Early Experiences Employing the Matrix Principles Modified for the Communications and Electronics Domain

Nasir Ayub[1] and Paul Filmore[2]

[1] MSc student, School of Computing Communication and Electronics, University of Plymouth, UK
[2] School of Computing Communication and Electronics, University of Plymouth, UK

Abstract

Different authors have developed examples of the TRIZ Principles in a number of domains ranging from finance to microelectronics. To the authors' knowledge, no one has attempted to develop examples for the 40 Principles in the electronics and communications domain. Also past authors have seemed reluctant to explain how the examples were derived. This paper explains how the examples were obtained systematically by interviewing a number of domain specialists who knew little of TRIZ. In fact experience of trying to explain TRIZ before the knowledge capture phase, proved highly problematic and weakened the task focus. A condensed list of the 40 Principles is included.

Keywords

TRIZ Principles, Communications, Electronics, Knowledge capture.

1 INTRODUCTION

TRIZ is a collection of problem-solving methodologies and tools originally developed by Genrich Altshuller (October 15, 1926 - September 24, 1998) of Russia. He created the Teoriya Resheniya Izobreatatelskikh Zadatch, translated as the Theory of Inventive Problem Solving, or TRIZ. By examining hundreds of patents, Altshuller was able to describe a framework of system conflicts and resolutions. These conflicts and resolutions provide a method for creative problem solving originally based in the technology domain. The body of work surrounding Altshuller has grown to include a number of techniques that provide structured creativity for analysing and solving problems. [6]

For trained engineers, TRIZ offers the best of all worlds; the individual tools are straightforward, the problem-solving process is systematic and repeatable, and with an open mindset, the creative opportunities are excellent. Engineers appreciate TRIZ better than anyone else because there are engineering success case studies, and it is perhaps most highly developed and used in the engineering domain [7]. It is thus surprising that no one has developed Principles with examples in the communication and electronics engineering domain.

2 TRIZ AS PROBLEM SOLVING TOOL

In recent years TRIZ has evolved to be an effective tool for innovative problem solving. A number of people have attempted to develop examples of TRIZ Principles in different fields. Stephen Dourson's "The 40 Inventive Principles of TRIZ Applied to Finance" [1] provides a good method to develop TRIZ Principles for finance. Another paper by Gennady Retseptor "40 Inventive Principles in Microelectronics" [2] presents good examples of TRIZ Principles from microelectronics. This paper discusses the editor's experience as a TRIZ teacher and says that "most people need a mixture of examples from their own field and from others" to trigger their minds and become more creative in their own field. A different paper "Application of 40 Inventive Principles in Construction" by Abram Teplitskiy and Roustem Kourmaev [3] discusses examples from construction and associates them with the 40 Principles. They have followed the general method of using the 40 inventive Principles as described in the original work of G. Altshuller and taken examples from US patents, the Russian Federation patents, and from their inventing, consulting practice, and construction experiences. NB A useful summary of the Principles being adapted for different domains is given in the TRIZ Journal [8].

The motivation and ideas for this research come from Dr Paul Filmore's papers "Teaching TRIZ as a Systematic Problem Solving Method: Breaking Mindsets" [4] and "The Real World: TRIZ in Two Hours for Undergraduate and Masters Level Students!" [5] which discuss the history and evolution of TRIZ as an effective tool for innovative problem solving in light of some practical examples and case studies. The papers also highlight the importance of teaching TRIZ in modern academia and give an experience based guideline for teachers to motivate students to learn TRIZ in practical ways.

3 TRIZ FOR ELECTRONIC COMMUNICATION SYSTEMS

This work to find Inventive Principles in the communication and electronics domain formed the basis of an MSc project for one of the authors(1) as part of their MSc Communications Engineering and Signal Processing course. The students found the project of growing interest as they started to get into greater depth. Making use of simple tools to solve problems and the way TRIZ has already been used in other domains was found to be quite encouraging. Browsing through the TRIZ Journal and other electronic resources gives a good idea of the papers published about the applications of TRIZ in different domains like microelectronics, construction, finance, manufacturing etc [8]. However, the author(1) could not find any work specifically undertaken in the electronic communication domain which is probably the fastest growing industry in modern world. To obtain a well documented list of the 40 Principles (published here as an addendum), the authors discussed the Matrix and the Principles for practical work based problems, with groups of professional electronic/ communications engineers who knew little of TRIZ. The people selected for discussion are highly skilled professionals and engineering postgraduate students who fall into three groups:-

1. Teachers from the School of Computing Communication and Electronics at the University of Plymouth (10 people).

2. Postgraduate students at the University of Plymouth, Manchester University, University of Edinburgh, University of Trento, Italy, Oxford University and the Ghulam Ihsaq Khan Institute of Engineering Sciences and Technology, Pakistan (35 people).
3. Professionals and engineers working in telecom companies like Ericsson, Vodafone, Orange, Microsoft and Alcatel (26 people).

The papers published about TRIZ Principles for other domains were used initially to trigger ideas in translating the 40 Principles for the electronic and communication domain. The authors' method was to interview a number of people from the above categories and take their opinion about the topic. To achieve this, the author(1) started off with emails to different people asking for their time to interview and discuss the topic. The task seemed easy at first but got difficult and the authors had to discuss and come up with a modification in the knowledge acquisition method later.

4 THE 40 PRINCIPLES

The author(1) started off with the list of 40 Principles. The idea was to gather examples for each Principle in the electronics and communication domain. "The 40 innovative Principles of TRIZ applied to finance" [1] provided a fine guideline to gather examples for this purpose. A file folder with a section for each Principle was made. The author(1) had to gather examples and points from different people and note them in the file. By the end of interviews, the author would re-organise the points and place them in their respective categories. Starting with emails to different people (from the above three categories) who are directly or indirectly involved in the electronic communication technology but had little or no idea of TRIZ, the author interviewed them and asked for suggestions and feedback to translate the TRIZ Principles for electronic and communication systems. In fact experience of trying to explain TRIZ before the knowledge capture phase, proved highly problematic and weakened the task focus.

5 PROBLEMS IN GETTING IDEAS FOR TRIZ PRINCIPLES

The aim was to look at how TRIZ is used in other domains especially in engineering and, by keeping a reference sheet for each Principle, generalising each Principle according to the needs of electronics communication systems. A small presentation about the history of TRIZ and some application examples in other fields was sent via emails along with a questionnaire to different people related to communication engineering. Realising that many people do not spend enough time reading presentations sent via email, the author made the presentation very small. Some replies were received with questions about TRIZ because many did not understand the concept and thus could not answer the questionnaire. Making the presentation fully explanatory could have resulted in people not bothering to read it due to size and even then it would not be easy to get the concepts over by just going through the slides. Also the email replies came from very few of those emailed so the author decided to interview them personally. Emails were sent to those who were easily approachable and request made for appointments. This time the outcome was encouraging and the author was successful in getting times for discussion sessions with many of them. The author started with an interview of a staff member in the Faculty of Technology, University of Plymouth. Luckily most of the faculty members know about or at least are familiar with the name TRIZ since Dr. Paul Filmore has already done some work in this area. However some were not familiar with the concept. The interview appointment was for limited time so starting by explaining TRIZ first and getting their suggestions later did not help because the author(1) had to skip a lot of background information to meet the time restrictions. This caused problems in the sense that questions were raised about the origin and development of TRIZ before integrating it with electronic communication systems. To answer these questions the author had to explain the background and history of TRIZ and then the applications in other disciplines which itself was time consuming. Eventually it was found that discussing history of TRIZ before getting the feedback was slowing down the process and the need for an alternative method raised itself. The authors discussed this and concluded that carrying on the interviewing process without mentioning TRIZ can still help in getting the required results. So in the following meetings, the author(1) started the discussion with the 40 Principles and asked those being interviewed to give examples from electronic communication domain for each principle. This gathered a lot of examples but most of them were similar or repeats. The reason was that none of them had had any preparation or any specific homework before the discussion session. They knew that a lot of examples could be found but during the interview time they were having difficulties to surface them. This was natural because it is not easy to stop someone 'cold' and ask for examples even if they are specialists in the field. Some of them promised to send further examples in emails later and with some, the author was able to get a further follow up appointment, which was productive.

6 MIND TRIGGERS

From the interviews and discussion sessions, notes were made of examples of each Principle but most of the examples were repeated and similar in nature. At this stage Dr. Paul Filmore who had ready solutions to many such difficulties, suggested using examples from other domains which can trigger minds and people would come up with similar examples from their own field. This trick proved to be very effective as the author(1) gathered a lot of examples in this part of the research phase. The interviewing process with this tactic continued and the author gathered a lot of examples compared to the previous approach. The author already had a folder with sections for each Principle and their examples. In the following discussion sessions, the author used the examples already gathered as further mind triggers and eventually this speeded up the process even more. In this way a good amount of examples for each Principle were recorded.

7 CLASSIFICATION

The next step was to classify the examples according to each Principle. There were already confusions about some examples like the term **triple play** [11] in broadband as an example of segmentation, combination, composite material or universality. Another term **clustering** raised questions about being an example of segmentation or composite materials, since by definition of composite; it could be a synonym of segmentation. To sort this out, it was needed to distinctly characterise the differences between the Principles, which could be thought of as the same. The papers discussed earlier also contained reasons for characterising Principles which could raise similar questions e.g., in the finance paper[1]; Principle 32 "Colour Change" could have an example of "Currency Colour" or "Colour of Money" (a term used in finance

meaning relating to fund allocation). In that case "Colour of Money" is presented as example because the currency colour is more a matter of aesthetics, ergonomics, and error-proofing. In this paper, attempts are made to distinctly characterise Principles to avoid such confusions. For example in the case of segmentation and composite materials, the confusion was that both had the same meaning since in electronic communication, engineers discussed the architecture of a network only with respect to the way the system works, i.e. designing RF Planning and the mathematics and science involved behind its working. But this limited the scope of the project so it was decided to include examples from circuitry involved in electronic communication systems and the equipment used. With this the principle, Composite Materials was strictly confined (characterised) to the equipment used and manufacturing of equipment used in telecommunication. This meant clustering is characterised as an example of segmentation and not composite materials. But **triple play** [11] is easily an example of combination, universality and nesting because it provides multiple services in one package.

8 FURTHER WORK

In the original project specification, a further activity was specified which was to try out these new Principles with two local 'electronics' companies. The result from these trails on practical in-house problems was to further refine the Principle set presented here. As the original knowledge capture stage over ran, this stage nor the follow-on final stage of having the Principles checked by TRIZ practitioners, was completed. This is left to a continuation project next year.

9 SUMMARY

This paper details the knowledge capture undertaken to formulate a set of Principles in the communication and electronics engineering domain. A summary of the Principles is attached in the addendum. Future work will test and further refine this new Principle set by practical usage in engineering companies.

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CONTACT

Dr Paul Filmore

University of Plymouth,

A320 Portland Square, Plymouth, PL4 8AA, UK

E-mail: pfilmore@plymouth.ac.uk

Phone: +44 (0) 1752 586231

FAX: +44 (0) 1752 586300

ADDENDIUM: THE 40 PRINCIPLES

(Based on the headings by Mann [12].) NB A comprehensive list will be published later [9, 10].

1. Segmentation

A. Divide a system into separate parts or sections.

- Clustering (cellular and/or wifi hotspots)
- For a range of different focal length lenses for a camera (cell phone) use one which is adjustable or use organic electronic lens (which changes focal length by varying voltage)
- Transmission mode (wired or wireless)
- Bandwidth (frequency bands, frequency reuse etc)
- GSM,CDMA, (2G, 3G,4G)
- Communication mode (telephone, fax, email, IM, VoIP)

B. Make a system easy to put together and take apart.

- Modules and functions in programming languages (especially Object Oriented)
- Splitting large computer networks into smaller subnets
- Plug and Play Devices/Operating Systems

C. Increase the amount of segmentation

- Segmenting a Larger Collision Domain in Computer Networks

- Sub dividing clusters for frequency reuse
    - Each cell has a base station. Cells when grouped together form a cluster. MSC (Mobile Switching Centre) is connected to all the base stations in a cluster. MSC itself is connected to MSCs of other clusters and to the PSTN (Public Switched Telephone Network)

2. Taking out

A. Where a system provides several functions of which one or more are not required (and may be harmful) at certain conditions, design the system so that they are or can be taken out.

- *Techniques t*o minimise interference
    - Frequency reuse
    - Using directional antennas
    - Using shielded cables
- Data Backup
- Encryption (use noise to encrypt)
- Test/Debug data for a Computer application's development stages

3. Local Quality

A. Where an object or system is uniform or homogenous, make it non-uniform

- Design equipment according to requirement of space. E.g. rack mount or tower routers and servers (in networks)
- Use drawer mounted keyboards to operated system computers.
- Use KVM switches to operate many computer systems via one keyboard/monitor display

B. Change things around the system (e.g. the environment)) from uniform to non-uniform

- Use of Variable Length Subnet Masking in a subnet
- Different modules/libraries functioning in a computer software
- Office software including word processing, spreadsheets and database programs

4. Asymmetry

A. Where an object or system is symmetrical or contains lines of symmetry, introduce asymmetry.

- Antenna Structure (size or area)
- Network architecture

B. Change the shape of an object or system to suit external asymmetries (e.g. ergonomic features)

- Special connectors with complex shape/pin configurations to ensure correct assembly

C. If an object or system is already asymmetrical, increase the degree of asymmetry

- Antenna design
- Networking structure
- Special connectors with complex shape/pin configurations to ensure correct assembly

5. Combination

A. *Physically join or merge identical or related objects, operations or functions.*

- Home entertainment centre
- Multi SIM handsets
- Share frequency band and antenna by multiple operators (cellular)
- Network Bridge (different subnets in LAN/WAN)

B. Join or merge objects, operations or functions so that they act together in time.

- Satellite TV
- Broadband (Triple Play)
- Internet radio
- VoIP

6. Universality

A. Make an object or system able to perform multiple functions; eliminating the need for other systems.

- Multiband handset
- Automatic Voltage Selector (110/220)
- Email, voice, text, conference calls, video calls in one package
- Personal Computer (used for many types of communication including voice and video)
- Broadband
- IP network
- Home entertainment centre

7. Nesting

A. Put one object or system inside another

- Camera in phone
- Mobile TV
- Use large touch screen instead of keypad
- GPS

B. Put several objects or systems inside others.

- Smartphone (office, mobile, GPS, calendar, calculator, internet)
- Navigators in Smartphone
- Call waiting, voice sms (short audio message), answering machine, text message, mms, speed dial functions within a handset (or service)

C. Allow one object or system to pass through an appropriate hole in another.

- Operational Amplifiers
- Darlington Transistors
- Retractable cables in electronic equipment

8. Counterweight

A. Where the weight of an object or system causes problems, combine it with something that provides lift.

- Multi SIM cell phones (used instead of taking off SIM and replaced by different one with different operator/carrying more than one handsets(useful for people who use different numbers/phones for home and work))
- Use solid-state electronic devices and heavy battery for longer life
- Use mobile signal for charging

B. Where the weight of an object or system causes problems, use aerodynamic, hydrodynamic, buoyancy and other forces to provide lift.

- Using hands free/ Bluetooth listening device with cell phone
- Circuit breakers instead of fuse wires
- Phone charging via Bluetooth
- Retractable car antenna

9. Prior Counteraction

A. Where an action contains both harmful and useful effects, precede the action with opposite or anti-actions to reduce or eliminate the harmful effects.

- Using repeaters/switches in networks
- Using Optical Amplifiers in Internet cable (submarine cable systems)
- Quality of Service (QoS)
- Using directional antennas for increasing range

B. Introduce stresses in an object to oppose known harmful working stresses later on.

- Security software in PC
- Firewall
- System restore/backups
- Uninterrupted Power Supply (UPS) in case of Power failure

10. Prior Action

A. Introduce a useful action into an object or system (either fully or partially before it is needed.

- Clustering to minimize interference
- Using directional antennas for increasing range

B. Pre-arrange objects or systems such that they can come into action at the most convenient time and place.

- Using cordless phone instead of traditional telephone

11. Cushion in Advance

A. introduce emergency backups to compensate for the potentially low reliability of an object ('belt and braces')

- Dual channel communication system
- Using UPS (Uninterrupted Power Supply)
- Data Backup /Zip-Files
- Battery back-up
- Automatic save operations performed by computer programs
- The Motorola MC68000 and initial Intel microprocessors had unused pins which were used in later models
- Installing extra antennas on BTS
  - **Base Transceiver Station** (**BTS**) is the equipment which facilitates the wireless communication between user equipments (mobile phones, wireless modems, WiFi etc) and the network (operator)
- Circuit breakers

12. Equipotentiality

A. If an object or system requires or is exposed to tension or compression forces, redesign the object's environment so the forces are eliminated or are balanced by the surrounding environment

- Frequency remain same throughout a cluster in cellular communication
- Multiple operators share the same band of frequency !
- Common ground (electrically) between connected devices

13. Inversion

A. Use an opposite action(s) used to solve the problem (e.g. instead of cooling an object, heat it).

- Modulation/Demodulation
- Coding Decoding

B. Make movable objects fixed, and fixed objects movable.

- Data Encryption
- Signal distortion for security
- Data Compression
- Voice commands in handsets

14. Spheroidality

A. Turn straight edges or flat surfaces into curves

- Change shape of the antenna (straight edges or flat surfaces into curves and vice versa)
- Error detection and correction

15. Dynamicity

A. Allow a system or object to change to achieve optimal operation under different conditions.

- Equipotentiality
  - Grounding the chassis of large electronic equipment containing different modules operating simultaneously. In that case we can save extra wiring for common grounding these equipments.
  - Ground equipotentiality in electrical wiring to avoid shocks
- Wireless communication

B. Split an object or system into parts capable of moving relative to each other.

- Rotating antennas
- Satellites in outer space

C. If an object or system is rigid or inflexible, make it movable or adaptable.

- Mobile handsets
- Universal handsets

D. Increase the amount of free motion

- External hard drives/flash memories
- External memory chips for mobile phones
- Extra batteries

16. Partial, overdone or excessive action

A. If exactly the right amount of an action is hard to achieve, use 'slightly less' or 'slightly more' of the action, to reduce or eliminate the problem.

- Extra battery in equipment
  - For power surges
  - Can be useful in devices that are on move (for longer journeys e.g. 9 cell laptop battery last longer than a 6 cell battery)
  - An extra battery to retain certain data in memory)
- UPS at Base Stations and towers
- Using excessive power to transmit

17. Moving to a new dimension

A. If an object contains or moves in a straight line, consider use of dimensions or movement outside the line.

- Multipath (LOS + Reflected waves) in wireless communication

B. Use a stacking arrangement of objects instead of a single level arrangement.

- Using touch screen in handsets (bigger screen and can serve keypad)
- Double sided PCBs

C. Re-orient the object or system, lay it on its side.

- Wifi access points instead of switches and hubs
- Cordless telephone sets

D. Use 'another side' of a given object or system.

- Mount computer chip components on both sides of a silicon card

18. Mechanical vibration

- Temperature and mechanical vibration change characteristics of laser in optical fibre communications
- A surface acoustic wave (SAW), which is used as signal delay line, involves the mechanical transmission of a wave that travels on the surface of a material
- Accelerometer in new phones
- Reaction of equipments (antennas, switches, amplifiers, power supplies etc) to shock and other physical disturbance

19. Periodic action

A. Replace continuous actions with periodic or pulsating actions.

- Logging events within a system
- Communication signals with periodicity

B. If an action is already periodic, change the periodic magnitude or frequency to suit external requirements.

- Dots and dashes in Morse Code transmissions
- CDMA techniques
- Packet switching in telephone communications

C. Use gaps between actions to perform different useful actions.

- Temporary Servers operation during backup

20. Continuity of useful action

A. Make all parts of an object or system work at full load or optimum efficiency, all the time.

- Parallel processing (clustering) in computer networks
- Transmission through power lines

B. Eliminate all idle or non-productive actions or work.

- Digital storage media allow 'instant' information access (as opposed to tapes which require to be rewound)
- Using DSP in communication

21. Rushing through

A. Conduct an action at very high speed to eliminate harmful side-effects.

- Compression and coding of data
- Packet transmission
- New technology
- Skipping security at unimportant access points (or data source)

22. Convert harm into benefit

A. Transform harmful objects or actions (particularly, the environment or surroundings) so that the deliver a positive effect.

- Multipath strengthens the signal
- Polarization (of wave) covers for absence of direct LOS (Line of Sight) in wireless communication

B. Add a second harmful object or action to neutralize or eliminate the effects of an existing harmful object or action

- Using noise for distortion (encryption) of signal
- Repeaters (switches) in computer network can also function as nodes

C. Increase a harmful factor to such a level that it is no longer causes harm.

- Increase the level of encryption of signal so the leakage risk is minimised.
- Using routers instead of switches in computer networks

23. Feedback

A. Introduce feedback to improve a process or action.

- Acknowledgment signals in communications

B. If feedback is already used, make it adaptable to variations in operating requirements or conditions.

- QoS calculation
- Operational Amplifiers with different feedback can serve as oscillator, amplifier, integrator, adder, differentiator

24. Mediator (Intermediary)

A. Introduce an intermediary between two objects, systems or actions.

- Retractable cord in telephone receiver
- USB peripherals for PC (USB memory, USB WLAN etc)
- UPS

B. Introduce a temporary intermediary which disappears or can be easily removed after it has completed its function.

- Car Antenna
- Retractable antenna in handsets

25. Self-service

A. Enable an object or system to perform functions or organise itself.

- Charging cell phone by Bluetooth or operator's signal
- Voice commands in phones
- Programmable devices
- Answering machines

B. Make use of waste resources, energy, or substances.

- Use noise for distortion (encryption) of signal
- Solar cells

26. Copying

A. Use simple and inexpensive copies in place of expensive, possibly vulnerable objects or systems.

- Virtual mock-ups/electronic pre-assembly modelling
- Data compression and coding
- Encryption

B. Replace an object, or action with an optical copy.

- Backups
- Transient copying (from public sources like internet)
- Carbon copy (electronic) in email

C. If optical copies are already being used; make use of infrared or ultraviolet wavelengths

- Conference instant messaging (internet)
- Conference calls

27. Inexpensive short life

A. Replace an expensive object or system with a multitude of inexpensive, short-life objects.

- Mobile handset
- Electronic components
- Organic electronics/semiconductors (inexpensive)
- Low quality batteries
- Low quality cables (in office buildings since expensive cables are replaced with new (and non-compatible) technology)
- Ad-hoc networks

28. Replacement of a mechanical system

A. Replace an existing means with a means making use of another sense (optical, acoustic, taste, touch or smell).

- A keypad in cell phone
- Mechanical dial replaced by touch tone keypad in traditional telephone set
- Mechanical switches replaced by transistors

B. Introduce electric, magnetic or electromagnetic fields to interact with an object or system.

- Field-activated switches
- Mechanical timers replaced by electronic timers
- Mechanical shutter replaced by optical sensors (cameras)
- Fingerprint/retina scan instead of a key

C. Change from static to movable, fixed to variable, and/or from unstructured to structured fields.

- Early communications used omni-directional broadcasting. We now use antennas with very detailed structure of the pattern of radiation.

D. Use fields in conjunction with field-activated (e.g. ferromagnetic) objects or systems.

- Traditional antennas (retractable) replaced by solid state antenna

29. Use pneumatic or hydraulic systems

A. Use gases and liquids instead of solid parts or systems

- Liquid Crystal Display (LCD)
- Organic semiconductors, OLEDs
- Rechargeable batteries (e.g. Li-ion batteries)

30. Flexible film or thin membranes

A. Incorporate flexible shells and thin films instead of solid structures

- Flexible electronics (OLED)
- Organic touch sensitive display to make thin and flexible (bendable/foldable) phones

B. Isolate an object or system from a potentially harmful environment using flexible shells and thin films.

- Stored energy in flexible bags – e.g. accumulators in a hydraulic system

31. Use of porous materials

A. Make an object porous or add porous elements

- Drill holes in electronic device's casing to reduce the weight
- Electronic or digital filters (low pass, hi pass, band pass etc)

B. If an object is already porous, add something useful into the pores.

- Digital filters using microprocessors and microcontrollers
- Drill holes in device's casing for air flow and cooling of electrical components

32. Changing the colour

A. Change the colour of an object or its surroundings.

- Coloured wires for different signals
- Different colours for different modules within a system
- GREEN for dial/accept and RED for drop/reject call (in handsets)
- Coloured wires in Networking cables (UTP, STP etc)

B. Change the transparency of an object or its surroundings.

- Different colours for different communication ports in a PC
- CISCO colour cabling for Console and AUX Ports

C. In order to change the visibility of things, use coloured additives or luminescent elements

- UV marker pens used to mark computers in public offices
- Reflecting paint on BTS towers and antennas

D. Change the emissivity properties of an object subject to radiant heating

- Use of parabolic reflectors in solar panels to increase energy capture.
- Paint object with high emissivity paint in order to be able to measure it's temperature with a calibrated thermal imager.

33. Homogeneity

A. Make interacting objects from the same material (or material with matching properties).

- Making a device of metal acting as common ground
- Designing ports in a way to prevent accidental plugging (e.g. RJ45, PC ports, power plugs, power cables etc)
- Special connectors with complex shape/pin configurations to ensure correct assembly

34. Rejecting and regenerating parts

A. Make elements of an object or system that have fulfilled their functions disappear (by dissolving, evaporating, etc.) or appear to disappear.

- Repeaters and Switches
- Electronic/Digital filters
- Amplifiers
- Memory functions in telephones/mobiles for contacts directory, dialled numbers etc
- Wireless channels
- CDMA
- Token Ring topology for computer networks
- TCP/IP

- Dialling through PSTN, mobile telephone networks
- TV channels
- Radio channels

B. Restore consumable or degradable parts of an object or system during operation.

- Encryption
- Coding/Decoding
- Modulation/Demodulation

35. Transforming physical or chemical states

A. Change an object's physical state (e.g. to a gas, liquid, or solid).

- Transformation (using transducers) to transform voice/video/data/text into electrical/optical/electromagnetic signal and vice versa
- Coding and decoding signals

B. Change concentration or consistency.

- Encryption types for different levels of security
- Modulation and demodulation of signals

C. Change the degree of flexibility.

- Heat sink for electronic components act as antenna
- Retractable antennas

D. Change the temperature.

- Antenna characteristics change with temperature
- Design antenna according to environment/region
- Design equipment according to environment/region

E. Change the pressure.

- Equipment function at altitude
- Antenna structure for optimum performance at different altitude

36. Phase transition

A. Make use of phenomena taking place during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).

- Dispersion and polarization of electromagnetic waves (signals)
- Distortion of signal (because of noise and interference etc)
- Transformation of signal from one form to another (e.g. electrical to optical etc)
- Delta-Wye (∆-Y) and Wye-Delta (Y-∆) transformation of electricity in high power transmission lines

37. Thermal expansion

A. Use thermal expansion (or contraction) of materials to achieve a useful effect.

- Transmission wires and towers
- Antenna characteristics change with temperature
- Heat sink for electronic components
- Super cooling conductors for superconductivity
- Super heating semiconductors for superconductivity

B. Use multiple materials with different coefficients of thermal expansion to achieve different useful effects.

- Bi-metallic strips used for thermostats, etc
- Two-way shape memory alloys.
- Combine materials with positive and negative thermal expansion coefficients to obtain alloys with zero (or specifically tailored) expansion properties – and use in installing equipment at high temperature zones

38. Use strong oxidisers

- Using phosphorous (oxidiser) for glowing in lamps
- Using phosphorous in camera flash for high intensity light

39. Inert environment

- Necessary in public places like hospitals etc to avoid electromagnetic interference (EMI)

40. Composite materials

A. Change from uniform to composite (multiple) materials where each material is optimised to a particular functional requirement.

- Use to make towers, handsets, networking equipments for extra strength
- Using composite materials in designing equipment can also increase aesthetics.