Spectrum Repack – Your RF Plant and What to Consider

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Abstract - *Repacking of the UHF TV band to free up valuable spectrum for new wireless services has the potential to impact every TV station in the USA. Changing the channel of a transmission facility will require careful planning and execution to be successful. This paper highlights some of the more important aspects of such a change, including transmitter, RF plant, transmission line and antenna. Furthermore, many ATSC transmitters in service today are either obsolete, or discontinued models that cannot be readily channel changed. It is even more important to note that older transmission equipment is often very inefficient when compared to modern state of the art designs. Depending on several factors, this may be an excellent opportunity to consider replacement of the transmitter along with other items in the RF chain. A tool for examining transmitter Total Cost of Ownership (TCO) and Return on Investment (ROI) will be discussed and examples based on typical transmitters in service today will be presented. A brief discussion on planning for future ATSC 3.0 operation will also be addressed.*

What's Spectrum Repack?

On March 17th, 2010, the FCC proposed an idea for a television spectrum incentive auction in the National Broadband Plan [1]. The plan was consequently approved by Congress two years later. This first-ever incentive auction process is now well underway and it comprises three interrelated activities:

- A Reverse Auction - where broadcasters can voluntarily sell their spectrum rights to the FCC. Broadcasters will bid downwards, against each other, to give up their spectrum.
- A Forward Auction - where wireless operators may bid against each other upwards to buy the newly available spectrum.
- Spectrum Repacking - a mandatory process where all broadcasters who stay on the air may be required to change channels.

The mandatory process for repacking could potentially affect any station, on any channel, in any market. Unless there are unforeseen delays, it is expected that the FCC will announce the auction results and new channel assignments in the next few months.

Your RF Plant is Unique

When repack comes, every television station will have a different situation to contend with. Along with a wide range of effective radiated power levels, there are many variations in transmitting equipment, RF systems, towers and antennas. There is no single solution or answer that applies to everyone. In essence, every station must take a close look at their own situation and evaluate the most economic and viable repack scenario.

What Equipment Could Be Affected by Repack?

A typical RF plant block diagram is shown in figure 1.

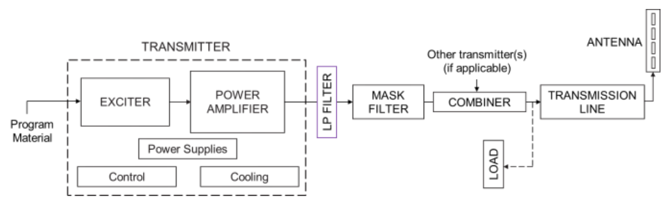

FIGURE 1 TYPICAL RF PLANT - MAJOR COMPONENTS

Your station may be different, but it will have several items that are operating with RF (on your current VHF or UHF TV transmitting channel). Items potentially affected by a channel change include the transmitter, harmonic filter, mask filter, transmission line (or waveguide), test load, patch panel(s), and the antenna. All of these items should be evaluated as to their suitability for use on the new channel that may be mandated for your station. In a few cases, switching channels may not have much impact - perhaps for example, you already own a frequency agile transmitter and a broadband antenna. In most cases this will not be true, many older transmitters are not easy to frequency change. Likewise, many antennas were designed for single channel use only and certainly Mask Filters will require retuning or replacement.

The Transmitter

The existing transmitter(s) at your station are likely to have either a tube final stage (IOT) or 100% solid state. Data on hand shows that TPO's vary from a few Watts to over 50kW of average ATSC power.

I. Tube Transmitters

Many high power UHF transmitters utilize IOT's as the final stage of amplification. These may be single collector or multiple-stage collector types (high efficiency). While the tube itself is inherently broadband, it becomes narrow-band in its circuit assembly which is tuned and optimized for a specific single channel of operation. It can usually be re-tuned to the new channel. Generally, this is not difficult, but it does require some degree of knowledge and a lot of care. Some components such as domes and coupling loops inside the cavities may need replacement (figure 2).

FIGURE 2 IOT CAVITY COUPLING LOOPS & DOMES (E2V)

Driver stages may be solid state and these may or may not be broadband. The best advice here is to consult your equipment manufacturer to find out the specifics regarding channel changing, if it is even viable and if it makes economic sense.

II. Solid State Transmitters

All VHF and many UHF ATSC transmitters in current ATSC service are solid state designs. Some newer models may be fully broadband, but most are "banded", meaning that each PA type covers only a portion of the frequency band (usually 3 or 4 bands). Since many of the earlier generation solid state designs are no longer in production, switching channels may not be practical. In addition, circulators are often used between stages. These may also be band limited and could belong on the list of items to be replaced.
Whatever the existing equipment type, age and condition, a careful analysis should always be made, looking at the cost and difficulty of a channel change, versus a full replacement. Also, the original equipment manufacturer may no longer be in business, making long-term support difficult. New solid state broadband ATSC transmitters are not only much more efficient that earlier solid state models, they are also more compact, more reliable and much easier to maintain. A Total Cost of Ownership (TCO) comparison between keeping the old transmitter versus purchasing a new one is strongly recommended. In addition, there are government funds allocated to pay for new transmission equipment, which may also be a deciding factor.

Filters, Patch Panels, and Transmission Line

I. Filters

Low pass filters are often "banded" to simplify their design and for cost purposes, so these may need to be replaced. Mask filters by definition, are single channel items. High power waveguide mask filters, along with magic-tee combiners are in general not suitable for retuning to a new channel due to their construction and design. The author recommends that you contact the manufacturer of these items for further information. Coaxial mask filters are often tunable to another channel, however, this is usually best accomplished by a skilled person with the proper test equipment (either on-site or at the filter manufacturer's facility).

II. Other Indoor RF Items

Patch panels may work on a new channel, but look for fine matchers (or tuning "*paddles*") between components. The test load should also be good for re-use (again there may be a fine matcher that will need to be adjusted).

III. Outside Transmission Line

Long runs of rigid transmission line will also need to be assessed. "VSWR build-up" will create issues on some UHF channels. This is due to the small but repetitive impedance disturbances caused by the flanges and anchor connectors adding up due to wavelength and spacing. Coaxial line comes in three standard lengths, 19-½, 19-¾, and 20ft. Figure 3 shows which line lengths should be avoided on specific 6MHz TV channels in the USA [2].

COAXIAL LINE STICK LENGTHS, 1.5MHz GUARD BAND

Line Length	Channel																		
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
20'				■				■				■				■			
19-3/4'	■				■				■				■				■	■	
19-1/2'		■				■				■					■			■	■

Line Length	Channel																		
	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
20'	■				■	■			■	■			■	■			■	■	
19-3/4'		■	■			■	■			■	■				■				■
19-1/2'			■	■				■				■				■	■		

■ Prohibited Channel per Catalog

FIGURE 3 PROHIBITED CHANNELS IN UHF-TV BAND

It is recommended that a broadband sweep of the entire run of line between the transmitter building gas barrier and antenna input be made using a Network Analyzer. This of course requires an adapter and a precision load be installed at the antenna end of the line. Replacement of the entire line or at least some re-matching may be required along with skilled labor to accomplish this successfully. If full replacement is necessary, it is often costly and may disrupt your normal transmission schedule.

The Antenna

It has been estimated that about 90% of the installed UHF antenna base in the USA use what is known as a pylon (or slotted coaxial) antenna.

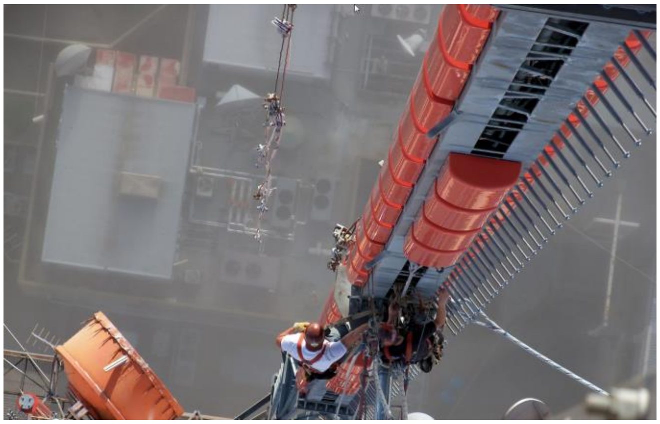

FIGURE 3 – PANEL ANTENNA INSTALLATION (COURTESY DIELECTRIC)

In spite of their advantages in cost, reliability and wind load, these antennas are inherently narrowband [3]. An antenna that was "cut" for a specific channel may possibly be used one channel down but no more [3]. If a new antenna is needed, it is important to note that as the frequency goes down, the wavelength increases and the antenna will get larger and heavier (for an equivalent gain figure). This may then also impact the tower structure and wind/weight loading factors. It goes without saying that a complete tower analysis will be required is any item on the tower is replaced, or moved. If that isn't enough, TIA 222-G a new revision of the standard for Antenna Mounting Structures and Antennas has been introduced and it may be required that it be met if any tower work is to be done. One estimate is that about 30% of existing broadcast towers will need work to comply with the TIA-222 rev G code [3]. The limited availability of tower crews and rigging equipment is likely to be of concern during the busy repack period.

Total Cost of Ownership (TCO) and Return on Investment (ROI)

As far as upgrading, or replacing, the transmitter itself, many stations have elected to act now rather than wait until final channel re-assignments are issued. This may seem counter-intuitive, given that many of the costs associated with a mandated channel change may reimbursable. However, reimbursement from this $1.75B fund does not apply to every station. As noted by the FCC [4] "*Of the broadcast stations that may be reassigned in the auction and repacking processes, only full power and Class A licensees that are involuntarily assigned to new channels in the repacking process are eligible for reimbursement*". In addition, many stations are in need of earlier replacement of at least the transmitter, particularly if the existing one is near its end of life, or repair and maintenance is becoming increasingly difficult.

Given that the new generation of solid state transmitters are far more energy efficient than models that were sold as recently as 4 or 5 years ago (in some cases, more than a 50% reduction in electrical power consumption can be expected), the savings in electrical power costs might alone provide a compelling argument for considering the purchase a new system. New solid state transmitters are likely to be far more reliable and redundant, as well as physically smaller and much easier to maintain compared to older units. Of course, if a UHF transmitter is purchased prior to any knowledge of a future channel change, it must also be fully broadband at least from your existing channel downwards to channel 14, or for VHF completely broadband across the specific VHF band in question. RF items such as filters should be replaced with re-tunable models which will be re-usable later.

A simple TCO calculator was created that allows GatesAir to provide some basic information and payback (ROI) information for broadcasters who may be considering purchasing a new transmitter. Some of the factors that can be inputted include:

- Efficiencies for both the existing and new transmitter
- Electrical energy cost per kW-h.
- Costs for HVAC needed to cool the heat load of existing and new transmitters
- Purchase price for the new equipment
- Installation and commissioning costs of the new equipment
- Maintenance costs, site visits and cost to visit the site
- Cost of floor space (if rented space)

The tool provides some quick and approximate at-a-glance figures that will allow the ROI and payback to be evaluated. In some cases, where the existing transmitter is very inefficient (sometimes only 15% to 17%) and the electrical power costs are fairly high, we have seen payback periods as low as 3 years. In other cases it may be longer. What is hard to include are additional weighting factors such as equipment reliability, warranty, availability of replacement parts and ease/speed of servicing. These factors may also play a role in the final decision process.

TCO Example 1 - First Generation Solid State Transmitter vs. New Solid State Transmitter

In this case, an existing Harris/GatesAir DiamondCD solid state ATSC transmitter using Class AB power amplifiers is compared with a new high efficiency solid state system, using Doherty, or similar PA technology. The existing system is air-cooled but in this example we will replace it with a state-of-the-art liquid cooled model. The overall AC to RF efficiency of the existing transmitter will be typically between 17% and 19.5%.

A new ATSC transmitter employing high efficiency power amplifiers can provide an overall system efficiency in the order of 42.5%. In this example, the AC power cost (including delivery charges, tax, etc.) is $0.16 per kW-h. This results in a very impressive breakeven period of approximately 3 years. (Excluding inflation and other factors). This example is shown in figure 3 and 4.

Transmitter TCO Comparison (Solid State to Solid State)			
	New Transmitter	Old Transmitter	
Product Series	Maxiva ULXT ATSC	DiamondCD	
Model	ULXT-24AT	DHD90P3	
Tx Maximum Output Power	21,100 W	21,935 W	
Required Output Power	20,000 W	20,000 W	
Purchase Price	479,500	0	
Installation	0	0	
Commissioning	0	0	
Training	0	0	
Total Cost	479,500	0	
Energy Costs: [1]			
Region	USA	USA	
Country/State	New Hampshire	New Hampshire	
Price/kWh	$0.160	$0.160	
Tx System Efficiency	42.5%	19.4%	
OPEX:	ULXT-24AT	DHD90P3	Estimated Savings
Annual OPEX	74,017	215,511	141,494
Year 1 TCO	563,017	267,011	-296,006
Year 5 TCO	859,086	1,129,057	269,971
Year 10 TCO	1,229,172	2,206,615	977,443
Year 15 TCO	1,599,258	3,284,172	1,684,914
Year 20 TCO	1,969,344	4,361,729	2,392,386
Breakeven Period			3.0 Years

FIGURE 4 TCO EXAMPLE - SOLID STATE TRANSMITTER REPLACEMENT

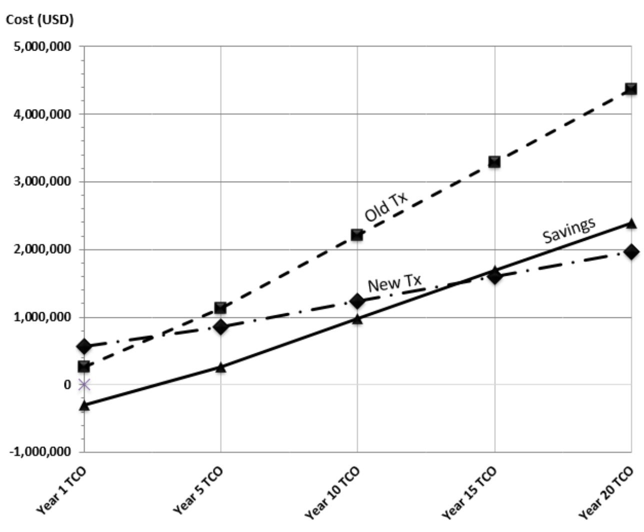

FIGURE 5 TCO EXAMPLE - SOLID STATE TRANSMITTER REPLACEMENT

The TCO calculator allows manual price inputs as well as adjusting AC power costs, and other variable factors to suit a wide variety of scenarios.

TCO Example 2 – Older IOT Transmitter vs. New Solid State Transmitter

Our research shows that there are many single-collector IOT transmitters currently in service across the USA. Some of the earlier models are standard collector types with efficiencies typically in the 25 to 31% range. Not only will there be an efficiency improvement if this is replaced, there are many other factors to consider.

In the example shown in figures 6 and 7, a 50kW average power single collector 2-tube IOT transmitter is replaced with a new high-efficiency broadband solid state transmitter.

Transmitter TCO Comparison (Solid State to Solid State)			
	New Transmitter	Old Transmitter	
Product Series	Maxiva ULXT ATSC	SigmaCD	
Model	ULXT-60AT	CD3260P2	
Tx Maximum Output Power	52,100 W	64,291 W	
Required Output Power	50,000 W	50,000 W	
Purchase Price	1,000,500	100,000	
Installation	0	0	
Commissioning	0	0	
Training	0	0	
Total Cost	1,000,500	100,000	
Energy Costs: [1]			
Region	USA	USA	
Country/State	New Hampshire	New Hampshire	
Price/kWh	$0.160	$0.160	
Tx System Efficiency	42.5%	28.6%	
OPEX:	ULXT-60AT	CD3260P2	Estimated Savings
Annual OPEX	176,373	290,731	114,359
Year 1 TCO	1,189,373	410,731	-778,641
Year 5 TCO	1,894,864	1,573,657	-321,207
Year 10 TCO	2,776,729	3,027,315	250,586
Year 15 TCO	3,658,593	4,480,972	822,379
Year 20 TCO	4,540,457	5,934,629	1,394,172
Breakeven Period			7.8 Years

FIGURE 6 - TCO EXAMPLE - IOT TRANSMITTER REPLACEMENT

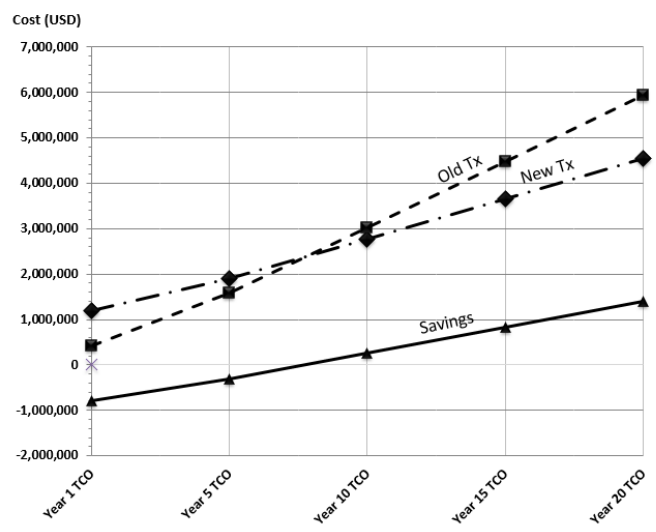

FIGURE 7 TCO EXAMPLE - IOT TRANSMITTER REPLACEMENT

In this scenario, the efficiency improvement will be from approximately 29% to 42.5%. Although the IOT transmitter has already been paid for, I have factored in the cost of a couple of replacement IOT's, as these may need replacing, or be near their end-of-life. The typical payback period is often in the 7 to 8 year range (as depicted in this example) but can vary considerably, depending on many factors.

It should also be noted that there are several other benefits gained by replacing any IOT system with solid state, that aren't easily factored into this TCO comparison:

- Vastly improved system level redundancy (and on-air reliability) at this power level (Typically 60 power amplifiers in parallel versus only 2 tubes.
- DC voltage of 50V for solid state LDMOS PA's versus 34kV or more for IOT's (safer and less prone to dust/dirt and humidity problems).
- Typically much more frequent maintenance requirements for IOT versus solid state.
- Repack – The solid state system is broadband versus channelized tuning and possible cavity parts change for the IOT system.

Plus a few final points that could apply to any existing older transmitter:

- Is it still supported by the equipment manufacturer?
- Are there engineers available who can fix it?
- Are parts readily available and obtainable quickly?
- Can the old transmitter by upgraded for future ATSC 3.0 operation?

ATSC 3.0

At this point, it appears that TV Spectrum Repack and the roll out of ATSC 3.0 are not aligned and are not going to occur simultaneously. I won't delve deeper into this topic other than to point out that there are a few items worth considering as your station strategizes and plans for equipment changes due to Spectrum Repack.

I. Transmitter Power

A question that is often asked: "*If changing channels within the same band, will the transmitter power be the same as it was prior to repack?"* The answer is "*probably not*" - If the coverage service area is to be replicated, there are several factors to look at, including frequency, antenna gain/pattern, beam tilt, line losses and HAAT.
Another question: "*Will the transmitter power be different for ATSC 3.0 compared to the current ATSC standard?*" This one is even trickier to answer. ATSC 3.0 has many differences compared to today's 8-VSB system. Details are defined in the ATSC 3.0 Candidate Standard for the Physical Layer Protocol [5]. OFDM versus 8-VSB modulation is in itself a big game-changer. Along with an increase in peak-to-average power ratio, there are a wide array of available constellation choices, from QPSK to 4096QAM, FFT size, code rates and other variables. As a result of these choices alone, the maximum data rate and robustness of the RF signal can vary considerably. The type of reception being targeted (fixed roof-top, fixed indoor, portable and mobile) will also be a big factor. With so many variables, the received signal strength needed to achieve the required C/N ratio for reception can obviously vary dramatically. With this in mind, it may be hard to think ahead and plan for every contingency. If that isn't enough, some broadcasters are planning to replace their existing horizontally polarized antenna with a new one that has some degree of vertical polarization, in an effort to improve mobile reception.
Depending on your station's needs, the required ATSC 3.0 average ERP can probably range from less than today's figure (for very robust, relatively low data rate modulation parameters, to a higher figure, especially if high data rates are required (including 4k UHD transmission perhaps).
With so much variability, it may be advantageous to at least plan for some amount of transmitter power increase in the future. A few broadcasters believe that they may need double the transmitter power to enable them to replicate their service area with the additional capacity and services that they may offer. One good thing to know is that most new transmitter designs lend themselves well to adding additional racks and amplifiers in the future. Final note here - Leave some room in the building for this possible future power increase.

II. Antenna

As noted previously, elliptically polarized antennas may be advantageous if mobile reception is to be targeted. The power rating needed for ATSC 3.0 may need to be higher than current needs. Peak to average power and voltage ratio's should also be factored in.

III. Outside RF Line

Again, it may be worth looking at higher average and peak power projections for ATSC 3.0, if replacing the RF line for Repack.

IV. Mask Filter & Other RF Components

The same argument can be made for the mask filter and other RF components inside the building. Plan ahead for a potential average power increase and save money later.

V. Transmitter Conversion to ATSC 3.0

A new transmitter being acquired specifically for the upcoming spectrum repack will likely have a useful life expectancy of well over 10 years. It is highly likely that ATSC 3.0 will be adopted across the USA well within that time period. It would be very useful if a transmitter purchased now, or at the time of spectrum repack can be modified quickly, efficiently and inexpensively for future ATSC 3.0 operation. Check with your equipment supplier and be sure to ask for details and costs regarding what may need to be changed/upgraded for such a conversion.

Conclusions

A transmission channel change brought about by spectrum repacking brings with it a wide variety of issues, challenges and potential headaches. It is obvious that careful advance planning, along with a good changeover strategy and proper execution are the key attributes to success.

Whether or not your station is moving voluntarily, or involuntarily to a new channel, there will be some potentially significant changes to the transmission plant.

In summary, the most important key items to consider are:

- Can my existing transmitter, mask filter, RF line, antenna and other items be used on the new channel?
- Is my existing transmitter still in production and can it still be serviced and supported properly?
- If a new transmitter is needed, should I purchase it now or later?
- Energy savings and other costs should be considered.
- Staying on the air during a channel change needs to be planned for ahead of time.
- If possible, when updating or replacing equipment, ensure that it can be used (or easily updated) for use with ATSC 3.0.

References

[1] FCC, "National Broadband Plan", March 2010, pp 84, Exhibit 5-E.

[2] Savage, K (Dielectric LLC), "FCC Repack Guide – Draft Copy", January 2016, pp 2.

[3] Fallon, DS (Dielectric LLC), "Repacking - Preparing Antennas, Combiners and Transmission Line" *NAB BEC*, April 2014, pp 1-2.

[4] FCC, "Primer For Broadcasters", *Reimbursement of Relocation Costs,* https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions/primer-broadcasters

[5] Advanced Television Systems Committee, "ATSC Candidate Standard: Physical layer Protocol", *Doc. S32-230r21*, September 2015

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