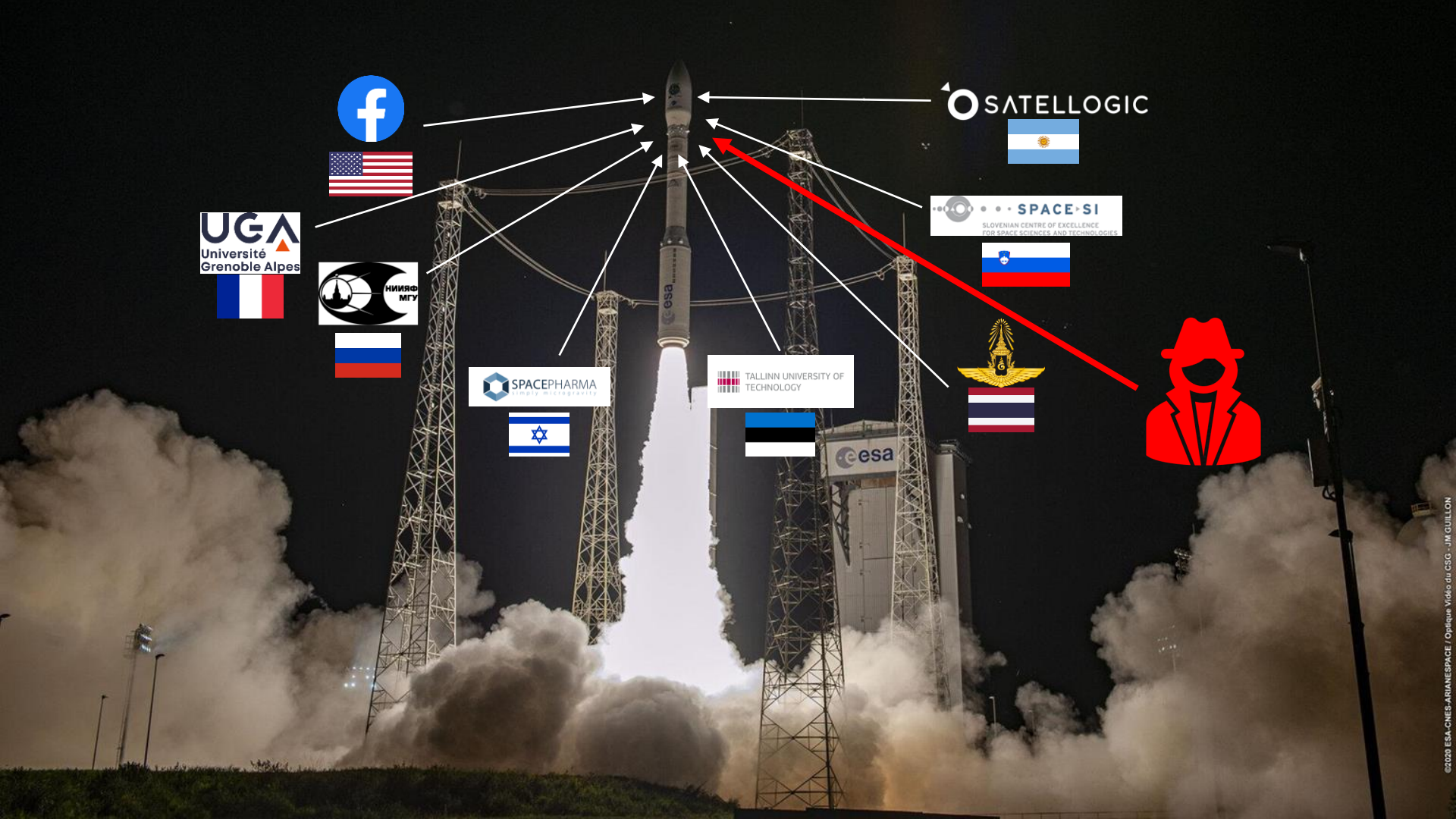
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Surely There are Rules?

CubeSat Design Specification Rev. 13
The CubeSat Program, Cal Poly SLO

	Document Classification
X	Public Domain
	ITAR Controlled
	Internal Only

CubeSat Design Specification

(CDS)
REV 13

CUBESAT
California Polytechnic State University

CubeSat Design Specification (CDS)

BY ORDER OF THE COMMANDER AIR FORCE SPACE COMMAND

AIR FORCE SPACE COMMAND MANUAL 91-710, VOLUME 3

15 MAY 2019

Safety

RANGE SAFETY USER REQUIREMENTS MANUAL VOLUME 3 – LAUNCH VEHICLES, PAYLOADS, AND GROUND SUPPORT SYSTEMS REQUIREMENTS

COMPLIANCE WITH THIS PUBLICATION IS MANDATORY

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Certified by: HQ AFSPC/SEK (Lt Col Daniel J. Wheeler)

Supersedes: AFSPCMAN91-710V3, 1 JULY 2004

Pages: 240

This manual implements Department of Defense Directive (DoDD) 3100.10, *Space Policy*, DoDD 3200.11, *Major Range and Test Facility Base*, DoDD 3230.3, *DoD Support for Commercial Space Launch Activities*, Air Force Policy Directive (AFPD) 91-1, *Nuclear Weapons and Systems Surety*, AFPD 91-2, *Safety Programs*, AFI 91-202, *The US Air Force Mishap Prevention Program* and the *Memorandum of Agreement between the Department of the Air Force and the Federal Aviation Administration on Safety for Space Transportation and Range Activities*. This volume contains information previously found in Eastern and Western Range 127-1, Chapter 3, *Launch Vehicle, Payload, and Ground Support Equipment Documentation, Design, and Test Requirements*. It establishes the system safety program requirements, minimum design, test, inspection, hazard analyses, and data requirements for hazardous and safety critical launch vehicles, payloads, and ground support equipment, systems,

AFSPCMAN 91-710 V3

Safety Controls

Safety Control	Primary Reference
Deployment switches prevent power-on in deployer	CDS 3.3
Software timers prevent RF transmission for 45 minutes	CDS 3.4
Battery power limitation	CDS 3.1
Software Safety Guidance	AFSPCMAN A2.2.4.14
RF Emission Compatibility	AFSPCMAN A2.2.4.10.2, Launch Vehicle User's Guide

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Let’s Break Some Rules…

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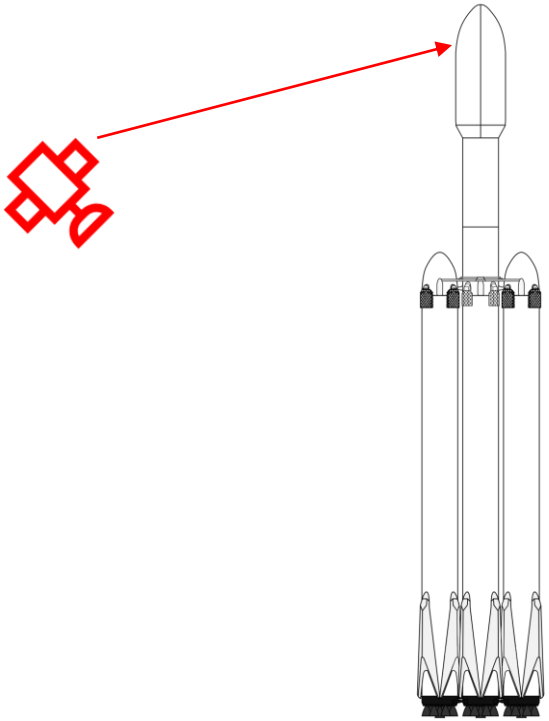
Attack Simulation

1 Integrate Malicious CubeSat On To Target Mission

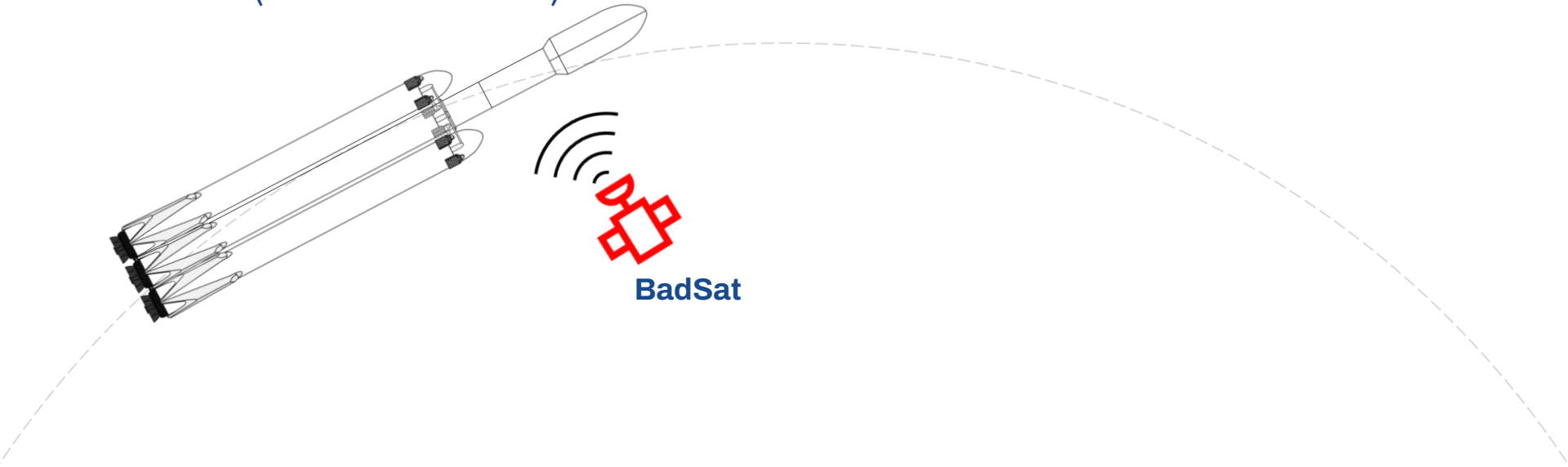
BadSat Requirements		
Size & Weight	Relevant RF Range	Attacker RF Tx Power
3U, 4kg	1.1–1.6 GHz (SDR)	1 – 10 W



Attack Simulation

2

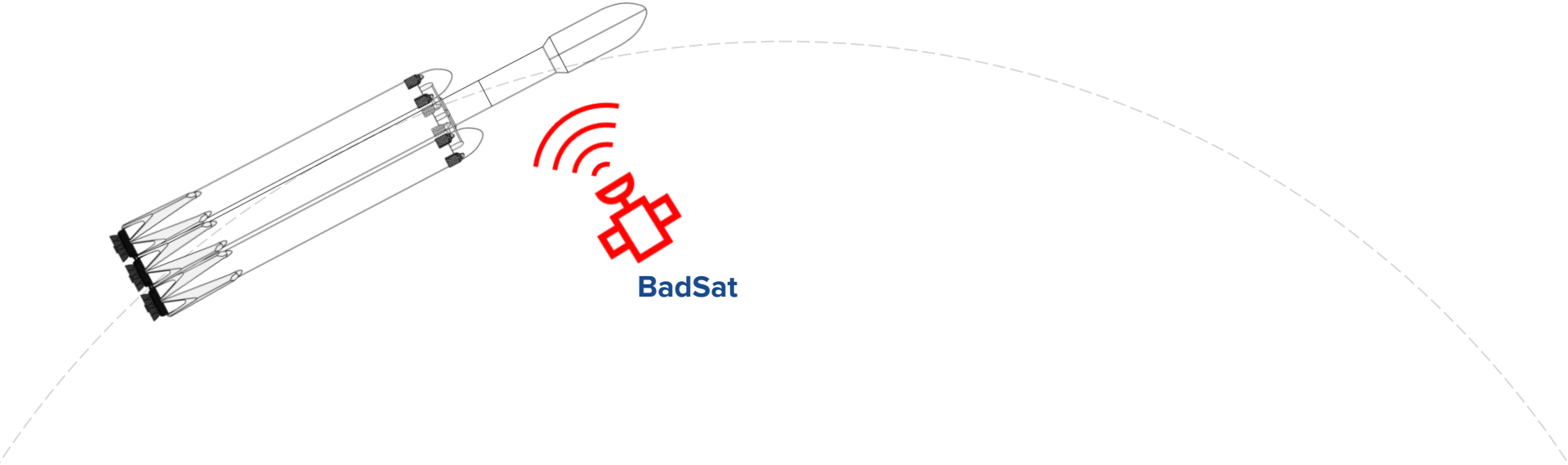
Power On CubeSat Radio Immediately After Deployment from LV (Violates CDS 3.4)



Attack Simulation

3

Transmit Interference at 1575.42 MHz to Jam GPS Reception (Violates AFSPCMAN A2.2.4.10.2)



Attack Simulation

4 Profit???

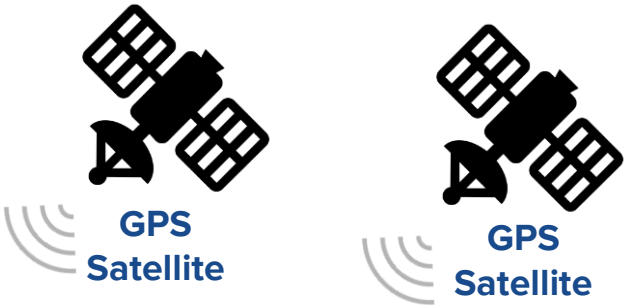
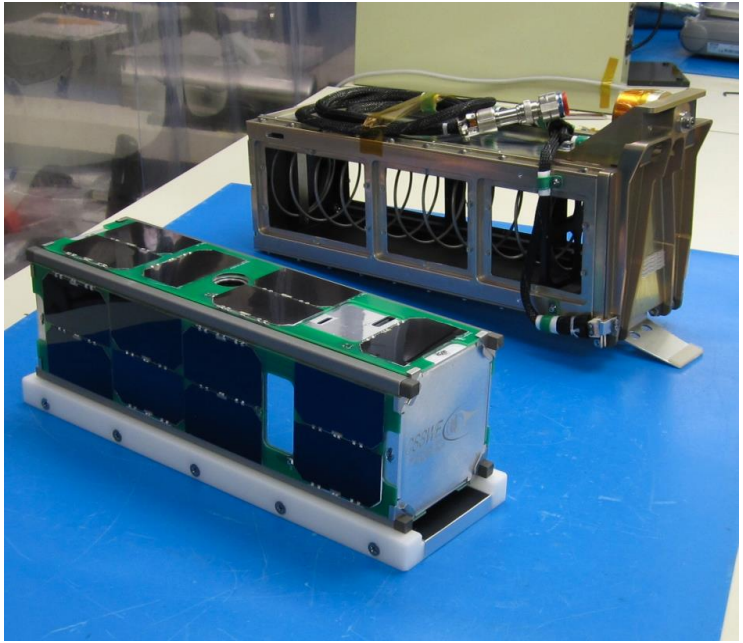
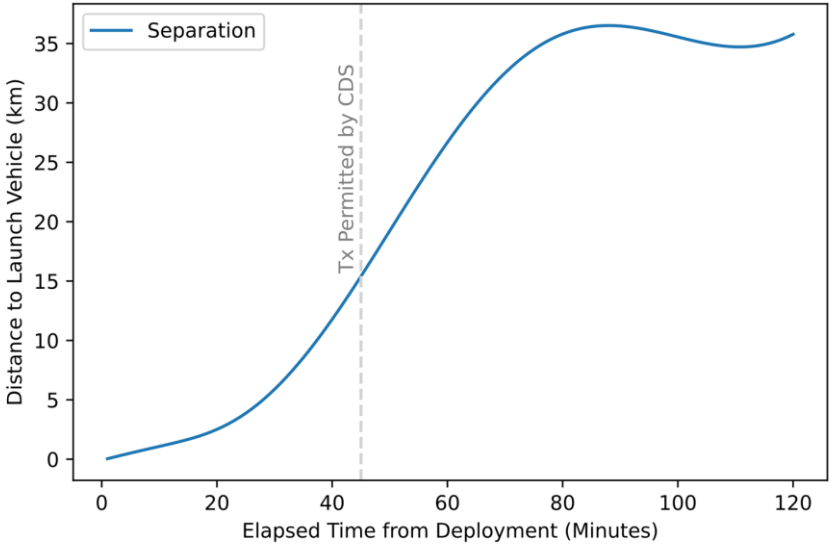


Image: Autonomous Flight Termination System, NASA, https://flightopportunities.nasa.gov/technologies/165/

Separation Model



CubeSat Separation over Time



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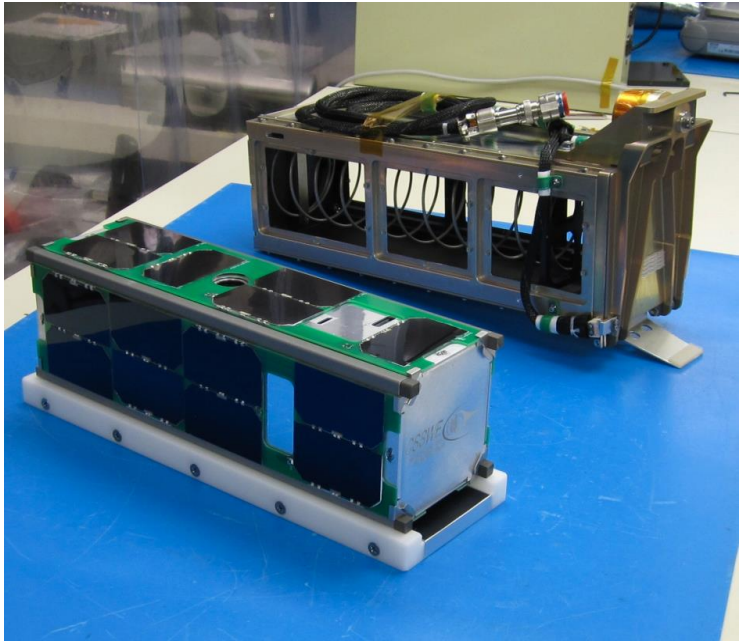

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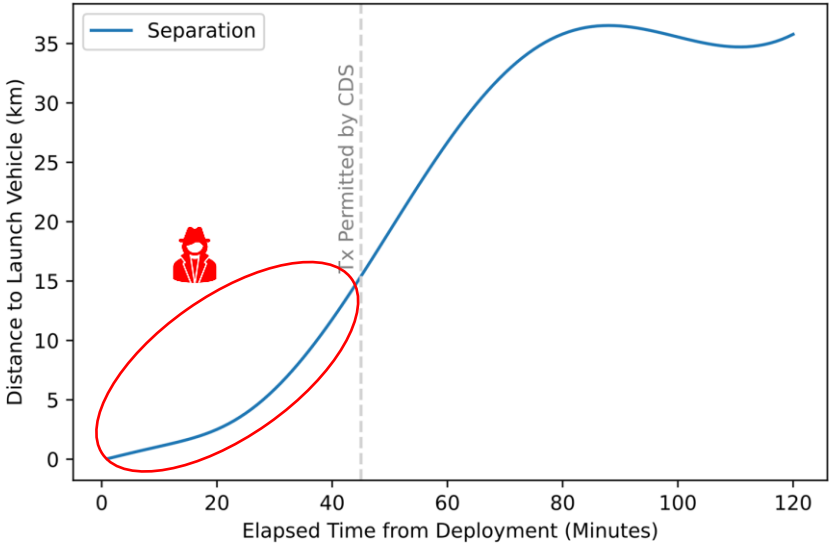
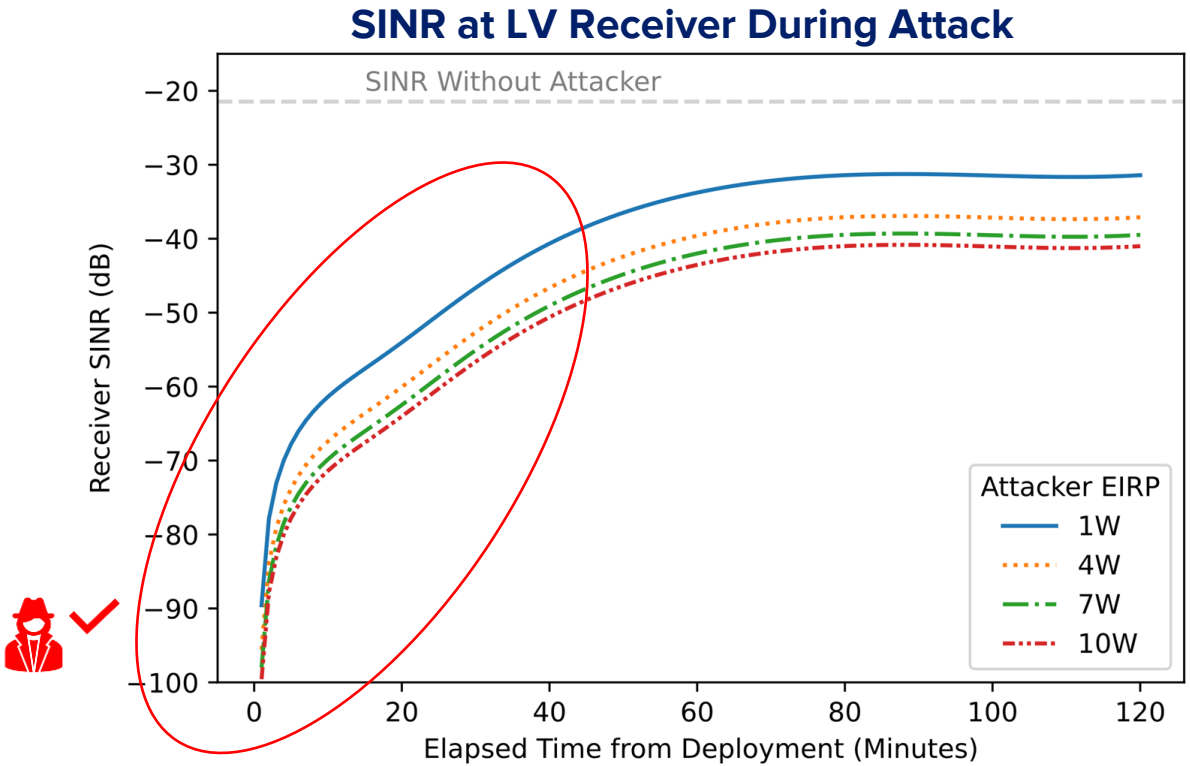


Reception Quality Model



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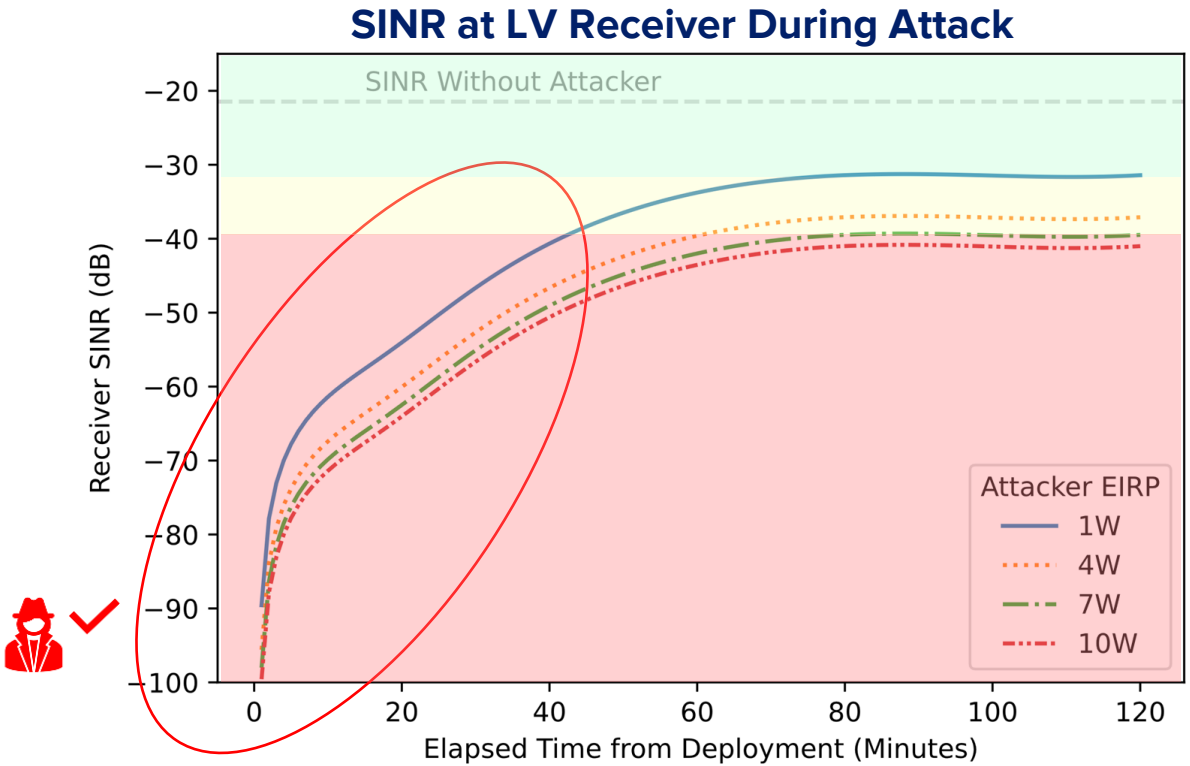
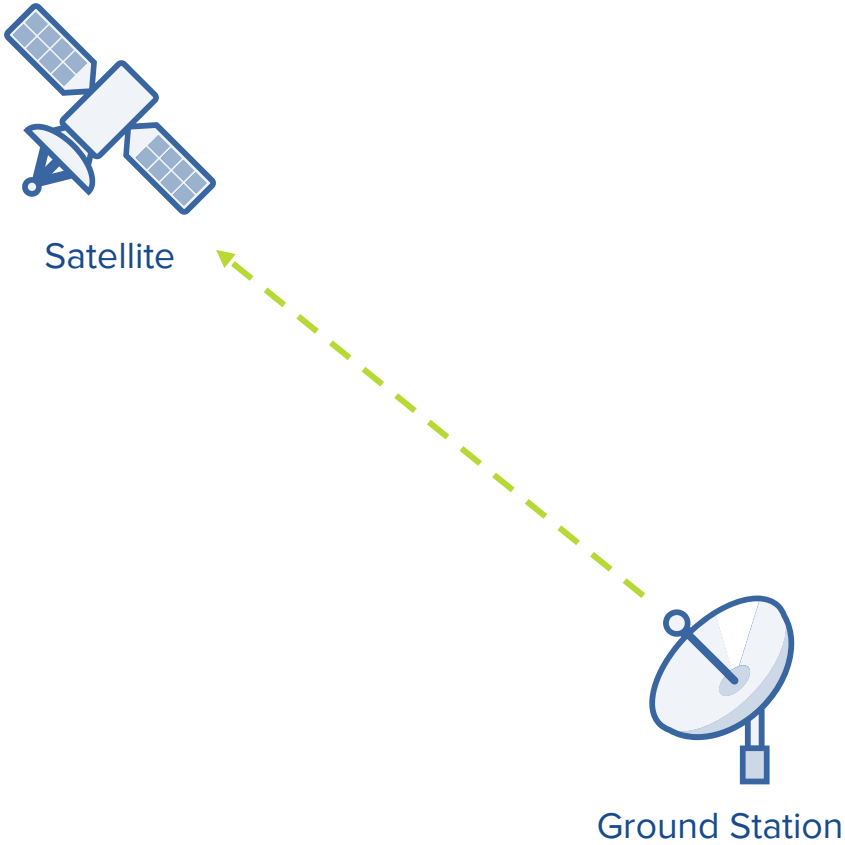


Example: Signal Hijacking

How (*most*) Broadcast Satellites Work

Ground Station

How (*most*) Broadcast Satellites Work



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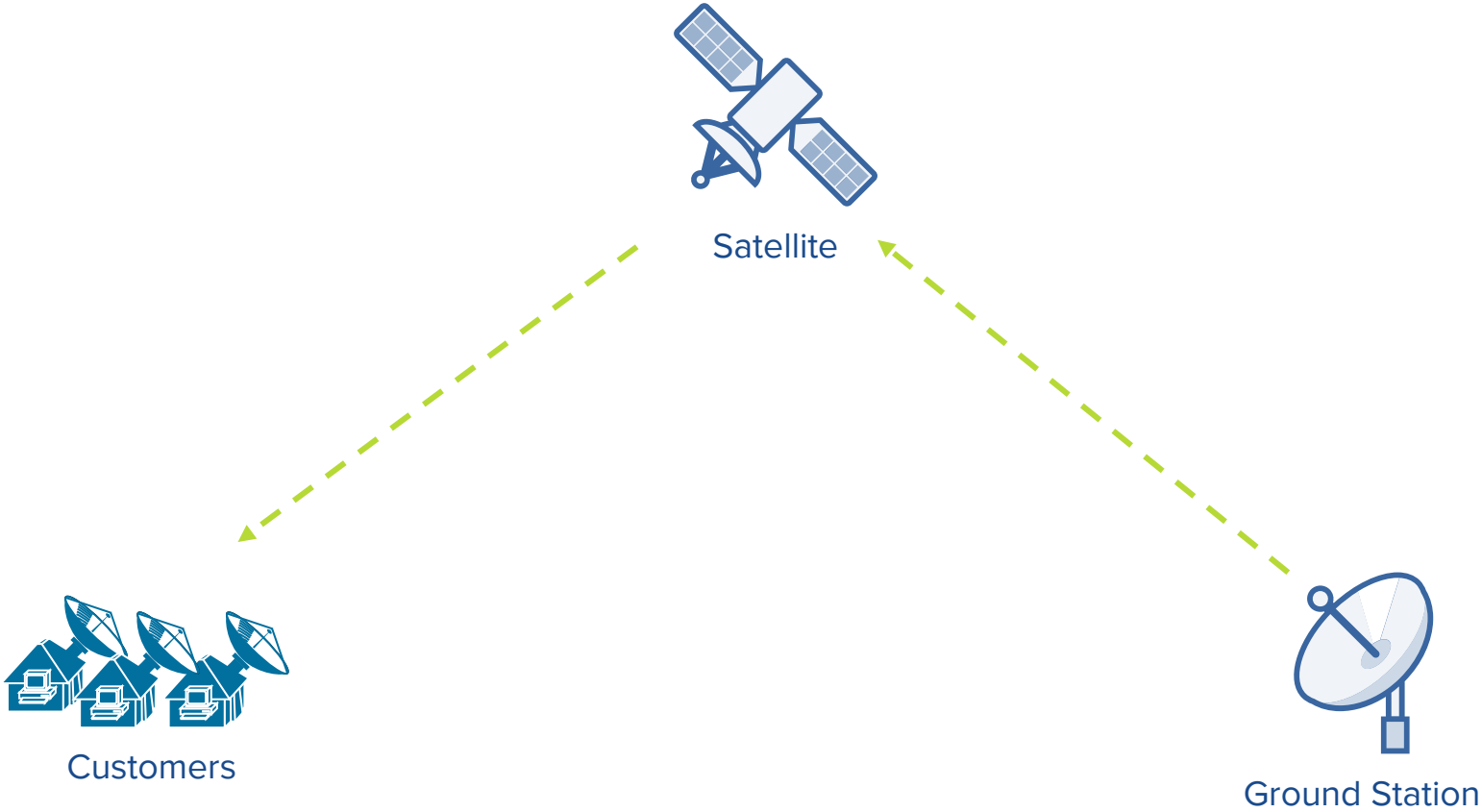

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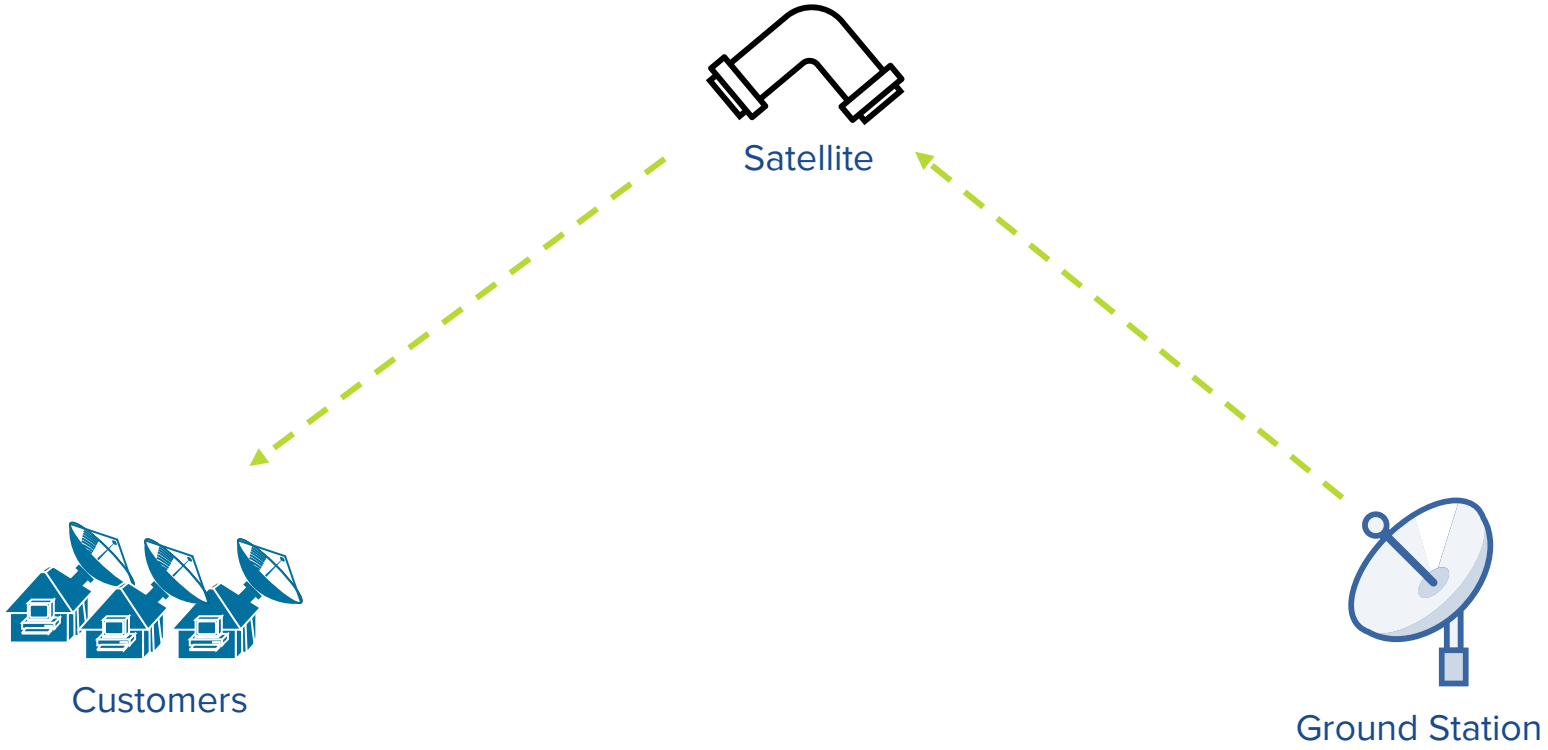
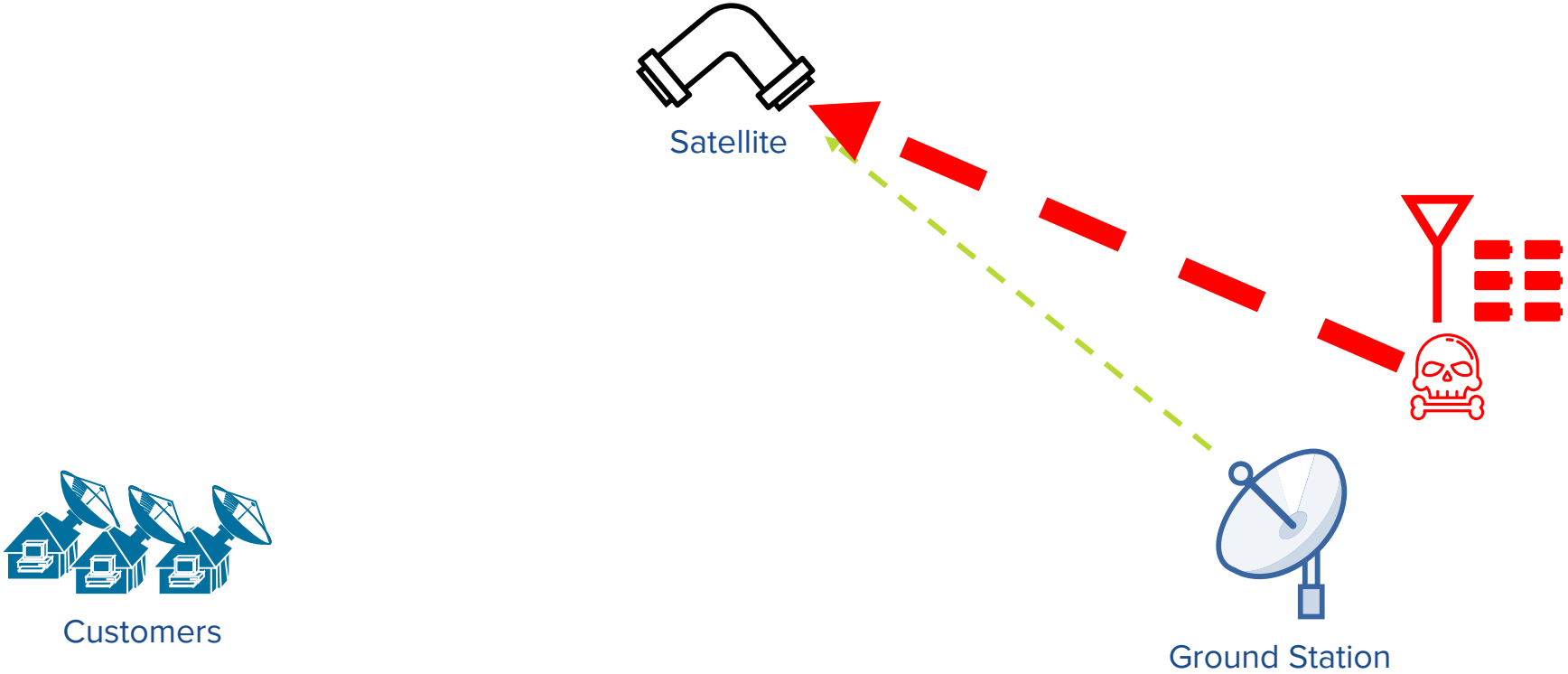


Signal Piracy Attack



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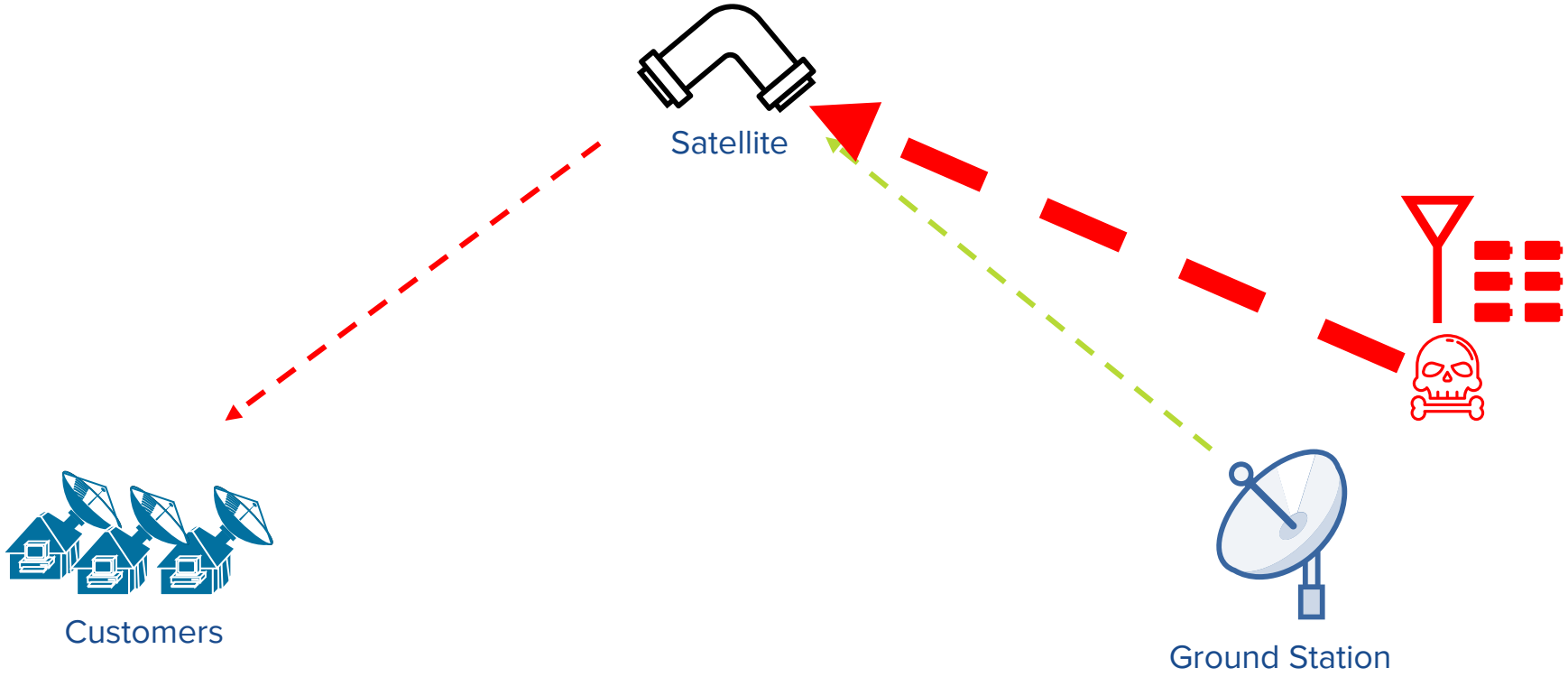


SATELLITE JAMMING SIMULATOR

Current Target: STARLINK-61

Time: 2022-07-07 00:03:10

Simulation Settings

Target Satellite

Search for a Satellite...

Simulation Period

7/7/2022 12:00 AM - 7/8/2022 12:00 AM

Simulation Step Size: 10s

Attacker

Satellite Not Visible

Jammer Coordinates

30° 00′ 00″ N 090° 00′ 00″ W

Attacker EIRP: 0 dBm

Defender

Satellite Not Visible

Ground Station Coordinates

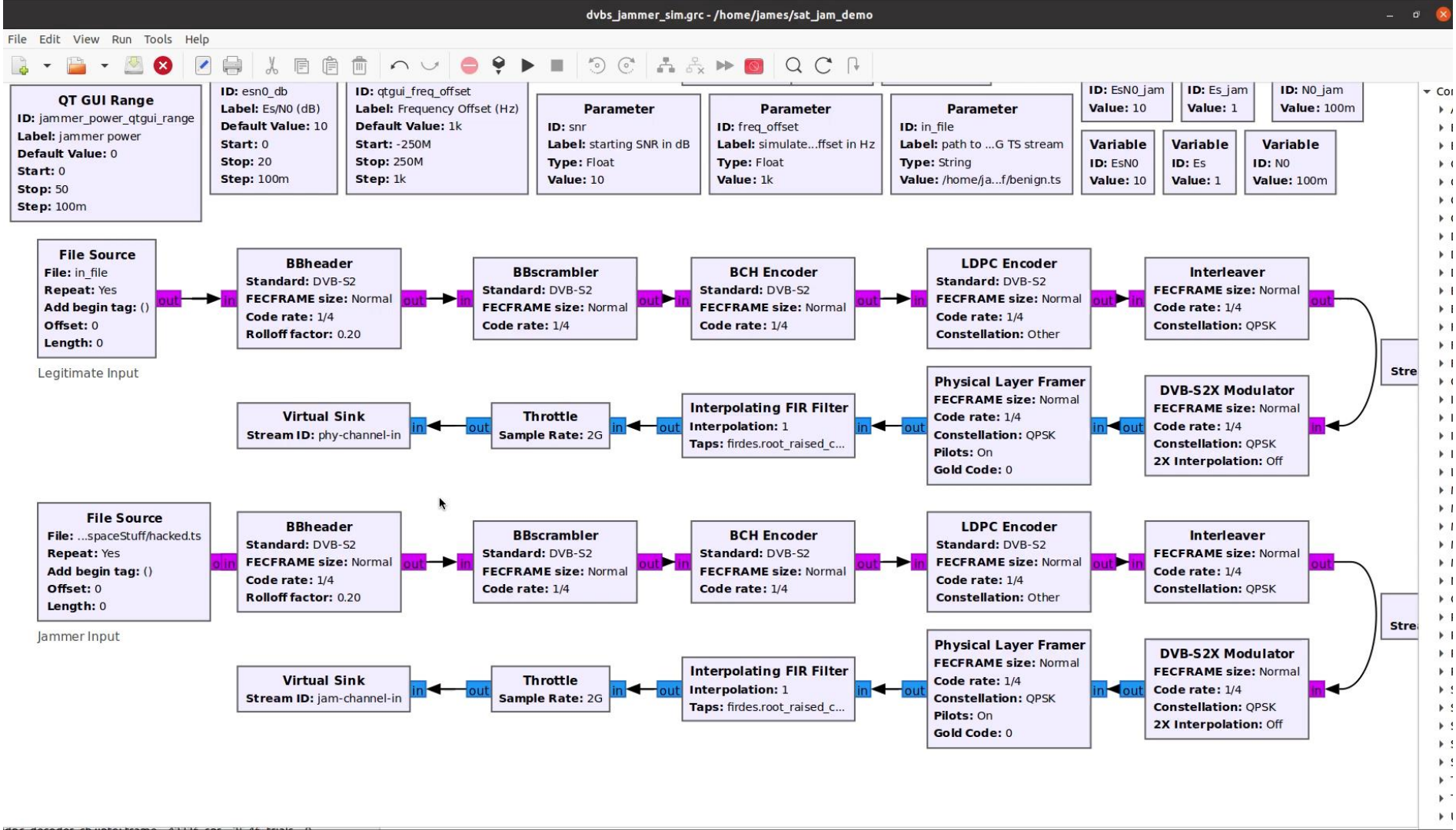
28° 34′ 24″ N 080° 39′ 03″ W

Defender EIRP: 30 dBm

SATELLITE OUT OF RANGE

SINR @ Target: -Infinity dB

SINR (Clear) @ Target: -Infinity dB


dvbs_jammer_sim.grc - /home/james/sat_jam_demo
File Edit View Run Tools Help
QT GUI Range
ID: jammer_power_qtgui_range
Label: jammer power
Default Value: 0
Start: 0
Stop: 50
Step: 100m
ID: esn0_db
Label: Es/N0 (dB)
Default Value: 10
Start: 0
Stop: 20
Step: 100m
ID: qtgui_freq_offset
Label: Frequency Offset (Hz)
Default Value: 1k
Start: -250M
Stop: 250M
Step: 1k
Parameter
ID: snr
Label: starting SNR in dB
Type: Float
Value: 10
Parameter
ID: freq_offset
Label: simulate...ffset in Hz
Type: Float
Value: 1k
Parameter
ID: in_file
Label: path to ...G TS stream
Type: String
Value: /home/ja...f/benign.ts
ID: EsN0_jam
Value: 10
ID: Es_jam
Value: 1
ID: N0_jam
Value: 100m
Variable
ID: EsN0
Value: 10
Variable
ID: Es
Value: 1
Variable
ID: N0
Value: 100m
File Source
File: in_file
Repeat: Yes
Add begin tag: ()
Offset: 0
Length: 0
Legitimate Input
BBheader
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
Rolloff factor: 0.20
BBscrambler
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
BCH Encoder
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
LDPC Encoder
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
Constellation: Other
Interleaver
FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
Physical Layer Framer
FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
Pilots: On
Gold Code: 0
DVB-S2X Modulator
FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
2X Interpolation: Off
Interpolating FIR Filter
Interpolation: 1
Taps: firdes.root_raised_c...
Throttle
Sample Rate: 2G
Virtual Sink
Stream ID: phy-channel-in
File Source
File: ...spaceStuff/hacked.ts
Repeat: Yes
Add begin tag: ()
Offset: 0
Length: 0
Jammer Input
BBheader
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
Rolloff factor: 0.20
BBscrambler
Standard: DVB-S2
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Code rate: 1/4
LDPC Encoder
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
Constellation: Other
Interleaver
FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
Physical Layer Framer
FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
Pilots: On
Gold Code: 0
DVB-S2X Modulator
FECFRAME size: Normal
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2X Interpolation: Off
Interpolating FIR Filter
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Taps: firdes.root_raised_c...
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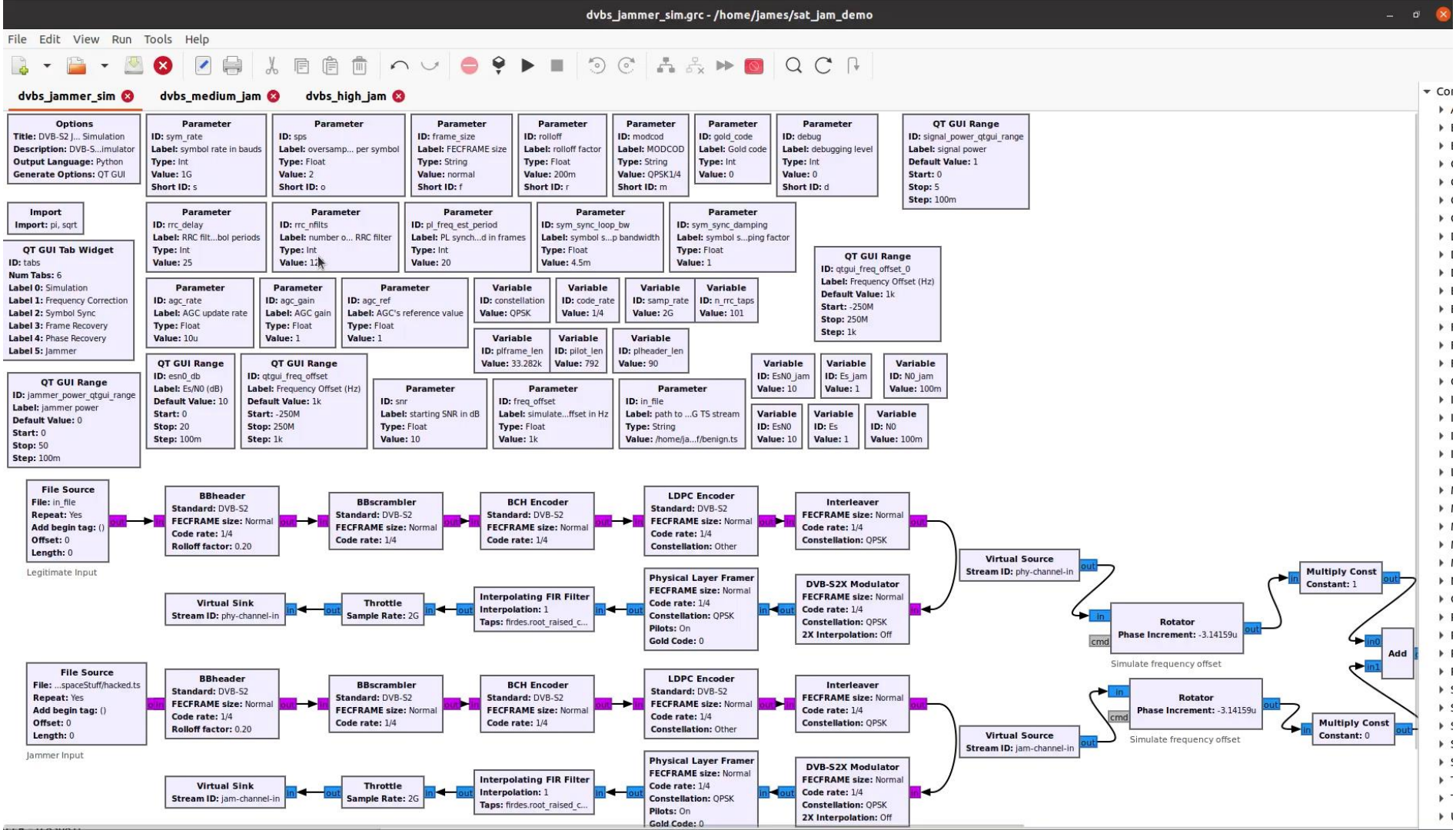
Virtual Sink
Stream ID: jam-channel-in


dvbs_jammer_sim.grc - /home/james/sat_jam_demo
File Edit View Run Tools Help
dvbs_jammer_sim
dvbs_medium_jam
dvbs_high_jam
Options
Title: DVB-S2 J... Simulation
Description: DVB-S...imulator
Output Language: Python
Generate Options: QT GUI
Parameter
ID: sym_rate
Label: symbol rate in bauds
Type: Int
Value: 1G
Short ID: s
Parameter
ID: sps
Label: oversamp... per symbol
Type: Float
Value: 2
Short ID: o
Parameter
ID: frame_size
Label: FECFRAME size
Type: String
Value: normal
Short ID: f
Parameter
ID: rolloff
Label: rolloff factor
Type: Float
Value: 200m
Short ID: r
Parameter
ID: modcod
Label: MODCOD
Type: String
Value: QPSK1/4
Short ID: m
Parameter
ID: gold_code
Label: Gold code
Type: Int
Value: 0
Parameter
ID: debug
Label: debugging level
Type: Int
Value: 0
Short ID: d
QT GUI Range
ID: signal_power_qtgui_range
Label: signal power
Default Value: 1
Start: 0
Stop: 5
Step: 100m
Import
Import: pi, sqrt
Parameter
ID: rrc_delay
Label: RRC filt...bol periods
Type: Int
Value: 25
Parameter
ID: rrc_nfilts
Label: number o... RRC filter
Type: Int
Value: 12
Parameter
ID: pl_freq_est_period
Label: PL synch...d in frames
Type: Int
Value: 20
Parameter
ID: sym_sync_loop_bw
Label: symbol s...p bandwidth
Type: Float
Value: 4.5m
Parameter
ID: sym_sync_damping
Label: symbol s...ping factor
Type: Float
Value: 1
QT GUI Tab Widget
ID: tabs
Num Tabs: 6
Label 0: Simulation
Label 1: Frequency Correction
Label 2: Symbol Sync
Label 3: Frame Recovery
Label 4: Phase Recovery
Label 5: Jammer
QT GUI Range
ID: qtgui_freq_offset_0
Label: Frequency Offset (Hz)
Default Value: 1k
Start: -250M
Stop: 250M
Step: 1k
Parameter
ID: agc_rate
Label: AGC update rate
Type: Float
Value: 10u
Parameter
ID: agc_gain
Label: AGC gain
Type: Float
Value: 1
Parameter
ID: agc_ref
Label: AGC's reference value
Type: Float
Value: 1
Variable
ID: constellation
Value: QPSK
Variable
ID: code_rate
Value: 1/4
Variable
ID: samp_rate
Value: 2G
Variable
ID: n_rrc_taps
Value: 101
Variable
ID: plframe_len
Value: 33.282k
Variable
ID: pilot_len
Value: 792
Variable
ID: plheader_len
Value: 90
QT GUI Range
ID: jammer_power_qtgui_range
Label: jammer power
Default Value: 0
Start: 0
Stop: 50
Step: 100m
QT GUI Range
ID: esn0_db
Label: Es/N0 (dB)
Default Value: 10
Start: 0
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QT GUI Range
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Value: /home/ja...f/benign.ts
Variable
ID: EsN0_jam
Value: 10
Variable
ID: Es_jam
Value: 1
Variable
ID: N0_jam
Value: 100m
Variable
ID: EsN0
Value: 10
Variable
ID: Es
Value: 1
Variable
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Value: 100m
File Source
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Repeat: Yes
Add begin tag: ()
Offset: 0
Length: 0
Legitimate Input
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Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
BCH Encoder
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
LDPC Encoder
Standard: DVB-S2
FECFRAME size: Normal
Code rate: 1/4
Constellation: Other
Interleaver
FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
Virtual Source
Stream ID: phy-channel-in
Multiply Const
Constant: 1
Rotator
Phase Increment: -3.14159u
Simulate frequency offset
Add
Virtual Sink
Stream ID: phy-channel-in
Throttle
Sample Rate: 2G
Interpolating FIR Filter
Interpolation: 1
Taps: firdes.root_raised_c...
Physical Layer Framer
FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
Pilots: On
Gold Code: 0
DVB-S2X Modulator
FECFRAME size: Normal
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FECFRAME size: Normal
Code rate: 1/4
Constellation: QPSK
2X Interpolation: Off

What’s Next?

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Sophisticated
RFI Attacks

What’s Next?

Sophisticated
RFI Attacks

RFI Defenses
& Mitigations

What’s Next?

Sophisticated
RFI Attacks

RFI Defenses
& Mitigations

Detection &
Monitoring

What’s Next?

Sophisticated RFI Attacks

RFI Defenses & Mitigations

Detection & Monitoring

Policy & Norms

Key Takeaways

Space is Physical

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Space is Physical

Space Cyber != New

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Space Cyber != New

Space Needs YOU

Key Takeaways

Space is Physical

Space Cyber != New

Space Needs YOU

Questions/Ideas?

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Twitter: @jamespavur

Resources & Further Reading

https://github.com/deptofdefense/dds-at-DEFCON

Jobs

https://www.dds.mil/join

Other DEFCON Stuff to Check Out

Kosher & Green - HACK THE HEMISPHERE
Wouters - Glitched on Earth
Aerospace Village
ICS Village